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Technische Universität Darmstadt, Fachgebiet Fahrzeugtechnik (FZD), Germany

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Paper for IFZ Conference

The Development of a 5 Star Motorcycle Clothing Assessment Program

Author:- Brian Wood

Presenter:- Brian Wood

Institution:- Australian Motorcycle Council

Abstract

The Motorcycle Clothing Assessment Program, known as MotoCAP, is an independent rating scheme for motorcycle protective clothing.

The aim of MotoCAP is to provide an independent process for testing and publicising the protective and thermal management performance of motorcycle clothing, to encourage usage of motorcycle protective gear and thereby reduce injury rates. The objectives are to:

- Enable riders to make informed decisions when buying protective garments
- Increase demand for better performing protective garments
- Allow riders to compare products on independently tested measures;
- Encourage industry participants to compare their products with those of their competitors;
- Providing incentives for industry to compete on safety and thermal comfort; and
- Improve overall safety for the riding community;

Motorcyclists wear protective clothing and helmets to both reduce the risk and severity of injuries in a crash and provide a degree of climate control. Evidence from crash studies indicates that the protective performance of motorcycle clothing was variable, with neither cost nor brand name reliably predicting protection. In addition, many motorcyclists choose to ride unprotected in hot conditions. This raised the question as to whether good crash protection was compatible with thermal comfort for motorcyclists in hot conditions and whether thermal discomfort could compromise safe riding, increasing crash risk. MotoCAP provides separate ratings for protection and thermal comfort so riders can make an informed choice on how they balance protection against thermal comfort to best suit their particular needs.

MotoCAP is the outcome of almost 20 years research and consultations, led by Dr Liz de Rome, with the support of the Australian Motorcycle Council.

Since the launch in September 2018 there have been over 22,000 unique users to the MotoCAP website, with over 1,300 subscribed to receive updates when more garments are added to the site. 78% of visitors originate from the target countries of Australia and New Zealand, with the remainder visiting from other countries. Almost 8% of visitors originate from Europe.

During the first year of operation 150 garments representing 10% of jackets, pants and gloves available across Australia and New Zealand were tested.

Introduction

Motorcyclists' clothing must serve a number of functions. On a day to day basis, it has to protect the rider from the weather, be suitable for use at their destination, in addition to protecting them from injuries in the relatively rare event of a crash. Evidence from laboratory tests and motorcycle crash studies indicates that the protective performance of motorcycle clothing is variable, with neither price nor brand name reliably predicting protection (Hoare 2005a, b, 2009, de Rome *et al* 2011a). Whilst international standards exist for motorcycle clothing, surveys of retail outlets conducted by the AMC found few products certified to any standard. Information to riders on protection was in short supply apart from advertising claims by manufactures. Particularly in Australia, it was found that many motorcyclists chose to ride unprotected in hot weather (Wishart *et al* 2009, de Rome *et al* 2011b).

This raised the question as to whether crash protection was compatible with thermal comfort for motorcyclists in hot conditions and whether thermal discomfort could compromise safe riding, increasing crash risk. This paper talks about the introduction of a motorcycle clothing 5 star rating scheme that was developed to inform riders of the protection and thermal comfort levels of clothing they buy.

The Australian rating scheme for motorcycle protective clothing, called MotoCAP, is the outcome of almost 20 years research and consultations, led by Dr Liz de Rome, with the support of the Australian Motorcycle Council and its member organisations. It's key aim is to provide independent information on the protection and thermal comfort of motorcycle clothing so riders can make an informed choice in what they buy.

MotoCAP won the 2019 *Fédération Internationale* de *Motocyclisme (FIM)* Road Safety Award.

The Australian rider

Riding in Australia is not that dissimilar to other places in the world. All styles of motorcycle and scooters are represented. The population of motorcyclist average 7 hours riding per week (de Rome *et al* 2016a). The majority ride for recreation (70%) but over half (53%) commute to work some (37%) riding larger distances on freeway networks to get to work. Scooters are not as common as would be found in a typical Italian city like Milan, representing just 12% of the fleet. They are most popular with young people living in inner-city areas and in warmer climate coastal environments.

Australia's climate is governed mostly by its size and by the hot, subtropical high-pressure belt. The climate is variable, with a wide variety of climates due to its large geographical size. The largest part of Australia is desert or semi-arid. Only the south-east and south-west corners have a temperate climate. The northern part of the country has a tropical climate, varying between grasslands and desert.

Depending on the location in Australian riders can be subjected to a wide range in temperatures. Tasmania has a very low latitude and has a colder climate than most of Australia. The majority of Queensland and the Northern Territory have very mild winters with lows rarely dropping below 20°C. Compared to Europe, Melbourne is 450 kilometres closer to the equator than Rome, so just about all of Australia is closer to the equator than Europe. In New Zealand, the latitude of Wellington, its capital, is almost the same as Rome.

The clothing available in stores represents this wide temperature range. It is quite hard to locate a leather jacket in a store in far North Queensland, where the majority of garments are vented textiles. Similarly, the range of wet weather pants available in store is less in Western Australia due to the drier climate.

Riders look for versatility and adaptability in garments. Controllable venting can be very important for a rider in Victoria who may experience 12°C on their morning ride which increases too 33°C as the day proceeds. Afternoon storms in coastal New South Wales are not uncommon in summer requiring breathable rain protection for a Sydney commuter

In Australia, all motorcyclists are required by law to wear a helmet. All motorcycle helmets sold in Australia, must pass Australian/New Zealand Standard AS/NZS 1698 or the international regulation United Nations Economic Commission for Europe Regulation No 22 (UNECE22.05). Motorcyclists are most likely to also wear motorcycle PPE jackets (82%) and gloves (73%) with over half also wearing PPE pants and boots.(de Rome *et al* 2016a)

Thermal discomfort can cause severe physiological strain which may affect rider safety by causing distraction, slowed reaction times and fatigue (de Rome *et al* 2015, de Rome 2019). The potential risks of thermal discomfort made the introduction of a performance rating scheme that evaluates both protection and breathability important.

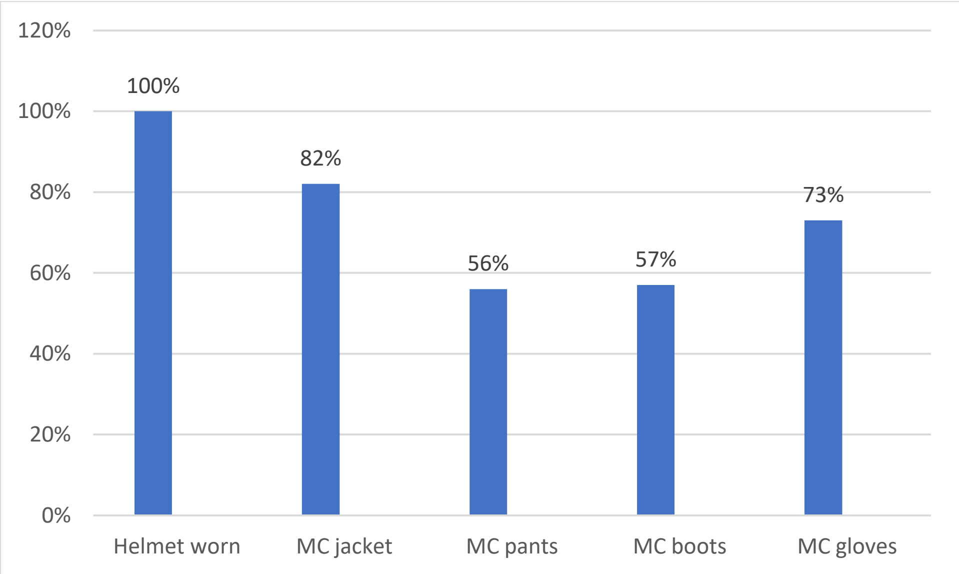

Figure 1. Levels of protection of clothing usually worn by riders and pillions (de Rome et al 2016a)

How MotoCAP works

MotoCAP tests the same garments as a rider would buy for general use. One of each item is bought from a retail store and the second is bought online. The garments are tested separately and their results are compared. No manufacturer, importer or retailer knows what products will be selected for testing, nor when or where their products might be purchased for testing.

Garments are tested for three protection elements; impact abrasion, seam burst strength and armour energy attenuation. The test methods followed are from the existing European Standard EN13595-1:2002 with some modifications made to allow for sampling from actual garments. These test methods were selected because they were well developed and had scientific evidence relating their performance to real world crashes. The testing of gloves follows a similar direction using the tests outlined in EN13594:2003.

Jackets and pants have additional testing for thermal comfort (breathability). The result is presented separately to the protection rating. This test is drawn from the sports clothing industry and evaluates the ability for clothing to expel body moisture in a hot environment. This measurement is important to introduce garments with both good protection and thermal comfort to suit Australia's diverse climate.

At present MotoCAP is testing approximately 10% of the Australian and New Zealand market which is 152 garments per year. Over 200 garments have been tested, rated and published for riders to view worldwide.

The tested gear includes some of the best sellers on the market as well as lesser-known brands. The objectives of MotoCAP are detailed below:

- Enable riders to make informed decisions when buying gear;
- Increase demand for better performing gear;
- Allow riders to compare products on independently tested measures;
- Encourage industry to compare their products with those of their competitors;
- Providing incentives for industry to compete on safety and thermal comfort; and
- Improve overall safety for the riding community;

The program is administered by Transport for NSW with all results published on the MotoCAP website (www.motocap.com.au and www.motocap.co.nz). A large number of parties are involved in the funding and direction of MotoCAP.

Partners

The MotoCAP working group is chaired and administered by Transport for NSW, who manage the development of the program.

Other members include:

- Government Agencies

- Department of State Growth (Tasmania)
- Department of Transport and Main Roads (Queensland)
- Transport for NSW
- VicRoads
- Road Safety Commission (Western Australia)

- Compulsory Third Party Injury Insurance Agencies

- Accident Compensation Corporation (New Zealand)
- Lifetime Support Authority (South Australia)
- Motor Accident Insurance Commission (Queensland)
- State Insurance Regulatory Authority (NSW)
- Transport Accident Commission (Victoria)

Insurance Companies

- Insurance Australia Group
- Royal Automobile Club of Victoria

Independent Bodies

- Australian Motorcycle Council

Consultants

- Dr Chris Hurren and Dr Liz de Rome from Deakin University for Frontier Materials are contracted as consultants for the MotoCAP program and were instrumental in its development.

How the 5 star rating scheme was developed (key milestones)

The following details the development timeline of the inception and development of a motorcycle clothing rating scheme.

- 2003 – The Motorcycle Council of NSW (MCC) obtained a grant from the Motor Accidents Authority of NSW (MAA) to commission the investigation of the features of effective motorcycle personal protective equipment (PPE).The outcome was a report and the establishment of websites for the MCC and the Accident Compensation Commission (NZ) to provide information about protective clothing and other motorcycle safety issues to riders in Australia and New Zealand (de Rome 2002, 2004b, a).

- 2005 – A national PPE industry seminar was held by the MCC with the support and funding of the MAA to consider the implications of the European Standards for PPE. A proposal to establish an Australian star rating scheme for PPE was canvassed and supported by the participants (de Rome *et al* 2005)

- 2007 – The National Roads and Motorists Association (NRMA) funded a survey of novice riders to establish their knowledge, information sources and usage of PPE (de Rome *et al* 2010, de Rome *et al* 2011b).

- 2008 – Swann Motorcycle Insurance funded a study of the injury reduction benefits of the clothing worn by injured and un-injured riders involved serious crashes. The study confirmed the potential for PPE to reduce the risk and severity of injuries, but also identified high rates of garment failure under crash conditions. The study also validated the impact risk zones framework of the European standards against clothing damage and rider injuries in real world crashes (de Rome *et al* 2011a, de Rome *et al* 2011b, de Rome *et al* 2012b, de Rome *et al* 2014, Meredith *et al* 2014).

- 2008 – PPE researcher invited to give a presentation on protective clothing research to members at the AMC Annual Conference

- 2009 – AMC successfully lobbied Federal Government for funding to publish and distribute a guide to riders on the features of effective motorcycle protective clothing ‘The Good Gear Guide’ (de Rome, 2009).

- 2011– The Australian and New Zealand Government Injury Insurance agencies commissioned industry consultations and research into the development of a model for providing riders with reliable information when buying motorcycle protective gear (de Rome *et al* 2012a).

- 2011 – The Victorian Transport Accident Commission (TAC) organised a series of state-wide seminars – entitled "What's Safe?" – which covered the testing and other assessments of motorcyclists' clothing, of which riders, retailers and clothing suppliers were amongst the interested parties who attended.
- 2014 – The AMC formed a Protective Clothing Sub-Committee which developed a Position Statement on Protective Clothing from a rider's perspective.
- 2014 2015, 2016 – AMC Annual Conferences invited PPE researchers to provide updates on research progress on protective clothing.
- 2015 – The AMC collated and listed CE approved gear available in Australia on its website to assist riders in choosing suitable gear. The AMC joined the Australian and New Zealand Working Group tasked to develop a 5 Star Rating scheme.
- 2015 – The Motorcycle Protective Clothing working group formed, consisting of 10 members from government agencies and motoring clubs, led by the TAC.
- 2016 - The science program 'Catalyst' produced a segment on motorcycle protective clothing, this was broadcast by the national broadcaster, the Australian Broadcasting Commission (ABC) https://www.abc.net.au/catalyst/motorcycle-clothing/11016386
- 2016 – The Transport for NSW, assumed the lead role for the Motorcycle Protective Clothing working group and commissioned the development of test protocols for a PPE star rating scheme in consultation with industry (de Rome *et al* 2016b). Transport for NSW actively sought interested parties, and the consortium grew to 20 members including the AMC.
- 2016 - Dr Liz de Rome and Dr Chris Hurren from Deakin University Institute for Frontier Materials were contracted to the consortium to develop test and rating protocols for motorcycle protective clothing.
- 2016 – The test protocols were distributed for comment to the motorcycle accessories industry in Australia and New Zealand including local manufacturers and importers.
- 2018 - Dr Liz de Rome and Dr Chris Hurren were contracted to the consortium to conduct testing of motorcycle protective clothing for publication under the MotoCAP program.
- 2018 – The Motorcycle Clothing Assessment Program, and the accompanying website, www.motocap.com.au, were launched in September by the MotoCAP working group,. At launch, there were twenty products rated on the website. At the time of this paper, there were 128 products on the website, with the site continuously updated.

Why stars and not a standard

Australian riders are hesitant for the introduction of a protective clothing standard. The introduction of a standard poses two main problems. The first is that a standard does not delineate how well a product performs. It produces product that is either a pass or fail. This leaves the rider still not knowing performance levels of a product. The second reason is the mandatory helmet laws in

Australia requiring a helmet to be worn that meets a standard. Riders are concerned the introduction of a standard may be followed by the introduction of a mandatory clothing law.

Significant work done by New Zealand with their Ride Forever program has shown that empowering the rider with the appropriate skills and knowledge often leads to a lower risk position for a rider. This is seen in their statistic showing that a rider is 27% less likely to be involved in a crash if they have done Ride Forever training (McMillan 2018).

1. **Need a consumer/rider centric test** – The ratings system uses the same test methods as the European standard EN 13595 for jackets, pants and one piece suits, but rather than using a simple pass/fail score, this allow products to be ranked and rated on their relative performance. A 5 star rating scheme enables riders to make informed decisions when buying protective garments based not only on protection but also breathability, allowing riders to choose the most appropriate gear for their riding conditions.

2. **Inappropriate for Australia's diverse climate** – Whilst protection is the main aim of motorcycle gear, comfort is an important factor for riders. If motorcyclists are comfortable, they will more likely wear motorcycle gear and perhaps, choose more protective gear for better safety on the bike.

3. **Does not provide a market incentive for manufacturers to improve the quality of their gear** – it has been found where testing is left to manufacturers, some companies avoid any reference to safety when marketing their motorcycle clothing products. The objective of the 5 star ratings scheme is to fully fund and manage the introduction of the scheme to allow local industry to improve their products where necessary.

4. **Helps riders make informed decisions about what is best for them** - The weight, flexibility, temperature control and fit of clothing can all contribute to motorcyclists' comfort levels and keep riders alert to minimise rider error. Riders can choose to buy based on level of protection, as well as comfort, taking into consideration the type of riding they do.

How MotoCAP is influencing the market

- What do Australian motorcycle consumers think?

The author, a motorcyclist for over 50 years - When I retired, I was given a leather jacket. I had been told that when leather is treated to make it soft, it can destroy its abrasion resistance. I was reluctant to wear the jacket not knowing how good it was. It hung in my wardrobe for 2 years until it came up on MotoCAP and it rated fairly well. I'm now quite happy to wear it.

- What do manufacturers think? Have manufacturers changed their product development?

1. Australian company Draggin Jeans, designers and manufacturers of the world's first pair of protective motorcycle jeans were about to discontinue their range of Next Gen Seamless jeans when they noticed an increase in international sales. The reason for the rise in sales was the jeans had performed well in the MotoCAP rating system. The protective jeans were awarded a 4 star safety rating and a 3 star comfort rating.

2. Manufacturers are recognising the standard and consumer confidence in the measurability of MotoCAP 5 star rating scheme. Two small Australian start-up companies have purchased laboratory testing time to develop their protective motorcycle gear. These products will have a go-to-market of more than 12 months.

3. A state government protective agency in Australia have used the MotoCAP testing facilities on a variety of protective motorcycle gear before issuing to their motorcycle riders. The test results influenced their decision on which garments they will purchase.

4. Some motorcycle gear manufacturers, such as Hood Jeans in the UK, have identified a short-coming with the Darmstadt Abrasion machine currently used with the introduction of the new PPE standards (EN 17092). The results of the Darmstadt Abrasion cannot be used in research and development to compare the performance of different materials because it replicates a slide and tests whether perforation of the construction is smaller than half a centimetre. This machine then only provides a 'pass' or 'fail' result, whereas the Cambridge machine used in the MotoCAP test provides a detailed performance value. From the results of the Cambridge machine test, manufacturers can use the MotoCAP published results to compare with the result of their competitors garments.

5. General Manager of major importer Cassons, Geoff Wood, told AMCN (AMCN 2019) he absolutely approves of the testing regime.
   "We are passionate as a team about motorcycle safety," he said, "(and) consumers need a reference point, as we don't have the standards on riding apparel that exists in Europe."
   That general view is backed up by Joel Ryan, business development manager at accessories distributor Ficeda.
   "I believe it's (MotoCAP) a great initiative. For us as a company, it helps support the message we have been telling our customers for years. It highlights the differences between products and makes customers think about their purchase and, hopefully, ask the question: How safe is this product?"

The future of MotoCAP

More publicity
Since the launch of MotoCAP in September 2018 there have been over 22,000 unique users to the MotoCAP website, with over 1,300 subscribed to receive updates when more garments are added to the site. 78% of visitors originate from the target countries of Australia and New Zealand, with the remainder visiting from other countries. Almost 8% of visitors originate from Europe.

More products
In the future, we would like manufacturers and importers to see the value of the 5 star ratings scheme and fund research of the protective and comfort ratings of their motorcycle gear.

Worldwide 5 star scheme
Other countries could adopt the MotoCAP test protocols and ratings methodology, which are published and available on application. The protocols are based on tests from current European standards, using commonly available test equipment. The tests used in the MotoCAP test protocols

have been modified only to account for the need for test samples to be harvested from completed garments, whereas common practice is to test representative samples in flat sheets of the materials and construction methods.

The current MotoCap website, where the results are published, is available to riders and industry globally, although currently only in English.

Conclusion

The introduction of a 5 star Scheme was supported by riders right from the start. MotoCAP allows riders to have options on what they buy depending on their needs and likes. MotoCAP educates riders and manufacturers on what features of a garment make it protective.

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Optimized protective clothing for motorcyclists: Which safety benefit can airbag-clothes deliver?

Dr.-Ing. Matthias Kühn, German Insurers Accident Research, Berlin

Antje Lang, German Insurers Accident Research, Berlin

Raúl Aranda, Institute for forensic medicine at LMU , Munich

Dr. rer. biol. hum. Dipl.-Ing. Klaus Bauer (FH), Institute for forensic medicine at LMU , Munich

Prof. Dr. rer. biol. hum. Dipl.-Ing. Steffen Peldschus, Institute for forensic medicine at LMU , Munich

Introduction

Motorcyclists still have a significantly higher risk than car occupants of being injured or even killed in an accident. Over 18% (583) of all road users killed in Germany in 2017 were motorcyclists. In the same year, almost 10,000 motorcyclists were seriously injured in road accidents, which is almost a third of the number of seriously injured car occupants. This also represents an increase on the share seriously injured ten years ago (Destasis, 2018). The total annual distance covered by motorcyclists in Germany amounts to only around 2% of the distance covered by cars (BASt, 2018). That means, in relation to the covered distance, motorcyclists have a considerably higher risk of being killed in a road accident than car occupants. In 2017 the risk was higher by a factor of 20. Moreover, the level of risk is constantly increasing. The accidents of motorcyclists are often serious collisions, since they do not have the benefit of the protective crumple zones or highly developed safety systems that have become standard in virtually all cars. Depending on the circumstances of the impact, the motorcyclist's body may have to absorb most of the energy involved, which often results in severe and fatal injuries. Accordingly, there is significant scope for optimizing the protective clothing of motorcyclists. In particular, new developments such as airbags in protective clothing are highly promising. However, a detailed analysis of the injury patterns and protective mechanisms is essential so that solutions can be developed and their effectiveness assessed. There has been insufficient research carried out into this so far. The aim of this project is to study the accidents that occur in order to identify typical accident situations and impact scenarios. In addition, a list ranking the regions of the body most badly affected will be produced. Based on these findings, selected "optimized protective clothing" will be thoroughly assessed in terms of its potential to prevent injuries and mitigate the severity of any injuries.

Underlying data and methodology

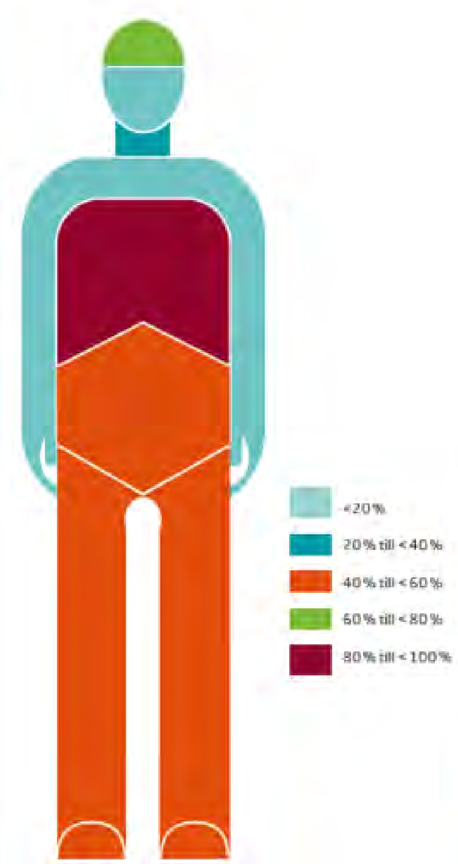
The regions of the body most often affected in motorcycle accidents were identified initially following an analysis of the available accident data. In addition, typical accident situations involved in motorcycle accidents, any relevant impact parameters of the motorcyclist and the characteristics of the object involved in the impact (including its geometry) were obtained from the accident data. The motorcyclist's speed of impact was of particular interest here in order to be able to calculate the force expected to be transferred to the motorcyclist.

Three samples were available, which largely account for the serious accidents. On the one hand, there were 76 fatal motorcycle accidents from the years 2004 to 2014 provided by the institute for forensic medicine at Ludwig-Maximilians-Universität München (LMU). In addition, there were a further 55 fatal motorcycle accidents (from the years 2003 to 2016) provided by a firm of experts. Autopsies of these motorcyclists or pillion passengers were carried out at the institute for forensic medicine at LMU. The motorcycle accidents were selected if they met the criteria of involving a motorcycle of the EU category L3e or L4e and a motorcyclist or pillion rider who had died as a result of the accident. Detailed records were available for the accidents in the form of technical and medical documents. These included accident analysis reports, technical reports and autopsy reports. The documented injuries were categorized on the basis of the Abbreviated Injury Scale© or AIS (2015). This case material was complemented by accidents involving motorcycles taken from the UDV accident database (UDB). 156 accidents were available involving at least one motorcycle belonging to the category L3e. 213 motorcyclists/pillion passengers were injured to varying degrees in these accidents. However, detailed medical information was available only on the 42 who were seriously injured and the 23 who were killed.

The circumstances of accidents involving two-wheelers are generally relatively complex, and when they are reconstructed, uncertainties often cannot be eliminated. In particular, the impacts of motorcyclists are difficult to describe because they often involve more than one object. This is also clear from the literature (COST, MAIDS). In order to be able to circumscribe the impact parameters of the motorcyclist during the accident without having to carry out a very time-consuming and detailed reconstruction of all accidents, the fatal accidents of LMU and the firm of experts were subjected to simplified kinematic encoding. In particularly complex scenarios and for some particularly relevant accident situations, multi-body system simulations (PC-Crash and Madymo) were carried out to complete the picture. Finally, based on these results, detailed finite-element model (FEM) simulations were carried out in order to assess and categorize the injury risk and the potential of optimized protective clothing to provide protection.

Injuries and most often involved body regions

As far as injury severity is concerned, it is clear that the available data largely concerns very serious accidents. Just over 30% of the motorcyclists on whom autopsies were carried out at LMU had an injury severity of MAIS 5, and just over 40% had an injury severity of MAIS 6, which is currently considered to be untreatable. 94% of all motorcyclists or pillion passengers on whom an autopsy was carried out at LMU had serious thoracic injuries at the level of MAIS 3+ (figure 1). The high prevalence of thoracic injuries tallies with the findings of other studies (COST, MAIDS, MOSAFIM). Frequent injuries included haemothorax, fractured ribs and lung injuries. Injuries to the thoracic aorta were found in around a third of the motorcyclists involved in these accidents.



MAIS Head 3+	87	63,8%
MAIS Face 3+	11	8,0%
MAIS Neck 3+	44	32,1%
MAIS Thorax 3+	129	94.2%
MAIS Abdomen 3+	66	48.2%
MAIS Upper Extremities 3+	8	5.8%
MAIS Lower Extremities 3+	75	54.7%
MAIS External 3+	3	2.2%

Figure 1: Percentage of people killed who had at least one serious injury (AIS 3+) in the regions of the body shown (LMU, n=137)

In addition to the motorcyclists killed in accidents, less seriously injured motorcyclists were also investigated using the UDB. This was done in order to address less serious injuries as well and get a better impression of all the accidents taking place. 78 motorcyclists from the sample taken from the UDB were categorized as “slightly injured” or “uninjured”. 112 people suffered injuries with a MAIS 1+ degree of severity. 42 of the motorcyclists had injuries with a MAIS 3+ degree of severity. Among the 44 motorcyclists and pillion passengers with MAIS 2 injuries, injuries to the extremities were most common, and thoracic injuries were of only secondary relevance (figure 2, multiple responses possible).

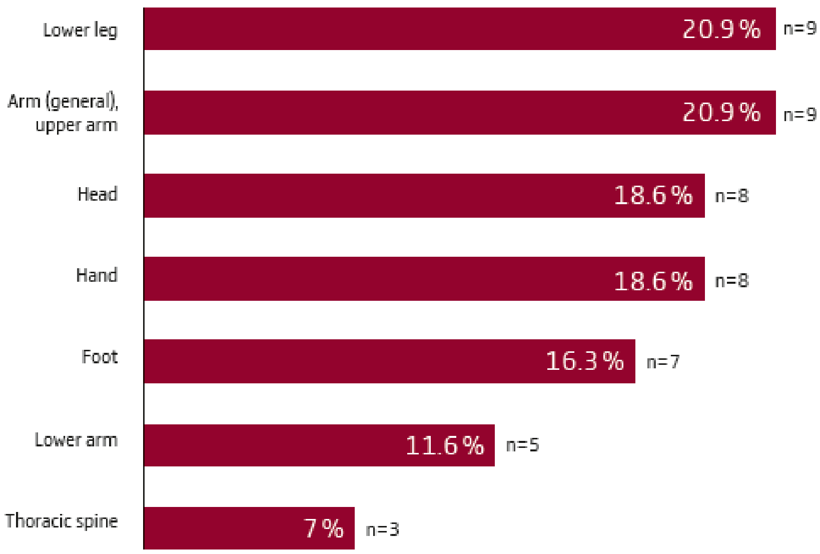


Figure 2: Region of the body with the highest AIS value (motorcyclists with AIS 2 injuries in the UDB, n=43)

This tallies with the analyses of minor motorcycle accidents in the literature. In the MAIDS study, for example, it was found that around 32% of the motorcyclists involved in accidents had AIS 1+ injuries to the lower extremities. This was the most commonly injured region of the body, followed by the upper extremities (around 24%). In Malczyk's dissertation, around 71% of the motorcyclists with AIS 1+ injuries had fractures in their lower extremities (MAIDS). Around 36% had a fractured femur, and 29% had a fractured tibia/fibula (Malczyk). It should also be mentioned that the percentage of head injuries in the samples studied was also high. In the current project, however, it was decided not to study this region of the body in any depth. Other studies (COST, MAIDS) have already addressed head protection for motorcyclists in depth. When all the findings obtained from the analysis of the injuries are compiled, it becomes clear that the thorax is by some distance the most relevant and very often the most seriously injured region of the body, particularly in serious and fatal accidents. Consequently, this project addresses thoracic impacts and analyzes the potential of optimized protective clothing.

Kinematic analysis and typical impact parameters

The kinematic analysis and advance categorization carried out before the detailed calculations enabled the subsequent grouping and identification of particularly frequent and relevant impact parameters. These were then analyzed in detail by means of simulations.

In each case, the available technical and medical documents were examined, and based on these the possible course of the accident, including the mechanical impact parameters, was described. In addition, rough calculations were carried out, and attempts were made to link the thoracic injuries with specific objects involved in the impacts. The objects involved in the impacts were categorized based on factors such as their radii and rigidity. It was found that the objects were largely highly rigid. The radius of the object or whatever the victim comes into contact with plays a key role in the mechanical analysis of the injuries and the protective clothing. For example, the impact forces can be transferred to the relevant part of the motorcyclist's body at particular points or distributed over a larger area. When the force is transferred against a particular point, there is an increased risk of injury. On the other hand, when it is distributed over a larger area, the intensity of the load to be expected is lower assuming the impact parameters are otherwise the same. The speeds of the motorcyclist on impact, in particular the vertical portion of the speed in relation to the object, which is of particular relevance to the injury caused, were also studied.

Based on the results of the kinematic analysis, the following key areas of focus can be identified for the thorax in the relevant impact scenarios:

- Impact with the road (vertical speed of around 17 km/h)
- Impact with an object with a radius of around 0.075 m, impact speed of around 25 km/h
- Impact with an object with a radius of around 0.075 m, impact speed of around 60 km/h
- Impact with an object with a radius of around 0.25 m, impact speed of around 50 km/h

A small impact radius is typically found with car structures such as the edge of the roof or the sill or objects at the side of the road such as the posts of crash barriers. A somewhat larger radius is characteristic of components such as the corners of bumpers, for example, but also, in particular, of trees or other vegetation at the side of the road. Within these key areas of focus, typical accident scenarios were identified and analyzed in detail. The procedure is described below using the example of one particularly relevant impact scenario (motorcyclist collides with the side of a car crossing its path). The accident was initially assessed on the basis of relevant parameters and then simulated using multi-body simulation in Madymo (figure 3). A motorcycle model available to LMU and a freely available vehicle model from the NHTSA database were used for this. The purpose of the multi-body simulations was to calculate the impact parameters of the motorcyclist, in particular the speed, orientation and exact point of impact. These then serve as the initial parameters for the finite-element model (FEM) simulation of the loads and injury risks to be expected.

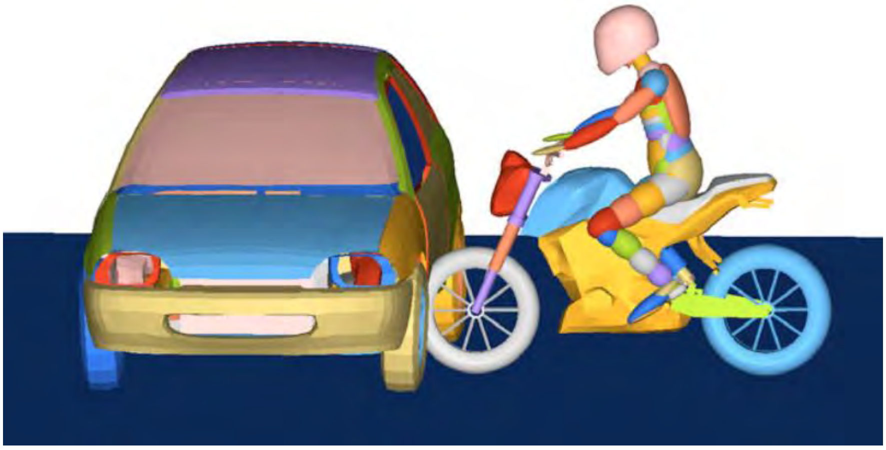


Figure 3: Multi-body simulation of the impact of a motorcyclist with the side of a car

Simulation of typical impact situations and injury-related mechanical assessment

The further simulation of the typical impact situations and the injury-related mechanical assessment was carried out by means of FEM simulations. The male 50th percentile of the Global Human Body Model Consortium (GHBMC) model was used for this. The model is being constantly further developed and has been adequately validated for the selected application scenarios.

The airbag concept was used as optimized protective clothing in this research project. In order to be able to ascertain the potential of the latest commercially available thorax airbags to offer protection, a corresponding generic (i.e. general) finite-element model was developed and adapted for the human body model (figure 4). To this end, a technical exchange was sought with well-known airbag manufacturers. In addition, in order to further circumscribe and examine the model parameters, a commercially available thorax airbag was tested multiple times on the basis of the valid test conditions specified by EN 1621-4. The generic model meets the requirements of safety level 2 of the EN 1621-4 standard.

Figure 4: FEM human model (GHBMC) and generic thorax airbag model

An “optimized” airbag with a significantly greater volume was modelled for further investigations. However, this was merely a model concept intended to illustrate the potential and limits of future developments. It will not necessarily be easy to implement this concept technically. Based on the results of the kinematic analysis, the generic scenarios identified as key areas of focus were then simulated. To this end, the human model was propelled at the calculated speed against an object with the relevant radius and the calculated rigidity (figure 5). The simulations were run both with and without an airbag.

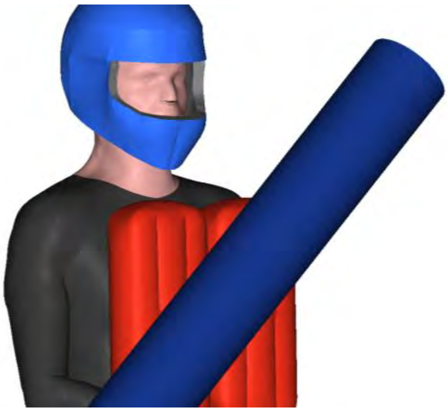


Figure 5: Essential setup of the FEM simulation of a generic scenario (radius of the object involved in the impact: 0.075 m)

In addition, a number of typical real accidents were replicated and simulated by means of FEM. The collision of a motorcyclist with the side of a car and the resulting impact of the motorcyclist's thorax with the edge of the roof is shown in figure 6.

Figure 6: FEM simulation of the impact of a motorcyclist with the edge of a car's roof

On the basis of these simulations, the loads and the thoracic injuries to be expected were then ascertained and assessed. Thorax deformation and fractured ribs were used for this, in particular, since it seems possible with the model used to calculate real injury risks using these parameters.

For the example of the impact of a motorcyclist at 60 km/h against an object with a radius of 0.075 m (e.g. the edge of a roof), the thorax is shown with the heart, aorta and lungs in its initial state (in the images on the left) and at the point of maximum compression (in the images on the right) in figures 7 and 8. It is clear that this is a very serious impact and that very serious injuries would be expected from it. In addition to serial rib fractures on both sides, the expected injuries would include life-threatening injuries to the heart or aorta. In this example, a state-of-the-art airbag would reduce the load on the body only slightly, if at all. It is likely that there would be little difference in the severity of the injuries with or without an airbag.

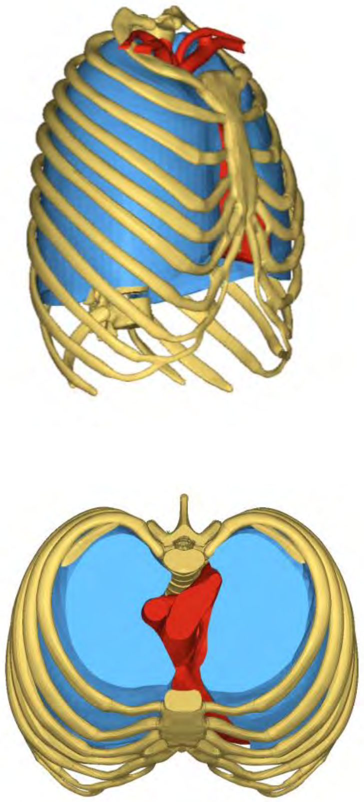


Figure 7: Condition before the collision

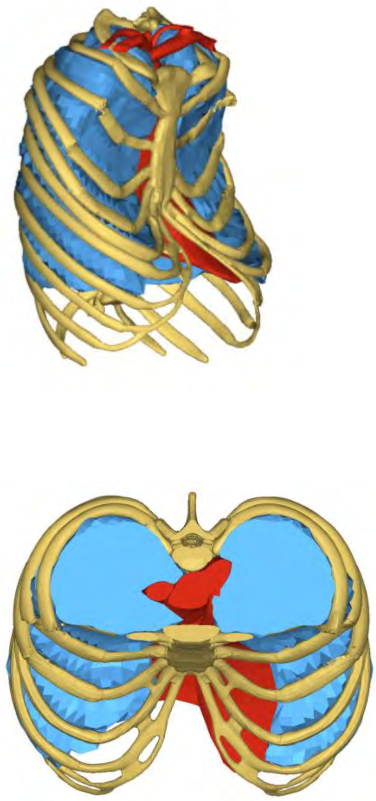


Figure 8: Deformation during the collision

The results of the mechanical analyses of the injuries make it clear that currently available thorax airbags can only offer protection at low speeds of impact. At a speed of impact of 25 km/h against the same object with a small radius (0.075 m), there are clear positive differences compared to an unprotected impact. Instead of the serial rib fractures on both sides that occur without an airbag, there are only two fractured ribs with an airbag. Thorax deformation is reduced from around 70 mm to around 45 mm, which would significantly mitigate injuries. In the case of an impact against a surface such as the road, which is most likely to occur as a result of a fall and generally happens at a speed of under 20 km/h (vertically to the surface), no serious injuries would be expected even without an airbag.

At speeds of impact of 50 km/h (radius: 0.25 m) and 60 km/h (radius: 0.075 m), current airbags reach their limits. No protective effect can be observed in terms of injury severity at these speeds. In these scenarios only an “optimized” airbag, which has not yet been implemented in this form, would help (figure 9). However, even a significantly optimized airbag comes up against its limits. It was possible to show by means of the simulations carried out that the protective effect decreases dramatically as of a speed of impact of slightly over 60 km/h. As of a speed of impact of 70 km/h, there is no longer an appreciable protective effect.

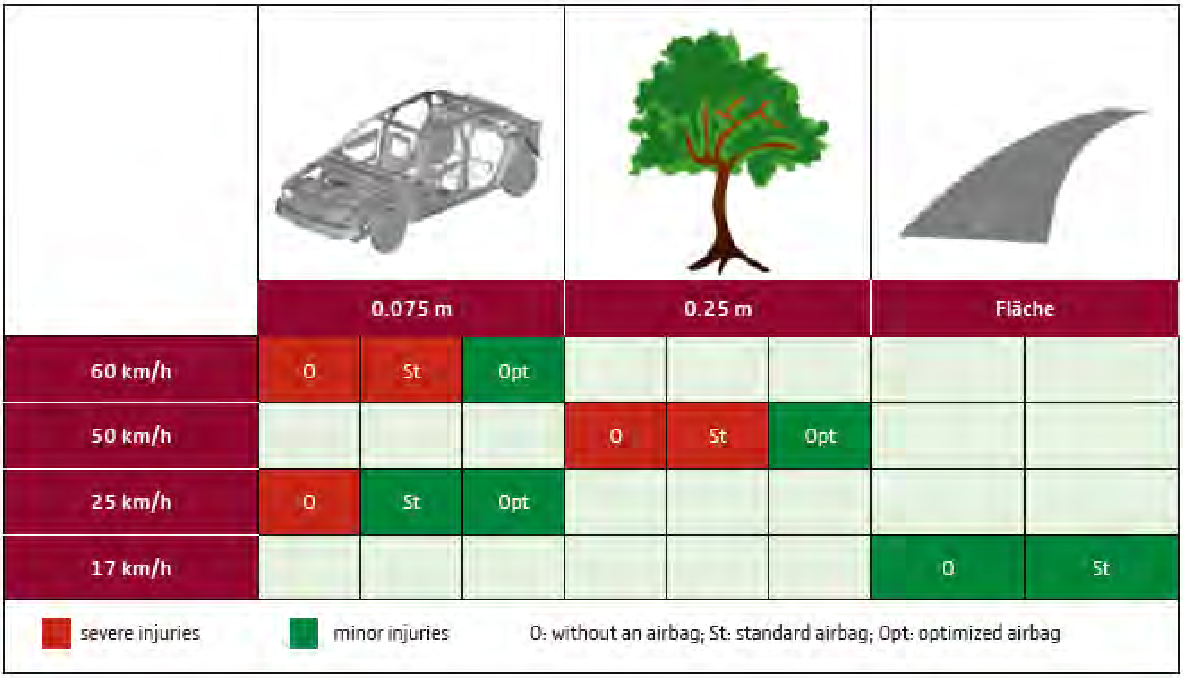


Figure 9: Simulation matrix and protection potential (red: severe injuries; green: minor injuries; 0: without an airbag; St: standard airbag; Opt: optimized airbag)

Recommendations on the protection offered by optimized protective clothing

Taking the results of the analyses together, it is clear that today's commercially available thorax airbags can mitigate injuries at lower speeds of impact. The higher the speed of the impact and the smaller the radius of the object involved in the impact, the smaller is the protective effect that can be expected. As of a speed of impact of at most 50 km/h, no appreciable mitigation of injury severity can be expected. Even a significantly optimized airbag, which can still have a protective effect in this speed range, is no longer effective as of a speed of impact of at most 70 km/h.

What that means in terms of accidents is that a thorax airbag can offer good protection in minor accidents, in particular. In such accidents, however, no severe injury consequences would be expected even with conventional protective clothing (without an airbag). The typical impact conditions ascertained (approx. 25 km/h) are in the range for which today's motorcycling helmets are designed and offer good protection against injuries. However, the analysis of accidents reveals that thorax injuries do not occur often in this group of minor accidents and are also not always very serious. Injuries to the extremities are most common in these accidents.

In more serious accidents at higher speeds of impact, the relevance of serious thorax injuries increases significantly. However, the protective potential of airbags in protective clothing decreases to the same extent. The benefits of today's thorax airbags should therefore be rated as acceptable, but given the overall context, they should be viewed as controversial.

DIN EN 1621, parts 1 to 4, is currently applicable in Germany for the marketing of approved protective clothing with mandatory labelling for motorcyclists and the protectors and airbags it contains. The standard specifies test procedures for ascertaining the extent to which this clothing absorbs shock and distributes impact forces. For example, chest protectors must allow only certain residual forces in an impact with a test object with a weight of around 5 kg and at a speed of around 16 km/h.

Inflatable protectors for motorcyclists are treated separately on the basis of a variety of parameters (e.g. intervention time, service life) and, in terms of their protective effect or shock absorption, only have to meet the requirements of conventional protectors. There needs to be a discussion about adapting the test parameters for optimized protective clothing developed in the future. In particular, the test weight used and the test speed should be increased appropriately.

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Presentation of MIPS Science

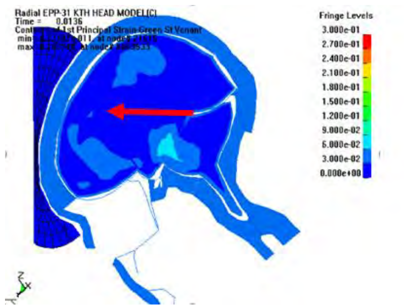
Peter Halldin[1,2] , Daniel Lanner[2]
[1] Division of Neuronic Engineering
Royal Institute of Technology (KTH)
Stockholm, Sweden

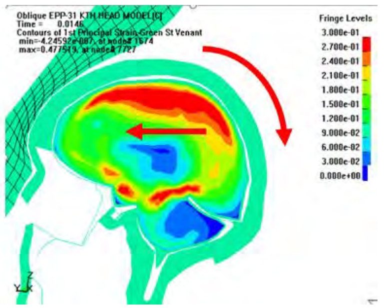
[2] MIPS AB, Stockholm Sweden

KTH Teknik och hälsa

Outline

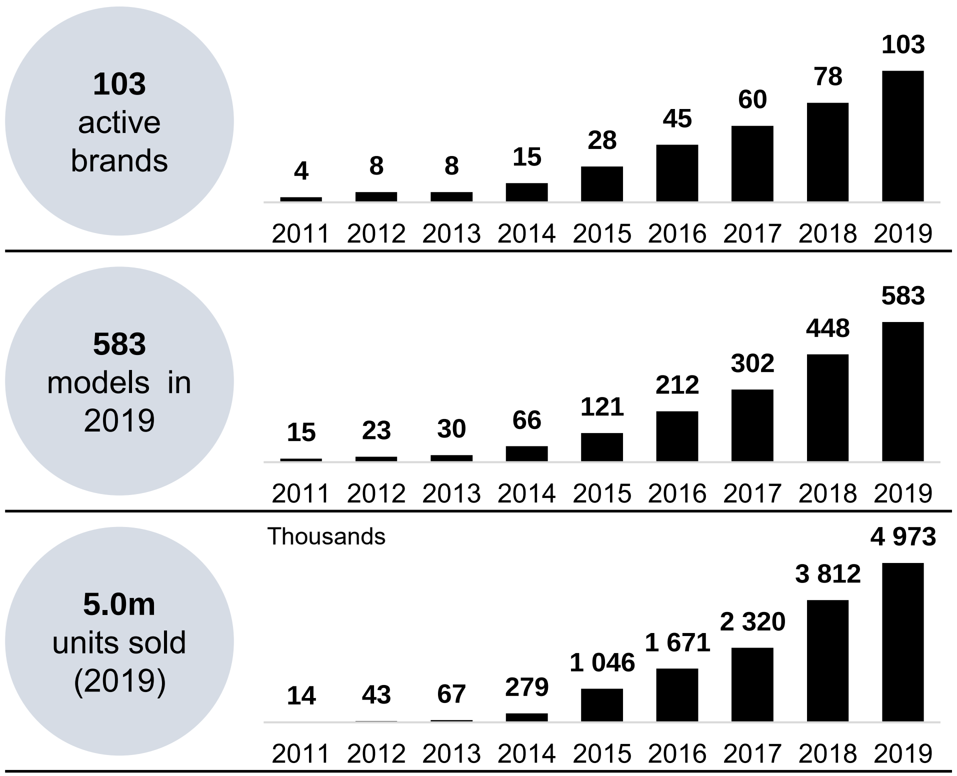
- Background to MIPS
- Research at the Royal Institute of Technology and FE model of the human brain
- MX accident reconstruction
- The Oblique test method
- MIPS test results





WORLD LEADING BRAND IN BRAIN PROTECTION SYSTEMS

- 103 helmet brands using the MIPS technology worldwide
- 583 helmet models
- 14m units delivered
- Established in three main categories:
  - Sports (Bike, Snow, EQ, Hockey and Mountaineering)
  - Moto (Road motorcycle and MX)
  - Safety (Industry and LEAF)



OUR HISTORY – FROM RESEARCH TO COMMERCIAL SUCCESS

1996-1998
Initial testing and seed funding, set up and patent filing costs

2001-2007
In 2001 MIPS AB is founded, followed by a start-up phase including a Swedish launch of a helmet with a MIPS solution

2010
MIPS becomes a true ingredient brand offering a global solution

2015
MIPS achieves profitability

2017
March 23, MIPS IPO on Nasdaq Stockholm

2019
More than 20 MOTO brands using the MIPS technology

Research | **Start-up phase** | **Growth / ingredient brand strategy** | **Scaling up / Cont. growth**

1995
Swedish neurosurgeon Hans von Holst contacts University to discuss solutions

2000-2001
First scientific publication regarding MIPS

2009
The first third party helmet with the MIPS Brain Protection System (BPS) is launched

2014
Establishment of the BRG and MIPS collaboration

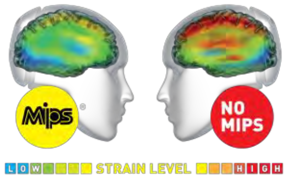
2016
The first street motorcycle helmet model with the MIPS BPS is launched

2018
Major legal disputes settled
→ proven strong patent portfolio

MIPS TODAY

25 Years of research at the Royal Institute of Technology and the Karolinska Institute.

4 Thesis and multiple research papers in international scientific publications.



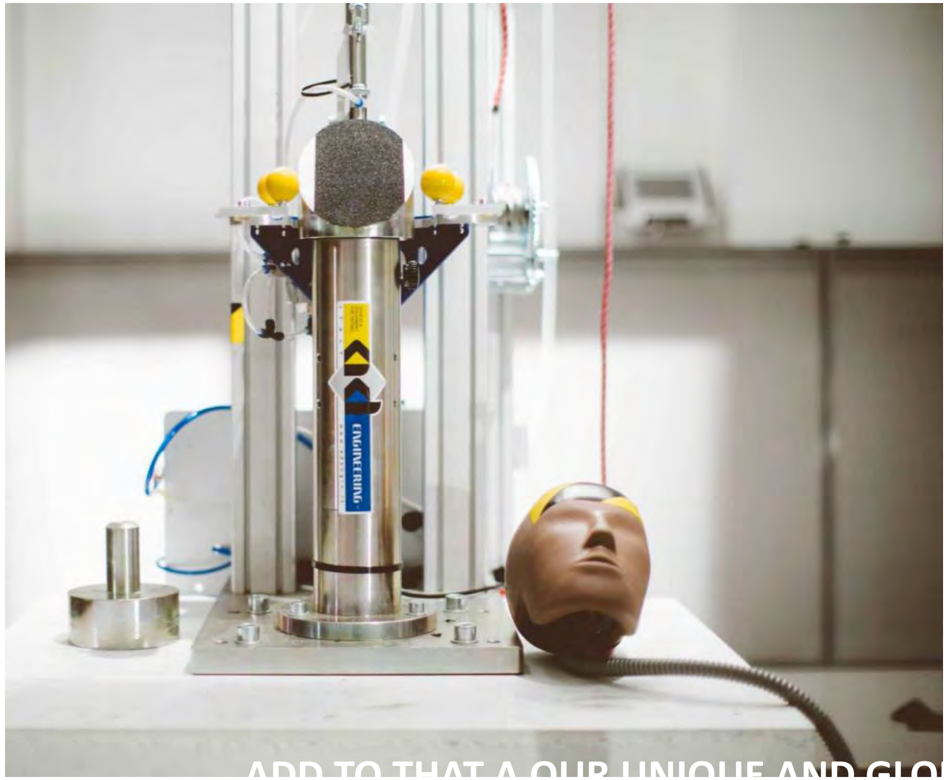
World renowned Finite Element (FE) Model of the human brain

35,000 State of the art test facility for all helmet categories.

Reconstructions from real life accidents.

BIOKINETICS External validation by 3rd party in US, Canada and Sweden.

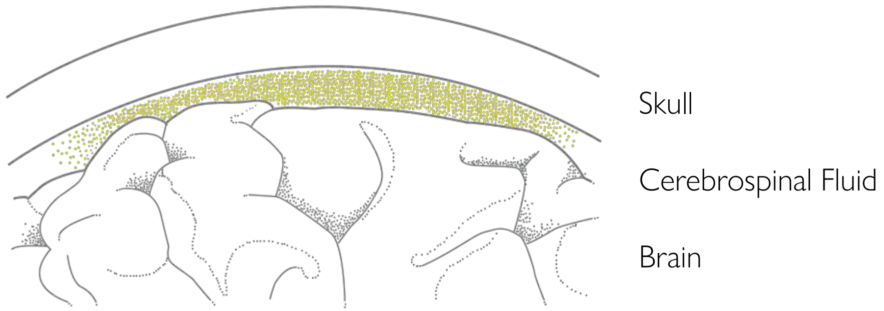
IP 36 Patent families

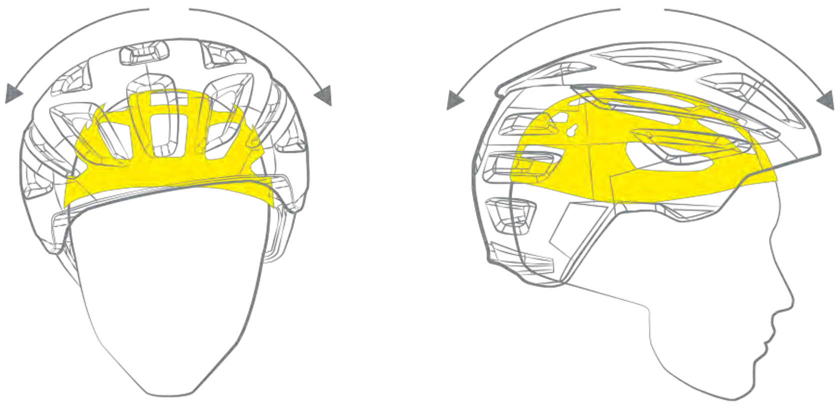


Multi-directional Impact Protection System

The cerebrospinal fluid is our natural protection system that allows the brain to move relative to the skull.

MIPS mimics the protective properties in the human brain and adds a layer of protection



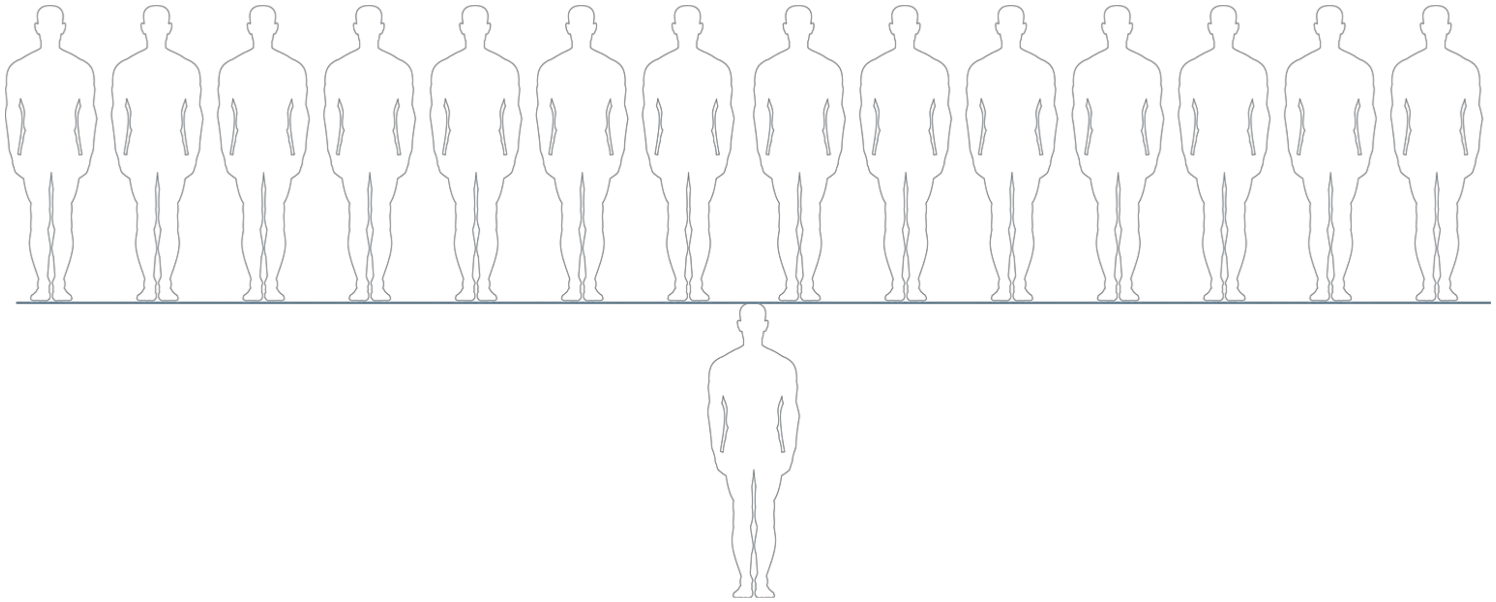


In the critical 5 -10 milliseconds of an impact ...

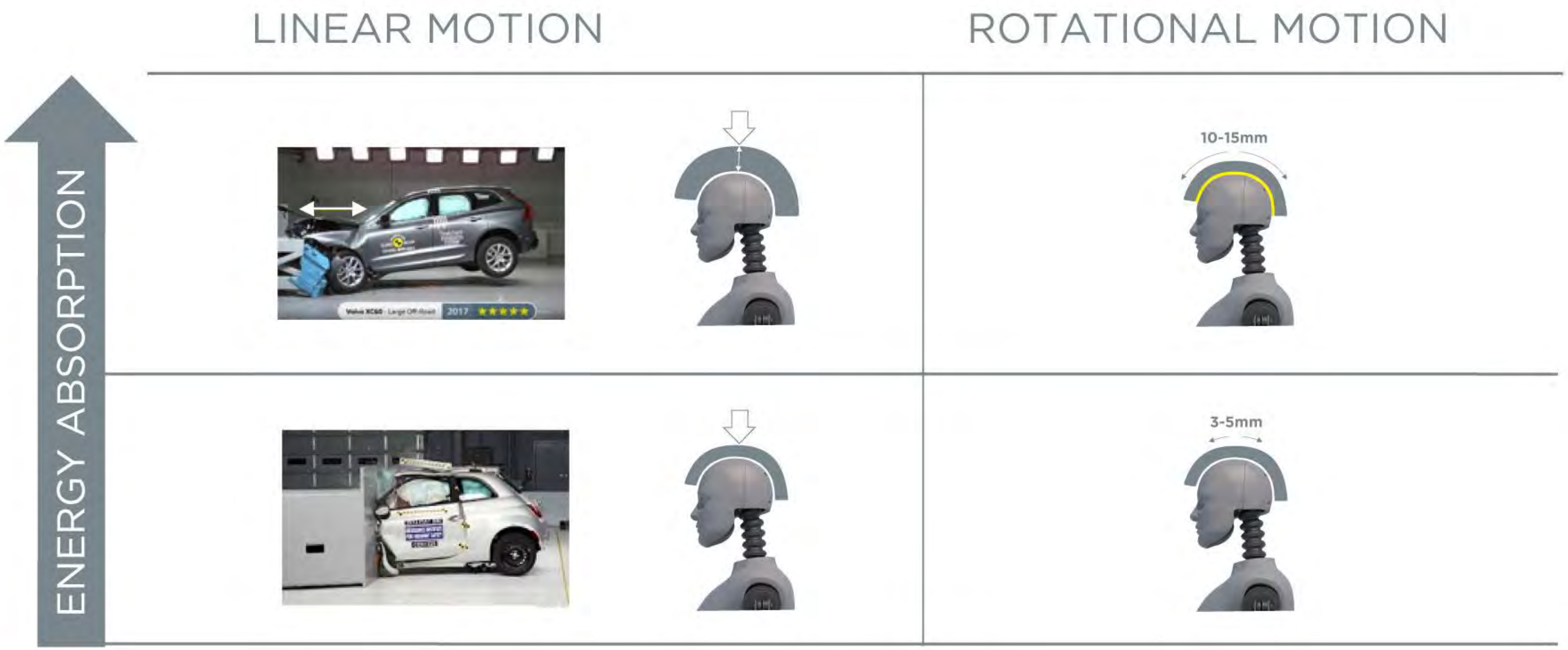
A blink of an eye lasts 100 milliseconds.

While under significant point loading

At the moment of impact the point load on the the head and the helmet is approximately 750 kg.

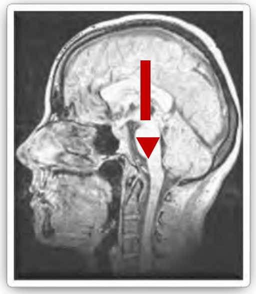


MIPS allows 10 – 15mm of relative motion between the head and helmet …



Why do we need MIPS?

Type of Injury dependent on Impact

Impact direction:	Linear	Rotational (Angled & Tangential)
Acceleration direction:		
Type of injury:	• Fracture • Epidural hematoma (EDH) • Contusion	• Concussion • Subdural hematoma (SDH) • Diffuse axonal injury (DAI)
Conclusion:	Conventional helmets are tested by dropping them vertically onto a flat surface and they are designed with that testing in mind.	By adding rotational protection to the helmet you add protection from those angled impacts.

Holbourn 1943
Löwenhielm 1974,
Ommaya et al. 1967,
Ommaya and Hirsch 1971,
Gennarelli et al. 1982
McIntosh et al 2011
Kleiven 2007

The team at KTH & Karolinska

Peter Halldin

FOUNDER OF MIPS

Assistant Professor
KTH, Royal Institute of Technology

Hans von Holst

FOUNDER OF MIPS

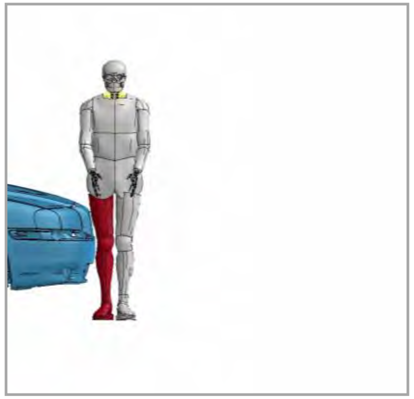
Professor and Neurosurgeon
Karolinska University Hospital.

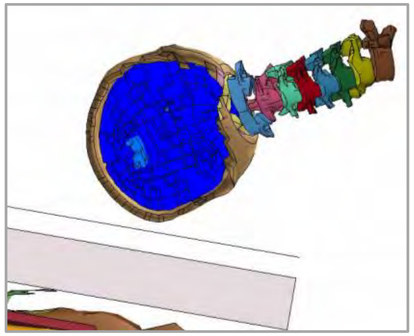
Svein Kleiven

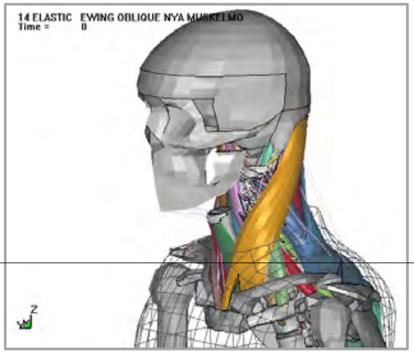
FOUNDER OF MIPS

Professor at
KTH, Royal Institute of Technology

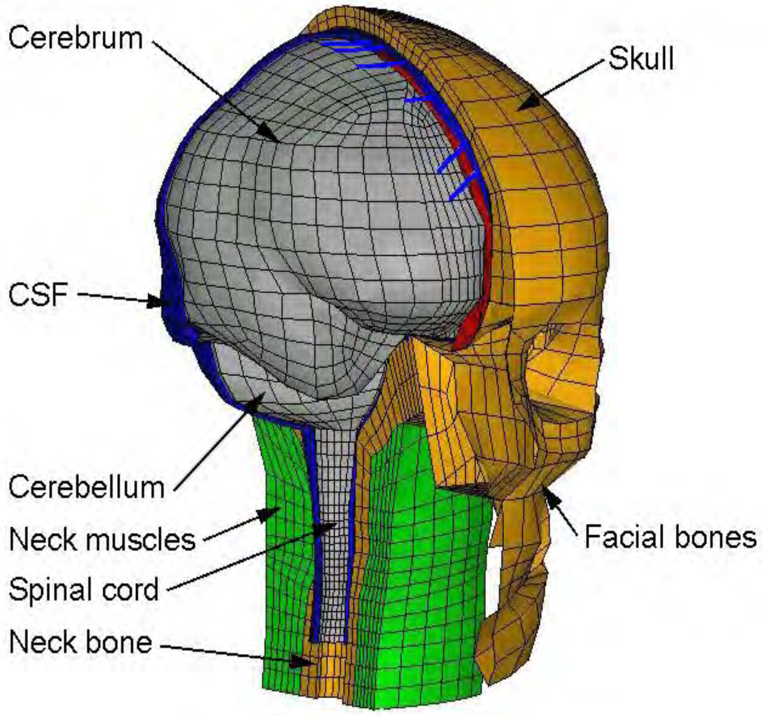
3-D model of the human brain



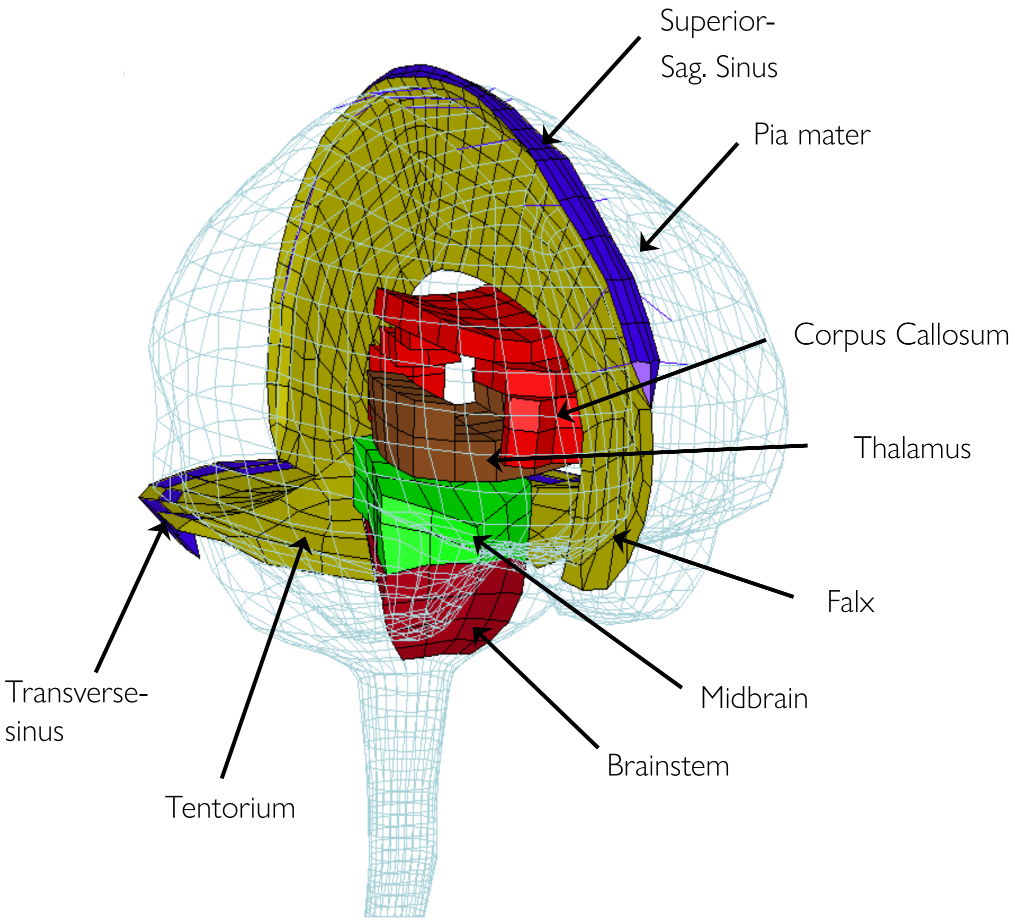




The KTH FE model of the human head and brain

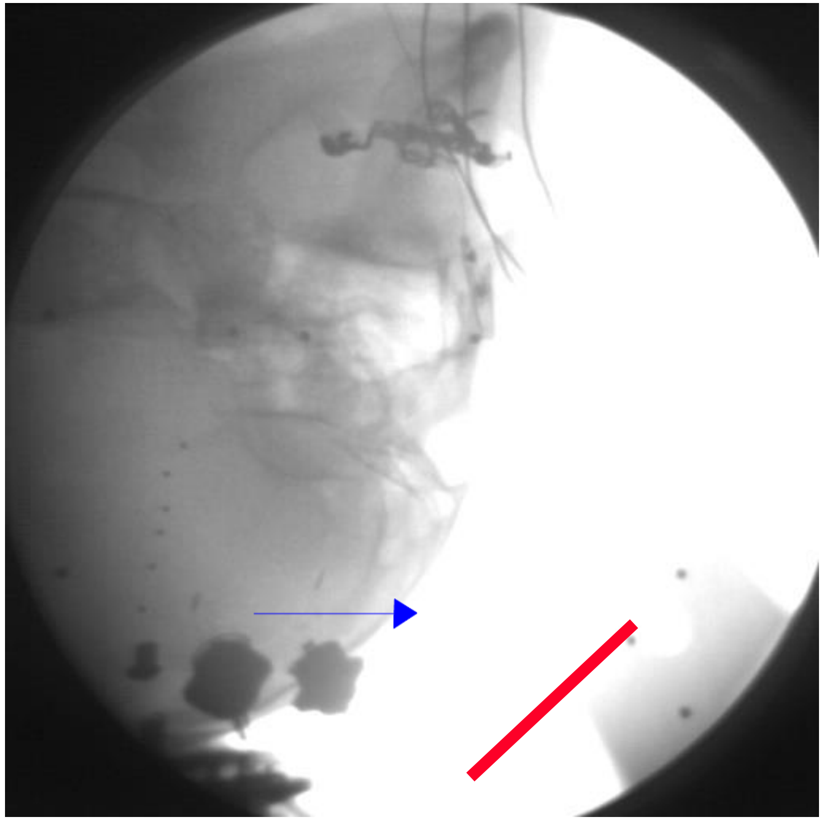


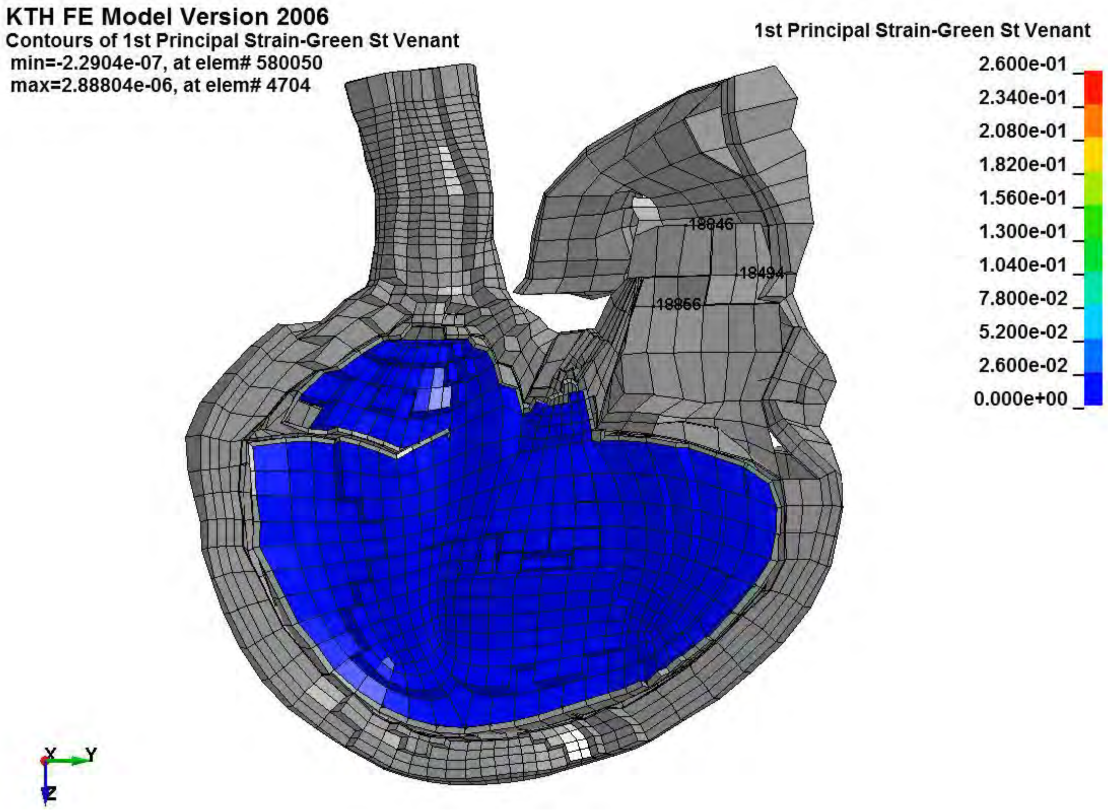
LS-DYNA



Kleiven et al. 2006

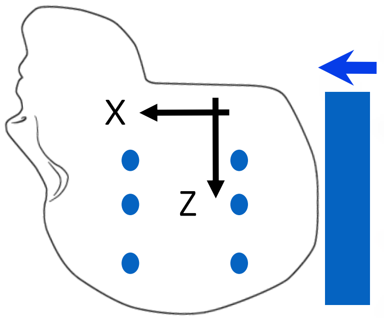
Validation of the KTH head model

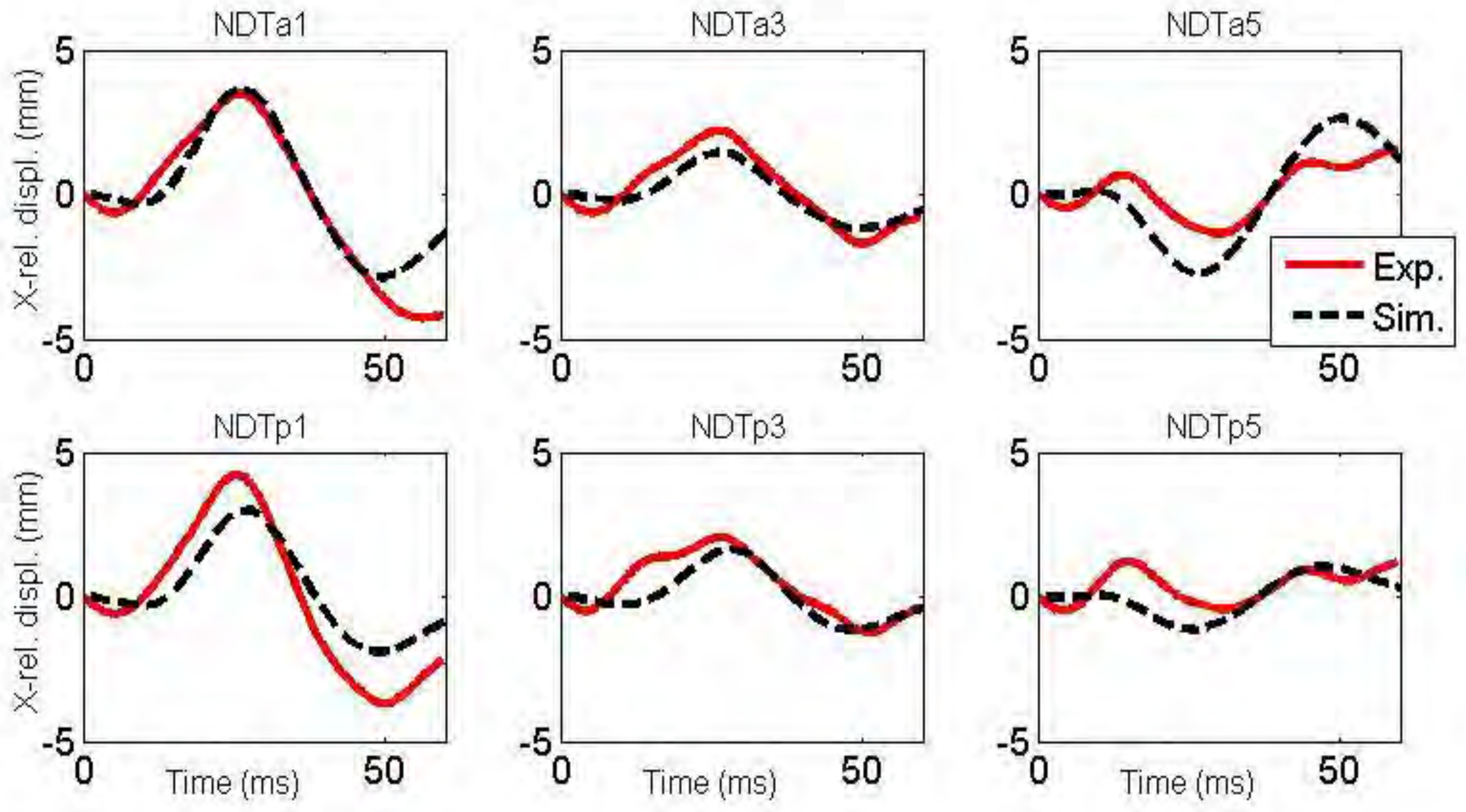




Kleiven and Hardy, Stapp Car Crash Journal 2002

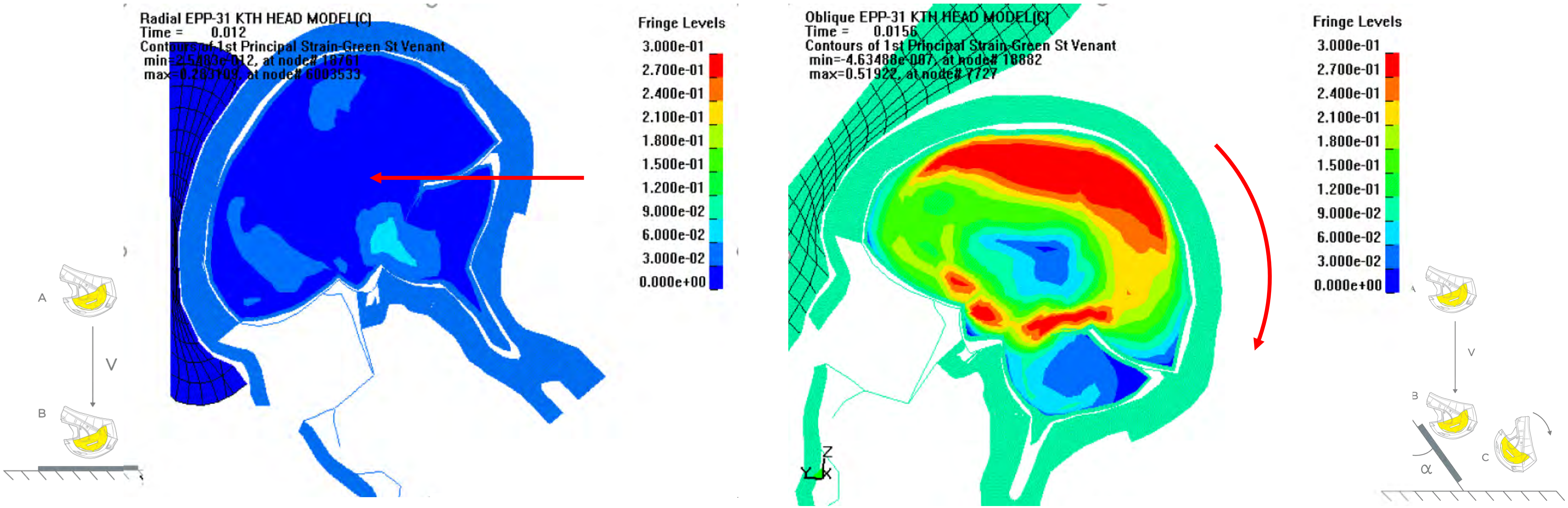
Validation of the KTH head model





Kleiven and Hardy, Stapp Car Crash Journal 2002

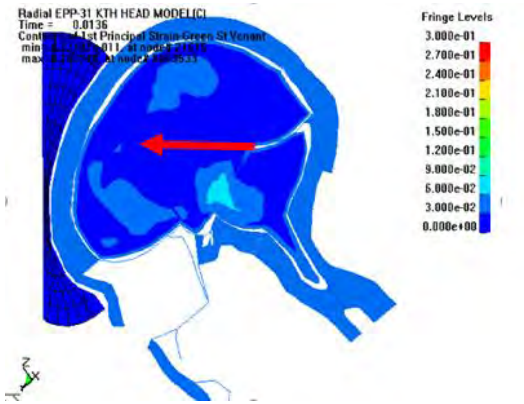
Comparing Radial v.s. Oblique impact

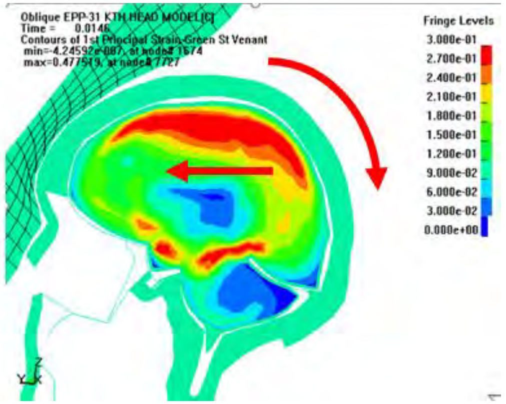


Kleiven, Enhanced Safety of Vehicles 2007

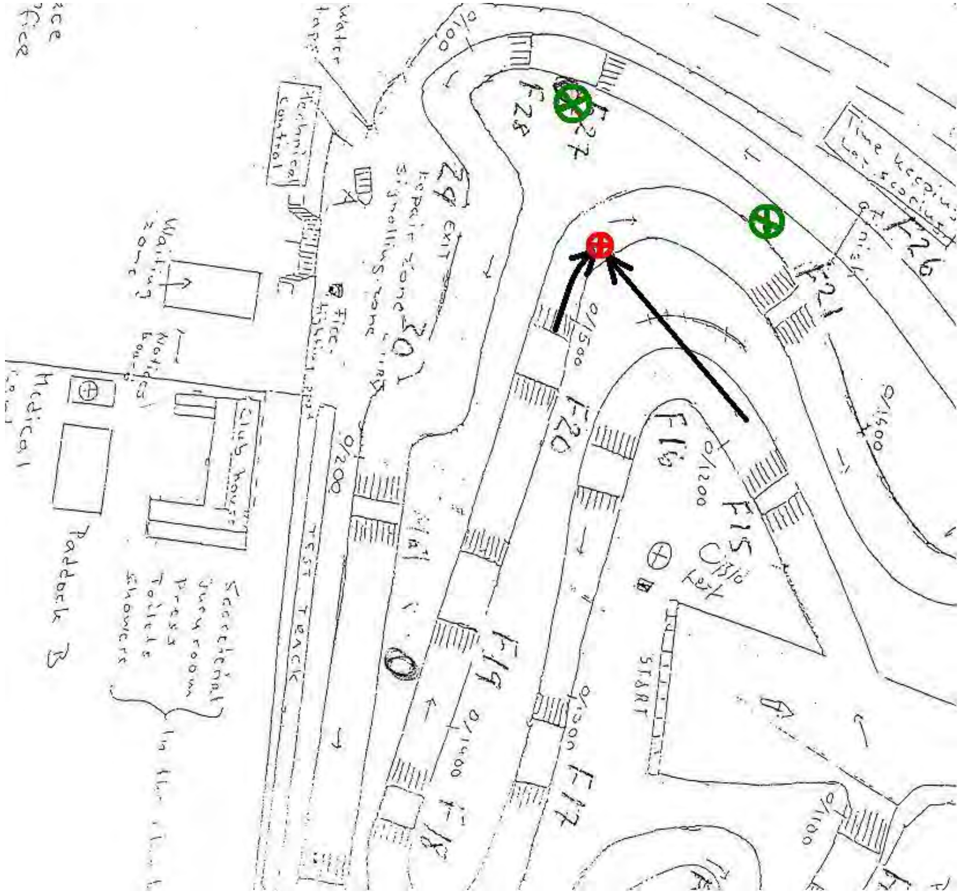
Outline

- Background to MIPS
- Research at the Royal Institute of Technology and FE model of the human brain
- **MX accident reconstruction**
- The Oblique test method
- MIPS test results





Accident scenario



The velocity was about 50km/h for both riders.

The impact was almost perpendicular.

Two cameras documented the accident.


TCR. 00:00:19:03*
V
A

Reconstruction set up

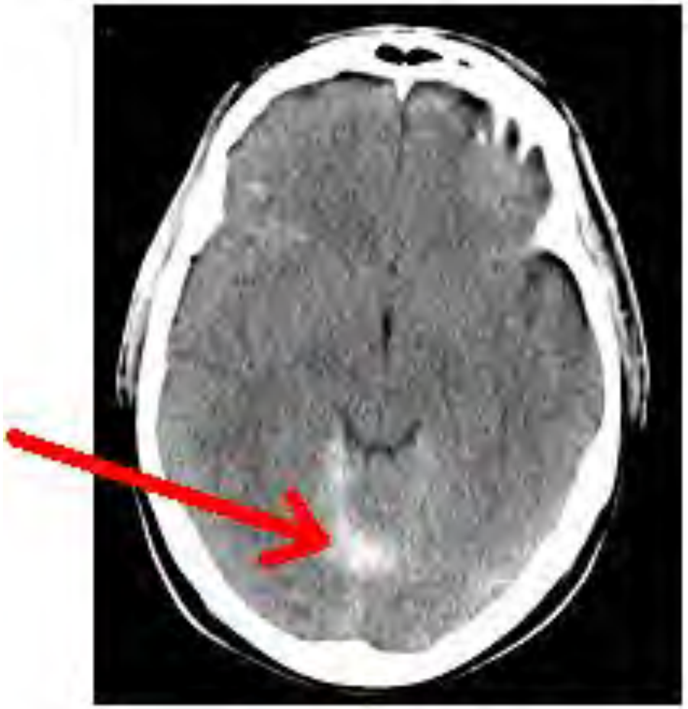
Based on the helmet and video from the accident we made a reconstruction of the accident by using our unique FE model.

The helmet with impact points

FE model of the impact

CT images from akademiska sjukhuset, uppsala

Hematoma in frontal lobe



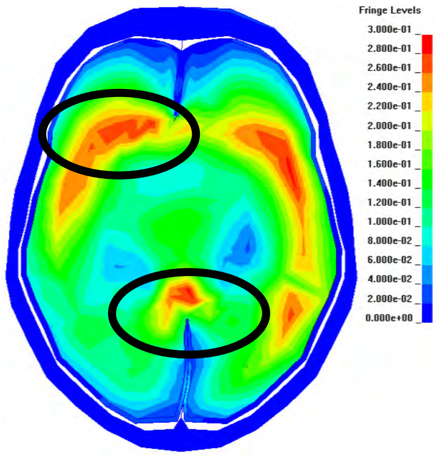
Hematoma along the tentorium

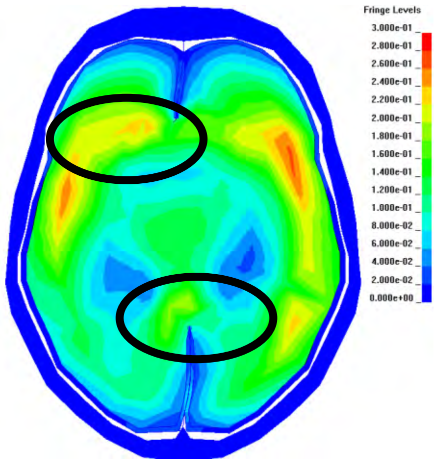
Strain pattern in the brain

Regular helmet design

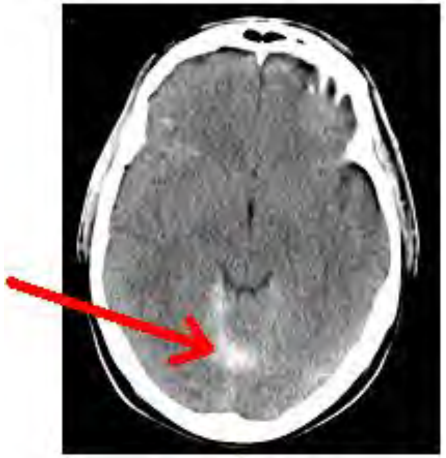
MIPS helmet design

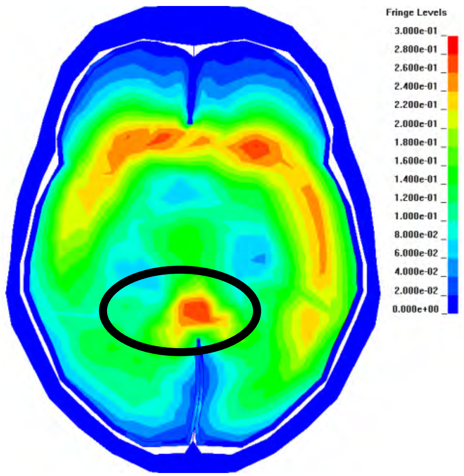
Hematoma in the frontal lobe

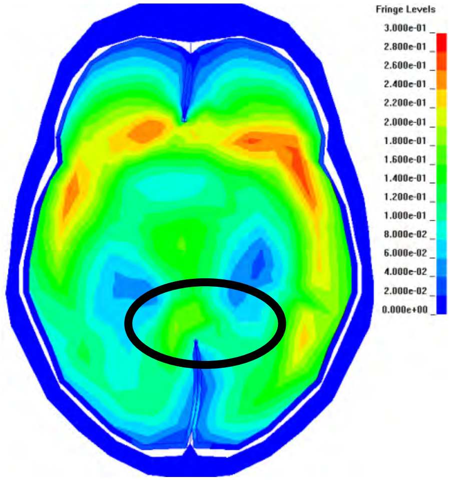




Hematoma in the rear part of the brain







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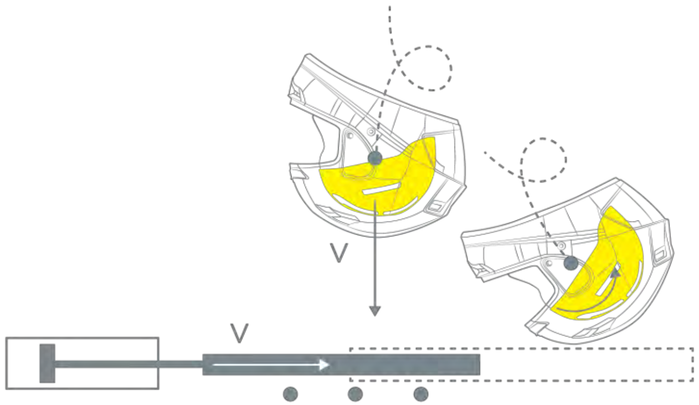
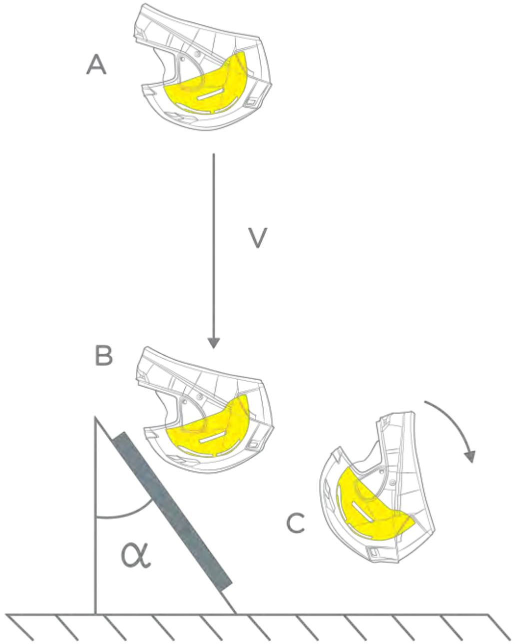




The direction of impact based on injury statistics & accidents reports

Bike

- Verschueren 2009, Bourdet et al. 2012
- 6,5m/s. 45 degree, road.

Equestrian

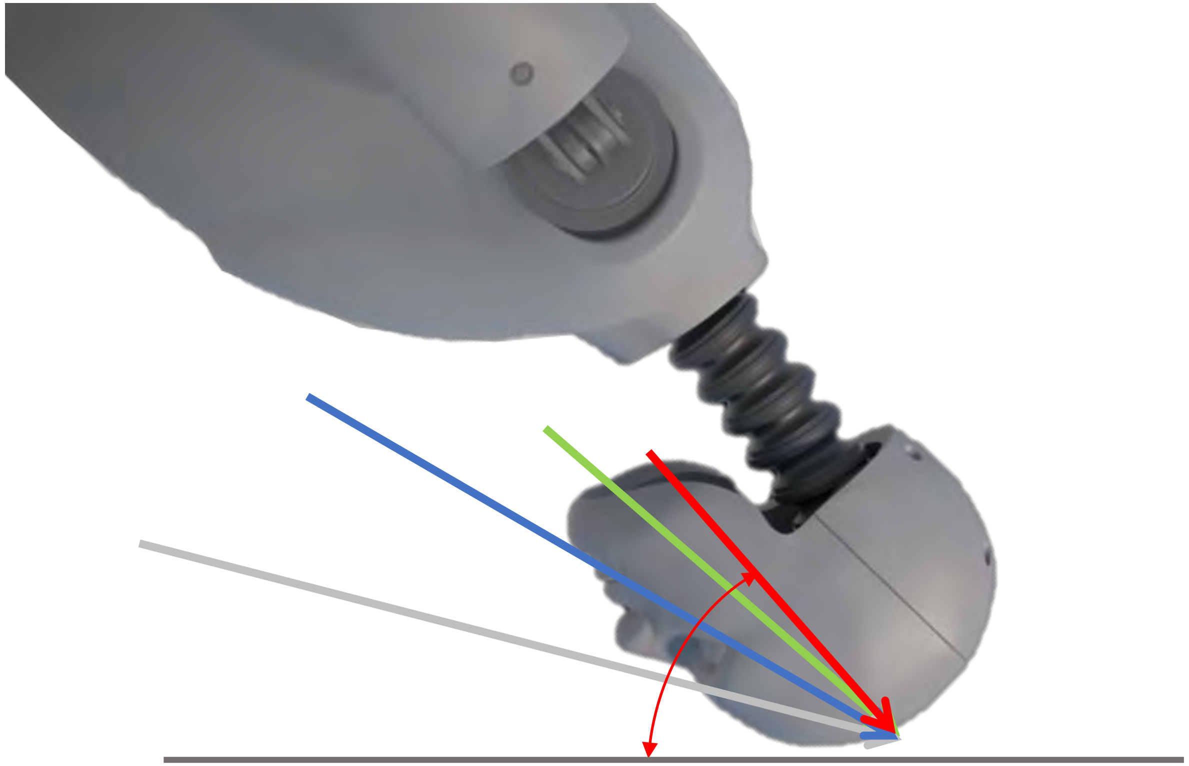
- Mellor and Chinn 2006
- 9m/s 37 degree, hard grass.

Motorcycle:

- Otte et al. 1999 (Cost 327)
- 12m/s, < 30 degree, side of a car or road.

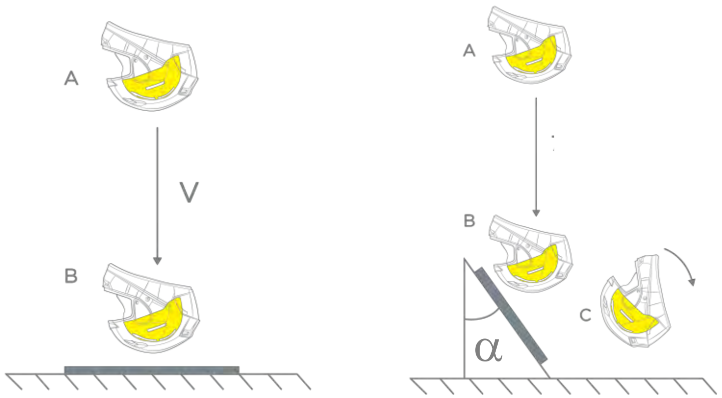
Snow

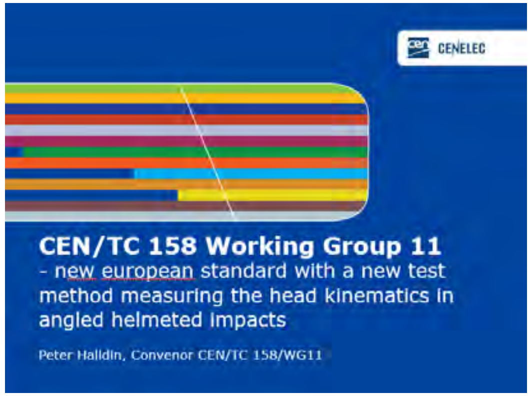
- DH and Super-G
- Ongoing FIS study
- 19m/s, 21 degree, hard snow.

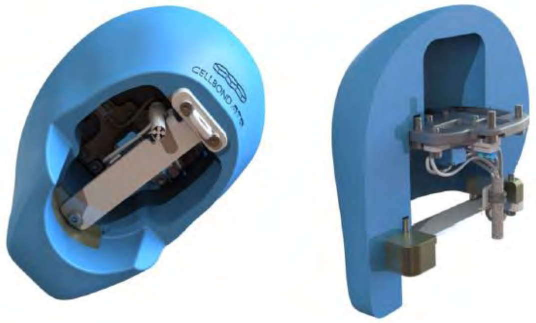


Ongoing work towards a new sport and motorocycle helmet test method

- Bike, Ski and EQ: **CEN TC158** (EU) New rotational test method.
- Motorcycle: **FIM** (Federation Internationale de Motorcyclisme)
- Motorcycle: **ECE 22.06** (European Motorcycle standard)
- Bike: **Virginia Tech** (New rating methods including tangential impacts)







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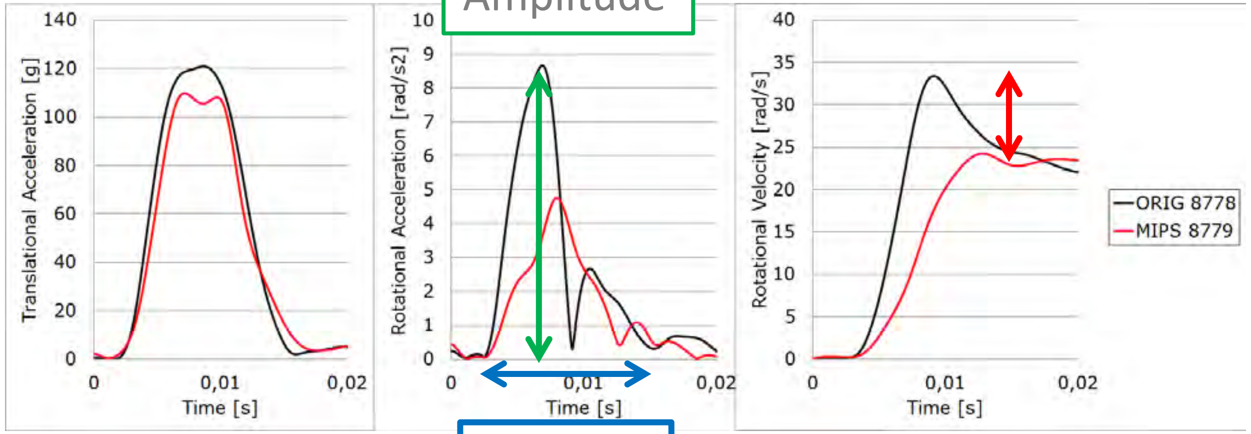
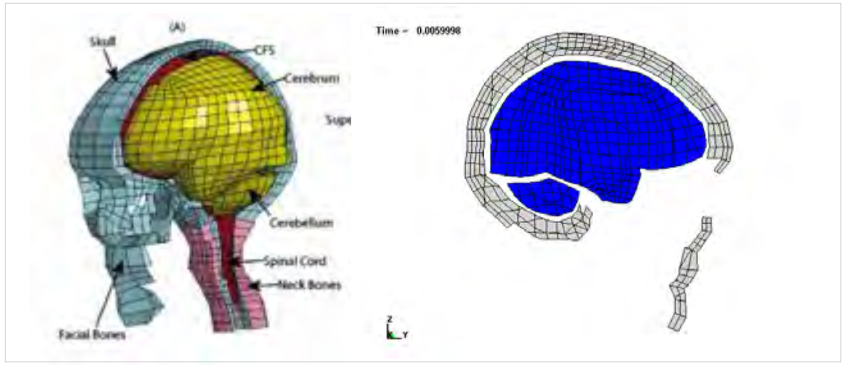
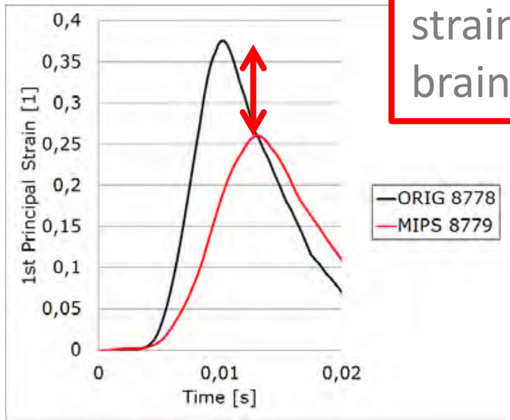
Example of test results with MIPS



Amplitude

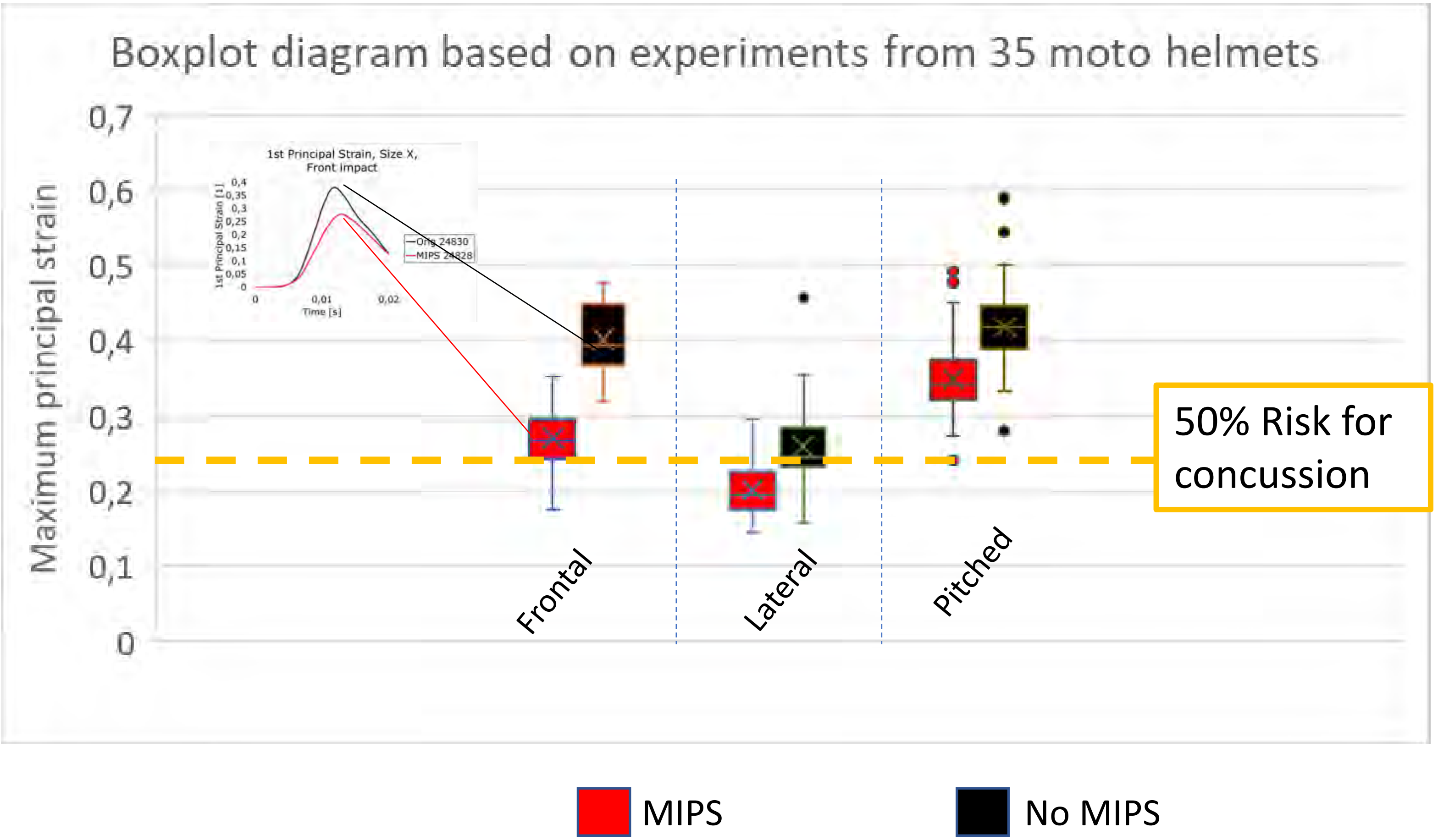
Duration





Reduction of strain in the brain

Results from 35 Moto helmets with and without MIPS

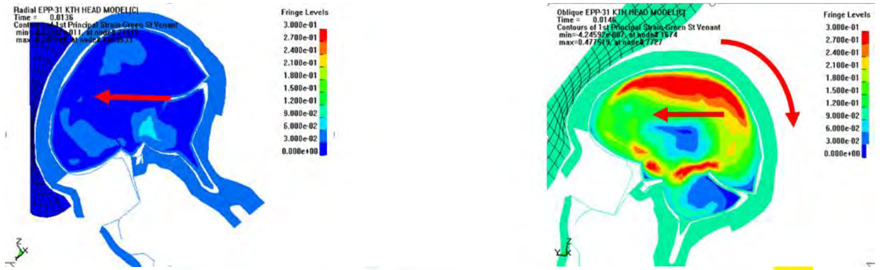


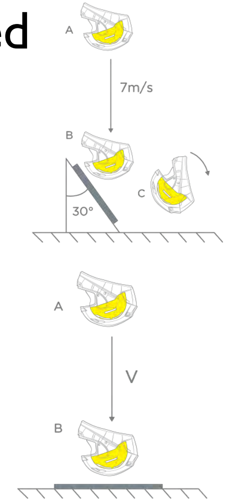
This boxplot diagram shows the strain for helmets with MIPS compared to the same helmet without MIPS installed.

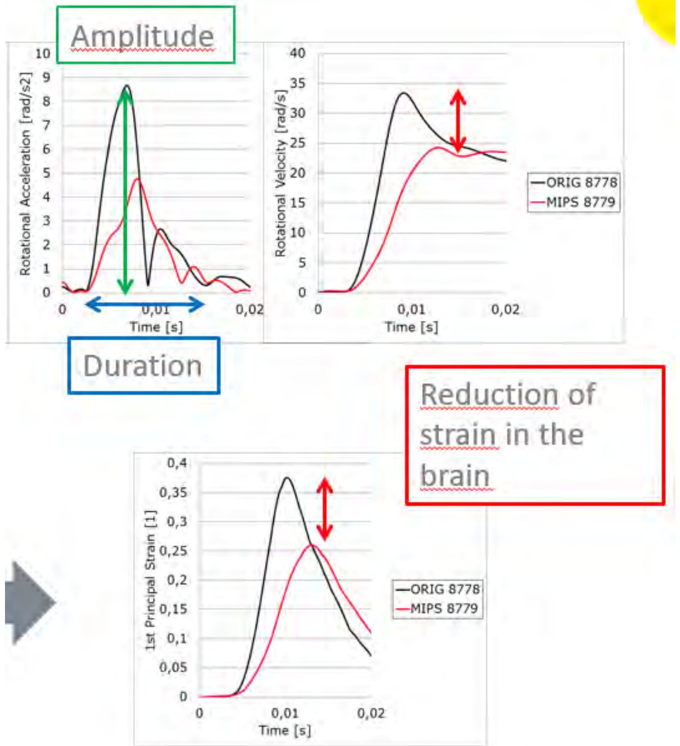
The reduction that we see in strain is a measurement on the reduction of energy transmitted to the brain for the specific impacts (7.5m/s; 45degrees impact angle).

Summary

- The human brain is more sensitive for rotation than linear motion
- MIPS is a proven technology to reduce the strain in the brain
- MIPS results in a 10-15mm relative motion between the head and the helmet (Not seen in other technologies)
- To tell how a helmet impact effects the brain, you need to analyze the rotational acceleration over time including both the **amplitude** and the **duration** of the pulse
- FIM are testing with the same test method as MIPS. The only difference is the head form and the impact points on the helmet.







Brain Protection System

CRASH SAFETY OPTIMISATION METHOD FOR THE INTEGRATION OF THE TRACTION BATTERIES INTO POWERED-TWO- WHEELERS

Alessio Sevarin*, Markus Fasching*, Christian Ellersdorfer*

*Vehicle Safety Institute, Graz University of Technology, Graz, Austria

Abstract

The number of electric powered two-wheelers (E-PTWs) shows a constant increase in the last years and most PTWs manufacturers have at least one E-PTW in their product portfolio. In order to achieve the desired performances high-energy batteries are used, which can lead to considerable hazards for people and the environment in case of damage, as for example in case of crash. Due the absence of crumble zones of E-PTWs and to the relevant influence on the vehicle dynamics that a battery protection structure can have, the safe integration of the traction battery represents a challenging process.

In this study, an optimization method for a crash safe integration of the traction batteries into E-PTWs is proposed.

Crash configurations for E-PTWs were analysed from the current literature and relevant scenarios were identified. The crash scenarios were used as inputs in a multi-step optimisation process, based on Finite Element Method, with the goal to identify the safest placement configuration of the cell in a representative vehicle and to define an optimal protection structure in case of crash.

The crash performance of the design concept was assessed through a substitutive crash and compared to a baseline concept of the traction battery.

The results showed that through the optimisation process, the intrusion into the traction battery could be reduced by 50 % in comparison with the baseline concept and a short circuit could be completely avoided without mass increase of the protection structure.

This method paved the way to achieve a safe integration of traction batteries in E-PTWs without affecting the mass and therefore the dynamic and the electric range of the vehicle negatively.

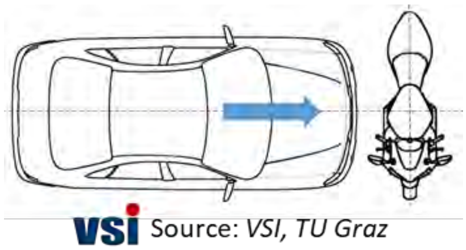
Introduction

The reduction of the emission of greenhouse gases is a worldwide goal. The negative effects of greenhouse gases on the humans health and on the environment have already be assessed in various research projects and publications [1–4]. Due to the relevant role that mobility plays for greenhouse emissions, notable focus is posed to this field in order to reduce the emissions of vehicles, especially on the road [5].

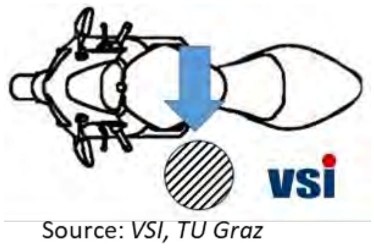
One of the applied strategies is the electrification of the vehicles powertrain, both for passengers and goods transport. This trend do not apply to four-wheelers only, but to two-wheelers too [6]. Electric Powered Two Wheelers (E-PTWs) can bring relevant advantages for the mobility and for the greenhouse emission reduction, especially in urban area [7].

In order to meet the range and performance requirements of electrified vehicles, currently lithium-ion batteries are used for the traction of these vehicles. While this technology brings relevant advantages in terms of volumetric energy density [8], in case of failure, relevant hazards can arise [9–11]. A failure of the traction battery can happen for example in case of electrical damage, i.e. caused by charging or discharging, but also in case of mechanical damage of the unit, i.e. caused by a crash [9,11].

Possible mechanical crash loads acting on the traction battery of E-PTWs were analysed by [11] and [12]. In these studies, relevant crash configurations with the potential to damage the traction battery of the vehicle were defined. In particular, two configurations are found relevant for the safety of the traction battery of an E-PTW: a side impact with a passenger car (Figure 1 a) and the collision with an object of the road infrastructure, such as a pole (Figure 1 b) [11]. In particular, this last configuration is considered as worst case scenario [13].



(a)



(b)

Figure 1 - Relevant crash scenarios (a) side impact with a passenger car (b) collision with a pole

In order to ensure the safety of the traction battery in case of crash, in case of four wheelers, the current State of the Art strategy is the integration of the battery into zones of the vehicle that experience reduced to no deformation. Nevertheless In powered two wheelers (PTWs), no deformation-free zones of the vehicle in case of crash can be found.

Other strategies can also be found in the State of the Art for the safe integration of the traction battery in electric vehicles.

One approach consist in the possibility to adopt a damage tolerant battery pack thanks to an appropriate module design, as proposed by [14]. In [14] energy dissipation components, in form of small tubes, are inserted between the cells in order to absorb the deformation energy in case of crash. The possibility to introduce a damage tolerant battery pack with an appropriate module design as described above leads inevitably to an increase of the mass and volume of the traction battery. These as consequence can lead to a violation of the boundary conditions of the design, to negative influence in the vehicle dynamic or to violation of the requirements of performance.

Another approach consists in the use of a crash absorber to limit the intrusion in the battery pack in case of crash and avoid the consequent cell deformation, as commonly found in passenger cars [15,16] and also in E-PTWs [12] in form of crash absorption brackets. Nevertheless, in [12] this strategy was combined with the use of the motorcycle frame as protective structure.

The use of a stiff structure for the protection of the traction battery can be found in various studies [14,17].This approach could be found also in [11], where the safety of a KTM Freeride E-XC was analysed. In the study the author highlighted the use of a reinforced battery housing for the protection of the cells. Furthermore, in this case, the frame of the vehicle offers consistent protection to the traction battery in case of crash.

It can therefore be resumed that the safe integration of a traction battery in E-PTWs is challenging due to the limited dimensions of the vehicle itself and the vehicle mass increase linked to use of extra protection components or a stiffening protection structure. Such strategies can lead to a reduction of the electric range and performance of the vehicle [10].

The goal of this study is the development of method for the crash optimisation of the traction battery of an E-PTW that can improve the crashworthiness of the traction battery without negative influence on the mass of the vehicle. A central pillar of the method is the substitution of the motorcycle frame with the traction battery, in order to avoid a mass increase of the vehicle.

Method

To achieve a crash safety optimised traction battery for an E-PTW a multi-step approach was used (see Figure 2).

In a first step a Finite Element (FE) based Metamodel optimisation of the traction battery is used to identify the optimal placement of the battery cells in the available space of the traction battery and the optimal thickness of the battery housing with the goal to increase the crashworthiness in a worst case scenario, a side collision of an E-PTW with a pole-similar object, while minimising the vehicle mass.

In a second step the concept of the housing of the traction battery, derived from the first step, is subjected to a topology optimisation. By use of FE simulations an optimal material distribution, to assess the stiffness requirements of a typical motorcycle frame is achieved.

The results of the two steps are combined to obtain a crash and stiffness optimised battery pack. The optimised battery pack design is prototyped and subjected to a crash test representative of the worst case scenario and compared to the results of a baseline concept.

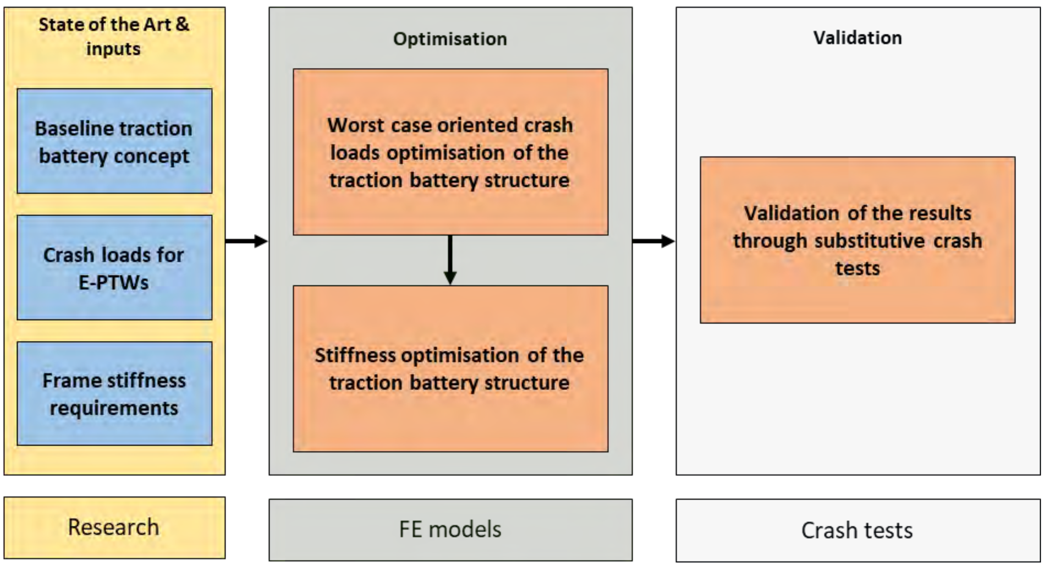


Figure 2 – Schema of the used method

The analysis is developed with a concept E-PTW for urban and commuting purposes. The baseline concept of the traction battery used in this study (see Figure 3) is composed by 3 identical modules, connected in series. The modules are composed by 18650 cells with the axial cell axis oriented in the Y direction of the traction battery.

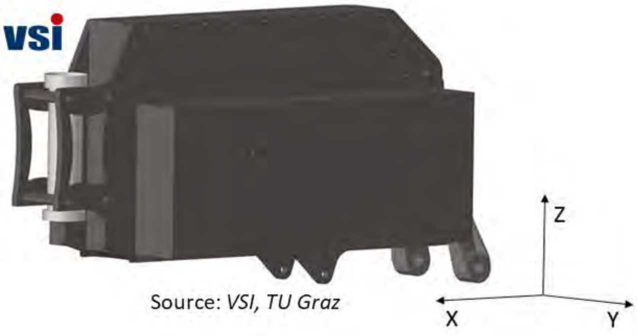


Figure 3 – Baseline concept of the traction battery

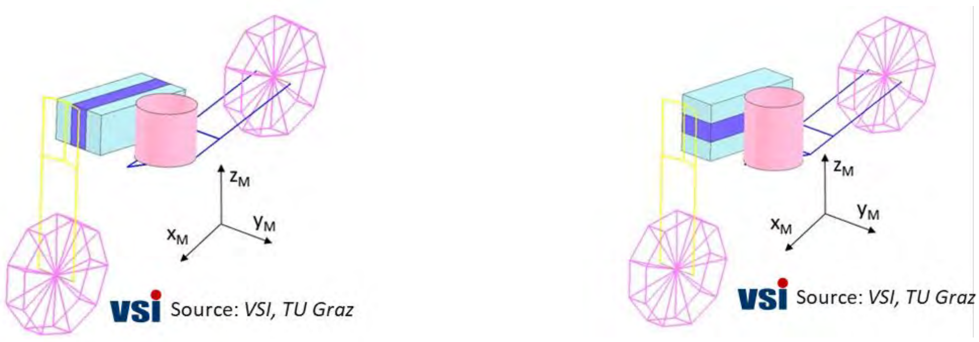
Crash loads optimisation of traction battery structure

In order to evaluate the influence of the placement of the cells in the volume of the traction battery and define the minimal thickness requirements of the battery housing, a FE based Metamodel optimisation through the software LS-Opt is used.

Metamodel optimisation refers to an optimisation process in which a simple and computationally inexpensive surrogate model of the phenomena under observation is built and used to analyse the influence of the variables´ variation on the phenomena instead of direct experiments or simulations. [18,19] A common metamodeling technique, which was used also in this method, is the surface response methodology (RSM). [20,21] The name "response surface" derives from the fact that using this method a response surface is fitted to the response values using a regression analysis. [22]

Two simplified vehicle models, representative of the concept vehicle, were modelled with FE (see Figure 4) and simulated in the defined worst case scenario. The simplified vehicle models are identical except for the orientation of the cells in the traction battery. In the Concept Y (see Figure 4 (a)) the axial axis of the cell is oriented in the lateral direction of the traction battery (Y_M in the coordinate system of Figure 4), as in the baseline concept. In the Concept Z (see Figure 4 (b)) the axial axis of the cells is oriented in the height direction of the traction battery (Z_M in the coordinate system of Figure 4)

The crash configuration uses a half cylindrical impactor with a diameter of 150 mm to reproduce the case of the side impact with a pole. The diameter of 150 mm is chosen in accordance with the test configuration defined in the SAE J2464 [23].The vehicle impact speed is 8,88 m/s as representative of a typical collision speed in an urban scenario.



(a) *(b)*

Figure 4 – Simplified FE model of the motorcycle and the impactor used for the safety evaluation: (a) Concept Y and (b) Concept Z

The simplified motorcycle model consist of two main groups: the traction battery and the rest of the motorcycle. Components of the rest of the motorcycle influence the inertia and mass of the vehicle, but do not have any other impact in the selected load conditions. They were therefore modelled using one-dimensional rigid elements. The density of the one-dimensional elements was chosen to achieve a mass and a longitudinal position of the center of gravity of the simplified model as in common motorcycles.

The model of the traction battery (Figure 5) itself consists in the following components:

- ***The housing***: the housing is composed by two components: the external plates, that defines the external contour of the housing, and the longitudinal plates, that are placed between the modules. Both components of the housing are made from aluminium and are modelled as shell elements using an elastic-plastic material model with failure criterion;
- ***The modules***: the modules consist in the following subcomponents:
  - o *The cell holder*s, responsible for holding the cells together, are modelled with a combination of shell and solid elements using an ABS elastic material model with failure criterion.
  - o *The cell*s are modelled using a combination of shell and beam elements, as described by Raffler et al [24]. Furthermore a short circuit criterion based on the results of the same paper is implemented.
- ***The connection between modules and housing***: is modelled with elastic one-dimensional elements.

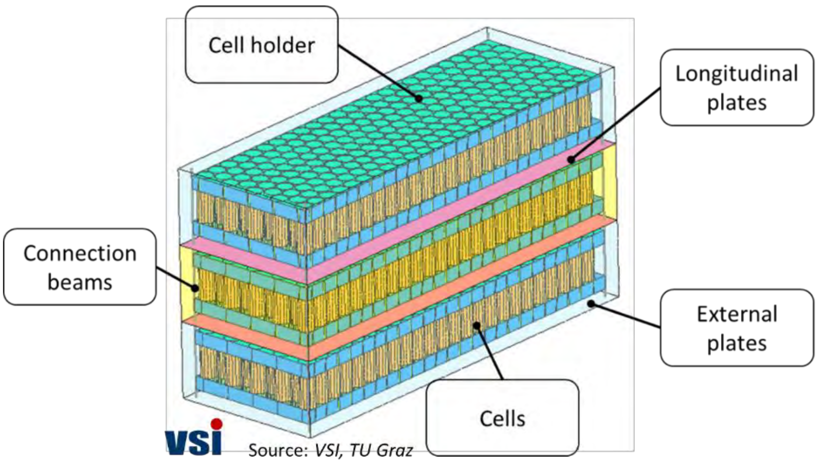


Figure 5 – FE model of the traction battery with its components for the Concept Z. Note that the external plates are semi-transparent in order to show the inner components of the traction battery

As the optimisation process aims to improve the crashworthiness of the traction battery while minimising the mass, two independent variables were considered: the thickness of the longitudinal plates and the thickness of the external plates. These two variables influence the mass and the crashworthiness of the traction battery. The crashworthiness is evaluated with the use of a deformation based short circuit criterion implemented in the FE model of the cells. In order to offer a comparison between the models a short circuit risk is defined based on the short circuit criterion. A short circuit risk of 0% indicates no deformation of the cell, while a short circuit risk of 100% indicates the achievement of the short circuit deformation. A short circuit risk major than 100% does not have a physical meaning but indicates the deformation of the cell exceeded the short circuit deformation.

The variables with their boundary conditions and the goals of the optimisation are exposed in Table 1.

Category	Parameter	Lower limit	Upper limit
Variables	Thickness external plates	3 mm	20 mm
	Thickness longitudinal plates	3 mm	20 mm
Goals	Vehicle mass	Minimise	
	Short circuit risk	Minimise	

Table 1 – Resuming table of the variables and goals of the optimisation

Four Iterations are considered in the analysis for every battery pack concept, while for every iteration 20 simulations with a different combination of the variables are used.

Stiffness optimisation of traction battery structure

As the traction battery structure should substitute the entire frame of the motorcycle, it should withstand not only crash loads but should also achieve the desired stiffness requirements. In order to assess this goal, a topology optimisation based on the Solid Isotropic Material with Penalisation (SIMP) technique is used.

In the SIMP method, a fixed finite element discretisation is used and every element is associated to a density function $\rho(x_i)$, whose values lays between 0 and 1 where 0 denotes a void element and 1 a "full" solid element. The index i indicates a general element of the structure subject of the optimisation. [25]

The Young modulus E_i of the element are then described by the function:

$$E_i = E_o \rho(x_i) \qquad \textit{Equation 1}$$

Where E_o defines the Young modulus of a "full" element (i.e. with a density function $\rho(x_i)=1$).

If the density function is allowed to vary continuously between the values of 0 and 1, the resulting density represents an artificial density which can be interpreted as a material mesostructure containing holes. [26]

As these material mesostructures are mostly not reproducible in the practice, homogenisation methods are needed in order to obtain a structure characterised by elements with a density of 1 ("full" elements) or 0 ("void" elements).

In order to fulfil the stiffness requirements of a motorcycle frame, three load conditions were defined and used for the topology optimisation (see Table 2) and the mass is limited to a maximum of 8 kg.

Direction	Lower limit	Sketch
Longitudinal stiffness	5 kN/mm	

Lateral stiffness	1 kN/mm	
Torsional stiffness	3 kNm/°	

Table 2 – Load cases and minimal stiffness requirements of a motorcycle frame based on Motorcycle dynamics [27]

Crashworthiness assessment

The crashworthiness assessment is developed based on substitutive crash tests representing the worst case scenario, considered also for the crash safety optimisation. A comparison between a baseline model and the optimised model is developed in order to assess the effect of the optimisation.

The represented worst case scenario is reproduced through the impact of a moving trolley with a mounted half-cylindrical impactor into the traction battery that is fixed on a crash wall (see Figure 6).

The trolley with a mass of 475 kg was accelerated until a an impact speed of 4,16 m/s. The half-cylindrical impactor with a diameter of 150 mm was mounted to the trolley. Between the impactor and the fixation plate two three axis load cells (Kistler Z20730A linearity error ≤± 2,5 kN) with a maximal force in axial direction of 500 kN were used (see Figure 6).

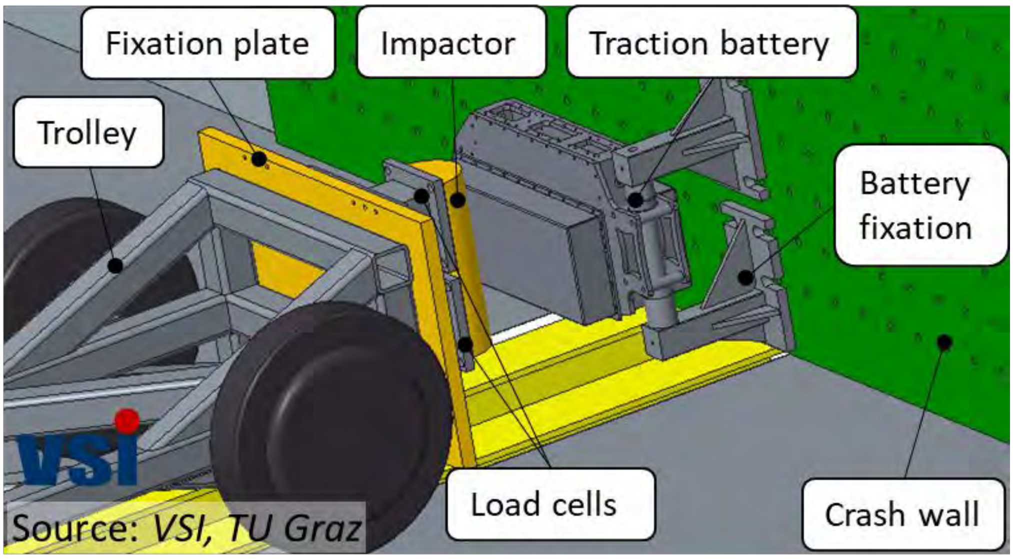


Figure 6 – CAD model of the crash environments with the main components

The traction battery is mounted to a crash wall with the use of two mounting structures resembling the way the traction battery is mounted in the vehicle.

The housing, the connection to the swingarm and the steering head resemble the respective components of the concept vehicle. No electronic component (i.e. BMS, charging system, etc.) were integrated in the test traction batteries as the test focuses in the assessment of the analysis of the crash behaviour of the traction battery, in particular observing the cells deformation.

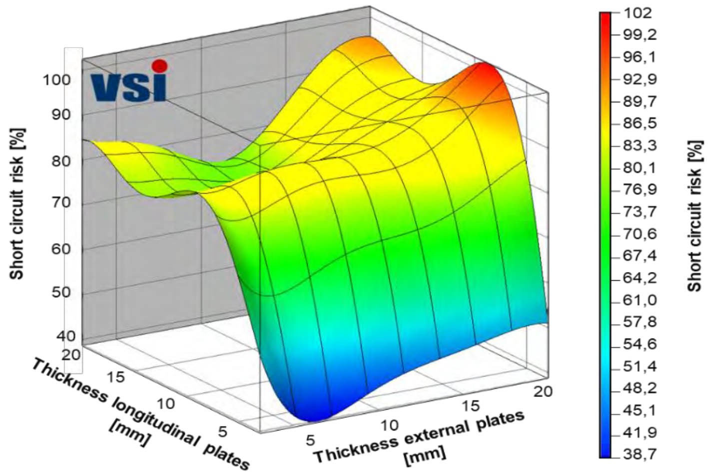
The cells were discharged to a state of charge (SOC) minor 10 % before performing the tests. In the most extern module, which is supposed to achieve the highest deformation, the voltage of 12 cells is measured in order to detect a short circuit in the cells.

To measure the occurring intrusion of the traction battery, a laser based measurement system was mounted above the traction battery. The tests are filmed by three high speed cameras with 1.000 fps to observe the behaviour of the traction battery from different point of views.

Results

Crash load optimisation of the traction battery structure

The Metamodel surface for the Concept Z, describing the variation of the short circuit risk, is presented in Figure 7. The short circuit risk is depicted dependent on different combinations of values of the thickness of the external and longitudinal plates of the battery pack.



Source: *VSI, TU Graz*

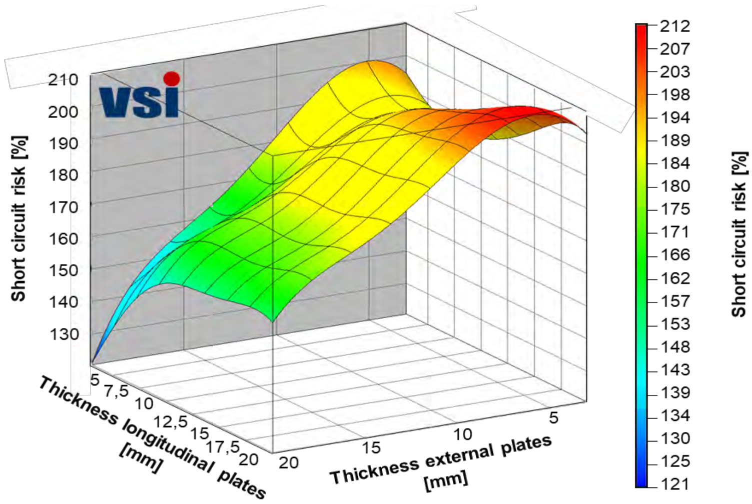
Figure 7 – Metamodel surface for Concept Z

Based on the boundary conditions of the analysis and the load case the short circuit risk ranges from 38,7% to 102%. It has to be noted that a short circuit risk bigger than 100% is not physically possible but indicates that a cell has achieved a deformation bigger than the short circuit deformation.

The minimal short circuit risk is achieved when the thickness of the longitudinal plates is at its minimum (3 mm as defined in Table 2). A variation of the thickness of the external plates, starting from the minimal thickness of 3 mm) cause at first a decrease of the short circuit risk until a thickness of 6,5 mm. After this thickness an increase of the short circuit risk can be noted.

An increase of the thickness of the longitudinal plates of the traction battery housing in case of Concept Z leads to a monotone increase of the short circuit risk until a thickness of 9 mm. After this thickness, it is not possible to observe a monotone behaviour of the short circuit risk function. Based on the combination of the longitudinal plates thickness and external plates thickness local increase or decrease trend of the short circuit risk function can be observed.

In case of the Concept Y, the Metamodel surface describing the short circuit risk in function of the thickness of the components of the housing is visible in Figure 8.



Source: *VSI, TU Graz*

Figure 8 - Metamodel surface for Concept Y

In case of Concept Y the short circuit risk ranges from 121% to 212%. No combination of the variables, with the defined boundary conditions, can avoid the onset of the short circuit in at least one cell of the traction battery.

As it can be noted by Figure 8, a decrease of the thickness of the external plates or an increase of the mass of the longitudinal plates leads almost monotonically to an increase of the short circuit risk.

In order to compare the two concepts, a comparison of the short circuit risk of the two models, for the same model mass, was calculated (see Figure 9).

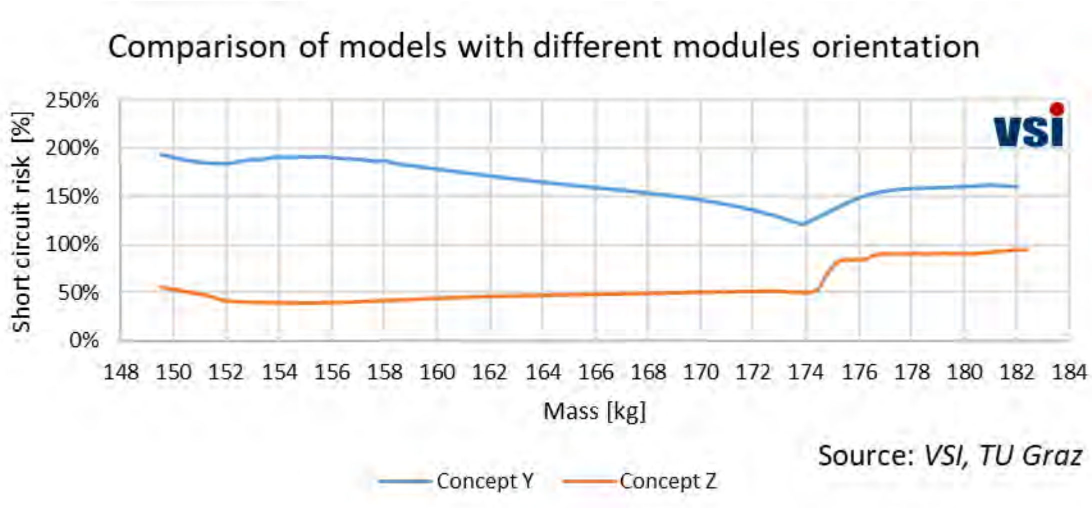


Figure 9 – Short circuit risk vs. mass comparison for the two concepts

Both curves show a decreasing trend of the short circuit for a vehicle mass between 149,77 kg and 151,44 kg. After this mass different trends are observable: in case of Concept Z a further short circuit reduction until a mass of 155,7 kg is visible, while in case of Concept Y an increase of the short circuit risk can be found in a mass range between 151,44 kg and 155,7 kg.

After this vehicle mass, the short circuit risk is increasing for Concept Z and decreasing for Concept Y direction until a mass of 174,3 kg. After a mass of 174,3 kg a short circuit risk increase is observable in both battery pack concepts.

It can therefore be assessed that concept Z achieve lower short circuit risk in the entire mass range. In particular in order to minimise the mass a combination of the battery pack housing of 3 mm both for the external plates and longitudinal plates is chosen for the next steps of the analysis.

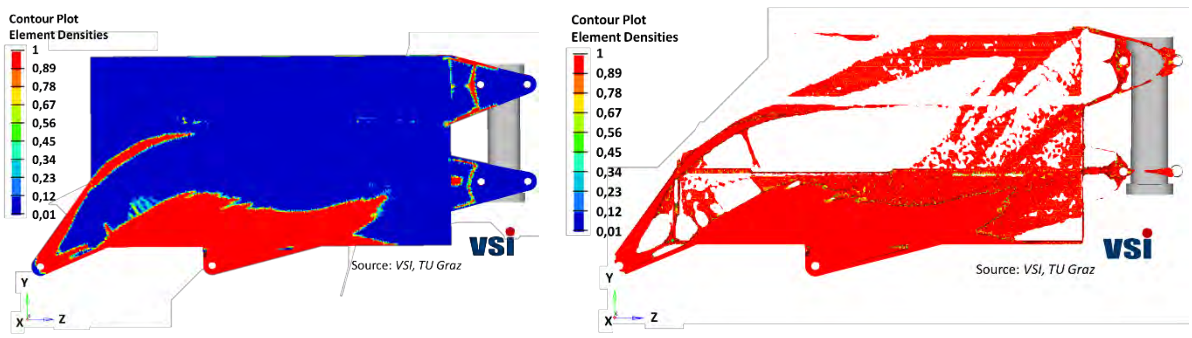
Stiffness optimisation of traction battery structure

Based, on the cell orientation of concept Z, a FE-model of the traction battery for the topology optimisation was developed (Figure 10). The model consists of 948.722 tetrahedral elements with aluminium properties. Modules are not integrated in the model, as the goal is to obtain the optimised material distribution in the battery housing. The total mass of the traction battery housing at this stage is 17,63 kg.

Figure 10 – FE model of the traction battery used for the topology optimisation

The results of the topology optimisation are presented in Figure 11. The topology optimisation converges to a feasible solution after 31 iterations. The traction battery housing achieves:

- A mass of 8 kg;
- A longitudinal stiffness of 36,36kN/mm
- A lateral stiffness of 8,13 kN/mm
- A torsional stiffness of 3,49 kNm/°



(a) (b)

Figure 11 – Results of the topology optimisation showing: (a) all the elements and (b) only the elements with a density higher than 0.85

The results of the topology optimisation show an intense material reduction in the middle and upper area of the traction battery, while in the lower region high material density can be observed.

A reinforced structure which connects the rear connection to the swingarm to the front upper region of the traction battery is build. Moreover patterns of elements with high density can be observed connecting the lower region of the traction battery to the connection with the steering head.

While observing Figure 11 (b) it has to be noted that a connection between the elements seems missing in the upper half of the model. In this area the longitudinal plates of the traction battery are present that increase the stiffness of this area and therefore the elements in this area achieve a reduced material density during the optimisation and are not displayed in this figure.

The results of the Metamodel optimisation and the topology optimisation were combined to obtain an optimised structure capable of withstand a worst case crash load scenario as well as achieve minimum stiffness requirements.

The final structure consist in a "basic housing" with a thickness of 3 mm, as retrieved by the results of the Metamodel optimisation, with reinforcements of 5 mm, in the region resulted from the topology optimisation. The final model can be seen in Figure 12.

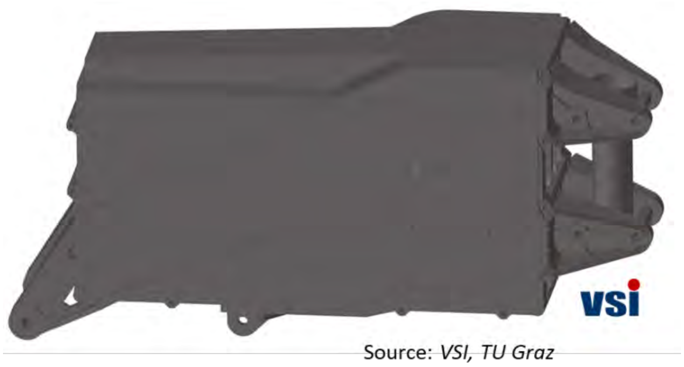


Figure 12 – Optimised traction battery pack housing

Crashworthiness assessment

A prototype of the optimised traction battery housing was built through CNC machining of aluminium and is visible in Figure 13 (b). The optimised traction battery is compared with a baseline concept of a traction battery visible in Figure 13 (a).

(a) (b)

Figure 13 – Photo of the: (a) baseline concept of the traction battery and (b) the optimised battery concept

The displacement versus time curve of the tests with the two traction battery concepts is presented in Figure 14. A displacement equal to zero represent the contact position between the impactor and the traction battery. The measured speed of the trolley at the impact was 4,17 m/s, therefore there was no relevant deviation from the reference impact speed of 4,16 m/s.

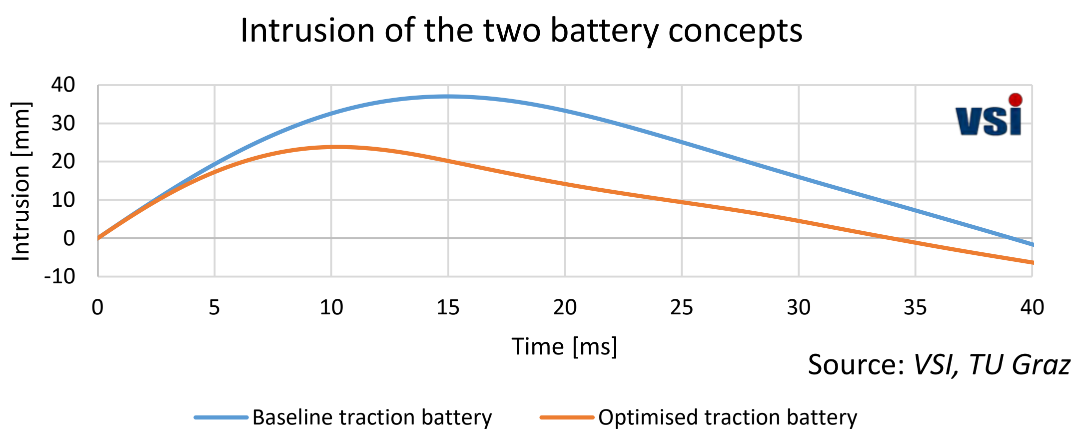


Figure 14 – Displacement versus time for the substitutive test with the baseline and optimised battery pack

The maximal measured displacement in the crash test with the baseline concept is 37,0 mm at 14,8 ms after the first contact. The maximal achieved displacement by the impactor do not represent the intrusion of the traction battery, as a deformation of the fixation points of the traction battery occurs which is visible in the test pictures and videos (see Figure 15).

(a) (b)

Figure 15 – Comparison of the deformation of the baseline traction battery at: (a) first contact and (b) the maximal measured displacement

In case of the optimised traction battery, the maximal registered displacement is 23,9 mm at 10,6 ms after the first contact.

As it is observable in Figure 16, the most of the achievement of the displacement is due to the deformation of the fixation components from traction battery to the crash wall. Moreover it is observable that minor screws for the fixation of the upper cover of the traction battery break during the impact. Anyway, the upper cover has little structural importance and the traction battery can support the crash loads without relevant cell damage.

(a) (b)

Figure 16 – Comparison of the deformation on the optimised traction battery at: (a) first contact and (b) the maximal measured displacement

In the baseline scenario the short circuit of 6 cells were measured, while in case of the optimised traction battery housing no short circuit was detected during the test.

Discussion

The results of the crashworthiness optimisation showed relevant differences between the concepts with different cell orientation. It has anyway to be noted that the optimisation was developed based on one load case only. Although the simulated load case is defined as worst case scenario in the current literature, the different concepts could show different results on different crash scenarios. The same can be stated also for the use of different materials or cells in the traction battery.

It has also to be considered that, although the use of metamodels gives the possibility to analyse in a resource and time effective way large design spaces, it lacks, due to its intrinsic nature, the possibility to find local minima or maxima of the optimisation function to be analysed.

A topology optimisation is a common method for mass reduction of components in the automotive sector. In this study the topology optimisation was developed on the battery pack housing only, without considering the inner components. While the inner components, as example the cells, should not be mechanically loaded during the normal working conditions in order to ensure a safe use, their consideration in the topology optimisation process could potentially influence the results of the topology optimisation and result in a further mass reduction.

Lastly, the authors would like to note that, although the prototypes were build considering also requirements for a large scale manufacturing, it was not possible to satisfy them all in the prototype phase, as for example in the case of connections between different components. Therefore successive crash tests could be needed in further phases of the traction battery development.

Conclusions

In this study a method is described for the design of the traction battery of an E-PTW with the goal to optimise the crashworthiness, while maintaining stiffness and mass boundary conditions.

With the use of two optimisation processes based on a metamodel optimisation, first, and topology optimisation in a second phase, an optimised structure could be found.

Substitutive crash tests and the comparison to a baseline concept offer on one side the validation of the optimisation process and deliver relevant feedback about the improvements that the method could deliver.

In particular the final derived traction battery concept exhibited a mass reduction of 7% in comparison with the baseline concept but, still more important, could withstand a worst case scenario crash load without cell short circuits.

While the method was specifically applied on an E-PTW for urban commuting purposes, it can be used also for different E-PTWs, by varying the boundary conditions of the optimisation process.

Acknowledgment

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Design of Electric Motorbike Embedded with Perovskite Solar Cells

Sai Abhiram Nibhanupudi*, Sai Rohan Gogulapati, Sri Sai Sumanth Pendyala & Venkata Ramana P*
Mahatma Gandhi Institute of Technology (MGIT), Hyderabad, Telangana, India - 500075
**Corresponding authors: abhiram.nibhanupudi@gmail.com, pvramana04@yahoo.com*

***Abstract*—In the present day scenario the usage of fossil fuels in the automobile industry is very high, which is causing the degradation, and price hike of these fuels. From the beginning of automobile era, there have been several improvements in the design of fossil fuel based automobiles for achieving energy efficiency. At a point of time when the world needs to go-green and help in reducing the usage of fossil fuels, there is now a lot of concentration on usage of alternative fuels. One of the important initiatives in this direction is introduction of electric vehicles. The recent trends show that electric vehicles are given a lot of importance but the range (distance travelled per charge) is not high, as desired. Hence, the need of the hour is to work on effective utilization of natural resources to charge the battery by innovative methods. This paper describes the innovative design and analysis of a hybrid bike which can be charged both with the regular electric power supply as well as with solar cells. This design basically consists of the flexible solar panels placed on the both sides of electric motorcycle, unlike conventional solar panels. This makes the bike design not only innovative but also reduces space occupancy and improves style. It also helps in maintaining the aerodynamic design and helps in achieving greater range. With the addition of the solar panels having more area of exposure to the sun, it is possible to generate an additional power, thus increasing the range. The innovative design presented here makes an effective difference in using resources for the motorbikes, thus making them more eco-friendly. This paper also presents the analysis of the average power generated in each month of the year considering the number of average sunshine hours in each month.**

***Index Terms*—Electric vehicles, flexible solar panels, aerodynamic design, range, sunshine hours, innovation**

I. Introduction

The beginning of automobile era dates back to a century and beyond. The invention of IC engine vehicles might remain one of the greatest inventions in the history of mankind for sole reason of their consistent performance and long-term working. Since then there have been several updates and improvements done but nothing like introduction of electric vehicles into the world. Especially, at a point when the world needs to go green and help reducing the usage of fossil fuels. But slowly this technology is shifting towards hybrid electric vehicles and fully electric vehicles because of various aspects. These aspects include the need for better efficiency, less pollution and more renewable in nature. [1]

The trend of updating vehicles to electric is not only happening with four-wheelers but also with two-wheelers. The electric motorcycles are becoming part of the fast-growing world. An electric motorbike is a vehicle which runs on electric charge from battery. A typical electric vehicle works as per the following process. Firstly, the battery is charged using electricity which transmits the required power to the motor and in turn the motor provides torque to the wheel connected to it, generally the rear wheel [2]. There are many positive considerations to be taken into account in case of electric vehicles, one of them is that they do not emit any toxic gases which helps in reduction of the pollution. In addition to this the electric vehicles run at moderate speed which lowers the chances of accident rate especially in countries where this rate is very high.

The industry of electric vehicles is ever evolving, so the concept of using the electric vehicles must be improvised by integrating them with renewable resources of energy to charge the vehicle. Daily the sun releases immense amounts of heat and radiation in the form of solar energy. This solar energy is free of cost. Sunlight which is an abundant and accessible source would assist the electric power source so that the charging can be done in comparatively less time and also increase the range (distance travelled per charge) of the vehicle. The other advantage of sunlight is that the vehicle can be charged while in motion also.

Shruti Sharma et al. studied and discussed about how to choose solar cells based on aspects such as geography, working mechanism, materials, and technology used. They have reviewed about solar cells of different generations and also stressed on the importance of using solar cells, ways to improve them and proposed future applications in automobiles [3]. Solar cells are made up of semi-conductor materials like silicon and germanium. They mostly comprise of silicon boules. But in recent times many other elements are being introduced into solar cells for obtaining better efficiency. One such type of solar cells is perovskite. Shi D., et al. discussed on how perovskite solar cells became an assuring cell in recent times by having a peak cell efficiency of 30%. They also proposed that combination of perovskite/ C-Si tandem structure with inverted nanopyramid morphology which then increases the efficiency more than 31%. Their results have provided useful instructions for the fabrication of perovskite solar cells [4].

Solar cells are classified into three types, First-generation (Mono crystalline), Second-generation (Polycrystalline), Third-generation (Thin film) based on the composition of material and usage. Askari et al. discussed about different types of solar cells such as Cadmium Telluride Solar Cell (CdTe), Copper Indium Gallium Solar cells (CIGS), Perovskite Solar cells, Hybrid Solar cells, Monocrystalline Solar cells (Mono-Si) and many other. They also discussed about various applications of solar cells ranging from households to automobiles [5]. The working of solar cells is based on the principle that when the light interacts with the silicon cells, it sets the electrons into motion, which initiates flow of electricity. This is known as Photovoltaic effect [6]. The major steps that occur in the process are, absorption of light to generate holes and electrons by the semiconductor followed by separation of these charge carriers and then reuniting these charge carriers on opposite sides of electrodes to generate a potential difference between the electrodes and there by producing current or electricity [3], [7]. Solar cells can be charged either with the natural light or with artificial light. Solar cells transform the photon energy from the sunlight into electricity which can be used for the charging the battery of the bike. This photovoltaic process of conversion of heat and light into electricity does not require any burning of fuel. The variable costs through the installation of solar cells will be less when compared to other forms of generation.

The solar panel is the accumulation of solar cells connected to each other by wires either in series or parallel connection depending upon their usage. These solar panels are available in both rigid and flexible forms. Mario Pagliaro et al. researched on thin-film flexible photovoltaics which are paving towards low-cost electricity production. They also discussed about organic, inorganic and organic–inorganic solar cells which are being deposited with flexible substrates by roll-to-roll printing technologies to achieve lightweight, economic solar modules that can be incorporated into any type of stringent surfaces. These types of photovoltaic cells are ready to provide cheap, clean electricity across the planet especially overcoming issues faced by the world such as increasing costs of electricity generated by burning of fossil fuel resources. They have also focused on recent achievements in the area of flexible solar cells, highlighted the principles behind the main technologies, and discussed future challenges in this area [8]. The Perovskite cells in flexible solar panel will be the best choice for automobile applications because of the efficiency they provide, which is up to 30% unlike any other cells and other reason being convenient manufacturing and assembly [4].

Mishra et al. discussed about the method of integration of the solar panels with an electric bicycle to increase the battery power. It was suggested that solar hybrid bicycles are becoming an alternative for the gasoline operated automobiles and thus making its manufacturing crucial [9]. In the similar manner, Shubham Rana et al. worked on integration of solar panels to a TVS make bike of 100 CC power. Solar energy is stored in four batteries of 12 V which act as a reserve power for the two-wheeler and the bike is eco-friendly in nature [10].

Sharada and Nataraj discussed about the combined effect of IC engine and electric motor in a motorbike supported with solar panel, where IC engine being the main active pickup and electric motor with solar cells being supportive propulsion unit for increasing the travel range of the two-wheeler [11]. Rajkumar et al. worked on similar setup as discussed in the above mentioned paper, in addition to that their setup is supported with regenerative braking power and solar energy to achieve the same goal of obtaining better range [12]. Fabian Fogelberg presented the method of sharing solar energy between numerous bikes by using a large solar panel for simultaneous charging of batteries in different weather conditions and positions of light incident on the panel and determined the range and efficiency of an individual bike [13].

As there will be no emission of gases from the electric vehicles, usage of renewable source such as solar energy to charge the vehicle lends a hand to the environment. Advantage with the solar cells is that their modules can be customized into required shapes and sizes of cells. Till date, research is carried out by placing the solar cells on the top of the bike as rectangular panels with which the frontal area (i.e., product of width of the bike and height of the bike including driver) of the bike has increased the frictional resistance on the bike. Keeping all the factors mentioned in above works, the present paper discusses a better way of arranging solar cells on the electric motorbike to achieve greater range.

II. Methodology

The present work discusses about the electric bike fitted with solar cells apart from a battery to supply the power, brushless DC (BLDC) motor to produce driving torque, and a belt drive for transmission of motion from motor to the wheels. The bike is set into motion when the power from the battery is utilized by the motor and produces torque to the motor shaft which connected to the rear wheel of the bike through a belt drive. This torque is varied accordingly by using an electric vehicle motor controller. A motor controller is used in altering the energy flow from battery to BLDC motor and hence helping in regulating the torque of the motor. The rotating motor shaft is connected to the rear wheel of the bike. This whole process involves numerous power losses due to which range of the bike reduces. So as to increase the range of the bike, the charging in the battery has to be enhanced. For this purpose solar cells are included onto the body of the bike, which will charge the battery continuously. A regulator is be used in order to convert the solar charge into DC power which is stored in the battery.

This process is advantageous because the battery gets topped up even during the movement of the bike. In addition, it

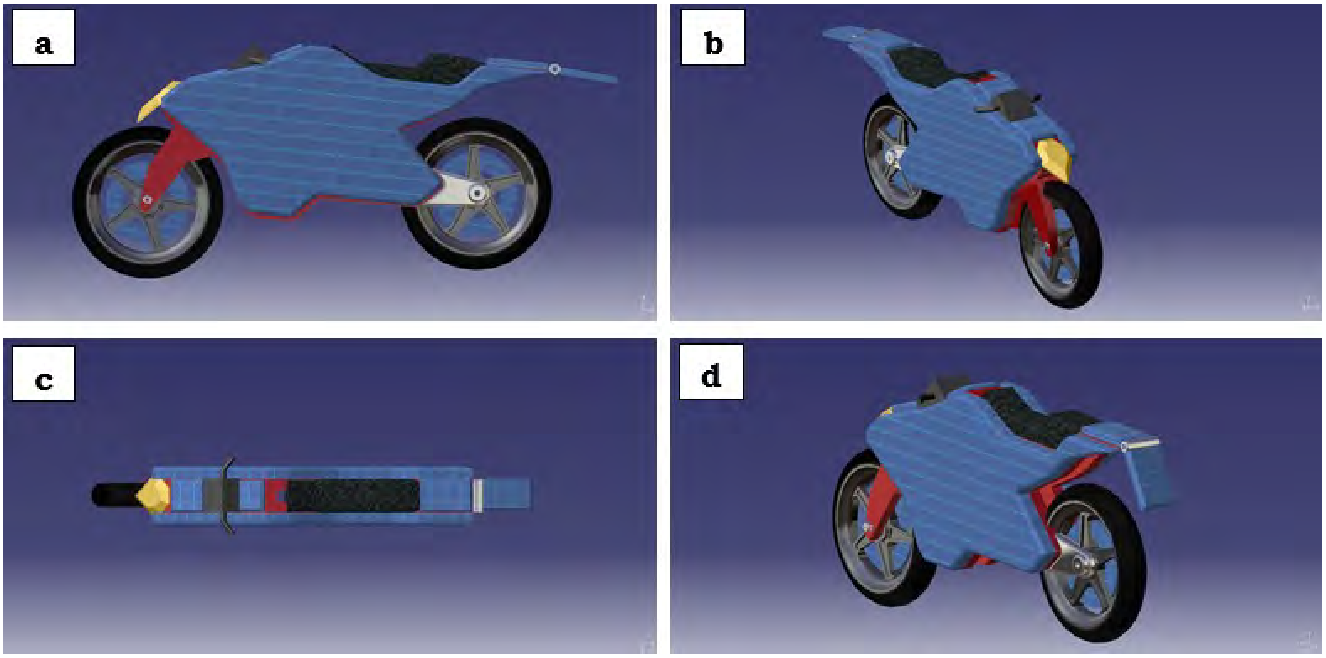

Fig. 1: CAD model of wheel

reduces the charging time required to power up the battery in idle position. This process increases the range of the bike by a significant margin.

III. Design Profile

In this work, design of two-wheeler electric motorbike with solar cells embedded on the body of motorbike as shown in the Fig. 1 is proposed. The entire body of the bike is supported by a Trellis Frame. This design basically consists of the flexible solar panels fitted on all the sides of motorbike as shown in Fig. 1. The solar panels are shown in blue colour are fitted on both sides (Fig. 1 (a) and (b)). Solar panels are also placed on the top as shown in Fig. 1(c) in the form of three distinctive panels with two in front of the seat and the other behind it. An extra solar panel is hinged to the rear end of the bike as can be seen in Fig. 1(d). This panel is adjustable according to the requirement i.e., when the motorbike is parked it can be completely unfolded and while in motion it can be folded beneath the pillion seat. Even the rims of two tyres are embedded with concentric flexible solar panels.

The specification of Lithium ion battery ($LiFePO_4$) used is 48 V 72 Ah required for the motion of the bike, resulting in an total output of 3456 Wh. In general, the complete battery capacity cannot be used effectively. Hence, 80% of maximum discharge can only be utilized practically resulting in effective energy of 2764 Wh [14].The specifications of bike dimensions are assumed as follows. The length(l), width(w) and height(h) are considered as 1990 mm, 735 mm, and 1135 mm respectively. The mass (m) of the bike is considered as 130 kg and the average human weight is assumed to be 70 kg. The wheel radius (r) is considered as 0.216 m (8.5 inches) and the pressure in tyres as $3x10^5$ Pa. Seat height from the ground according to the dimensions considered as 1015 mm and the driver height (h_d) from the seat as 400 mm. Hence the frontal area (A) of motorbike will be equal to product of height of motorbike with driver and width of the motorbike. However there are many parameters that reduce the area like, the area of the face will not be same as the body of the rider and so an adjustment is made to consider only 70 percent of the area from the total [15]. The average speed (v) the bike is considered as 45 kmph. The solar cells embedded are Perovskite Cells. Shi D., Zeng Y. and Shen W, stated the applications of Perovskite solar cells in automobile industry have an efficiency of 30%. In reference to this, 30 percent efficiency is considered for the calculations [4]. In general the solar output of these cells is considered to be around 1 kW/m^2 [15], [16].

IV. Calculations

A. Power requirement

The total tractive effort of the bike is effected by various parameters [17]–[19]. The rolling resistance and aerodynamic drag are considered with the coefficients as 0.015 and 0.6 respectively [20], [21]. The bike is assumed to be travelling on a levelled asphalt road.

Tractive effort = $(M * g * v * C_{rr}) + (1/2 * \rho * C_d * A * v^3)$

where M = mass of the bike with driver in kg
g = acceleration due to gravity = 9.81 m/s^2
v = average speed of bike in m/s
C_{rr} = coefficient of rolling resistance = 0.015

ρ = density of air in kg/m^3
C_d = coefficient of drag = 0.6
A = frontal area of the bike with driver = 0.72 m^2
By performing the calculations, the power required by the bike to overcome the tractive effort is 0.96 kW. Hence a motor with 3 kW peak power can be considered by taking into account the remaining losses.

B. Torque requirement

The RPM (N) required for the wheels of the bike to move at 45 kmph and a linear distance of 1.35 m is
N = Total distance covered per minute / 2 * π * r
Therefore N = 45000 / (1.35 * 60) = 555.55 rpm
Assuming the efficiency of the motor as 85 percent the torque required is 13 N-m [22].

C. Range

As it is considered that the bike runs at a speed of 45 kilometers in 1 hour. Therefore the power consumption of the bike will be 960/ 45 = 21.33 Wh/km. Hence the range (S) of the bike can be estimated as S = Battery capacity / power required for 1 km = 130 kilometers.

D. Solar Cells Area

Depending on the design characteristics, the areas of cells are calculated using the dimensions, obtained in 2D CAD model.

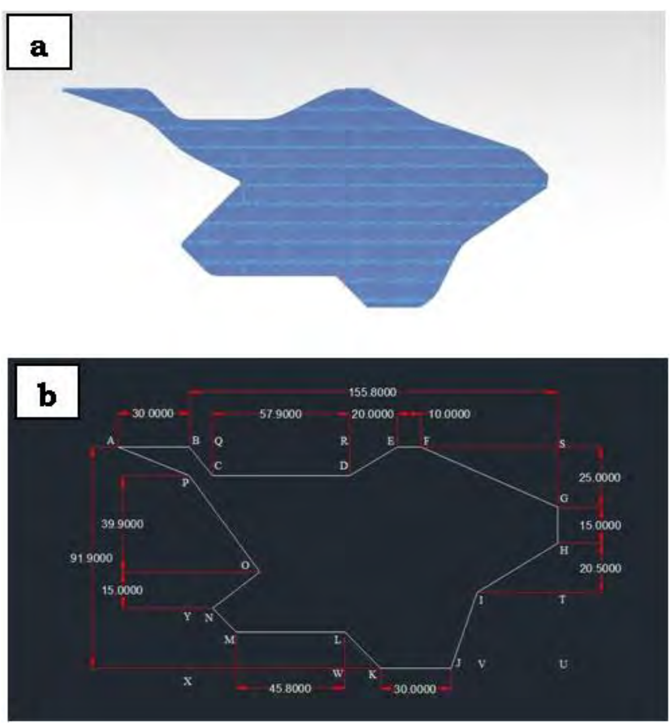

Fig. 2: Side view of the body

1) Side Cells Area: From 3D model of the solar panel, a 2D model is drafted with the dimensions as shown in the Fig.2 (a). The total area of the panel from Fig. 2(b) is considered as sum of areas of rectangle(BSUX) and triangle (ABP). From this, areas of rectangles QCRD, IVUT, YLWX and triangles BCQ, DRE, FSG, HIT, IJV, LWK,POY are subtracted resulting in a surface area of 0.93 m^2.
Solar side surface area = BSUX + ABP - (BQC + QCRD + RED + FSG + HIT + ITUV + IJV + LWK + LYXW + POY) = 0.93 m^2.

2) Area of cells in wheel: The solar cells on the wheel are placed as a disc as shown in the Fig. 3. The area of this disc is approximated as 0.1 m^2 for each wheel.

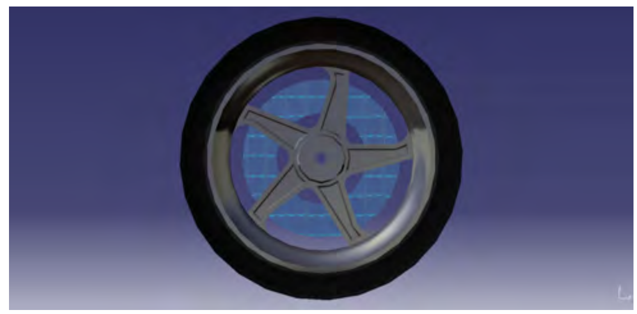

Fig. 3: CAD model of wheel

3) Top Cells Area: By considering the design of the top view, all the cells are approximated as rectangular panels as shown in Fig. 4(a) . Hence the total area of the cells on the top will be equal to sum of areas of rectangles RIHQ, PGFO, NEDM, LCBK, ASTG, PVJU as shown in Fig. 4(b). After the calculations being done, the area of solar cells on the top is 0.52 m^2

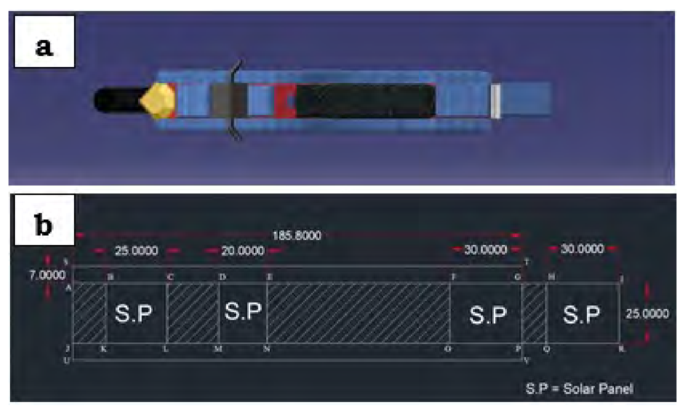

Fig. 4: Top view of the body

E. Solar Power Output

Considering on a hot sunny day, the sunlight starts at Seven o'clock in the morning and ends at Six o'clock in the evening. So the bike receives the light for 11 hours approximately on the given day. But the same amount of light will not be incident on all the cells of the bike.

Hence, the day is divided into three different time periods and accordingly the power output from the solar cells is calculated.

1) From 7 AM to 11 AM and 3 PM to 7 Pm: Assuming that the area of solar cells on one side of the bike and wheels (0.93+0.2) of the bike and 50% of the top (0.52) are exposed to the sunlight in the mentioned time, the power generated from this area of cells in this period is 1.39 * 300 * 8 = 3336 Wh.

2) From 11 AM and 3 PM: In this period of time (i.e., from 11AM to 3PM), the sunlight will be incident mostly on the top(0.52) along with 50% of the side(0.93+0.2). The power generated from this area in this time period will be = 1.085 * 300 * 4 = 1302 Wh

3) Total power: The total solar power generated in the assumed conditions is 4638 Wh. As previously derived, the power required for the bike to travel 1 kilometer is 21.33 Wh/km. The distance that the bike can travel using the power generated by the solar cells is 4638/21.33 = 217 kilometers

4) Average power in a year: From the above calculations, as the time periods are equally divided, the weighted mean of the area will be equal to the average of the area in three time periods. Hence the weighted mean of the area is 1.28 m^2. The data of average sunshine and the power output in different months is calculated and represented in the graph as shown in Fig. 5 [23].

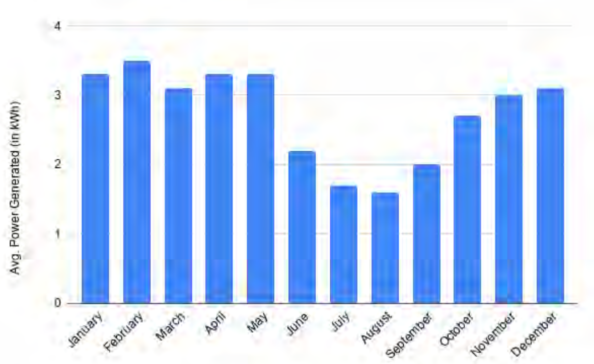

Fig. 5: Average Power Output

V. Results and Discussion

A better environment is created when electric vehicles are used on large scale rather than an automobile running on IC engines. The present work discusses about an electric motorbike which is modified into a solar hybrid bike by fixing flexible solar panels onto the body. The design proposed provides a better efficiency and range for electric bike theoretically, making it convenient for daily commute. The proposed model has demonstrated that the range of normal electric bike can be increased through the method of including solar panels. As mentioned, the vehicle is required to have the design suggested, to get the optimum solution. So, the range obtained for the electric motorbike from battery is 130 kilometers with fixed parameters like constant speed of 45 kmph, coefficient of drag of 0.6 and having a motor with peak power of 3 kWs. Now, with the addition of these solar panels on to body of bike which have a mean area of exposure to sun of approximately 1.29 m^2, it is able to generate an additional power of 4.6 kW per day which increases the range by 217 kilometers, summing up to total of 347 kilometers. The present work also shows a bar chart analysis of this motorbike with proposed design, on how much average power is generated (kWh) in each month of the year from January to December considering the number of average sunshine hours in each month of the year in Hyderabad, India.. From the analysis (Fig.5) maximum power, range and efficiency is in the month of February and the minimum in the month of August. This change in the power generation may be attributed to the amount of sun light available. As per the availability of sunlight, during summer the motorbike is expected to have high efficiency and while in the rainy season it is expected to be low. Nevertheless, this is a new method in the ever-trending automotive field and all the work related to similar concepts and automobiles must take this route for greater development and advancements to achieve a clean and green world.

The design which is showcased here makes effective difference in countries located close to equator which have more sunshine hours. As the cells used here are durable, these last long for a considerable amount of cycles. Apart from this, less weight, easy handling, stress free daily commute will add to its pros. The only disadvantage is that it is not at all efficient during rainy and cloudy weathers. Compared to IC engine motorbikes this solar-electric motorbike is more efficient and economic because of its unique profile. On a long- range graph, it has a very negligible decline in the performance as the power is generated by an abundant source. Furthermore, solar energy adds almost one and half times of range to the total range, making it require a lot less charging time. This motorbike will be a new innovation in automotive era, it is more eco-friendly.

VI. Conclusion

The present work is on a proposed design of electric powered hybrid bike with solar panels. An attempt is made in this work to design an electric bike fitted with flexible solar panels on all sides of the bike. The theoretical calculations carried suggest the following:
(i) An additional power of 4638 Wh can be generated by the solar panels fitted on the bike.
(ii) The additional power generated can increase the range (distance travelled per charge) by 217 km.
(iii) The solar panels fitted will help in enhancing the efficiency of the bike during summer.
(iv) The solar electric hybrid bike is a better solution as a replacement of fossil fuel driven bikes.
(v) It is a performance enhanced eco-friendly system.

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Assessment of Visual and Haptic HMI Concepts for Hazard Warning of Powered Two-Wheeler Riders

Alessio Sevarin, Sebastian Will**,* Janis Rößer**, *Nikolaus Mikschofsky*, Luca Menato*, Thomas Hammer**, Norbert Schneider**, Christian Mark***

*motobit GmbH, Reitschulgasse 23/6, 8010, Graz, Austria

**Würzburger Institut für Verkehrswissenschaften (WIVW GmbH), Robert-Bosch-Straße 4, Veitshöchheim, Germany

Abstract

Whilst the integration of assistance systems such as anti-lock braking systems (ABS) or traction control in modern motorbikes increases, motorcyclists continue to be one of the most vulnerable road users. The introduction of new rider assistance systems derived from the automotive sector, such as Collision Warnings, have the potential to influence positively current accident scenarios. Yet, it must be investigated how assistance systems' information regarding potential hazards can be transmitted to the rider in a way that facilitates suitable responses such as braking or avoidance maneuvers. This is a challenging task as the Human Machine Interface (HMI) of motorcycles has not evolved as fast as the comparable HMI solutions in four-wheelers. Additionally, only few empirical evidences on motorcycle specific warning design has been published.

In this study, the acceptance, and effects of new HMI solutions for the hazard warning of Powered Two-Wheeler (PTW) riders were evaluated. In a first phase, HMI concepts were defined within focus groups of motorcyclists as representative end-users. A first acceptance assessment was developed based on an online survey with more than $N = 200$ respondents. The best evaluations were achieved for a Head-up Display (HUD) and a haptic bracelet. Prototypes of these solutions were integrated in a static motorcycle riding simulator. A participant study with $N = 12$ riders was conducted to investigate the effects of both HMI solutions' influence on rider behavior in potential accident scenarios.

While the results showed no statistically relevant differences regarding the reaction time between the two HMI solutions, the haptic bracelet was rated to be tendentially less distractive and easier to be noticed. This was especially prominent after participants had the chance to get to know the bracelet while riding the simulator.

The results of this study provide food for thought on how new HMI concepts that aim to overcome the restrictions of classical head-down displays could increase the efficacy and acceptance of current and future rider assistance systems.

Introduction

The European Union has set a challenging goal with halving road fatalities by the year 2030, as expressed in the Sustainable Development Goal 3.6 [1]. To achieve this goal, motorcyclists must be considered too. As can be seen in Figure 1, in the year 2018 motorcyclists represented the third most relevant group for road fatalities in the European Union after "car + taxy" and "pedestrians" [2].

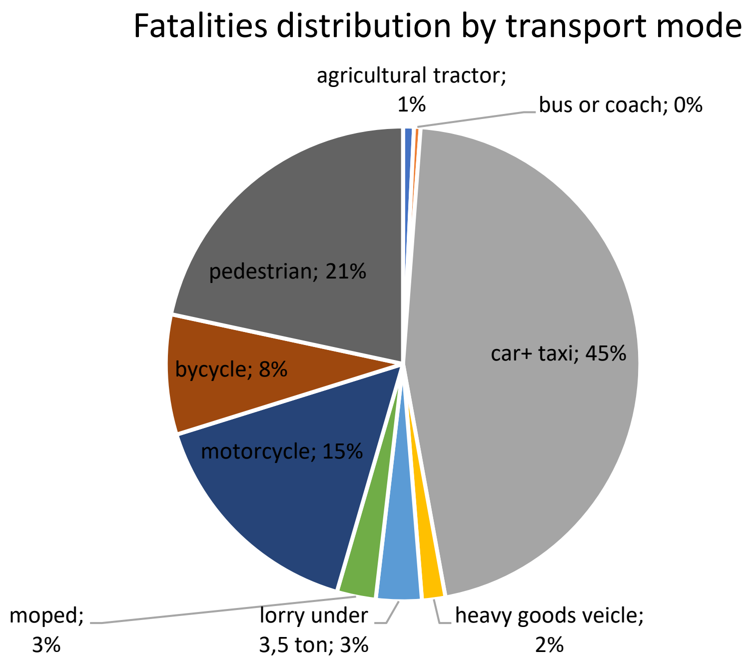

Figure 1 – Road fatalities distribution by transport mode in Europe in the year 2018 [2]

Moreover, the number of motorcyclists' fatalities is decreasing with a much slower trend compared to other transport modes and the risk of being involved in a deadly motorcycle accident in Europe is still 18 times higher than for car drivers [3].

To change this trend, new rider assistance systems, such as Forward Collision Warnings or Vehicle to Vehicle Communication, are being developed. The influence of future rider assistance systems for the current accident scenarios has been evaluated in different studies [4] [5] [6].

In a recent study, it was found that radar-based assistance systems could help avoid one out of seven motorcycle accidents [5] while another study suggests, based on intersection accidents, that up to 40% of the accidents could be avoided [4]

Gruber et al. [6] analyzed different strategies of Forward Collision Warning systems. Four different activation strategies were analyzed: one considering a deceleration by the rider after receiving a warning signal and three considering an autonomous system with different working parameters. The results showed that, between the different strategies, the one with the best results in terms of accident avoidance and collision speed reduction was the one when the rider initiated the deceleration after receiving the warning by the system [6].

This example shows that for the newly developed rider assistance systems to exploit the full potential, an adequate HMI for hazard warning is needed. Unfortunately, the same progress in the HMI warning design seen in four-wheelers cannot be found in motorcycles.

Moreover, the HMI plays a role not only for the correct functioning of the system but for its acceptance too. Huth et al. found in their study that how the information is transmitted to the rider plays a relevant role to increase the usage intention of the system [7]. Validation of these results could be found also in the results of Huth et al., where two different haptic HMIs were tested: a haptic throttle and a haptic glove, with relevant differences in the acceptance between the two interfaces. This was caused by the feeling of "limitation" provoked by the haptic throttle [8].

On a PTW, typically three different sensory information channels are available for information transmission to motorcyclists: visual, acoustic, and haptic.

The use of visual interfaces through the motorcycle dashboard, is state-of-the-art as it is used in every motorcycle, for example, to display the current velocity. The possibility of its use for hazard warning was e.g., evaluated by Will et al. [9], while also the assessment of newly developed Head-Up Display (HUD) can be found in the current literature [10] [11].Acoustic interfaces are commonly used in the automotive domain and the possibility of its use for hazard warnings was evaluated by Song et al. with the use of a helmet-mounted headset [12]. The assessment of haptic interfaces for hazard warnings of motorcyclists, based on motorcycle mounted devices, as for example the throttle twist grip, or motorcyclists mounted devices, such as a vibrating glove, can be found in the current literature as well [13].

In this study, the general acceptability by motorcyclists of different HMIs for hazard warning while riding is investigated with a focus on the assessment of visual and haptic HMIs.

Method

With the goal to assess which HMIs could be used for hazard warning in rider assistance systems for powered two-wheelers, a multistep method was used (see also Figure 2).

In a first phase, two focus groups with N = 13 participants were held to generate HMI concepts for hazard warnings as well as to obtain in-depth insights about the personal evaluation of the concepts by the participants.

To get quantitative information about the acceptance of different HMI concepts based on focus group data, an online survey was developed and distributed.

Two concepts were defined with the insights of the developed survey and implemented in a static motorcycle simulator to offer a direct comparison of their performance in realistic riding scenarios.

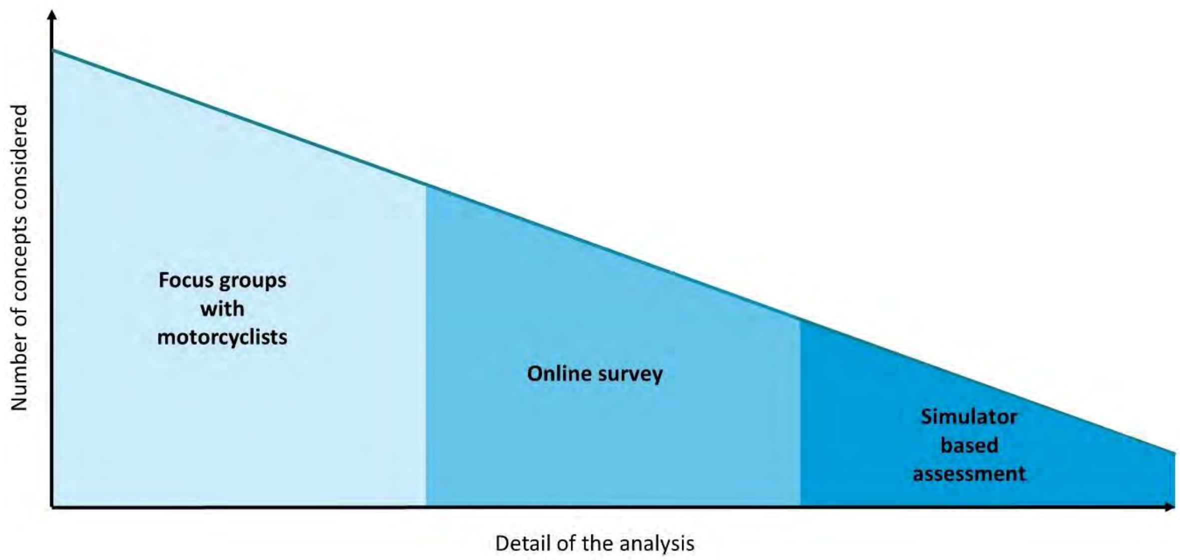

Figure 2 – Steps of the analysis in relation with the number of concepts analyzed and the quantitiative detail of the analysis

Qualitative acceptability of different HMI concepts through focus groups

Focus groups are a widely accepted user-centered method to get qualitative information about the problem to be investigated [14]. Two focus groups were conducted with a total of N = 13 participants, between the age of 25 and 57 years. The participants were recruited from active motorcyclists in the region of Styria, Austria.

The two focus groups were moderated by one person while an assistant took care of recording relevant verbal and non-verbal expressions of the participants. Although interview questions were structured around self-management categories, participants could speak freely.

After a short introduction round of the participants, the discussion was then steered by the moderator to the topic of motorcycle safety, asking which of the participants already had a motorcycle accident.

From that point, the discussion covered topics as to which motorcycle safety systems could have avoided their accidents (if any) or could avoid accidents of other motorcyclists. Finally, the discussion came upon how the participants thought they should have been warned in case of the onset of a dangerous situation.

Quantitative acceptability of HMI concepts through an online survey

The results of the focus groups were used to develop an online survey to get quantitative data on the assessment of potential hazard warning strategies.

The survey was composed of three parts:

- The first one focusing on the identification of the rider type as well as the riding experience
- The second one focusing on the acceptance of different HMIs
- The third one aimed to collect demographic information regarding the survey participants.

To assess the acceptance of different HMIs the participants of the survey were asked to answer the following questions:

- *Which is in your opinion the best possibility to receive information about a dangerous situation while riding a motorcycle?*
- *Which is in your opinion the most distractive way to receive information while riding a motorcycle?*

Simulator based assessment and HMI concept acceptance

To allow an evaluation as near as possible to real riding conditions for the HMI concepts, a motorcycle-riding simulator was used for a participant study with a total number of N = 12 voluntary participants (ten males and two females). All participants came from the WIVW test rider panel and were trained to ride the simulator.

The HMI concepts derived from the previous phases of the study were prototyped to be integrated into the motorcycle simulator (see Figure 3). The haptic bracelet was prototyped with a wi-fi connection capable microcontroller which can trigger the start of four vibration motors integrated in the bracelet. A burst of the duration of 1 second was used as haptic feedback.

The helmet mounted HUD was simulated by displaying a warning symbol in the upper left corner of the central simulator display. The warning was triggered, independently form the rider behavior, with a Time-Headway of 2.5 s.

Figure 3: Haptic device (left) containing a bracelet and the controller. Simulated Head-Up Display warning icon (right).

The study was conducted on the static motorcycle riding simulator at WIVW (see Figure 4) using SILAB® simulation software. Visual cues are provided by three 55" LCD screens offering a 180° horizontal field of view, whereas the instrument cluster is displayed on a 10" LCD screen. A KTM 1290 Super Adventure R is installed as a motorcycle mockup using an automatic gearbox. All relevant controls such as throttle twist grip and the front and rear brake levers are active. Acoustic cues come from a stereo loudspeaker set, while haptic feedback on steering torque is provided by an electric motor with a maximum torque of 50 Nm.

Figure 4 - Static motorcycle riding simulator at WIVW.

In the beginning, the participants were informed of the goal of the study, and they were asked to define their preferred information channel between visual, auditory or haptic cues.

After the introduction, all subjects had the possibility to familiarize themselves with the simulator by riding for approx. 5 minutes before starting the tests.

The tests were conducted in two rides for every participant with a total duration of approx. one hour. To achieve an acceptance evaluation as independent as possible from the test scenario, five different hazard scenarios were developed and implemented in the simulated ride. The hazard scenarios comprised dangerous situations on a rural road, as for example the presence of gravel on the road, as well as on urban roads, as for example an intersection with low visibility. Figure 5 shows exemplary rural and urban test scenarios.

Figure 5: Exemplary test scenarios. Rural road (left) and urban road (right) with changing road surface (low friction ahead).

After each test scenario, the riders were asked to rate the recognizability and usefulness of the HMI concept on a scale from 0 to 10 (see Table 1). Moreover, at the end of the test session, the riders were asked to choose again their preferred information channel for hazard warning.

Table 1: Categorial classification scale to rate warnings' recognizability, usefulness, distraction, and experienced situation criticality. Verbal anchors were adjusted to match the question.

Not at all	Very poor									Very good
0	1	2	3	4	5	6	7	8	9	10

Results

Qualitative acceptability of different HMI concepts through focus groups

Amongst all participants of the focus groups, it became apparent that the safety topic is particularly important. More than half of the participants faced at least one motorcycle accident already.

Regarding a possible HMI solution for retrieving information during the ride, and especially hazard warning, a consensus originated from the participants to avoid the smartphone display as a method for information transmission and was described as distractive and dangerous.

The participants described different concepts from information transmission, focusing especially on three possibilities: visually via a Head-Up Display, acoustically, and haptic through a vibrating wearable device.

The use of an acoustic signal (e.g., a Bluetooth headset) was commonly accepted as feasible, but at the same time, a concern regarding a potential annoyance and/or distraction was expressed in discussions.

On the other side, the possibility to use a Head-Up Display was defined as interesting, nevertheless, due to the relative novelty of this technology in the automotive domain and even more in the motorcycle area, it was unknown to many participants of the focus groups and had to be explained by the moderator. After the explanation, a wide interest could be noted with a big price concern about such a solution.

The use of haptic feedback for hazard warning was described by the focus groups as non-invasive but at the same time difficult to be perceived due to strong external vibrations from the motorcycle. No consensus could be retrieved, to which body region the haptic feedback should be applied best.

Quantitative acceptability of HMI concepts through an online survey

Based on the results of the focus groups, an online survey was used to quantitatively investigate the acceptance of two HMIs: The Head-Up Display and a haptic bracelet. Two other visual HMIs, the onboard dashboard, and a smartphone display were also considered to validate the focus group's results.

The survey was completed by 211 motorcyclists with 97,1 % respondents coming from the European Union.

Only 11 % of the respondents were younger than 24 years old. 30 % were between 25 and 34, while 35 % were between 35 and 50 years old and 24 % of the respondents were older than 50 years. The high frequency of accidents among motorcyclists was also found in the results of the survey: in fact, 59 % of the respondents have had one motorcycle accident already.

The results regarding the preferred HMI by motorcyclists to receive hazard warnings are presented in Figure 6.

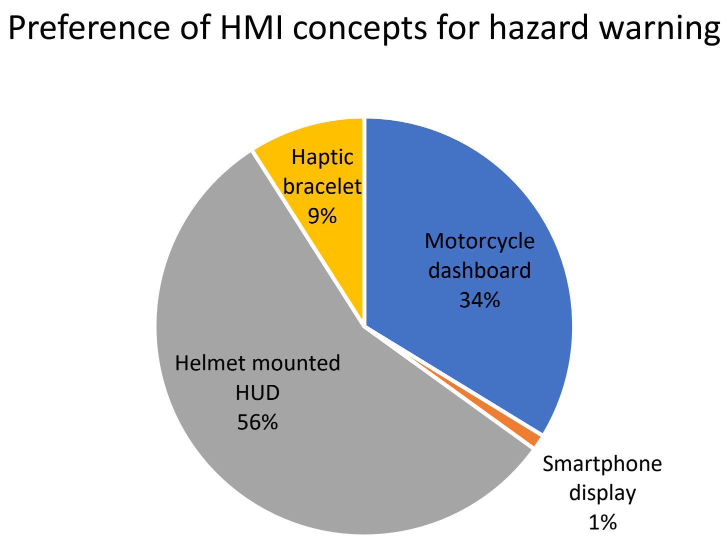

Figure 6 – Acceptance of four HMI concepts for hazard warning

The smartphone display as an information source for hazard warning during the ride achieved the lowest preference: only 1% of the respondents indicated it as the best possibility to receive information about a dangerous situation during the ride.

The haptic bracelet achieved low acceptance too: only 9 % of the respondents indicated it as the best solution to get warned during the ride.

The last two visual HMI concepts were indicated as a good source of information to receive a warning by 90 % of the respondents. In particular, the use of the motorcycle dashboard for information transmission was selected by 34 % of the respondents, while 56 % indicate the HUD as the best option.

The results of the opposed question: “Which is the most distractive way to receive information while motorcycling?” are presented in Figure 7.

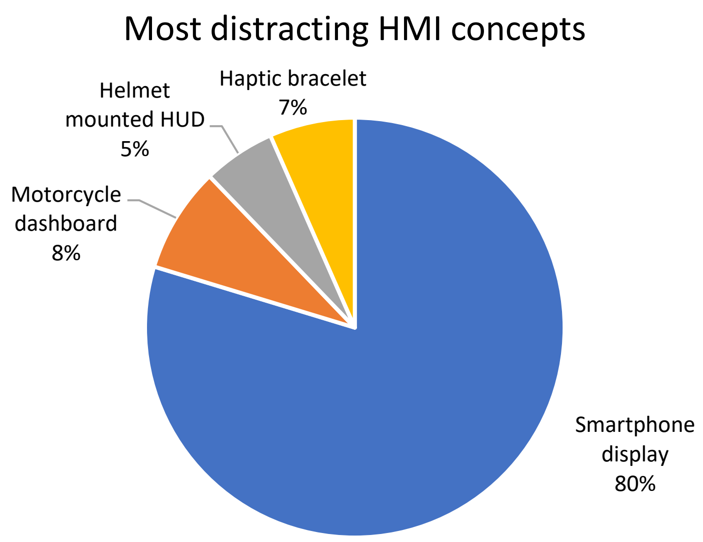

Figure 7 – Distribution of the most distracting HMI concepts as defined by the respondents of the online survey

The results of this question confirmed the information of the previous one: the smartphone display is commonly perceived as a distracting HMI by a motorcyclist. In fact, 80 % of the respondents indicated it as the most distracting way to receive information during the ride, whereas 20 % of the respondents were split between the other three HMI concepts without relevant differences.

In order to assess the possible use of the motorcycle dashboard for hazard warning, the respondents were also asked how frequently they check the dashboard during the ride (see Figure 8).

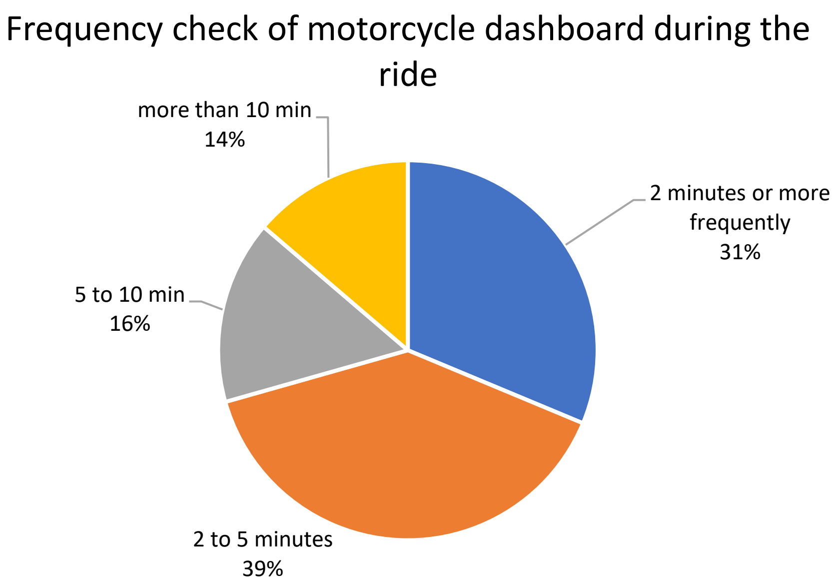

Figure 8 – Subjectively estimated frequency of gazes towards the dashboard while riding.

The results showed that only 31 % of the motorcyclists check the motorcycle dashboard every two minutes or more frequently while the most frequent range found between the survey respondents was between 2 to 5 minutes (39 % of the respondents). 16 % of the respondents check the motorcycle dashboard every 5 to 10 minutes while 14 % do a check less than once in 10 minutes of riding.

Due to the reduced frequency at which the motorcycle dashboard is checked during the ride by motorcyclists it was considered not suitable for immediate hazard warning and not considered for the next step of the analysis. Due to the reduced acceptability also, a smartphone-based HMI was removed for the concept to analyses in the simulator study, leading therefore to two concepts for the next steps of the analysis: a helmet-mounted HUD and a haptic bracelet.

Simulator based assessment and concept comparison

Figure 9 displays riders' ratings on warning recognizability and usefulness with a box plot visualization. A thick line indicates the median value, while the box refers to the 25th and 75th percentiles. The whiskers mark ranges without outliers. Both HMI concepts achieve good perceptibility scores. The HUD receives a median score of approx. 7. In contrast, the haptic bracelet consequently showed high ratings across all situations and participants, achieving a median value of approx. 9. It has also to be noted that a wider spread regarding the perceptibility was found in the case of the HUD. Analyzing the usefulness of the warning no relevant differences can be seen in the observation of the median values achieved by the two concepts, which lie around 5 in both cases. In this case, anyway, was the haptic bracelet showing the widest spread between the two concepts.

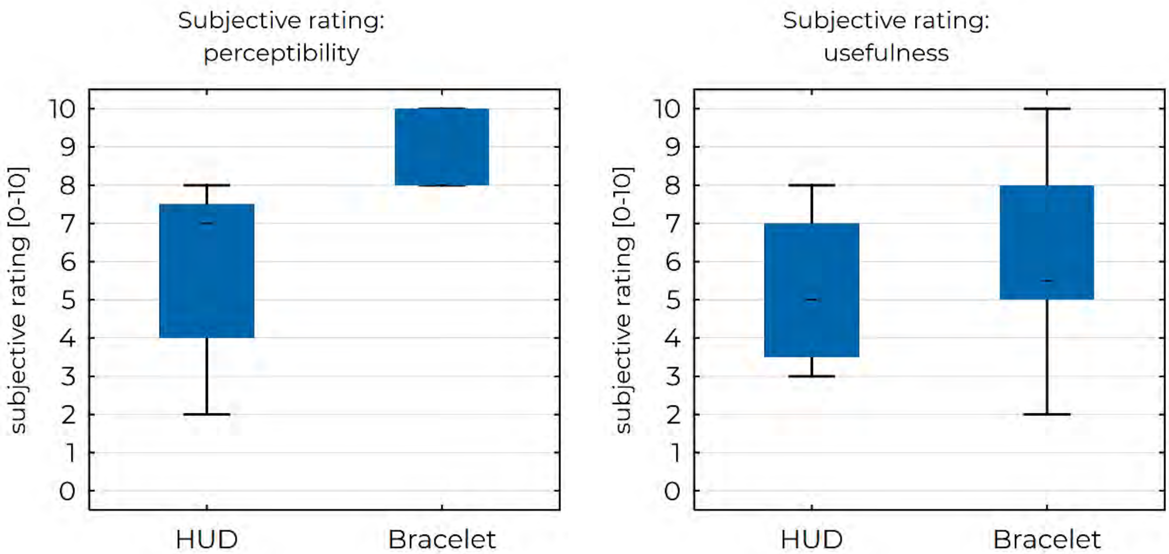

Figure 9: Ratings on warning perceptibility (left) and usefulness (right) as a function of warning concept (HUD or bracelet).

The results of the preference of the different information channels by the participants is presented in Table 2.

Prior to the tests, visual feedback was preferred by most of the testers. This data correlates with the results of both the focus groups and the online survey. The second most preferred information channel was auditory, while haptic feedback was preferred only by one rider.

After the tests, a different preference could be found, with a strong dominance for haptic feedback, which was selected by 54 % of the participants, while the use of visual feedback was preferred by 27 % of the responders and the auditory feedback just by 18 %.

Table 2: Percentage of participants who prefer one of three warning modalities before and after the tests.

Warning modality	*Prior to the test*	*After the study*
Visual	**66 %**	**27 %**
Haptic	**8 %**	**54 %**
Acoustic	**25 %**	**18 %**

Discussion

In this study, the acceptability and acceptance of different HMIs for hazard warning of PTW riders were investigated. Focus groups were used to get a first impression of possible hazard warning concepts.

While notable interest for HUDs was raised in the focus groups, only a few participants had already tried such a system in another vehicle or were aware of a possible application for motorcyclists. Therefore, false expectations could have been raised during the discussion. A similar problem could be observed in the online survey. Therefore, it was decided to follow up on the HUD solution in the simulator study, which provides an experience of what it could feel like. Further, it is important to note that the use of the motorcycle dashboard was excluded in the last phase of the analysis due to the relatively low frequency with which motorcyclists tell to check the dashboard during the ride. Even if haptic wearables scored relatively low, the concept was included in the simulator study, which has the advantage of being less distractive and easy to recognize while riding was emphasized. Once again, it is relatively hard to imagine such a warning device without any prior experience.

In terms of riding behavior, the rider's reactions to visual warnings via HUD and haptic warnings via bracelet did not differ significantly. The inquiries before and after the study show that preferences regarding the relevance of different sensory modalities shift from visual warnings to haptic warnings. It must be considered that in this study the HUD was simulated by a visual warning at a fixed position, independent from the rider´s head. This restriction could have potentially reduced the acceptance of the HMI. On the other side, the results regarding the haptic feedback delivered through the bracelet could be overestimated by the tester as no external vibrations were delivered during the tests.

Conclusions

In this study, potential HMI concepts for hazard warning delivery were defined in focus groups and an online survey was conducted at a later stage before favorit solutions were prototyped and tested in a motorcycle riding simulator. The two tested HMI concepts, namely a haptic bracelet, and a HUD, triggered similar safe rider reactions with higher acceptance for the haptic bracelet after conducting the tests. Nevertheless, external factors that can influence the perception of the feedback need to be assessed during on-road tests to ensure a safety benefit of both PTW warning concepts under realistic riding conditions. This study provides food for thought on how HMI warning concepts can be developed further to increase rider safety.

Acknowledgment

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Impact of a Head-Up Display on motorcycle riding: A pilot study using a motorcycle riding simulator

Sofie Boets[1], Stéphane Espié[2], Aline Delhaye[1], Martijn Teuchies[1]
[1]*Vias institute, Haachtsesteenweg 1405 1130 Brussels,*
Sofie.Boets@vias.be , Aline.Delhaye@vias.be , Martijn.Teuchies@vias.be
[2]*Gustave Eiffel University (formerly Ifsttar), TS2 / SATIE / MOSS, stephane.espie@ifsttar.fr*

Abstract
New technologies, driving aids and/or original or after-market devices (e.g. mobile phones more or less integrated in the vehicle) allow to exchange useful information for driving (e.g. navigators) but can also disturb the driving and cause blindness to the outside environment (phones used to maintain conversations, chatting, watching TV shows). Drivers are sometimes caught between several priorities: a priority relating to their movement and security issues induced for them and for other road users, a priority linked to interactions with driving aids, and finally an egocentric priority relating to considerations that are not related to driving (phone, infotainment, social media...). After the car for which the addition of infotainment functions is now common and is the subject of a competition between manufacturers (connected car, etc.), the motorcycle is currently facing the emergence of communicating systems. Bluetooth devices allow sound to be conveyed while on-board screens (phones or screens integrated into vehicles) can provide the rider the equivalent of what exists in automobile. The manufacturers support or precede the request. In the case of motorcycle riding, the question is critical as far as the level of attention required to manage a trajectory is significantly higher than for car, and emergency manoeuvres much more complex to perform. Even for "classic" uses, motorcycle driving is much more demanding than driving a car because of: the intrinsic non-stability of the vehicle, infrastructure designed for cars and sometimes unsuitable for powered two-wheelers, vulnerability of the riders linked to the absence of "mechanical" protection, but also to the "vehicle" effect (vulnerable therefore losing priority) involving more complex interactions with cars, vans and heavy goods vehicles. The driver of a powered two-wheeler must therefore constantly manage both the stability of his/her vehicle and the interactions that are sometimes critical with other users and / or infrastructure.
Head-Up Display (HUD) technology has a very long history in the aerospace industry and has also appeared for decades in cars. HUDs for motorcyclists have only recently appeared on the market. A pilot experiment using a riding simulator was set-up to compare the effects of using a Head-Up Display (integrated in the helmet) and a Head-Down Display (smartphone on the motorcycle handlebar) in different riding situations on winding suburban roads. Displayed information were navigation, riding speed and the maximum speed limit. The experiment involved 35 subjects and allowed the analysis of intra-subject variability on riding and subjective variables across both display conditions. The study results show the value of the HUD over the HDD in relation to compliance with speed limits and stability of position on the road, and the subjective results are congruent.
While the results of this study are positive with regard to “head-up” displays, the question of transposing the results acquired for devices that have made different choices in terms of the complexity of the proposed messages remains.

Keywords

Road Safety; Motorcyclists; Head Up Display (HUD); Simulator

1. Introduction

Head-Up Display (HUD) technology has a very long history in the aerospace industry and has also appeared for decades in **cars**. Automotive HUDs are mainly projections of information reflected on the windscreen slightly below the centre line of vision, and provide a virtual image distance of 2-3 metres (covering the asphalt) which is the resting distance of the eye. Unlike most information systems for conventional vehicles that display visual messages on installed or dashboard-mounted displays, the head-up display allows drivers to concentrate more quickly from front to back between the road and HUD information. HUDs can thus support the dual task of monitoring the road and processing the information presented (Pauzié, 2015; Häuslschmid et al., 2018). Safety benefits from empirical research in the car sector include the following (Gish & Staplin, 1995; Horrey et al., 2003; Liu & Wen, 2004; Doshi et al., 2009; Ablaßmeier et al., 2007; Pauzié, 2015): more time observing the road (less time looking at the screen) and less time visually re-accommodating (especially for older drivers), faster reactions to events, more constant speed control, fewer infringements, early detection of road obstacles and critical events, a decrease in mental workload and a better knowledge of situations. These benefits may differ though depending on interactions with independent variables such as driver age, mental load and information complexity. On the other hand, some critical aspects related to car HUDs have also been found (Mendes, 2015; Gish & Staplin, 1995; Tretten et al., 2011; Ablaßmeier et al., 2007; Pauzié, 2015): perceptual tunnelling (less peripheral detections), cognitive capture (automatic shift of the attention towards the HUD), the scan saving time may be valid only for low workload situations, contrast interference masking external objects, size/ distance misperceptions as the eye focus on the display is not at infinity (but nearer) which can cause objects on the road to appear smaller and more distant, visual clutter, view blocking, decreased visual attention, and information overload leading to distraction. Mahajan et al. (2015) summarize that the most important demonstrated advantage of HUDs in cars is that they keep the driver's eyes and attention directed towards the road, allowing faster reactions and more time available to avoid collisions, thus improving road safety. HUDs displaying information that normally requires long glances away from the road, such as navigation on a dashboard screen, could therefore provide a safety benefit, because the longer the off-road observation time, the greater the probability of an accident, with the critical value for the car being "greater than 2 seconds" (Pauzié, 2015; Mahajan et al., 2015). The trade-off between the increase in time spent on the road and the possible negative effects in terms of sensitivity to possible critical events on the front driving scene remains to be determined (Pauzié, 2015).

HUDs for **motorcyclists** have only recently appeared on the market, still mostly as add-on devices to mount on the helmet (e.g. Reyedr, BikeHUD, EyeLights), and with first initiatives of helmet-integrated systems (e.g. Livemap). Most current rider HUDs do not provide windshield display but are helmet-based using a screen in a close peripheral area of one eye, e.g. lower or upper right corner, mostly on the right side as this is mostly the lead eye. Displayed information on rider HUDs can be current speed, speed limit, route guidance (e.g. distance), navigation, gear position, time, phone calls (e.g. caller id), music tracks, rear-facing camera… (Mendes, 2015; Häuslschmid et al., 2018). Häuslschmid et al. (2018) evaluated some of the available motorcycle HUDs on the market and provided the following summaries:

- *“The BikeHUD [2016] utilizes a non-see-through display which displays the image below the left eye and at an optically infinite distance. The display unit blocks the riders’ view and requires a direct glance downwards for reading the content. The BikeHUD requires a wired connection to the bike.”*
- *“The Reevu MSX1 [2016] is also a rather simple version of a helmet-mounted display and presents a digital rear view mirror at the top edge of the helmet. As the distance to the eyes is very low, it is difficult to visually focus on the display.”*
- *“The Skully AR-1 [2016] is a fundraising project that recently failed. The optical concept was similar to the Google Glass and the peripherally placed image was planned to display, e.g., a rear view camera and navigation information.”*
- *“The Nuviz Ride [2016] is also a fundraising project. The display unit is attached to the outside of the helmet and presents its image below the right eye. The helmet can be connected via Bluetooth to the smartphone and controlled via a customized control unit for the handlebar.”*
- *“The LiveMap [2016] helmet displays a binocular image at a distance of about 4 m and within the central field of view. The company justifies this placement by promising that they will limit the central display of complex content to very low speeds. The system is based on a projector, integrates sensors such as a Gyroscope and can be connected to the smartphone. The helmet is still under development.”*

Research on the impact of motorcyclist HUDs on traffic safety is still quite rare. Available studies mostly aim at developing prototype HUDs and evaluating design aspects (e.g. Mendes, 2015; Ito et al., 2018). Available studies are mainly aimed at developing HUD prototypes and evaluating design aspects (e.g. Mendes, 2015; Ito et al., 2018). One of the few studies available on a limited number of variables indicate that HUDs can induce a lower workload, less interference with the driving task and lead to greater compliance with speed limits compared to conventional displays (Häuslschmid et al., 2018). However, a pan-European survey (Baldanzini & Delhaye, 2015) of nearly 5,000 motorcyclists in 23 European countries on 53 motorbike safety innovations found that "Helmet visor information display", "Real-time display of rear view on the helmet visor" and "Head-up display of vehicle information on the helmet visor" were among the top 10 features assessed as the most dangerous. The fear behind these devices is that they require active interaction with the driver, resulting in information overload and distraction at a critical moment in the driving experience.

It has been assumed that most of the advantages of car HUDs also apply to powered two-wheeler HUDs, while some disadvantages do not apply to motorcyclists or are different for motorcyclists (due to differences in devices), although issues such as cognitive capture and perceptual tunnelling should also be considered for motorcyclists' HUDs (Mendes, 2015). Furthermore, there are marked differences between driving a car and riding a motorbike (e.g. vehicle mastering is much more complex for motorbikes than for cars, intrinsic instability of motorbikes, roads primarily designed for cars, vulnerability of motorbikes when interacting with cars). This makes it necessary to take into account the typical characteristics of motorbike riding in the design of HUDs.

The current study analysed simulated riding behaviour with a helmet-mounted HUD providing navigation information, current speed and speed limit, as compared to riding with a HDD smartphone on the motorcycle handlebar providing the same information. Effects on relevant riding parameters for road safety are evaluated, during normal riding conditions as well as in more hazardous situations. The experimental measures include simulator data on lateral (road position) and longitudinal (speed) riding control, and subjective data (user experience and workload, and system attractiveness). Based on the initial hypothesis that the use of head-up and head-down displays have a different impact, the objectives of this study were to compare the usefulness, user experience and rider interaction of both systems.

2. Methodology

2.1 Participants

The sample consisted of 35 experienced motorcyclists between 27 and 56 years old (mean age 37.5 / standard deviation (sd) 7.3), who participated in the study between 21 November and 2 December 2019. Despite the desire to reflect the ratio of men to women in the passing of motorbike licenses (approximately 10% of women), this proportion could not be respected on the basis of the validation criteria for voluntary testers (1 woman). Motorcyclists had to have more than 5 years driving experience, with a regular driving record of more than 3,000 km/year in recent years. All participants had an A/A2 driving license for an average of 12.3 years (sd 8.5) (min/max 5 years / 38 years). 33 participants also held an A1 license for an average of 17.5 years (sd 6.6); min/max 6 years / 28 years). Most of the participants (32) also held a driving license for category B vehicles (cars) (average duration 18.7 years (standard deviation 7.4); min 8 years / max 37 years). The average number of kilometres travelled over the last 3 years was 13,538 km/year (sd 8,395) with a min-max of 5,000 to 40,000 km/year. The participants were compensated with a monetary reward.

2.2 Material

Motorcycle simulator

The UGE has an original and high-performance motorbike driving simulator. This simulator was developed at INRETS (former UGE) in 2006 as part of the SIMACOM research project. This simulator has enabled a number of studies to be carried out (Lobjois 2016a, 2016b; Bougard 2015). The motorbike simulator is one of the 10 "high-end" prototypes currently in use around the world. (see Figure 1). The UGE's motorbike simulator is a virtual environment:

- 3 large tv screens (3 x 55'' → ~ 3 x 1.2m width, 0.7m height), pseudo-circle → lateral visual field 130° (~40 pel by degree), 60 Hz
- 4.5 DOF motion base: (pitch, roll, yaw ~10° ; haptic feedback systems on the MC frame (to reinforce acceleration/deceleration) feeling ; force feedback system on the steering column
- Sound rendering 5.1
- Full MC mock-up
- Proprietary software (ARCHISIM + SIM²)

Figure 1 - View of the UGE motorbike simulator "SIMACOM". (Copyright: UGE)

The software used for the visual rendering (SIM², in its SIMU&MOTO version) allows the visual horizon to be placed at the eye level of each subject according to their morphology. The virtual environment used (GIF2) consists of a loop of about seven kilometres representing a real environment (area of the town of Gif sur Yvette). The network consists of a 3.5 km zone used twice because it is looped at its ends (see Figure 2 A and B).

A B

Figure 2 A and B - GIF2 motorbike scenario (A); GIF2 network view (B) (Copyright: UGE)

The software used to simulate the motorcycle model (and thus enable the driver to move the virtual vehicle in the virtual world) and to animate interactive traffic (ARCHISIM, in its SIMU&MOTO version) records the state of the sensors, positions, attitudes (heading/roll/pitch), speeds and accelerations of the subject vehicle as well as of the vehicles encountered. ARCHISIM is also in charge of producing the sound output via a 5.1 hi-fi system enabling spatialization of the various sound sources in the virtual environment (vehicle ego and simulated vehicles).

Visualization devices

The EyeLights HUD system for motorcyclists (http://www.eye-lights.com) was used for the study as well as a "standard" browser on the phone.

The EyeLights system consists of a device that is attached to a helmet with Velcro. An LCD screen is reflected through a semi-transparent mirror, which is integrated into a transparent prism with a square cross-section. The position is adapted to each driver. The system is placed in front of the right eye, above the horizon line. The driver must look up to read the information displayed.

For the HDD, the "smartphone" navigator was attached to the handlebars of the motorbike driving simulator by means of a "gooseneck". The flexibility of the "gooseneck" and its positioning allows the driver to adjust the position to suit his needs. The screen does not interfere with manoeuvring, the view of the road or the vision of the speedometer.

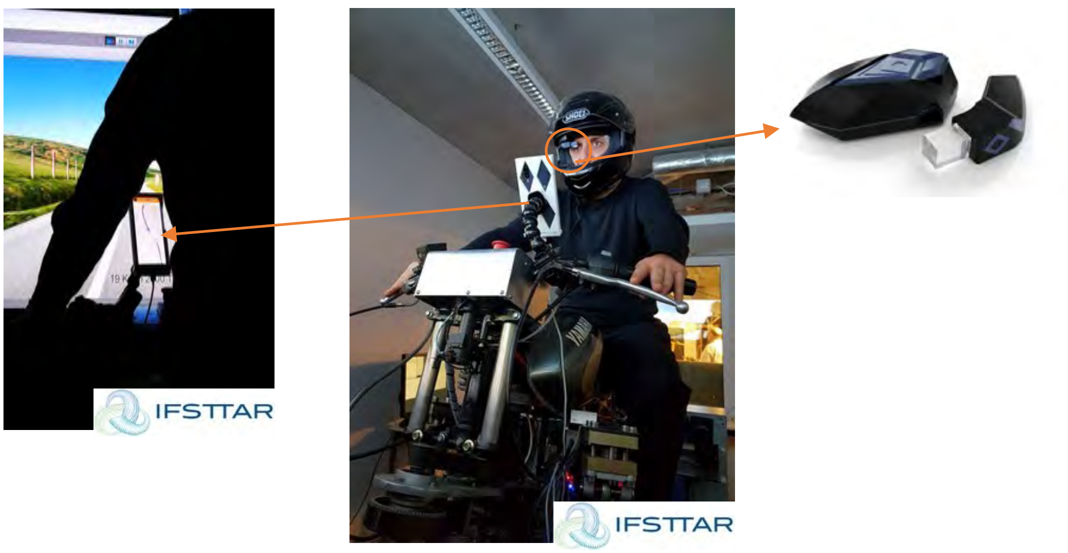

Figure 3 - Two display modalities: HUD (Eye-Light system) and HDD using a smartphone mounted on the MC handlebar (Copyright: UGE)

Questionnaires

French versions from the following questionnaires were administered :

- Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) (HDD & HUD)
- NASA TLX (Hart & Staveland, 1988) for mental workload (HDD & HUD)
- Subjective ride evaluation (HDD & HUD)
- Presence questionnaire (Witmer & Singer, 1998)
- HUD opinion questionnaire (after participation)

2.3 Experimental situation

The study plan was intra-subject. The order of use of the 2 displays was counter-balanced between subjects. The starting point of the scenarios was also counterbalanced between and within participants to minimize order effects.
The experimental situation consisted of free driving on the GIF2 road circuit with traffic in the opposite direction (when possible) and traffic in the same direction outside the "test" areas where there is no traffic in the same direction as the rider. The participant got the instruction to pick up his/her companion under "standard" time constraints (i.e. no over- or under-speeding) following the displayed navigation instructions, and to manage the traffic in a natural way without breaking the traffic regulations. The displays informed the rider on the next directions, the current speed limit and the currently driven speed. During his journey the rider passed roundabouts, intersections and curves. Traffic was light. The speed limit changed during the journey and was indicated by traffic signs. The travel time for each trip was about 15 minutes (7 km completed at an average of 30 km/h due to the presence of roundabouts on the route).

2.4 Study design and variables

The experimental design was as follows: 35 participants * display modes²
The effects on driving parameters relevant to road safety were evaluated, both under normal driving conditions and in situations more dangerous for motorcyclists. Experimental measures included riding data: mean and standard deviation of speed, standard deviation of lateral position – distraction-sensitive measures (Papantoniou et al., 2015) – , losses of control and subjective data (simulator sickness, mental workload, subjective ride evaluation, opinions on HUD/HDD).

2.5 Procedure

The full procedure took about 1h30, and included the following ordered steps for each participant:

- Welcome by the experimenter, who explained how the experiment would be carried out
- Reading of the "research information leaflet"
- Signing of "free and informed consent form"
- Balance test
- Completion of the first general questionnaire (demographic data)
- Simulator familiarization ride (free driving on a road network lasting about 15 minutes followed by a rest phase of about 5 minutes)
- Test leader gives the standard instructions for the first ride
- Completion of the first ride (counterbalanced HUD / HDD between participants)
- Completion of the questionnaires on the mental work load and simulator sickness
- Test leader gives the standard instructions for the second ride
- Completion of the second ride (counterbalanced HUD / HDD between participants)
- Completion of the questionnaires on the mental work load and simulator sickness
- Completion of the final questionnaires: presence questionnaire and opinions
- Debriefing interview
- Monetary award
- Balance test to check the ability to return home safely (if not, the participant was invited to rest on the spot while waiting for a return to "normal")

2.6 Data processing and analysis

The raw data was pre-processed to identify relevant zones for analysis:

- 4 masked curves limited to 50 km/h (the rider cannot identify the geometry of the curve)
- 4 junctions limited to 50km/h (roundabouts / intersections)

A "loss of control" (falls or accidents) was identified when "speed" data was equal to 0 km/h for more than 3 seconds. The speed data associated with the loss of control was removed until the participant's speed was again 80% of the original (pre-loss of control) speed. The means and standard deviations of speed and lateral position were calculated within a 3s square sliding window (60 samples). The data for the first three seconds of the rides were removed (values not relevant because they were related to the start-up). Aggregated means and standard deviations of speed and lateral position by area/participants/display condition were calculated.
For the analysis of the simulator data, the aggregate means and standard deviations were first calculated for each zone. Repeated Measures ANOVAs were then performed in SPSS 22. Display and zone were defined as intra-subject factors, with speed (mean speed and standard deviation) and standard deviation of lane position as dependent variables.
Paired sample "t" tests and Wilcoxon signed rank tests were used in SPSS 25 to compare questionnaire data (NASA TLX, SSQ, subjective assessment of the rides) for both display conditions.

3. Results

3.1 Ride data

Mean speed

There was a significant main effect for display type on mean riding speed (curved: $F(33) = 19.51$, $p < .001$; intersections: $F(33) = 15.81$, $p < .001$). This shows that for curved zones with a speed limit of 50km/h (Figure 4A) and for zones with intersections and a speed limit of 50 km/h (Figure 4B), the mean speed was significantly lower in the head-up condition (curved M = 69.24 km/h, sd = 13.07; intersections M = 65.02 km/h, sd = 10.91) compared to the head-down condition (curved M = 78.75 km/h, sd = 13.28; intersections M = 71.76 km/h, sd = 11.96).

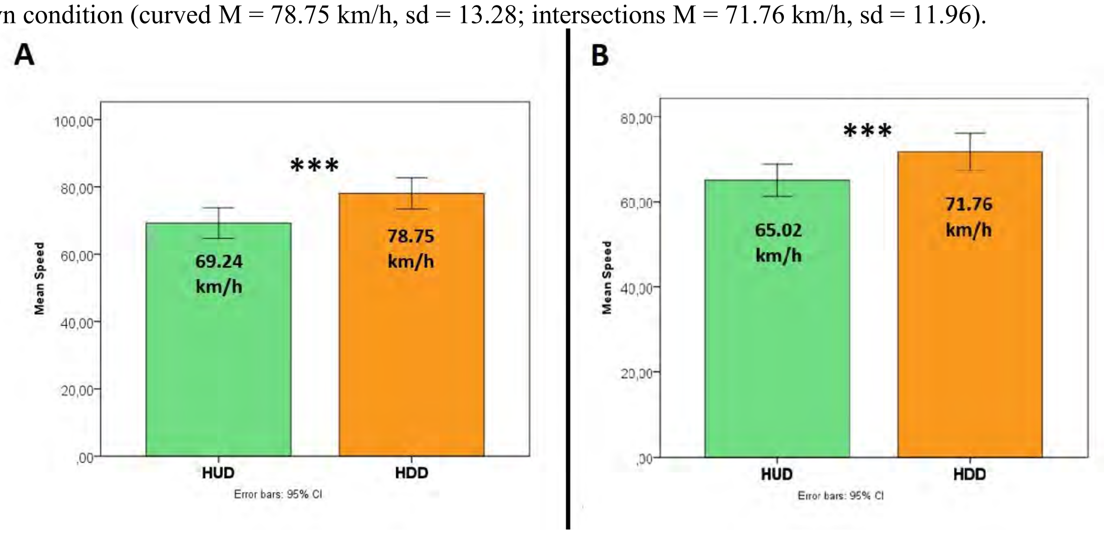

Figure 4 A et B: Mean speed (km/h) for the head-up display (HUD) condition and the head-down display (HDD) condition for curved zones with a speed limit of 50 km/h (A) and zones with intersections with a speed limit of 50 km/h (B).

Standard deviation of speed

There was found no significant main effect for display type on speed variability (curved: $F(33) = 0.35$, $p > .05$; intersections: $F(33) = 0.29$, $p > .05$). This shows that for both zone types (curves: Figure 5A; intersections: Figure 5B), the standard deviation of speed was similar in the head-up condition (curved M = 5.7 km/h, sd = 2.5; intersections M = 7.1 km/h, sd = 2.1) and in the head-down condition (50 km/h M = 6.7 km/h, sd = 5.3; intersections M = 7.4 km/h, sd = 3.6). This indicates that the mean speed did not variate more or less in one of the two conditions.

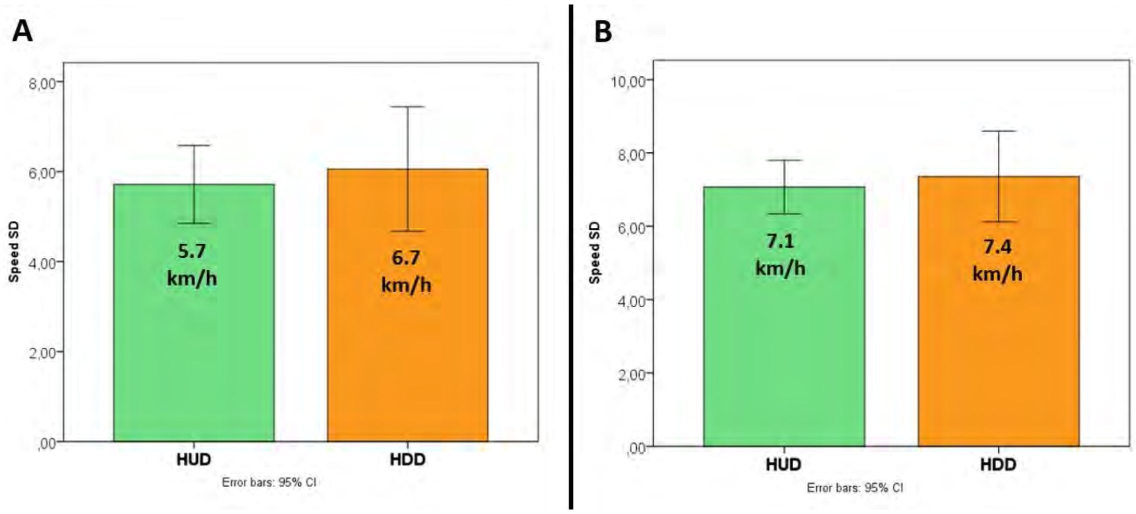

Figure 5 A et B: Standard deviation of speed (km/h) for the head-up display (HUD) condition and the head-down display (HDD) condition for curved zones with a speed limit of 50 km/h (A) and for zones with intersections with a speed limit of 50 km/h (B).

Standard deviation of lateral position (SDLP)

There was a significant main effect for display type (curved: $F(33) = 4.99$, $p < .05$; intersections: $F(33) = 5.21$, $p < .05$) on the SDLP. This shows that for curved zones with a speed limit of 50km/h (Figure 6A) and for zones with intersections and a speed limit of 50 km/h (Figure 6B), the SDLP was significantly smaller in the head-up condition (curved M = 301mm, sd = 270mm; intersections M = 282mm, sd = 154mm) compared to the head-down condition (curved M = 351mm, sd = 228mm; intersections M = 328mm, sd = 175mm).

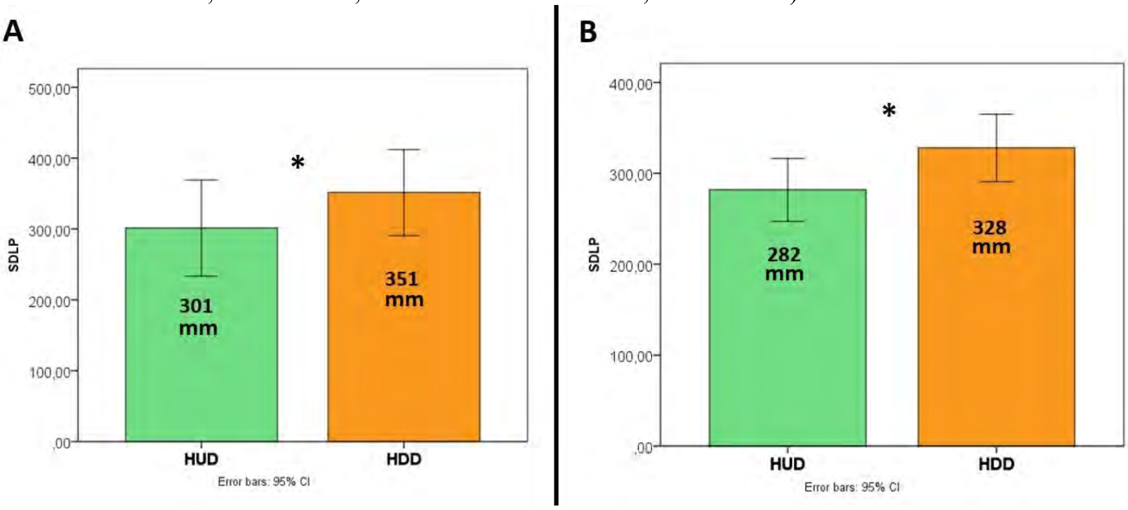

Figure 6 A et B: Standard deviation of the lateral position (mm) for the head-up display (HUD) condition and the head-down display (HDD) condition for curved zones with a speed limit of 50 km/h (A) and for zones with intersections with a speed limit of 50 km/h (B).

Loss of control

The total number of losses of control, which could be falls or accidents, was 10 in the HUD and 15 in the HDD. It was tested whether this difference was significant using a Wilcoxon Signed rank test in SPSS. The test showed that the number of falls did not significantly differ between both conditions ($Z = -.691$, $p > .05$).

3.2 Questionnaire data

Presence questionnaire (PEQ)

The participants rated their presence in the virtual simulator environment generally high, indicating a rather good level of immersivity of the motorcycle simulator and scenarios: mean total score of 109.4 (sd 21.34) which is slightly above the norm (M 104.39, sd 18,99).

Subjective ride evaluation

The participants rated each ride (HUD / HDD) subjectively on 10 parameters on a 10-point rating scale from 1 (favourable evaluation) to 10 (not favourable evaluation).
All scores relating to the HUD are on the favourable side of the rating scale, while most scores related to the HDD condition cross the midline towards a more negative evaluation.
The scores differ significantly in favour of the HUD condition. Participants found riding with the HUD, compared to riding with the HDD, significantly less dangerous ($Z = -4.408$; $p = .000$), less difficult ($Z = -4.02$; $p = .000$), less disruptive ($T(34) = -3.484$; $p = .001$), less distracting ($Z = -4.068$; $p = .000$), and more comfortable ($Z = -3.453$; $p = .001$). Moreover the HUD was perceived as significantly more easy to look at ($t(33) = -5.582$; $p = .000$), with a significantly more easy transition of the visual focus between the device and the road ($t(34) = -6.856$; $p = .000$). Participants also found the navigation significantly more easy to follow in the HUD ($t(34) = -3.374$; $p = .002$). Finally, the HUD was considered to be more a support for the ride than the HDD, but this was only marginally significant ($t(33) = -1.845$; $p = .07$). Only the visual obstruction parameter did not differ significantly: both devices led to a similar low level of visual obstruction ($Z = -.960$; $p = .34$).

NASA Task Load Index (NASA TLX)

To estimate how much effort it took participants to complete both rides, the NASA task load index was taken after each ride. This questionnaire measures 6 dimensions: mental load, physical load, time pressure, performance, effort, frustration. On a descriptive level, the mean scores on the NASA TLX are on the lower task load side (below midlevel) and generally lower (less task load) for the HUD ride than for the HDD ride.
According to the participants, the ride with the HUD required significantly less effort ($t(34) = -2.987$; $p = .005$) and induced less mental ($t(34) = -3.549$; $p = .001$) and temporal ($Z = -2.688$; $p = .007$) pressure, as compared to driving with the HDD. The self-estimated ride performance was also better in the HUD condition, but this was a marginally significant difference ($t(34) = 1.853$; $p = .073$).

HUD opinion questionnaire

After their participation, the subjects were asked to give their opinion on HUDs. The large majority of the participants had a favourable perception of both the HUD used and of HUD technology in general on motorcycle riding, although the perception was clearly more positive for the technology in general than for the specific device that was used in the experiment. Table 1 shows the results.

	More safe	**Less safe**	**No opinion**
According to you, the HUD device that you used in the experiment is a solution which will make motorcycle riding …	80%	3%	17%
According to you, HUD technology (in general) could be a solution which will make motorcycle riding …	91%	3%	6%

Table 1: Opinion on the HUD used in the experiment and on HUD technology in general after study participation (%).

4. Discussion and Conclusions

This was a within-subject experimental motorcycle simulator pilot study to evaluate the effects of using a HUD (integrated in the helmet), as compared to using a HDD smartphone (on the motorcycle handlebar) – showing navigation information and the actual and maximum speed limit – on riding on curvy (sub)urban roads. Effects on different safety related riding parameters as well as on subjective parameters were analysed.

First of all it should be stressed that the results of this pilot study relate specifically to the current experimental set-up, with specific HUD and HDD devices (systems, software and content/visualisation), in this particular motorcycle simulator and in the specifically developed road scenarios), and therefore cannot be generalized towards any HUD and HDD system and real-life situations.

Main findings with regard to the study set-up are:

- Most of the participants (80%) have a favourable opinion about technology in the motorcycling sector and believe that : « *Technology is an opportunity to make the road more safe, more ecological and fluent (less traffic jams). It is the solution to a constantly growing traffic demand.* » It may be possible that there was a sample bias in this study, with persons having a more positive idea about new technologies being more inclined to participate in this type of studies. This may also have had an influence on the subjective results in this study.
- The feeling of immersivity in the motorcycle simulator and scenarios was rather good. The simulator riding experience can thus be considered as a valid proxy of the real-life riding experience.

The results of the riding data analyses indicate that:

- The mean riding speed in masked curves and around intersections was significantly lower, and more conform with the maximum speed limit, while using the HUD, as compared to using the HDD. It can be hypothesized that the speed limit was more accessible or more easily or quickly looked at in the HUD than in the HDD condition.
- Speed variation did not differ significantly between both conditions, indicating that the speed in the HUD condition was consistently lower and more conform with the legal limit than in the HDD condition.
- Variability in lane position in masked curves and around intersections was significantly lower while riding with the HUD, indicating a better road position stability, than in the HDD condition. This shows that the riding was more adapted in the HUD condition, even though this device did not provide road geometric information, as opposed to the HDD.
- There were 50% more 'loss of control' events (falls or crashes) in the HDD condition than in the HUD condition, but this was not a significant difference.

All in all, the ride results indicate that riding with a HUD and with a HDD led to significant differences in safety related riding parameters, in the advantage of the HUD condition.

The subjective evaluations of the participants are congruent with the objective results:

- Riding with the HUD, as compared to the HDD, was evaluated as significantly less dangerous, less difficult, less disruptive, less distracting, more comfortable, more easy to look at, and a bigger support for the ride.
- In the HUD, the transition of the visual focus between the device and the road was considered significantly more easy, and the navigation was considered more easy to follow.
- According to the participants, the ride with the HUD required significantly less effort and induced less mental and temporal pressure, as compared to riding with the HDD.
- The self-estimated ride performance was also better in the HUD condition.
- 80% of the participants found the HUD which they just used in the a solution to make motorcycling more safe (17% had no opinion, 3% thought it would make motorcycling less safe).
- And finally, the perceived value of the HUD 'used in the experiment' was slightly lower than the perceived value of HUD technology 'in general', indicating that the participants did perceive space for improvement of the HUD used in the study.

Limitations of the study

There were several limitations in this pilot study:

- The visualised content in the experimental HUD and HDD differed. In the HDD the navigation also displayed the road geometry while in the HUD only arrows were shown without input on road geometry. The found differences may therefore also relate to the different content (besides the different position). Nevertheless, the comparison was done with devices as they are currently on the market, and therefore, they do reflect realistically the current situation.

- We cannot exclude a possible effect of sample bias or social desirability, at least on the subjective results, as the sample may have been generally in favour of new technologies and some participants may have thought that the study team was not fully independent from the HUD provider, and therefor may have given more positive feedback on the HUD. Such biases should be maximally controlled for in future studies.

Conclusions and prospects

While the results of this study are positive with regard to "head-up" displays, the question of transposing the results acquired for devices that have made different choices in terms of the complexity of the proposed messages remains.

The display content scope was rather limited in this pilot study. In order to measure the impact of future infotainment devices, it is necessary to conduct studies with prototype devices allowing not only navigation but also telephone and music (and management of the music tracks) interactions, and even exchanges on social networks.

Such studies are needed necessary to inform and help public decisionmakers about future sensitization campaigns and/or regulations, to guide system designers towards safety compatible systems, but also to raise awareness among users.

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TITLE: Autonomous Emergency Braking system for Powered-Two-Wheelers: testing end-user acceptability of unexpected automated braking events deployed in typical pre-crash trajectories

AUTHORS: Cosimo Lucci[1], Pedro Huertas-Leyva[1], Mirko Marra[1], Marco Pierini[1], Giovanni Savino[1,2], and Niccolò Baldanzini[1]

PRESENTER: Cosimo Lucci cosimo.lucci@unifi.it

AFFILIATIONS:

1) Dept. of Industrial Engineering, University of Florence, Via di Santa Marta 3, 0139 Florence, Italy
2) Monash University Accident Research Centre, 21 Alliance Ln, Clayton VIC 3800, Australia

ABSTRACT

Research question / Starting point for investigation:

One of the emerging technologies in road vehicles safety is Autonomous Emergency Braking (AEB), which applies autonomously a braking force to reduce impact speed in pre-crash conditions. Some studies showed that motorcycle AEB (MAEB), could be very effective and reliable in reducing serious consequences of Powered-Two-Wheelers (PTWs) accidents. The main issue before the introduction of MAEB on standard vehicles is related to the acceptability of the system to end-users and the controllability of the vehicle.

This study, organized within the EU funded project PIONEERS, wants to assess with common users the acceptability and the controllability of MAEB, deployed in realistic pre-crash scenarios and avoidance manoeuvres.

Methods:

Field test involved common riders on two test vehicles (a scooter and a tourer motorcycle style) equipped with MAEB functionality. The intervention was triggered in the speed range 35-50 km/h during riding manoeuvres: straight path, lane-change, slalom (meant to mimic traffic filtering), and curve. The participants rode in a circuit; MAEB was activated via remote control unexpectedly at random times. The tested decelerations and jerks were nominally 3 m/s^2 and 5 m/s^2, and 15 m/s^3 and 25 m/s^3 respectively.

Results:

A total of 51 participants took part in the study, each one riding one of the two vehicles; MAEB was activated more than 900 times in different conditions. Participants reported that they were always able to manage the interventions and control the vehicle with minor effort in straight activations and moderate effort in lateral manoeuvres.

Impacts / Effects / Consequences:

This study investigated the acceptability of MAEB among end-users. Results indicate that the conditions of safe intervention of MAEB may be broader than riding along a straight path. Also, the higher levels of tested deceleration turned out to be safe and acceptable by end-users, suggesting that MAEB intervention could be more effective than what was assessed assuming more conservative decelerations.

KEYWORDS: Motorcycle, Scooter, Active safety, Autonomous emergency braking, Feasibility tests, Rider acceptability

1 Introduction

The worldwide growing diffusion and usage of Powered-Two-Wheelers (PTWs) is linked with an increasing burden of the PTWs users' crashes (WHO, 2018). In order to mitigate injuries and reduce fatalities among this vulnerable road users, in recent years researchers worked to develop on motorcycles the Autonomous Emergency Braking (AEB) system, available on four-wheeled vehicles that are inherently more stable than single-track vehicles. This technology, which is capable to reduce pre-crash speed or even prevent crashes by autonomously deploying a braking force, showed great efficacy and reliability among passengers cars and trucks (Fildes et al., 2015). The main concerns related to AEB application on motorcycles and generally PTWs (MAEB), are related to its interaction with the rider and the safety of its intervention.

Previous research on motorcycle braking to increase safety has focused mainly on optimal braking models (Cossalter et al., 2004; Sharp, 2009), braking performance of riders during hard braking or pseudo-emergency braking (Davoodi and Hamid, 2013; Huertas-Leyva et al., 2019), rider stability (Gail et al., 2009; Huertas-Leyva et al., 2020) or assessment of the effectiveness of advance braking systems such as anti-lock braking systems, combined braking systems or braking enhancing systems (Anderson et al., 2010; Dinges and Hoover, 2018). At the same time, riders' reactions to a frontal collision warning in a rear-end collision scenario have also been studied (Biral et al., 2010). Nevertheless, to develop and implement AEB on motorcycles, comprehensive and specific research on MAEB providing new insights is required. Early research focused on assessments of MAEB benefits via crash reconstructions and field tests to evaluate rider stability during the deployment of Automatic Braking (AB), involving PTW prototype systems and participants (Savino et al., 2020). The first study focusing on field testing MAEB was conducted in 2010 involving professional riders with a PTW equipped with a laser-scanner and producing automatic decelerations in correspondence with a target obstacle (Giovannini et al., 2013; Savino et al., 2012). A following study, in order to reduce the level of predictability of AB tested by participants, was carried out testing AB with decelerations of the test vehicle up to 0.2 g deployed unexpectedly via remote control (Savino et al., 2016). The latest experiments were conducted with professional riders testing undeclared AB events with decelerations up to 0.7 g and jerk up to 1.2 g/s (Merkel et al., 2018). In conclusion, the results of these studies suggest that automatic decelerations greater than 0.3 g can be managed by common riders in straight-line motion.

However, some preliminary studies which analysed the effectiveness of MAEB suggested that these working parameters and conditions may not be sufficient to reduce the likelihood of sustaining serious injuries in case of crashes (Piantini et al., 2019). Moreover, the scenarios other than the simple straight-line motion which are currently untested need to be evaluated to better understand the possible risks and possible applications of MAEB. It is therefore crucial to test the applicability of MAEB in a broader range of manoeuvres more representative of the PTWs pre-crash scenarios and with more effective parameters of intervention.

The goal of this study is to evaluate both the acceptability of the MAEB among end-users and the controllability of the vehicle during AB activations in more realistic pre-crash scenarios and with higher levels of deceleration and jerk than those tested in previous studies. The results of this study will allow extending the field of applicability of MAEB in conditions which are relevant to improve the safety of PTWs users.

2 Methods

This study obtained ethical approval by the Ethics Committee of the University of Florence (Written opinion N. 46, 20/03/2019). The participants were recruited among active riders characterized by two years or 10000 km of riding experience and aged between 20 and 65. The advertisement for the participants' recruitment was disseminated through the university web page, social media, flyers and biker groups.

Two test vehicles were involved in this study. The first vehicle was a Ducati Multistrada 1260S, a sport-touring motorcycle equipped with Bosch ABS (Anti-lock Braking System), combined braking, four-stroke engine with a displacement of 1262 cm^3 and semi-active suspensions. This motorcycle was provided with outriggers to prevent the vehicle from lateral fall. The second test vehicle was a Piaggio MP3 500, a two-front-wheels scooter with automatic power transmission, brakes with ABS independently actuated by hand levers. Both test vehicles (sport-touring motorcycle and two-front wheels scooter, from now on called Multistrada and MP3 respectively) were employed to test the intervention of AB in straight-line and lane-change manoeuvre. In addition, the intervention of AB in lateral manoeuvres such as cornering and slalom was tested with the sport-touring motorcycle (Multistrada) that was equipped with outriggers.

The two test vehicles were provided with two different Automatic Braking (AB) devices, which were able to brake each PTW with nominal values of deceleration of 0.3 and 0.5 g. The AB devices were set to provide a nominal fade in-jerk of 1.5 g/s for the Multistrada and 1.5 and 2.5 g/s for the MP3. The ABs were triggered manually by an investigator using a remote control (Lucci et al., 2019). Both test vehicles are shown in Figure 1.

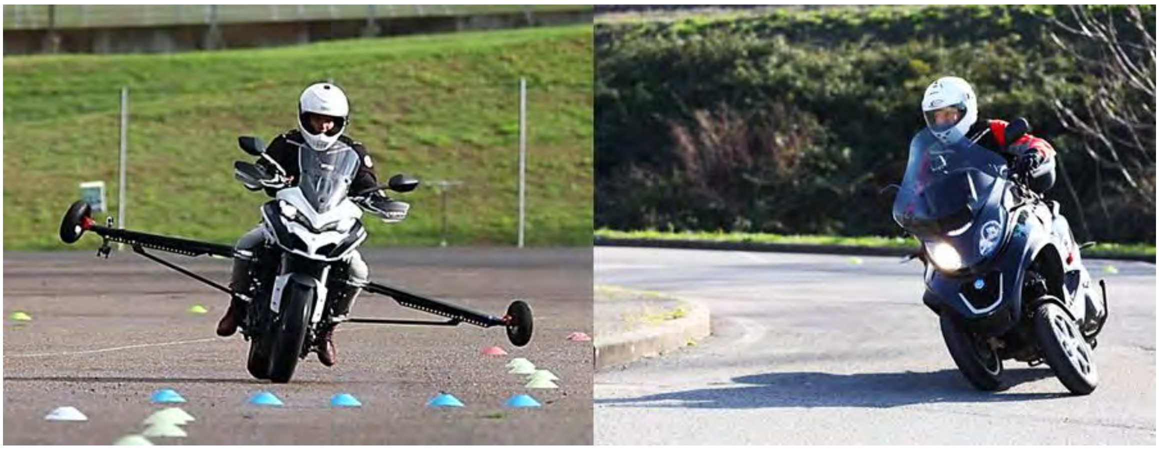

Figure 1 – Test vehicles: Ducati Multistrada 1260 (left) and Piaggio MP3 500 (right)

The two vehicles were provided with a similar data acquisition system, able to record signals from the PTWs' CAN-Bus (throttle, brake action, steering angle, vehicle tri-axis acceleration and gyro). The recording unit was also provided with a second tri-axes accelerometer and GPS receiver to record position during the field tests. Both test vehicles were provided with a "GoPro Hero 4 black" action camera placed on the top cover of the top case, to record the driver's body and at the same time provide an environmental overview of the ride. The Multistrada was also provided with a second "GoPro Hero 4 black" placed in a lateral position on the right-side extension arm (see Figure 2). The aim of this camera was recording the rider from the right side and monitor his/her behaviour during the AB.

Figure 2 – Action camera view on Multistrada: Back position (left-side), Right side position (right-side)

Moreover, an Inertial Measurement Unit (IMU) was attached on the back of the participants to record the chest movement during the tests. In order to collect subjective data, questionnaires were adopted to ask participants their opinion on the test, on the tested AB system and the controllability of the vehicle during the AB activation in the different manoeuvres.

The field test procedure to test the AB with the two test vehicles was developed based on a test protocol of a previous study (Savino et al., 2016) and a work of pilot testing and literature review carried out by authors (Lucci et al., 2020). For both vehicles, the tests took place in a flat area closed to traffic only during daytime hours (see Figure 3). The AB interventions were tested at different velocities ranging from 30 km/h to 60 km/h (depending on the requested manoeuvres) in conditions that included the following: straight-line riding, lane-change, slalom, cornering. After a brief explanation of the test, the participants were free to ride the PTW in the test track for about ten minutes, in order to familiarize with the vehicle (especially if it was provided with outriggers) and the track. After that, the participants were required to perform five manual brakings in straight-line conditions with increasing decelerations. Before testing the AB in unexpected conditions, the participants also experienced a familiarization with the AB system, consisting of deploying declared AB interventions in straight-line.

Figure 3 – Test area: Ducati Multistrada 1260 (up) and Piaggio MP3 500 (down)

Finished the familiarization session with the PTW and the AB, the participants tested unexpected AB in different phases. In these sessions, the participants rode along the test track and the AB activations were manually triggered by one investigator via remote control. The AB was triggered only when the PTW was in precise spots of the track while the participants were performing the specific manoeuvres. For the Multistrada the test included two phases with a nominal value of deceleration of respectively 0.3 g and 0.5 g and fade-in jerk of 1.5 g/s^2 tested in four manoeuvres (straight-line, lane-change, slalom, and curve). For the MP3 the test included four phases to test a combination of two levels of deceleration (0.3 g and 0.5 g) and two levels of fade-in jerk (1.5 g/s^2 and 2.5 g/s^2), tested in two manoeuvres (straight-line and lane-change). For both vehicles, the AB was deployed in the different manoeuvres with a pseudo-random order and with an average frequency of one activation every 100 s of riding. The participants were not aware of the sequence of activations or the timing. This approach was devised to obtain AB events that are as unexpected for the rider as possible while keeping a low learning effect.

In case the road surface was not completely dry, a reasonable subset of the planned activations was performed in order to guarantee the execution of the tests in safe conditions for the participants. In any way, before each test session started, the set of AB interventions (i.e., the type of manoeuvres and level of deceleration) was disclosed to the participant and each participant was allowed to choose under what conditions to test the AB or not. At the end of each test session, the participant had a short break and was required to fill in a questionnaire.

3 Results

3.1 Test participants

Fifty-one participants (10 female, 41 male) were included in this study testing only one of the two test vehicles (see Figure 4). The age of participants ranged from 21 to 59 years and they were characterized by different levels of education and a broad range of riding experience. All the participants included in the tests owned at least one PTW and rode it at least on a weekly basis. The majority of participants selected to test the Multistrada used their own PTW mainly for leisure, travel or sports reasons and a lower percentage used PTWs mainly for commuting and or for work. On the contrary, among the participants selected to test the AB intervention on the MP3, most of the participants used PTWs mainly for commuting.

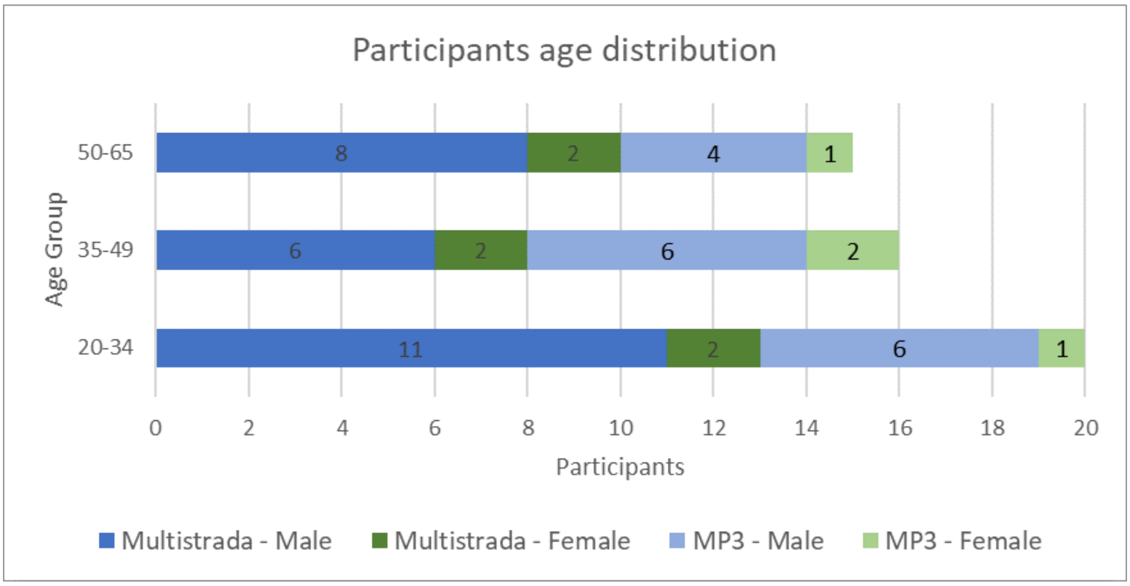

Figure 4 – Participants age and gender distribution for Multistrada and MP3 tests

3.2 Tested Automatic Braking intervention

For both test vehicles, the Automatic Braking (AB) was deployed at pseudo-random times and unexpectedly for the participants in the manoeuvres established with the participants before of every test session. A first important result is that all the participants accepted to test the intervention of the AB unexpectedly in the manoeuvres proposed by the investigator and only a few of them required to test a declared AB intervention in the manoeuvres before testing them unexpectedly. Table 1 shows a summary of the AB tested intervention for the two test vehicles.

Table 1 – Summary of AB tested interventions

PTW	Manoeuvre	Nominal deceleration [g]	Nominal fade-in jerk [g/s]	Reference speed [km/h]	Participants	N° of AB tested
Ducati Multistrada 1260S	Straight-line	0.3	1.5	45	31	63
	Lane change			40	31	65
	Slalom			35	29	62
	Curve			35	29	115
	Straight-line	0.5	1.5	45	31	62
	Lane change			40	31	65
	Slalom			35	29	59
Piaggio MP3 500	Straight-line	0.3	1.5	40	20	42
	Lane change			40	18	34
	Straight-line		2.5	40	20	37
	Lane change			40	16	32
	Straight-line	0.5	1.5	40	20	40
	Lane change			40	18	33
	Straight-line		2.5	40	20	39
	Lane change			40	16	33

The participants involved in the test with the Multistrada test vehicle tested the intervention of the AB in four manoeuvres: straight-line, lane-change, slalom and curve (see Figure 5). Due to the weather conditions, not all the participants were involved in testing the AB with all the manoeuvres included in this study. The AB was deployed with two different levels of nominal deceleration, respectively 0.3 g and 0.5 g. The nominal fade-in jerk applied in these tests was the same for all the participants and manoeuvres and equal to 1.5 g/s. The participants executed the manoeuvres in a range of speed from 30 km/h to 50 km/h according to their natural feelings and skills. Overall, the AB was tested with the Multistrada almost 500 times in the different conditions and manoeuvres planned by the test protocol. AB was tested on the curve manoeuvre at the 0.3 g level and sessions included right-hand curve and left-hand curve AB interventions for all participants.

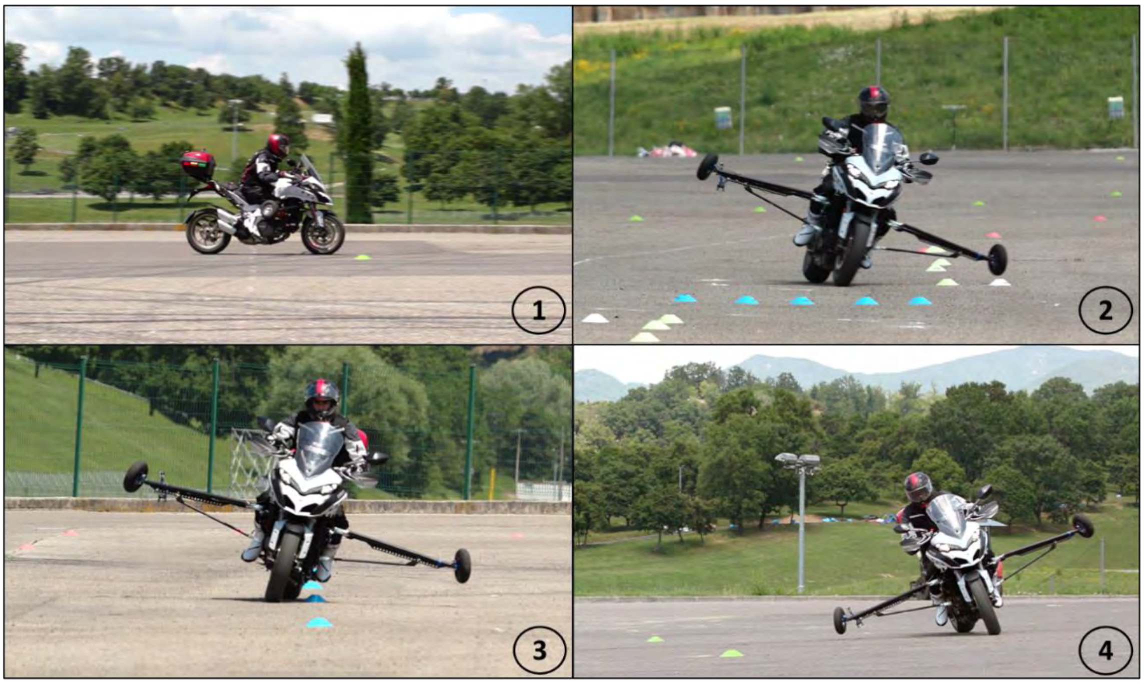

Figure 5 – AB activation on Multistrada in the four manoeuvres: 1) straight-line, 2) Lane-change, 3) Slalom, and 4) curve

Since the MP3 was not provided of outriggers, the participants involved in the test with the MP3 test vehicle tested the intervention of the AB in the two manoeuvres that involved a lower risk of lateral fall: straight line and lane-change (see Figure 6). As with the Multistrada test vehicle, the AB was deployed with two levels corresponding to the nominal deceleration of 0.3 g and 0.5 g. Two levels of nominal fade-in jerk were also tested, respectively 1.5 g/s and 2.5 g/s, each one in a separate test session. Overall, the AB was tested in four test session with different combinations of the two levels of decelerations and jerks. Due to weather conditions, not all the participants were involved in testing the AB in all the manoeuvres and with all the levels of intervention planned for this vehicle. The participants executed the manoeuvres at a nominal speed of 40 km/h with slight variations according to their natural feelings and skills. Overall, the AB was tested with the MP3 almost 400 times in the different conditions and manoeuvres defined by the test protocol for this vehicle.

Figure 6 – AB activation on MP3 in the two manoeuvres: 1) straight -line, and 2) Lane-change

Figure 7 shows a typical intervention of the AB system deployed in straight-line condition. In both test vehicles, the AB system produced a braking pressure profile able to decelerate the PTW following the parameters previously set up. The target level of deceleration was reached with a ramp of deceleration with a constant fade-in jerk, which was nominally 1.5 g/s for the Multistrada and 1.5 g/s and 2.5 g/s for the MP3. The nominal time of intervention in which the system reached the target value of deceleration and the time of intervention at constant deceleration, the so-called time of intervention, was around 1 s. After that, the system executed a reduction of deceleration up to reach the disengagement of the AB with a nominal fade-out jerk of 1.5 g/s. This profile of deceleration reproduced by the AB system, which is called ramp profile, was employed in both test vehicles with slight differences due to different construction of the AB devices.

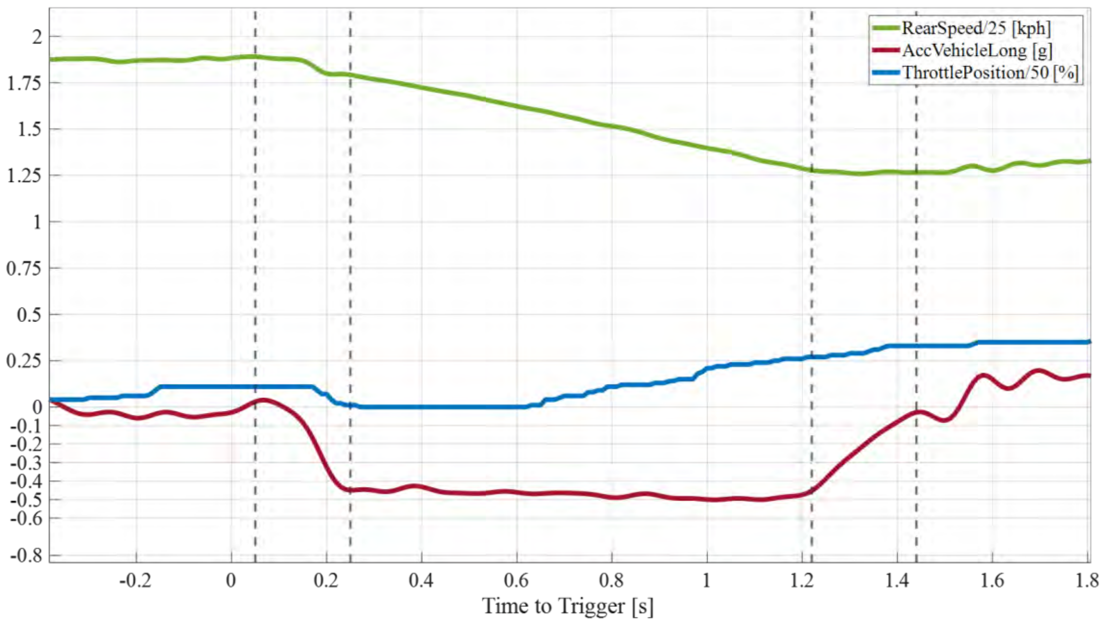

Figure 7 – Example of AB activation in straight-line conditions

3.3 Automatic Braking assessment

At the end of the test, the participants assessed the Automatic Braking system based on the conditions they experimented (see Figure 8). Among the 31 participants who tested the AB intervention with the Multistrada, a very high percentage of participants rated positively the system (excellent 23 %, very good 23 % and good 45 %). Just a very slight percentage of participants (6 %) had a fair opinion concerning the AB system and only one participant (3 %) gave a negative rating of it. Among the 20 participants who tested the AB intervention with the MP3, the trend of ratings was quite similar to the other vehicle. Again, most of the participants rated positively the system (excellent 15 %, very good 40 % and good 30 %) and just one participant (5 %) was indifferent to the AB. Two participants (10 %) gave a negative rating of AB.

Even if after testing the AB there were few negative opinions about it, for both test vehicles all the participants managed to complete the whole test without asking to interrupt the trials due to the intervention of the AB or other reasons. Moreover, no potentially dangerous situations were created by the intervention of the AB nor the participants' behaviour.

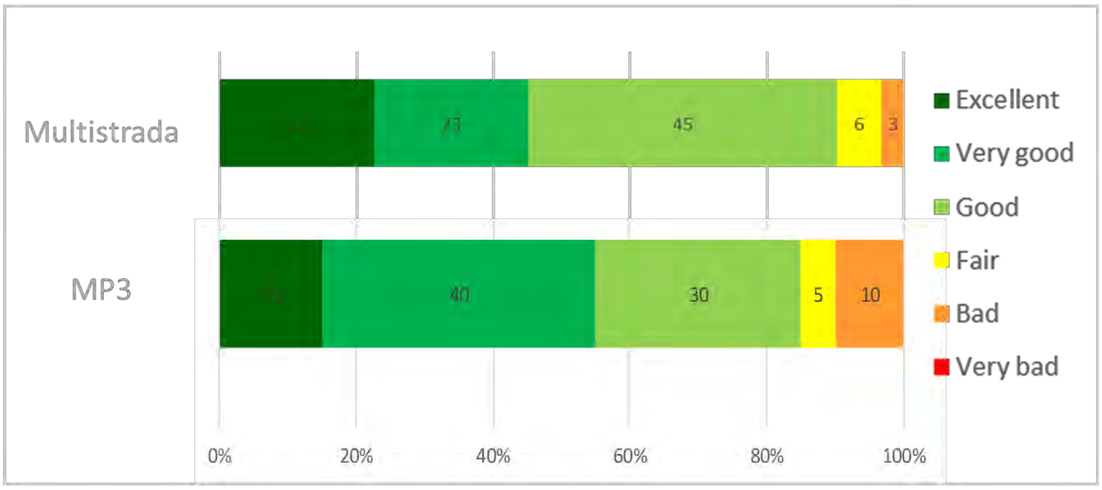

Figure 8 – Participants general assessment of tested AB system for the two test vehicles

4 Discussion

The field tests presented in this paper involved 51 common riders as participants to test pseudo-unexpected automatic decelerations on two different test vehicles, a sport-touring motorcycle and a two-front-wheels scooter. The Automatic Braking (AB) was deployed manually by investigators via remote control employing a similar approach to a previous study (Savino et al., 2016). The intervention of the AB was tested in different manoeuvres (straight-line motion, lane-change, slalom and curve), with two levels of deceleration and two levels of fade-in jerk. This allowed testing the AB in a broad range of working conditions and parameters, which were never tried before.

This study involved the largest sample size of participants (51) among the field research concerning the Motorcycle Autonomous Emergency Braking system (MAEB) so far. The two sub-samples of participants were characterized by wide ranges of ages, sex, riding experience and motivations for riding. However, despite this large sample and the wide variability, the participants involved in this study may not be completely representative of all PTW user populations.

The AB tested intervention was deployed with a ramp profile, which was previously shown to be effective and manageable by expert riders (Merkel et al., 2018). The parameters of nominal intervention (0.3 g and 0.5 g of deceleration and 1.5 g/s and 2.5 g/s of fade-in jerk) tested in this study allow assessing the feasibility of MAEB with common users with the most effective working parameters tested so far, which could be potentially effective in injury reduction in real-world crash conditions (Piantini et al., 2019). The final applicability and feasibility of MAEB with these working parameters will be the results of the analysis of the data collected in this study and will be presented in future papers. This will allow to understand which the optimal working parameters are to introduce the MAEB on standard vehicles. However, a first important result is that the Automatic Braking intervention was tested in these field tests more than 1000 times on two different types of vehicles and by 51 participants, with different levels of intervention and manoeuvres involved. All the participants completed the experiment and agreed to test the intervention of the AB unexpectedly in the conditions proposed by the investigators and no dangerous situation occurred in the context of the deployment of AB.

Concerning the acceptability among end-users of MAEB, the participants expressed generally a positive opinion about the tested system. For both the test vehicles, more than 80% of participants rated positively the Automatic Braking system and just a few of them (one out of 31 with Multistrada and two out of 20 with MP3) had a bad opinion concerning the system, mainly for discomfort reasons rather than for doubts about its safety or effectiveness. Moreover, during the tests, the controllability of the test vehicles by participants during AB interventions was never uncertain and participants were always able to execute the manoeuvres required by investigators. Another important indication that the AB system was positively accepted by participants it is that after testing declared interventions of AB, all the participants accepted to test it unexpectedly in the manoeuvres proposed by the investigators and only a few of them required to test them before as declared one.

Thanks to the contribution of this study and the field tests presented in this paper in the next future will be possible to have a comprehensive understanding on the limits of the feasibility and the acceptability of the Autonomous Emergency Braking system applied on powered-two-wheelers.

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TRAFFIC VIOLATIONS OF MOTORCYCLE RIDERS IN FATAL AND SERIOUS INJURIES ACCIDENTS IN SWEDEN

Maria Nordqvist[1], Dimitris Margaritis[2], Jesper Christensen[1,2]

[1] Sveriges MotorCyklister (SMC) Gamla Tunavägen 30, 784 60, Borlänge, Sweden

[2] FIM Europe Via Giulio Romano 18, I-00196, Roma, Italy

***Presenter**: Maria Nordqvist ("substitute-presenter": Dimitris Margaritis)*

Abstract

It becomes more evident that many serious traffic violations are a problem mainly amongst those who ride a motorcycle without a valid driver license. In Sweden within 2011-2018, 94 riders were missing a valid driver's license out of 297 fatalities, which corresponds to 32%. The average age of those who died and did not have a valid license was 32.6 years old, a much younger group compared to the average of 45.64 years of the license holders. 97% were men. The proportion of fatalities without a valid driver's licenses has increased significantly in 2011-2018 compared to 2005-2010 when it was 25%. Many riders who died in a motorcycle accident had no license, had never undergone training and did not have the knowledge required to ride a motorcycle. Their average age of about 33 years old indicates that the problem is not only about young people. Thus, a driver's license is considered as an absolute requirement for any rider, especially when so much effort is spent in the country to reach the Vision Zero goal.

Keywords: Motorcycle accidents, serious traffic violations, motorcycle riding lisence, training.

1. Introduction

Motorcyclists are conscious about road safety like all other road users. The majority do not take unnecessary risks and enjoy riding their motorcycles. It is obvious that a motorcyclist should have a valid driver's license when driving. This confirmed in a study conducted by SMC, VTI and NTF [1], [2].

In the case of fatal accidents amongst motorcyclists, there are some factors that recur repeatedly. SMC has previously called these factors "extreme behavior". It contains four factors, namely: 1. Illegal riding without a valid license, 2. Riding under influence of alcohol and/or drugs, 3. Aggressive riding and 4. Very high speed combined with carelessness in traffic. SMC has decided to use the concept serious traffic violations instead which is the correct term for these crimes for all road users. The proportion of fatalities involving one or more of these factors is increasing, while at the same time, the total number of motorcycle accidents is decreasing. It is becoming clear that serious traffic violations are a problem mainly amongst those who ride a motorcycle without a valid driver's license. This group is difficult to reach and influence with traditional road safety measures. They are also not members of SMC and the motorcycle community.

VTI analysed 236 cyclists who were killed in 2006-2010. Of these, 27 had alcohol in their blood, 156 did not have alcohol in their blood, and for the remaining 53 cyclists the presence of alcohol was unknown. One had drugs in the blood and among 35 of those with unknown alcohol presence drugs were found. None of the fatalities affected with alcohol used a helmet. VTI's study also shows that cycling with alcohol in the body seems to be socially accepted, even though the interviewees pointed out numbers of disadvantages [5].

In 2018, VTI published a study showing that a quarter (25%) of the affected truck and bus drivers who were involved in fatal accidents or seriously injured during 2008-2015 lacked a valid driver's license. This percentage is high compared to the two percent who were affected amongst all bus and truck drivers involved in serious accidents [6].

SMC compared those who were killed on a motorcycle (riders and passengers) to the killed car drivers (not passengers) without a valid driving license 2010-2014. The use of alcohol and drug effects was also studied. Seven percent of the car drivers did not have a driver's license. 25 percent of the fatal motorists who did not have a driver's license were affected by alcohol. This is a much higher share compared to all car drivers where seven percent were affected by alcohol. 50 per cent of the fatalities among car drivers who did not have a valid driver's license were affected by drugs, which is significantly higher compared to all car drivers where seven per cent were affected by drugs [7].

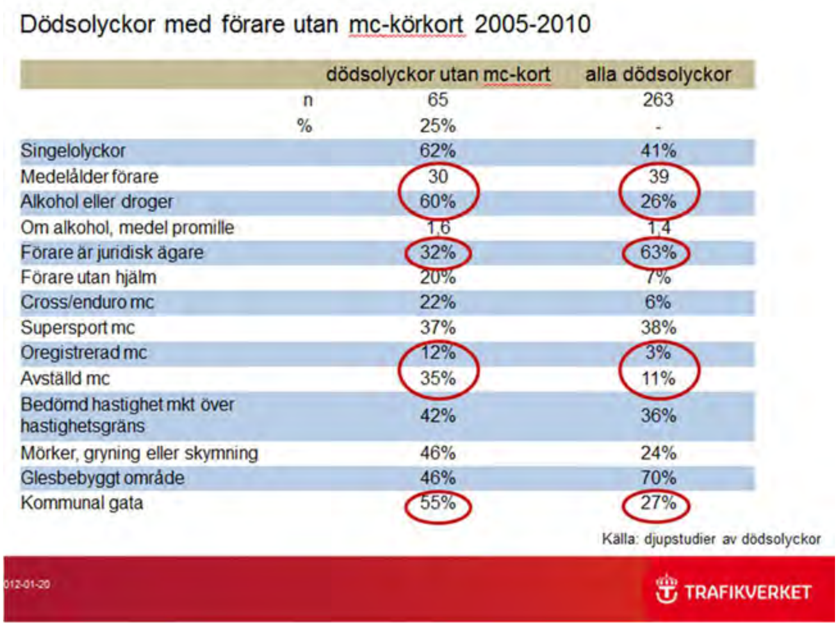
2. Methods

SMC has compiled data from in-depth studies of fatal motorcycle accidents at the Swedish Transport Administration since 2010. The data used in this study includes rider, passenger, age, gender, driver’s license status, ownership, vehicle status, type of accident, usage of helmet and influence of alcohol and/or drugs.

SMC has gathered data from the Swedish Transport Agency on police reported motorcycle accidents involving seriously injured motorcyclists and passengers. The data included e.g. rider, passenger, age, gender, motorcycle model, driver's license status, ownership and driving ban. SMC has compiled data between 2005- 2018. The analysis of the data has been made on the bases of descriptive statistics.

3. Results

Too many people who die on a motorcycle have no driver’s license, have never undergone training and do not have the knowledge required to ride a motorcycle. Within this group, other serious traffic offenses are also over-represented. The share of riders lacking a valid license represented 25 percent of all fatal motorcyclists in 2005-2010. This is shown in Figure 1.



Dödsolyckor med förare utan mc-körkort 2005-2010

	dödsolyckor utan mc-kort	alla dödsolyckor
n	65	263
%	25%	-
Singelolyckor	62%	41%
Medelålder förare	30	39
Alkohol eller droger	60%	26%
Om alkohol, medel promille	1,6	1,4
Förare är juridisk ägare	32%	63%
Förare utan hjälm	20%	7%
Cross/enduro mc	22%	6%
Supersport mc	37%	38%
Oregistrerad mc	12%	3%
Avställd mc	35%	11%
Bedömd hastighet mkt över hastighetsgräns	42%	36%
Mörker, gryning eller skymning	46%	24%
Glesbebyggt område	46%	70%
Kommunal gata	55%	27%

Källa: djupstudier av dödsolyckor

Figure 1. *Fatal accidents on motorcycle between 2005-2010, without driving license compared to all fatal accidents where riders without a license are included. Source: The Swedish Transport Administration.*

Unfortunately, this is not the entire truth about the fatalities between 2005-2010. Many of the riders without a license did not own the motorcycle used in the fatal accident. In addition, the motorcycles were often unregistered and uninsured, and are therefore not allowed to be used on the road. One fifth of the riders in this group did not wear a helmet when riding which has been a legal requirement in Sweden since 1975. Furthermore, in the "killed without a driver's license" group, a majority (60 percent) were intoxicated and/or under influence of drugs during 2005-2010.

3.1. Illegal driving amongst fatal accidents on motorcycle between 2011-2018

SMC has compared the group that did not have a valid driver's license with those who had a valid driver's license between 2011-2018 [3]. Out of 297 fatalities, 94 people did not have a valid driver's license, which corresponds to 32%. The average age of those who did not have a valid license was 32.6 years old, which is significantly younger compared to 45.64 years old in the fatalities of license holders. However, an average age of about 33 years old indicates that the problem is not only about young people. The proportion without driver's licenses has increased compared to the period between 2005-2010 when they accounted a 25 percent.

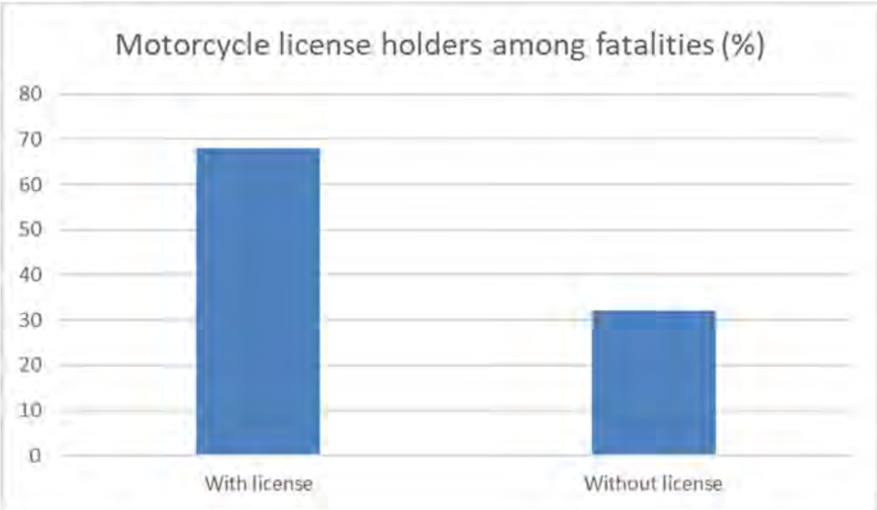


Figure 2. *Driving license status among fatal accidents at two-wheeled motorcycle 2011-2018.*

3.2. Influenced by alcohol and/or drugs

When SMC compared the group without a valid license against the license holders, the picture clearly shows that this group was guilty of several serious traffic violations during the ride that led to the fatal accident. One example is that the majority of the people without a valid license who died on two-wheeled motorcycles were affected by alcohol and/or drugs. As many as 73 percent were affected by alcohol and/or drugs, compared to eleven percent affected in the driver's license group. Riding a motorcycle without a driver's license and being affected also increases the risk of serious accidents. The proportion of riders affected by alcohol and/or drugs amongst the people without a valid license has increased compared to the previous period 2005-2010 when it was 60 percent. At the same time, it is a positive sign that the proportion of riders affected with alcohol and drugs falls among those who had a driving license.

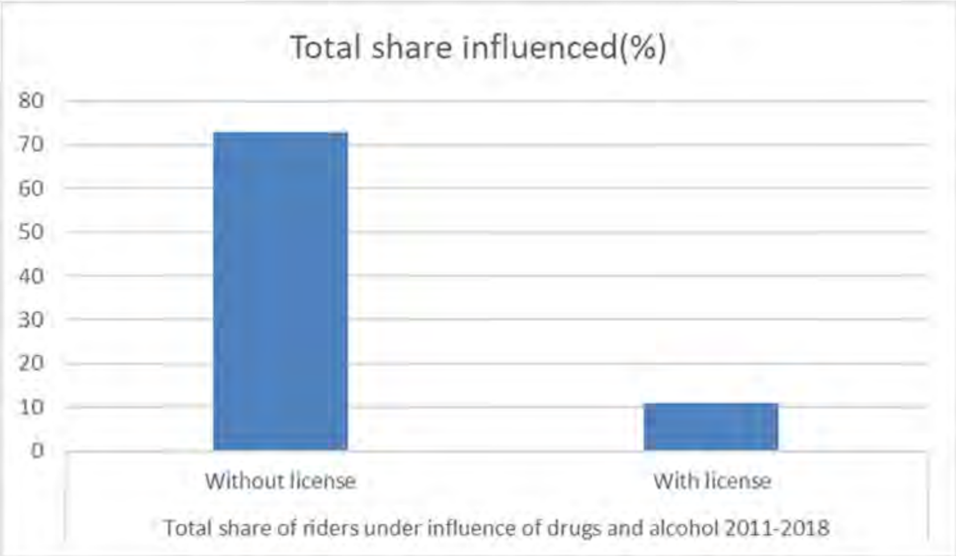


Figure 3. *Percentage affected by alcohol and/or drugs amongst fatal motorcycle accidents based on driver's license for motorcycle between 2011-2018.*

3.3. Helmet use

Seven riders out of 203 fatal accidents with a valid driver's license did not use a helmet at the time of the accident or the use of a helmet use was unclear. Amongst the fatalities without a valid driver's license, the corresponding proportion was 23 of the total 94 killed. Riding a motorcycle without a driver's license and not using a helmet means a significant increase of risk for serious injuries and death in case of an accident.

3.4. Ownership

Just over half, 52 percent, of those who did not have a valid driver's license owned the motorcycle they were riding at the fatal accident. This can be compared to 87 percent amongst those who had a driving license. Limited experience from a motorcycle increases the risk of being

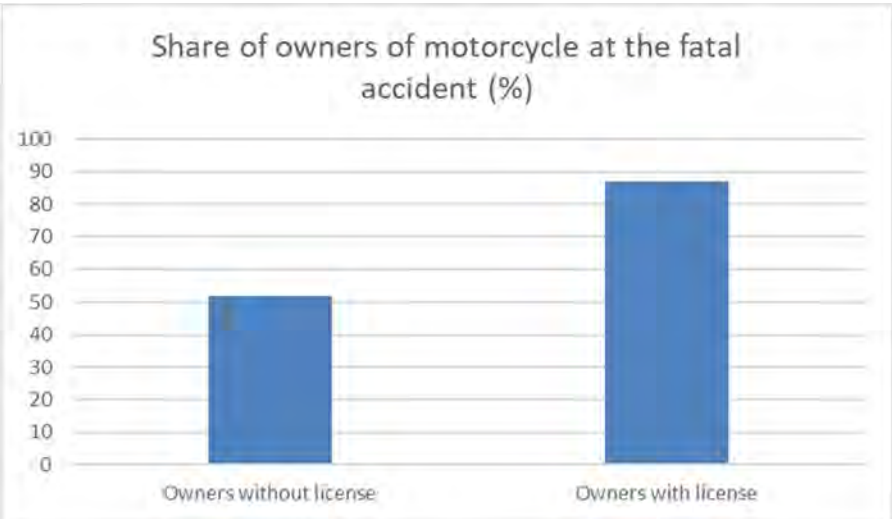


Figure 4. *Ownership conditions among those killed on motorcycles based on driver's license holdings 2011-2018.*

killed or seriously injured significantly. However, the proportion of owners amongst the riders without a valid driver’s license has increased significantly compared to the period 2005-2010 when it was 32 percent.

3.5. Use of illegal motorcycles in connection with the fatal accident

More than four out of five, 77 percent, of those without a valid driver's license rode a motorcycle that was illegal to use in traffic. This means that even if the share of owners has increased among the riders without a license, the PTWs were illegal to use. These motorcycles were taken out of traffic and/or unregistered and/or uninsured or stolen. This problem is small in the group of people with valid driving licenses where only three percent were riding illegal motorcycles, mainly due to a riding ban for not visiting the PTI. Only one driver with a valid license was riding an unregistered motorcycle that was not allowed to be used on the road at the time of the accident, compared with twelve people who did not have a driver's license. Ten people out of the 94 riders without a valid driver’s license drove a stolen motorcycle in connection with the fatal accident. None of the people of license holders were riding on a stolen motorcycle.

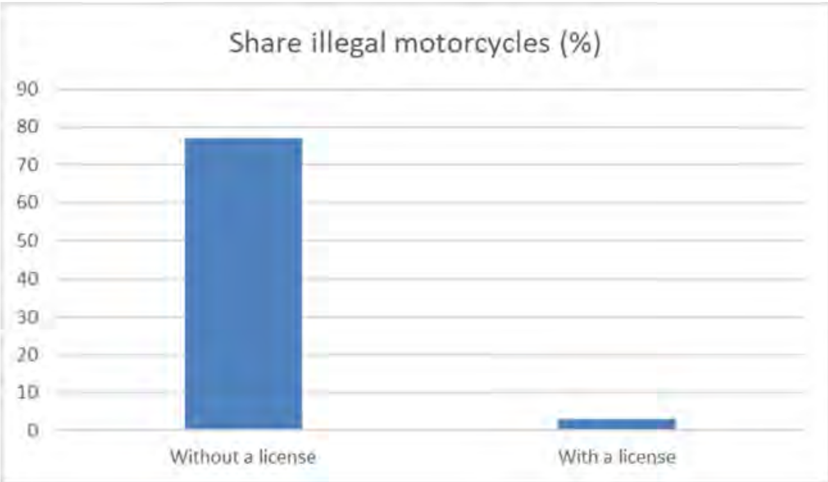


Figure 5. *Percentage of unregistered, stolen and uninsured motorcycles based on driver's license status amongst those killed on two-wheeled motorcycle 2011-2018.*

3.6. Other differences in ownership

SMC has looked at the differences in ownership between the rider groups with and without a valid driver's license in 2017. Nine out of 13 fatalities without a valid driver's license owned the motorcycle. The others were stolen or borrowed. However, when SMC looks at ownership in the group, it turns out that only one person was riding a motorcycle that was taxed and insured. Two motorcycles were unregistered enduro bikes which the owners had owned for respectively one year and three months, both where illegal to use on the road. The other five owners had owned the motorcycle on an average of two days before they cancelled the insurance and stated that it was not being used in traffic. The owners died between a day to a year after buying the motorcycle. Only one of 13 motorcycles used in the accidents was allowed to be used on the road.

When we compare this with the 23 riders who had a valid driver's license, all of them rode a legal motorcycle that was insured and allowed to use in traffic. Only two out of 23 where riding a motorcycle they did not own. Seven out of 21 used a motorcycle that has been owned for less than a year.

3.7. Gender and type of accident

It is mainly men who are involved in the fatal accidents with several serious traffic offenses. Collisions with other vehicles in which other road users have caused the fatal accident are far more common amongst the valid license holders while the single accidents dominate the group without a valid license.

3.8. Summary of fatal accidents based on driver's license holdings 2011-2018

The table below is another version of Figure 1 that is covering the period between 2005-2010. The difference with Figure 1 is that the groups are reported separately in Table 1 for the period between 2011-2018.

Table 1. *Killed between 2011-2018 on a motorcycle with two-wheels, with and without MC driver's license. (Source: Swedish Transport Administration's in-depth studies 2011-2018).*

	Without a license number (%)	**With a license, number (%)**
Number (share)	**94 (32 %)**	**203 (68%)**
Average age	32,6	45,64
Alcohol	23 (24 %)	14 (7 %)
Promille, average (2011-2017)	1,698	1,13
Drugs	28 (30%)	9 (4%)
Both alcohol and drugs	18 (19 %)	0
Total affected	**69 (73 %)**	**23 (11%)**
Without a helmet	20 (28%)	7 (3%)
Owner	48 (52 %)	177 (87%)
Not in traffic/unregistered/riding ban	50(53 %)	6(3%)
Cross/enduro	12 (13%)	1 (0,05)
Stolen motorcycle	10 (11%)	0
Total illegal motorcycles	**72 (77%)**	**7 (3%)**
Singel accident	60 (64%)	81 (40%)
Collision	32 (34%)	112 (55%)
Wild animals	2 (2 %)	11 (5 %)
Men (riders and passengers)	91 (97%)	192 (95 %)
Women (riders and passengers	3 (3 %)	9 (6 %)

3.9. Seriously injured on a motorcycle with two wheels between 2013-2018

The statistics includes age, motorcycle model, driver's license status, ownership and driving ban. The statistics clearly show that **illegal riding** is an important factor not only amongst fatal accidents but also amongst motorcyclists who are seriously injured.

1,422 people were seriously injured on a two-wheeled motorcycle during 2013-2018 [4]. There were 1,323 drivers in the group. Nearly, 23 percent of them lacked a **valid driver's license**. In addition to these, information on driving licenses is missing for eleven percent. Only two-thirds, 66 percent, had a valid A-driver's license.

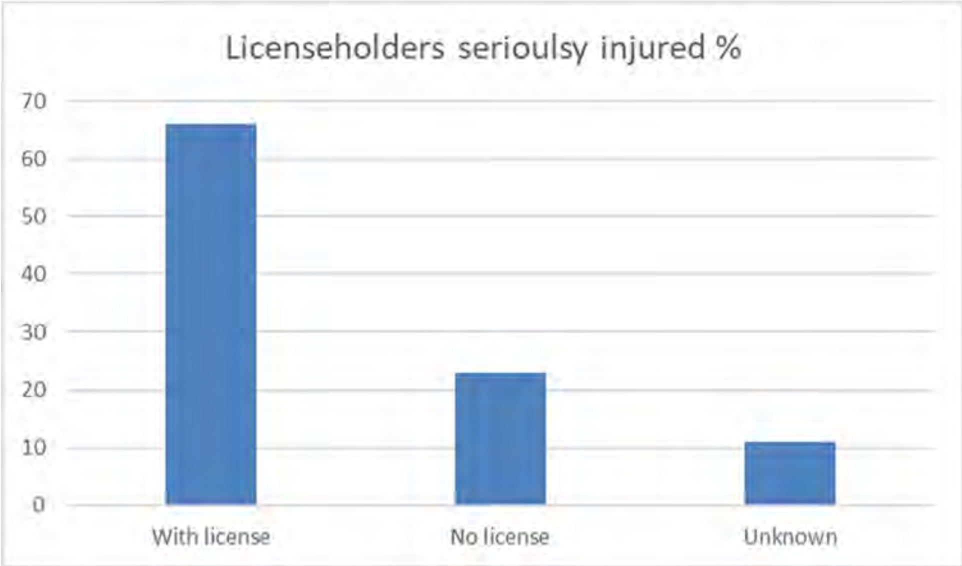


__Figure 6.__ Driving license holders amongst severely injured on two-wheeled motorcycles 2013-2018.

SMC has also studied the **ownership** amongst the severely injured in the period between 2013-2018. Just like among those who are killed on a motorcycle, there are significantly more riders without a valid license who were riding a motorcycle they did not own at the time of the accident. One third, 37 percent, of those who did not have a valid driver's license did not own the motorcycle they were riding at the time of the accident. Amongst those who had a driving license, the corresponding figure was eleven percent.

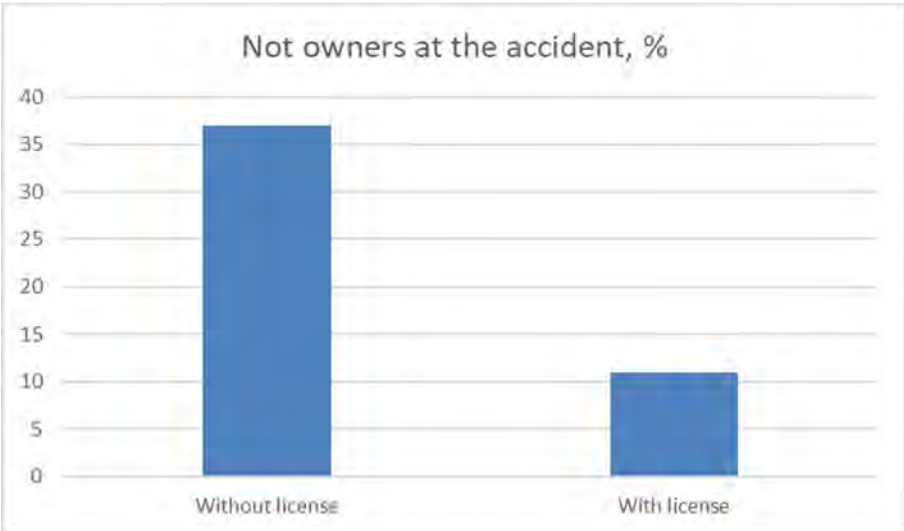


__Figure 7.__ Ownership ratio at the time of the accident based on driver's license between 2013-2018.

The proportion who were riding a motorcycle that was not allowed to use due to a **riding ban** was significantly higher amongst the riders without a valid license, which corresponds to the fatal accidents. Over a fifth, 21.3 percent of those who were severely injured, where riding a motorcycle banned to used, compared with 5.25 percent amongst those who had a valid license.

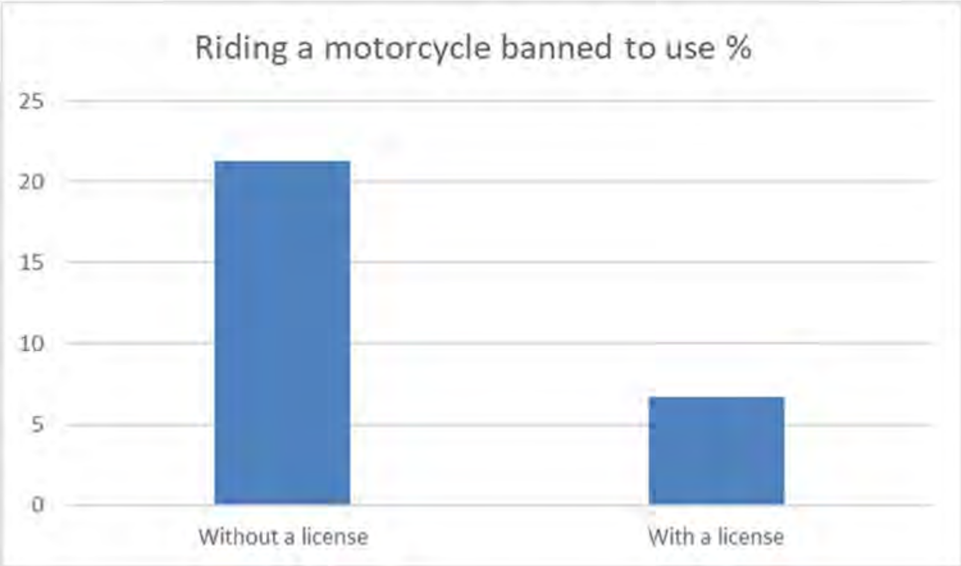


Figure 8. Riding a motorcycle banned to use, based on driver's license 2013-2018.

Amongst the people without a valid license, only 35 percent were riding a motorcycle that was **insured**. The corresponding percentage amongst the group with valid license was 89 percent.

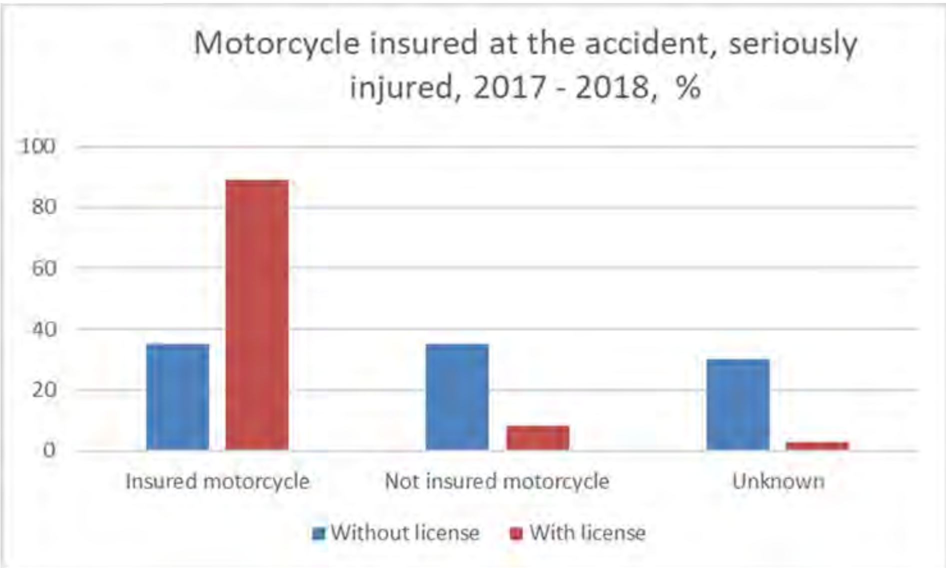


Figure 9. Riding a motorcycle that was insured, based on driver's license between 2017-2018.

4. Include driver's license in the Swedish Zero Vision work

The accident statistics clearly show a different picture of motorcyclists compared to the SMC and NTF study on motorcyclists' attitudes to road safety that was published in 2010 [1]. In this study, everybody states that it has a valid motorcycle driver's license. The attitude to riding drunk and/or under the influence of drugs is clearly distancing. The motorcyclists in the study showed a much better attitude towards the usage of alcohol and drugs in traffic compared to other road users. To pay vehicle tax, insure and ride a registered vehicle was a matter of course in the study. All riders were using helmets and a majority was also using comprehensive protective equipment. Statistics from the Swedish PTI inspection show that the motorcycle owners are the owner group with highest approval rate year after year. There is only one factor where motorcyclists are "inferior" to motorists - motorcyclists are less likely to obey the speed limits. It must be a priority that all drivers and riders of a motor vehicle have a valid driver's license in the work to reduce the fatalities and seriously injured and reach the goals of Vision Zero. SMC considers that a valid driver’s license is an absolute requirement and urges all concerned to include this as a top priority in the road safety work.

Annual statistics are needed in this context from the Swedish Transport Agency and the Swedish Transport Administration, where driver license holdings are found amongst drivers who are killed and seriously injured, as well as sobriety, ownership and driving bans based on the driver's license holdings. There are statistics in STRADA and in-depth studies that allow to measure and track in the same way as SMC has been doing annually since 2011. These statistics should be published and disseminated to all stakeholders in the road safety work annually.

It is also extremely important that the high proportion of serious traffic offenses in fatal accidents and the severely injured are made visible in order to raise awareness amongst the various stakeholders in the road safety work. There is a need to increase awareness for insurance companies, road safety organizations, traffic schools, authorities, courts, politicians, media, family and friends. If the knowledge about the high risk is disseminated, there is an opportunity for everyone to both inform and take actions. For example, can an insurance company require a driver's license to insure a vehicle? How can the Road Traffic Register (with data about licenses, vehicles and insurances) be used?

5. Discussion

SMC has been working with road safety for motorcyclists since 1963 when the organization was founded. However, SMC do not reach the growing group where the riders neither own a motorcycle, nor have a valid motorcycle driver's license. Efforts are required from everyone who works with road safety for this group. Below are listed some examples.

The police have the best opportunity to intervene against riders and drivers who do not have a valid driver's license. Many times, there are people in this group who are well known by the police for previous serious traffic offenses. The police should have a clear mandate to take actions, to do controls and to initiate sanctions specifically directed at the group. Through driver's license checks, the police can also detect people who are wanted in other legal matters.

The absolute requirement to have driving license, when using a vehicle with a motor engine, should be given priority on a large scale. There is a high proportion of people without a valid driver's license in serious accidents, both fatal and seriously injured. Statistics show that there are also many drivers without a valid license amongst those who are killed in passenger cars and amongst bus and truck drivers. Their usage of vehicles is of high risk to other road users, which is a fact that is well known.

SMC is looking forward to the government's review of the penalties for driving/riding under the influence of drugs and alcohol and illegal driving. A sharpening of penalties is needed, especially for those who are involved in traffic offenses over and over again. The police must have more tools to prevent further crime, for example, to make it possible to put people in arrest after repeated serious traffic crimes, efficient equipment for detecting drugs and to be able to confiscate the vehicles that are used.

It is quite important to change the road users' attitude towards road safety. The fact that so many people are killed and injured while driving and riding a motor vehicle without a valid license indicates that it in certain groups it is acceptable to drive illegally. SMC believes that training should be started early at school age, long before a driver's license is relevant. The basic education from the school should lead to an active choice to get a driving license or not to drive/ride motor vehicles at all. Regardless of a holding of a driver's license, knowledge and traffic safety are matters for the entire community, including pedestrians, cyclists and the new light electric vehicles that are now widely used on streets and sidewalks.

6. Conclusions

This paper presents the traffic violations of motorcycle riders in fatal and serious injuries accidents in Sweden. Within 2011-2018, out of 297 fatalities, 94 riders were missing a valid driver's license, which corresponds to 32% The proportion of fatalities without rider's licenses has significantly increased in 2011-2018 compared to 2005-2010 when it was 25%. Many riders who died in a motorcycle accident had no license, had never undergone training and did not have the knowledge required to ride a motorcycle.

The motorcycle driving license system need to be reviewed. The world's leading road safety experts have set training as the foremost measure for increased safety amongst motorcyclists. With this as a starting point, we must work to ensure that as many people as possible have access to education, that the education is cost-effective and accessible to everyone who meets the requirements for driving licenses.

Acknowledgements

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The Dynamics of Motorcycle Crashes

Focus on Advanced (Antilock) Braking Systems and Post-crash Motion

Authors:

Elaine Hardy, Research Analyst, Investigative Research, UK
James V Ouellet, Motorcycle Accident Analysis, USA
Dimitri Margaritis, Senior Researcher, CERTH, HIT, Greece
Martin Winkelbauer, Senior Researcher, KfV, Austria

Abstract

An online survey was carried out in 2019 which focused on motorcyclists who had been involved in a crash. The survey was disseminated throughout Europe, the USA, Canada, Asia, Australia and South America in order to get as much of a global response as possible.

The study extends and expands a pilot study based on a survey of motorcyclists whose motorcycles were fitted with the technology of Advanced (Antilock) Braking Systems (ABS), which was carried out in 2016/2017.

Because this study involved riders responding to an online survey, an important element is that the data involve their perspective of how a crash occurred rather than that of academic research. They also provided information about injuries and long term recovery that is usually not a part of on-scene, in-depth studies.

A sample of 1,578 motorcycle riders from 30 different countries answered a questionnaire which included 39 questions on much more than the typical parameters of crashes.

Particular focus was put on questions most relevant to motorcycles like the use of protective equipment and assistance systems, in particular ABS.

Many interviewees provided comments throughout the questionnaire and 832 provided further descriptions of their crashes, which allows deep insight to the dynamics of crashes and their circumstances, which would not be captured in a usual survey.

The survey's overall results highlight the relationship between speed, protective equipment, assistance systems and injuries, as well as how post-crash motions change the patterns of crash occurrence and injury outcome.

Contact Elaine Hardy
e.mhardy@btinternet.com
www.investigativeresearch.org

1. Introduction

The relevance and importance of Advanced (Antilock) Braking Systems (ABS) has been at the centre of debates for motorcycle safety researchers, governments and industry even more so as the European Commission considers mandating ABS on smaller motorcycles (i.e. 51-125cc). This paper aims to take a closer look at the outcome of crashes in particular for ABS-equipped motorcycles in relation to the post-crash motion of the rider and the eventual outcome in terms of injuries.

ABS are expected to improve collision avoidance by assuring that both front and rear brakes are applied and to reduce the possibility of riders falling or sliding in an emergency situation. However, what has been highlighted in this study is that over a third of the riders did not use their brakes, whether they just did not have time or were unable to because of the circumstances. In a similar way, the on-scene, in-depth Hurt and Thailand studies reported high levels of failure to take collision avoidance action: 32% in the Hurt study[1] and 49% in Thailand (Ouellet and Kasantikul 2006)[2].

However what differs in this study from the two studies mentioned above, is that over the last 20 years, motorcycles have developed and modernised such that technology is an integral part of how the machine operates. How the ability to brake or not can be addressed is relevant to the fact that in this study one third of the motorcycles were equipped with ABS. Does technology matter in a crash scenario? Consider that the time between the event that leads to the crash and the impact rarely exceeds 3-4 seconds (Ouellet and Kasantikul, 2006)[3] while rider perception/reaction time – typically 0.75 – 1.5 seconds[4] consumes a sizable portion of the time available for collision avoidance. The assumption that technology will save the day, may miss the obvious fact that what matters in an emergency situation is the rider him/herself and his/her ability to control the technology.

Over a third (36.3%) of the respondents of the survey had ABS brakes fitted to their motorcycles, while 12% had traction control fitted with 6.4% reported having cornering ABS fitted. What is not known is whether this sample is representative of larger population of motorcycles on the road.

Included in this paper in Annex one, is a profile of six motorcyclists and their motorcycles which were fitted with ABS. In each case the riders describe the circumstances of the event and their injuries.

2. Methodology

2.1 Survey

In order to have a more valid understanding of the dynamics of motorcycle crashes, this study extends and expands a previous pilot survey and covers eight different languages: English, French, Swedish, German, Spanish, Italian, Greek and Norwegian.

This survey took place between May and October 2019 and was disseminated through magazines, Facebook, motorcycle forums and web sites. The wealth and depth of information provided by the motorcyclists who participated allowed for a wide range of analysis of the details that resulted from the questionnaire and the responses.

The questionnaire had 39 questions divided into four sections:

1. “About you and your motorcycle” (16 questions)
2. “Background” (11 questions)
3. “Crash Details” (11 questions)
4. “Further Comments” (this allows plenty of space for the rider to comment freely)

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2.2 Sample characteristics and Data analysis

The motorcyclists participating in the survey came from 30 countries throughout the world. In total 1,578 motorcyclists replied to the survey. Due to the dissemination of the survey through organisations, clubs, social media and websites typically frequented by motorcyclists, it suggests that the rider is more inclined to be a “life-style” motorcyclist. However, this is a sample of people who have crashed irrespective of where they came from or their motivation for riding a motorcycle.

Analysis of factors such as seasons depending on whether the rider came from the southern or northern hemisphere and whether the distance was measured in kilometres or miles were taken into account.

Data analysis was carried out using Excel and SPSS. Pearson Chi-Square test of independence was used to discover if there was a relationship between two categorical variables in the cross-tabulation tables. Also analysed were the comments left by the respondents, of whom 832 left further comments detailing the events surrounding their crash.

3. Accident scenario

3.1 Collision characteristics

When

These crashes were distributed somewhat evenly around the week, with Saturday over-represented (20%) and Monday underrepresented (9.5%). About three-fourths occurred between 8 a.m. and 6 p.m. Only 6% occurred between 8 p.m. and 5 a.m. Not surprisingly, far fewer crashes occurred in winter (11%) than summer (36%).

Where

Eighty-four percent of riders reported living in EU countries (including the UK), 6% in the USA-Canada, and 8% in Australia. Of n. 1446 riders who gave an answer about the type of road where they crashed, n.657 (45%) said they crashed on a straight segment of roadway, 14.5% on a curve to the left, 14% on a curve to the right and 8% (n.120) at a roundabout.

Nearly one-third of the respondents reported that the road surface had some kind of problem. Of the minority of road surfaces that presented control problems, loose gravel or dirt accounted for 24% of those problems and water another 24%. Lubricants such as oil or diesel accounted for another 15% of the surface contaminants.

Who

Ninety-one percent of the respondents were male; the median age was 44 and the largest age group was in the 45-54 age range. Eighty-six percent held a full licence. Only one in 40 (2.5%) said they had been riding less than a year while five percent said they had been riding over 40 years consecutively. The median riding experience was about 14 years with 8 consecutive years of riding before their crash. Only about 7% were carrying a passenger when they crashed.

Forty-three percent of riders (n.684) said they had taken a voluntary post-licence rider safety course, for a total of nearly 3,300 courses or an average of five per rider. Overall, n.314 said they had taken a course in emergency braking with ABS (about 55% of the n.573 who said their motorcycle was equipped with ABS).

The type of licence held by the riders at the time of the crash indicated that 85.4% (n.1347) held a full licence (A in Europe) while 5.5% (n.87) held an A2 licence (in Europe) or provisional licence and 2.8% (n.44) held an A1 licence (in Europe).

The motorcycles

Table 1 shows some of the motorcycle types that accounted for about 90% of the total. Scooters and mopeds combined made up about another 5%. In terms of style and injuries, this reflects the overall proportion of motorcycles that were ridden by the respondents, equally, the highest proportion of injuries of the riders are indicated as Naked (30%) followed by Adventure (15.9%) then Supersport (14.6%) with injuries[5].

Table 1

Style	Frequency	Percent
Naked (Streetbike)	484	30.7
Adventure	251	15.9
Supersport	232	14.7
Sports Tourer	168	10.6
Touring	118	7.5
Cruiser	87	5.5
Custom	84	5.3
Total	**1424**	**90.2**

The distribution of motorcycle engine size is shown in Table 2. Fifty-seven percent fell into the 500-1000 cc range and another 28% were larger than 1000cc. Motorcycles under 500cc were only 15% of the total. This distribution (as well as the information provided regarding country of residence) reflects the fact that the great majority of respondents were from developed nations.

Table 2

	Frequency	Percent	Valid Percent
Up to 50cc	16	1	1.0
51cc to 125cc	66	4.2	4.2
126cc to 250cc	59	3.7	3.8
251cc to 500cc	91	5.8	5.8
501cc to 750cc	499	31.6	31.8
751cc to 1000cc	389	24.7	24.8
>1000cc	448	28.4	28.6
No Answer	10	0.6	-
Total	**1578**	**100**	**100**

As noted earlier, 36% of riders (n.573) indicated that their motorcycle was equipped with ABS, 12% (n.190) with traction control and 6.4% (n.101) with cornering ABS.

Table 3

	Frequency	Percent
Antilock brakes (ABS)	573	36.3
Traction Control	190	12
Cornering ABS	101	6.4

3.2 Motorcycle pre-crash speed

Based on the findings of previous motorcycle crash investigations (Hurt and Thailand studies), riders typically have a reasonable estimate of how fast they were going before the situation turned ugly yet no clear idea of their speed when they actually crashed. We asked riders to estimate their speed within a 10 km/hr range and assumed they were giving us the pre-crash speed. Figure 1 shows a cumulative percent distribution of the estimates given by 1,413 riders (150 estimated in miles per hour, while 15 gave no answer.) The median speed fell in the 31-40 km/hr range (19-25 mph) while the 90th percentile speed was around 80 km/hr (50 mph).

[5] See table 62 of the report "Dynamics of Motorcycle Crashes".

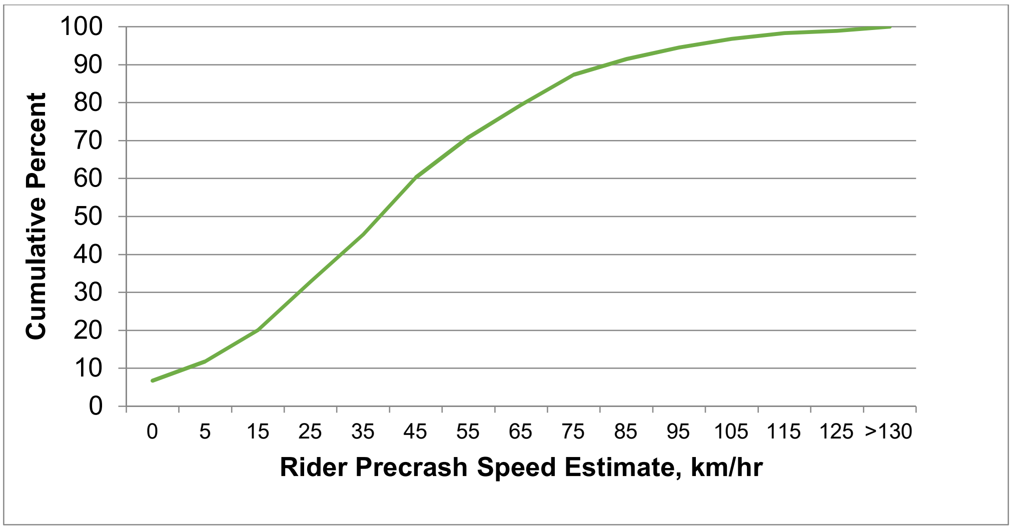

Figure 1 Cumulative percent distribution of estimated speed

3.3 Speed, days in hospital and rehabilitation - comments by riders

How speed effects the severity of injuries is a major focus of debate amongst road safety analysts. The following table 4 identifies estimated speed, days in hospital, days in rehabilitation post-crash and the type of injuries of n.33 respondents of the n.45 respondents who spent more than n.20 days in hospital.

The rider who was stationary when hit, spent 90 days in hospital (possibly due to the speed of the vehicle who crashed into the rider) and 120 days in rehabilitation while the rider whose speed was above 130 kph spent 51 days in hospital and further 120 days in rehabilitation[6].

Table 4

Estimated Speed	Comments injuries	Days in hospital	Days rehab.
Stationary	Damage to left lung	90	120
1 to 10 kph	Lost consciousness – severe lower limb injuries	45	300
1 to 10 kph	The rear footrest bore into the calf above the boot and slit the calf open.	20	
21 to 30 kph	Left leg	20	180
31 to 40 kph	Lost a lot of hearing on both ears. Almost deaf on the left. Wearing hearing aids today	90	30
31 to 40 kph	Broken humerus left side. Muscle pains in shoulder and lowerback	38	
31 to 40 kph	Leg amputated (Right leg was cut off in the middle of the thigh on a sharp-edged guardrail post.	28	120
31 to 40 kph	Complicated fracture ankle, shin and fibula	20	90
31 to 40 mph	Damage to Lungs and Spleen.	60	150
41 to 50 kph	Spinal cord infarction leading to lower paralysis and three years in a wheelchair.	72	110
41 to 50 kph	The bone was twisted, doctors said it was the most severe knee injury they had seen in 15 years. They were thinking of amputating first, could not walk again. Prosthesis was surgical after MANY trips for 3.5 years. Wheelchair bound for 2.5 years.	30	720
41 to 50 mph	There were indications of spine damage on the initial CT scan, however I have not had any back problems since then.	35	365
41 to 50 mph	Collapsed lung , haemothorax, pneumothorax, bruised kidneys, broken & bruised thumb & fingers	20	
51 to 60 kph	Fracture of the right internal malleolus, open fracture of the right femur, three cracked ribs on the right, a pneumothorax. Fracture of the right clavicle, open fracture of the radius and ulna and slight head trauma.	158	1000
51 to 60 kph	Fracture of the right tibial plateau dislocation of the left shoulder	150	180
51 to 60 kph	Ribs, vertebra and teeth	40	

[6] Further details of the speed versus injuries correlation are found in Chapter 9 of the report "Dynamics of Motorcycle Crashes".

Table 4 continued

51 to 60 kph	Explosion of the acetabulum and lesion of the right sciatic nerve	25	60
51 to 60 kph	Lost most of my upper teeth, leg amputated after 25 operations over a 2 year period.	21	1500
51 to 60 kph	Punctured lung from broken ribs, fractures: 2 in neck, 1 in back, collarbone, shoulder, both shoulder blades, breastbone cracked, 22 rib fractures, minor nerve damage left leg (from slide)	20	90
51 to 60 kph	Fractured left leg and ankle broken in 7 pieces , Shoulder injuries split and separated main muscle. Still bad bloodflow and pain.	20	1000
51 to 60 mph	Fractured jaw	75	1000
51 to 60 mph	Spinal injuries	36	1200
61 to 70 kph	Pelvic fractures	60	180
61 to 70 kph	Small brain bleed. Broken wrist requiring surgery. Broken pelvis--no walking for eight weeks, three cuts to face.	39	39
71 to 80 kph	Wounds to the scrotum, Wounds to the knees, Detachment of the pleura, Fracture vertebra D2	150	600
71 to 80 kph	life threatening septicemia	56	200
71 to 80 kph	Broken collar bone, three broken ribs, broken pelvis front and back on both sides and a pneumothorax.	30	30
81 to 90 kph	Mental trauma which affects me for several years.	38	550
81 to 90 kph	Plexus brachial	22	600
81 to 90 kph	Held in coma for 5 days, 16 rib fractures, fractured vertebra, 2 folding lungs, torn lung, 8 litres of blood drained in, broken knee	21	365
81 to 90 kph	Fracture in the right hand and L5 vertebra	20	30
>130 kph	Hip fracture	51	120
> 130 kph	Broken Clavical (right) and 7 ribs (right)	30	

3.3 Speed and age of riders

Respondents who were travelling at a low speed of one to 10 kph prior to crashing, varied from 18 to 74 years with an average age of 46 years. Respondents who were travelling at speeds of between 91 to 100 kph varied from 17 years to 71 years with an average age of 42 years. Of the n.95 riders who were hit by another vehicle while stationary, the age varied from 17 years to 69 years, with an average age of 44 years. Of the n.15 respondents who indicated that they were travelling at >130 kph prior to crashing, the age varied from 22 years to 53 years and the average age was 39 years.

3.4 Braking prior to crash

Eight and a half percent of riders were uncertain or did not answer if they had braked or not. Of the 1,443 who answered either Yes or No (i.e. excluding uncertain or no answer), 38% said they had failed to apply the brakes. Table 5 highlights that over a third (35%) of the respondents did not use their brakes prior to crashing.

Table 5

Braking Action	Frequency	Percent
No	553	35.0
Yes	890	56.4
Uncertain/No Answer	135	8.5
Total	**1578**	**100**

3.5 Prior to crashing, did you apply the brakes?

Table 6

MC had ABS	Applied Brakes prior to crashing			
	No Answer/ Uncertain	No	Yes	Total
No	72	282	605	959
	53.3%	51.0%	68.0%	60.8%
Yes	56	259	258	573
	41.5%	46.8%	29.0%	36.3%
Uncertain /No Answer	7	12	27	46
	5.2%	2.1%	3.0%	2.9%
Total	**135**	**553**	**890**	**1578**
	100%	**100%**	**100%**	**100%**

Of the riders who had ABS-equipped motorcycles 45% (n.258) reported braking before they crashed, while 68% (n.605) of riders on a motorcycle without ABS reported using their brakes before the crash. The difference was highly significant (chi-square = 46.2, $p < .001$, df = 1) – and not easily explained.

Possibly more of interest is that of the n.553 who did not use their brakes prior to crashing, n.258 (46.6%) motorcycles had ABS brakes fitted, which raises the issue of perception/reaction time for the rider which is indicated at between 0.75 to 1.5 seconds by forensic crash scene investigators. In other words, the rider may not have had time to react[7]. A study on reaction times was carried out by Vavryn and Winkelbauer (1996) who found 2 peaks which were 0.18 seconds apart, suggesting that those with the finger on the brake lever were faster to react[8].

3.6 Separation from Motorcycle on Impact

Table 7

Separation from MC	Frequency	Percent
No	393	24.9
Yes	1135	71.9
No Answer	50	3.2
Total	**1578**	**100.0**

A quarter of the respondents (n.393) did not separate from their motorcycles on impact. Of these, n.95 of the riders were stationary when the crash occurred.

3.7 Trajectory or Post-crash Motion

Table 8

Trajectory	Frequency	Percent
Fell backwards	37	2.3
Highside and fell left	75	4.8
Highside and fell right	88	5.6
Left low-side - fell over to the left	313	19.8
Right low-side - fell over to the right	244	15.5
Topside, over the front of the handlebars	288	18.3
Other	106	6.7
Don't know/No Answer	427	27.0
Total	**1578**	**100**

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[7]Forensic Aspects of Driver Perception and Response, Paul Olsen, Lawyers and Judges Publishing Company Inc. 1996. ISBN 0-913875-22-8

[8] Vavryn, K., & Winkelbauer, M. (1996). Bremsverzögerungswerte und Reaktionszeiten bei Motorradfahrern

The trajectory or post-crash motion of the riders (Table 8) indicates that the Left low-side with n.313 (19.8%) was the direction of the highest proportion of riders, followed by Topside, over the front of the handlebars, with n.288 (18.3%) and Right low-side with n.244 (15.5%).

3.8 Trajectory of rider after separation – Left Hand Traffic (LHT) and Right Hand Traffic (RHT)

The comparison with left hand traffic and right hand traffic in terms of trajectory (post-crash motion) is useful to understand whether riding on the left or the right side of the road has any bearing on the type of crash. The accepted view is that when crashes occur at bends in countries that drive on the left side of the road, the propensity to crash at a bend would be that the rider would go wide towards the right side of the road and head into oncoming traffic, conversely where a crash occurs in countries that drive on the right, the rider would go wide towards the left side of the road and head into oncoming traffic.

Table 9

Right Hand Traffic	Frequency	Percent
Highside and fell left	61	10.3
Highside and fell right	76	12.8
Left low-side - fell to the left	251	42.3
Right low-side - fell to the right	206	34.7
Total	**594**	**100**
Left Hand Traffic	**Frequency**	**Percent**
Highside and fell left	14	11.3
Highside and fell right	12	9.7
Left low-side - fell to the left	61	49.2
Right low-side - fell to the right	37	29.8
Total	**124**	**100**

LHT Countries Where Crash occurred: Australia, Guyane Française, Hong Kong, India, Nepal, New Zealand, South Africa, Thailand, UK.

RHT Countries Where Crash occurred: Austria, Belgium, Canada, Croatia, Denmark, Finland, France, Germany, Greece, Italy, Lithuania, Luxembourg, New Caledonia, Norway, Poland, Romania, Romania, Spain, Sweden, The Netherlands, USA

As table 9 above indicates, in this survey there appears to be little difference in the outcome of the trajectory whether riding in left hand traffic or right hand traffic when the rider fell Left low-side. Of those travelling on the right of the road n.251 (42.3%) indicated that their trajectory was Left low-side while n.61 (49.2%) of those travelling in left hand traffic indicated that their trajectory was also Left low-side – i.e. the majority of both groups indicated that they fell to the left. Could this be due to the fact that the front brake lever is on the right of the motorcycles? It is an interesting dilemma.

3.9 Where was the impact on the Motorcycle?

The biggest proportion of the position of impact on the motorcycle was frontal (15.4%) with 10.1% lateral left side and 12.4% lateral right side. This is followed by those motorcycles that were rear-ended (9%).

Table 10

Impact	Frequency	Percent
Frontal	243	15.4
Lateral - left side	160	10.1
Lateral - right side	195	12.4
Rear end	142	9.0
Other	50	3.2
Don't know/No Answer	788	49.9
Total	1578	100.0

The area of impact is indicated by the type of damage that the motorcycles sustained e.g. with the highest proportion on the handlebars (61.6%) and mirrors (66.2%), indicators (61.5%), front lights (38.3%) and front mudguard (36.6%). Other indicators are damage to the fairing, Screen, front forks and front wheel (Table 11). However, sooner or later, most of the motorcycles fall to the side, damaging handle bars, indicators, brake and clutch lever and the mirrors, thus the information is purely indicative.

3.10 What Damage Did the Motorcycle Sustain?

Table 11

Damage	Frequency	Percent
Mirrors	1045	66.2
Handlebars	972	61.6
Indicators	971	61.5
Fairing	927	58.7
Front Lights	605	38.3
Front Mudguard	578	36.6
Screen	562	35.6
Front Forks	552	35
Front Wheel	538	34.1
Tank	510	32.3
Gear Lever	508	32.2
Engine and Casing	468	29.7
Rear Brake Lever	437	27.7
Frame	399	25.3
Top Box & Panniers	386	24.5
Instruments	346	21.9
Other	332	21
Sub Frame	281	17.8
Brake Reservoir	219	13.9
Tail (Rear) Lights	207	13.1
Clutch Reservoir	197	12.5
Swing Arm	160	10.1
Back Wheel	155	9.8

3.11 Trajectory (Post-crash Motion)

Tables 12a, b and c identify the trajectory or post-crash motion of the motorcyclist when separated from the motorcycle.

The respondents whose trajectory was Left low-side indicated that a third (33.5%) had motorcycles with ABS brakes but did not use their brakes, while 26.2% (n.64) fell to the right (Right low-side) in both cases, just over half did not use their brakes prior to crashing.

Of particular interest is that 37.1% (n.107) of the n.288 respondents with ABS brakes on their motorcycles were projected Topside – i.e. over the front of the handlebars. This compares to 33.5% (n.105) left low-side and 26.2% (n.64) right low-side.

Table 12a

Trajectory	Did your motorcycle have ABS brakes			
	No Answer /Uncertain	Yes	No	Total
Fell backwards	1	21	15	37
	2.8%	3.7%	1.6%	2.3%
Highside and fell left	3	28	44	75
	6.5%	4.9%	4.6%	4.8%
Highside and fell right	2	33	53	88
	4.3%	5.8%	5.5%	5.6%
Left low-side - fell over to the left	5	**105**	203	313
	10.9%	18.3%	21.2%	19.8%
Right low-side - fell over to the right	9	**64**	171	244
	19.6%	11.2%	17.8%	15.5%
Topside, over the handlebars	11	**107**	**170**	**288**
	23.9%	18.7%	17.7%	18.3%
Other	0	40	66	106
	0.0%	7.0%	6.9%	6.7%
Uncertain/No Answer	15	175	237	427
	32.6%	2.6%	24.7%	27%
Total	**46**	**573**	**959**	**1578**
	100%	**100%**	**100%**	**100%**

The trajectory or the direction the body travels after a collision appears to be closely linked the type of crash. As an example, a rear end collision where the motorcycle rear-ends another vehicle would typically cause the rider to go over the front of the handlebars. The information from table 12a above and the following tables, 12b and 12c, is the comparison between motorcycles with and without ABS and whether the rider used the brakes prior to crashing.

Table 12b

Prior to crashing, did you apply the brakes?		Did your motorcycle have ABS brakes			
		No Answer /Uncertain	No	Yes	Total
Uncertain		*6*	*57*	*45*	*108*
No	Fell backwards	0	7	8	15
		0%	2%	3%	3%
	Highside and fell left	0	14	11	25
		0%	5%	4%	5%
	Highside and fell right	0	24	17	41
		0%	9%	7%	7%
	Left low-side - fell over to the left	3	**75**	**55**	133
		55%	**27%**	**21%**	24%
	Right low-side - fell over to the right	4	**47**	**34**	85
		89%	**17%**	**13%**	15%
	Topside, over the front of the handlebars	3	**38**	**43**	84
		33%	**13%**	**17%**	15%
	Other	0	21	18	39
		0%	7%	7%	7%
	Uncertain/No Answer	2	56	73	131
		22%	20%	28%	24%
	Total	**12**	**282**	**259**	**553**
		100%	**100%**	**100%**	**100%**

The comparison of riders whose motorcycles were equipped with ABS brakes and did not apply their brakes (table 12b) with those that did (table 12c), is instructive. There were n.259 whose motorcycle had ABS brakes but did not use them and there were n.258 who had ABS brakes and used them prior to crashing. Of those that fell Left low-side, 21% did not use their brakes compared to 17% who did use them. Of those that fell Right low-side, 13% did not use their brakes, while 10% did use them.

Finally, 17% who did not use their ABS brakes, fell topside (over the front of the handlebars) while 18% used their brakes. The proportion of those who were uncertain whether they had crashed or did not answer represents 30% of the respondents. As this is empirical data – we are unable to hypothesize what may have happened.

Table 12c

Prior to crashing, did you apply the brakes?		Did your motorcycle have ABS brakes			
		No Answer /Uncertain	**No**	**Yes**	Total
Yes	Fell backwards	0	8	11	19
		0%	1%	4%	2%
	Highside and fell left	3	26	10	39
		11%	4%	4%	4%
	Highside and fell right	2	23	13	38
		7.4%	4%	5%	4%
	Left low-side - fell over to the left	2	115	44	161
		7.4%	19%	17%	18%
	Right low-side - fell over to the right	5	113	27	145
		18.5%	19%	10%	16%
	Topside, over the front of the handlebars	5	118	47	170
		18.5%	20%	18%	19%
	Other	0	39	16	55
		0%	6%	6%	6%
	Uncertain/No Answer	10	163	90	263
		37%	27%	35%	30%
	Total	**27**	**605**	**258**	**890**
		100%	**100%**	**100%**	**100%**

In the case where the riders used their brakes prior to crashing, the proportion of those that fell Left low-side and did not have ABS brakes (19%), was similar to those that did (17%). While there was a notable difference for those that fell Right low-side – 10% with ABS and 19% without. The outcome for those who fell topside is similar – 18% with ABS and 20% without. This suggests that the type of brakes on the motorcycle (i.e. whether they were ABS or not) had little effect on the trajectory of the rider.

3.12 Trajectory (post-crash motion) and injury locations (type of injuries*)

The following tables indicate the type of injuries (*type of injuries in this study, means the location on the body of the injury) identified, depending on the trajectory (post-crash motion) of the respondents.

What these particular responses do not indicate is the severity of the injuries or whether the injuries resulted in time spent in hospital. Table 13a focuses on lower limb and pelvic injuries as well as upper limbs and indicates that the two. It shows that two trajectories, Left-low-side and Topside dominate injuries to these regions. Left low-side averaged 20% (excluding pelvic internal) and Topside averaged about 25%.

However, note that being thrown forward over the handlebars accounted for nearly half the pelvic internal injuries this suggests a role of the fuel tanks in groin injuries as highlighted in previous research Oeullet, JV and Hurt HH 1981[9], Meredith L et al 2016)[10]. Pelvic-internal injuries were uncommon – only 5% of the injuries reported.

[9] Ouellet, JV & Hurt, HH, Jr., Groin injuries in motorcycle accidents, *Proceedings of 25th Conference of the American Association for Automotive Medicine,* San Francisco, CA 1981.
[10] Meredith, Lauren & Baldock, Matthew & Fitzharris, Michael & Duflou, Johan & Nevo, Ross & Griffiths, Michael & Brown, Julie. (2016). Motorcycle fuel tanks and pelvic fractures: A motorcycle fuel tank syndrome. Traffic injury prevention. 17. 10.1080/15389588.2015.1136061.

Table 13a

Trajectory	Lower limbs, including knees, feet and/or ankles		Upper limbs - arms, elbows, wrists, hands		Pelvic internal		Pelvic external	
	Fr	%	Fr	%	Fr	%	Fr	%
Fell backwards	16	2.4	10	1.9	1	1.4	0	0.0
Highside and fell left	37	5.5	30	5.7	2	2.7	5	5.8
Highside and fell right	47	7.0	41	7.8	5	6.8	5	5.8
Left low-side - fell over to the left	129	**19.2**	108	**20.6**	5	6.8	17	**19.8**
Right low-side - fell over to the right	97	14.4	75	14.3	8	11.0	10	11.6
Topside, over the front of the handlebars	130	**19.3**	123	**23.4**	27	**37.0**	18	**20.9**
Other	56	8.3	32	6.1	9	12.3	10	11.6
Uncertain/No Answer	160	23.8	106	20.2	16	21.9	21	24.4
Total	**672**	**100.0**	**525**	**100.0**	**73**	**100.0**	**86**	**100.0**

Once again 13b highlights the two dominating post-crash motions with the highest proportion of injuries as Left low-side and Topside. However, across the range of types of injuries, Topside dominates with an average of 30% for abdomen and chest injuries and Left low-side has an average of 20% for chest injuries.

Table 13b

Trajectory	Abdomen internal		Abdomen external		Chest internal		Chest external	
	Fr	%	Fr	%	Fr	%	Fr	%
Fell backwards	3	5.3	1	2.0	4	2.7	3	3.4
Highside and fell left	3	5.3	0	0.0	10	6.7	3	3.4
Highside and fell right	2	3.5	4	8.0	13	8.7	11	12.4
Left low-side - fell over to the left	3	5.3	7	14.0	26	**17.3**	20	**22.5**
Right low-side - fell over to the right	8	14.0	7	14.0	23	15.3	11	12.4
Topside, over the front of the handlebars	23	**40.4**	17	**34.0**	40	**26.7**	19	**21.3**
Other	6	10.5	4	8.0	16	10.7	6	6.7
Uncertain/No Answer	9	15.8	10	20.0	19	12	16	17.9
Total	**57**	**100.0**	**50**	**100.0**	**150**	**100.0**	**89**	**100.0**

Table 13c tabulates back and shoulder injuries by rider trajectories. In this case, the post-crash motion, Topside overwhelmingly dominates with 29% compared to the remaining trajectory types.

The question relating to back injuries was not asked, this was a shortfall in the survey, however the respondents who replied to the question about trajectory, were then asked to comment on “other injuries” and n.87 replied with details of the type of back injuries with the varied severity, that they had received[11].

[11] See Annex III in the report “Dynamics of Motorcycle Crashes” for details of back injuries.

Table 13c

Trajectory	Back		Shoulders	
	Fr	**%**	**Fr**	**%**
Fell backwards	5	5.7	9	2.6
Highside and fell left	9	10.3	25	7.1
Highside and fell right	9	10.3	35	10.0
Left low-side - fell over to the left	5	5.7	53	15.1
Right low-side - fell over to the right	10	11.5	52	14.9
Topside, over the front of the handlebars	27	**31.0**	95	**27.1**
Other	11	12.6	22	6.3
Uncertain/No Answer	11	12.6	59	16.9
Total	**87**	**100.0**	**350**	**100.0**

Table 13d provides details of neck, face, head and brain injuries and the Topside trajectory (post-crash motion) dominates with an average of 38.5% for all these types of injuries.

Table 13d

Trajectory	**Neck**		**Face**		**Head**		**Brain**	
	Fr	**%**	**Fr**	**%**	**Fr**	**%**	**Fr**	**%**
Fell backwards	4	3.0	1	2.0	3	3.8	1	1.7
Highside and fell left	6	4.5	4	8.2	4	5.1	2	3.4
Highside and fell right	9	6.7	0	0.0	8	10.3	0	0.0
Left low-side - fell over to the left	19	14.2	8	**16.3**	4	5.1	4	6.8
Right low-side - fell over to the right	15	11.2	6	12.2	6	7.7	9	15.3
Topside, over the front of the handlebars	48	**35.8**	16	**32.7**	35	**44.9**	24	**40.7**
Other	9	6.7	6	12.2	3	3.8	5	8.5
Uncertain/No Answer	24	17.9	8	16.3	15	19.3	14	23.8
Total	**134**	**100.0**	**49**	**100.0**	**78**	**100.0**	**59**	**100.0**

What the tables above highlight is that the trajectory is significant in establishing the percentages of injuries. Overwhelmingly, the Topside motion has the highest proportion of declared injuries for all types, with the exception of “external chest”.

The Left low-side motion had the second highest proportion of type of injuries. As mentioned above, the type (or location) of injuries highlighted do not determine the severity of the injuries.

3.13 Topside – Over the front of the handlebars

A total of n.288 riders stated that their trajectory was Topside (compared to n.313 Left low-side) while, n.232 whose post-crash motion was “Topside” stated that they were injured (compared to n.206 Left low-side).

Overall, n.96 “Topside” were admitted to hospital (compared to n.25 Left low-side), whereas when the Trajectory was Topside, n.59 stayed in hospital between one to seven days while n.20 stayed in hospital between eight to 20 days and n.17 stayed in hospital for more than 20 days.

3.14 Crashed with and Trajectory of motorcycle post-crash

Table 14 below compares the post-crash motion to what the motorcycle crashed with and demonstrates that of the n.696 motorcycles that crashed with a car, 63.5% (n.183) of the motorcyclists' trajectory was Topside (n.288). Of the single vehicle crashes (n.191) where the rider lost control and did not crash against an object or vehicle, the predominant trajectories were Left low-side (18.8%) and Right low-side (19.3%).

Table 14

Crashed with	If you were separated from your motorcycle, which way did you go?								
	No Answer/ Uncertain	**Other**	**Fell back wards**	**High-side and fell left**	**High-side and fell right**	**Left lowside - fell over to the left**	**Right low side - fell over to the right**	**Topside, over the front of the handle bars**	**Total**
Bicycle	6	2	0	0	1	2	0	4	15
	1.4%	1.9%	0.0%	0.0%	1.1%	0.6%	0.0%	1.4%	1.0%
Bridge	0	0	0	0	0	0	0	1	1
	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.1%
Bus	2	0	0	0	1	0	0	1	4
	0.4%	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%	0.3%	0.3%
Car	198	45	18	27	35	102	88	183	696
	47.3%	42.5%	48.6%	36.0%	39.8%	32.6%	36.1%	63.5%	44.1%
Flying objects (e.g.birds or insects)	1	2	0	0	0	2	0	1	6
	0.2%	1.9%	0.0%	0.0%	0.0%	0.6%	0.0%	0.3%	0.4%
Large animal (e.g. moose, horse, deer)	10	4	4	1	2	3	6	5	35
	2.4%	3.8%	10.8%	1.3%	2.3%	1.0%	2.5%	1.7%	2.2%
Motorcycle/scooter moped	22	4	4	6	7	15	14	10	82
	5.2%	3.8%	10.8%	8.0%	8.0%	4.8%	5.7%	3.5%	5.2%
Other	26	9	3	9	10	30	12	9	108
	6.1%	8.5%	8.1%	12.0%	11.4%	9.6%	4.9%	3.1%	6.8%
Pedestrian	3	0	0	0	0	2	1	0	6
	0.7%	0.0%	0.0%	0.0%	0.0%	0.6%	0.4%	0.0%	0.4%
Road hump	4	0	1	0	3	3	5	3	19
	0.9%	0.0%	2.7%	0.0%	3.4%	1.0%	2.0%	1.0%	1.2%
Road side (crash) barrier	13	6	1	5	3	11	6	5	50
	3.1%	5.7%	2.7%	6.7%	3.4%	3.5%	2.5%	1.7%	3.2%
Road side (crash) barrier with motorcycle guard rail	3	0	0	0	0	3	0	1	7
	0.7%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.3%	0.4%
Single vehicle	35	15	1	4	8	59	47	22	191
	8.3%	14.2%	2.7%	5.3%	9.1%	18.8%	19.3%	7.6%	12.1%
Small animal dog, fox	2	1	0	1	0	1	1	2	8
	0.4%	0.9%	0.0%	1.3%	0.0%	0.3%	0.4%	0.7%	0.5%
Tractor (agricultural vehicle)	2	1	0	0	0	0	1	0	4
	0.4%	0.9%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.3%
Truck	4	4	0	1	1	1	2	3	16
	0.9%	3.8%	0.0%	1.3%	1.1%	0.3%	0.8%	1.0%	1.0%
Truck with trailer/s	4	0	0	0	2	1	0	2	9
	0.9%	0.0%	0.0%	0.0%	2.3%	0.3%	0.0%	0.7%	0.6%
Tuk tuk (rickshaw)	1	0	0	0	0	0	0	0	1
	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Van	18	5	2	3	2	12	8	21	71
	4.3%	4.7%	5.4%	4.0%	2.3%	3.8%	2.9%	7.3%	4.4%
Uncertain/No Answer	72	8	3	18	13	66	53	15	249
	17.0%	7.5%	8.1%	24%	14.8%	21%	21.7%	5.2%	15.7%
Total	**427**	**106**	**37**	**75**	**88**	**313**	**244**	**288**	**1578**
	100%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

3.15 Days in Hospital and brakes

Overall there were n.109 riders whose motorcycles had ABS who were recovered in hospital ranging from between one day to n.180 days. Of these n.41 applied their brakes prior to crashing while n.50 did not (n.15 were uncertain). Conversely there were n.185 riders whose motorcycles did not have ABS and who were hospitalized ranging from one day to n.183 days. Of these n.115 applied their brakes prior to crashing and n.47 did not (n.21 were uncertain).

4 Findings

The findings from the report "Dynamics of Motorcycle Crashes" relating to post licence training is important in order to understand whether the courses that the riders participate in have any effect on their ability to avoid crashing. Of the respondents, 43% indicated that they had done some form of post licence training, but still crashed. A shortfall of the survey was that the question of when the respondents did training, was not asked and this may have an influence on their skills and knowledge in emergency situations.

As an aside, but worth considering from the Dynamics report, is the common hypothesis suggesting that younger riders though less experienced, take greater risks in terms of speed. However, the responses indicate that the correlation between age and speed appears to be random.

Most relevant for this paper is those riders who took part in specific training for braking with ABS represented 19.9% (n.314). Of these, 65% (n.204) indicated that they were riding motorcycles with ABS brakes at the time of the crash.

Yet an interesting finding here is that riders on ABS-equipped motorcycles were significantly less likely to brake than riders without ABS: only half the riders on ABS-equipped motorcycles reported braking before they crashed compared to two-thirds of those on a motorcycle without ABS.

Technology on motorcycles has the purpose of aiding the rider to control the motorcycle in order to be able to accelerate, ride, lean and stop. As the findings of this paper demonstrate, over a third of the respondents (35%) did not use their brakes prior to crashing and of these, n.259 (46.8%) had ABS brakes fitted. Also to keep in mind is that both the Hurt and Thailand studies found that a substantial minority of riders seem to take no evasive action before they crashed – 30% in the Hurt study and nearly half in Thailand. So it should be no surprise that many riders in this survey would report taking no evasive action. And indeed, about 38% said they did no braking.

On the other hand, this suggests that brake performance had a role in 65% of the crashes, which is more than the 54% Kramlich & Sporner[12] calculated 20 years ago, when ABS was rather new on the market.

The distribution of post-crash motion of riders with and without ABS and those who had applied brakes vs. those who had not, clearly indicate that ABS changes crash records. Considering the technical function of an ABS, it may be argued that ABS primarily reduces low-side crashes, which leads to a higher share of top-side motion. But the methodological nature of this study does not allow to conclude on a crash-reduction potential of ABS.

Motorcycles more than any other form of transport have developed and modernised such that technology is an integral part of how the machine operates but more importantly, how this technology interacts with the rider and his/her ability to control the technology.

This study provides evidence that indicates that the link between speed and the seriousness of injuries is random, this is based on the correlation of speed, the type (or location) of injuries and the number of days that the rider spent in hospital and in rehabilitation.

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[12] Kramlich, T., & Sporner, A. (2000). Zusammenspiel aktiver und passiver Sicherheit bei Motorradkollisionen. GDV, Institut für Fahrzeugsicherheit, München.

What is possibly the most important finding of this study was that the mechanism of each crash, in particular, the trajectory of the rider post-crash, determines not only the type and range of injuries but also the severity of the injuries in terms of the area of the injuries on the body.

The identification of post-crash motion is used in motorcycle racing circuits to explain the trajectory of the motorcyclists when they separate from the motorcycle after impact with an object, roadside furniture or infrastructure or because the rider has lost control of the motorcycle. These definitions are to understand how the rider falls and what the potential type of injuries may occur from the mechanism of the fall. These definitions are not universally used and it would be helpful to decide amongst analysts that a guide should be adopted to facilitate comparative research.

The post-crash motion “Topside” occurred in 63% of those cases where the rider collided with a car. In terms of injuries this type of trajectory dominates both the range of type or location of injuries and the severity.

The following types of trajectories: Left Low-side and Right Low-side also have high levels of injuries by type. But compared to the Topside trajectory, less time was spent in hospital.

This study suggests that the rider's trajectory in the crash strongly influences the range of injuries riders sustain and also the injury severity. In nearly every body region, "Topside" – ejection forward over the handlebars – accounted for more injuries than any other trajectory. In addition, riders who ejected Topside were more likely to be hospitalized than riders who had some other trajectory and they were more likely to be hospitalized for longer.

Annex one provides a sample of the information available in the study based on the comments of motorcyclists who describe the circumstances of the crash. The sample of six riders is an example of the depth and wealth of information through the responses of 1578 motorcyclists throughout 30 countries.

The full report “Dynamics of Motorcycle Crashes” can be found here:

https://investigativeresearch.org/the-dynamics-of-motorcycle-crashes-2020/

Annex One: Case study of six motorcyclists who crashed

Profile of the Six Motorcyclists

- Three from France, one from Norway, One from Germany and one from the UK. All male but two accompanied by female riders.
- Ages varied from 16 to 62 (average age 35). Five had full licence and one had A1 licence (125cc).

- Four had full face helmets and two had modular (flip ups). All six wore armoured jackets and five wore armoured trousers. All wore gloves and boots.
- Average annual distance ridden was 13166 (minimum 6000 kilometres, maximum 25000 kilometres). Average number of years riding was 12 (minimum 1 year, maximum 40 years).
- Four of the riders had taken part in emergency braking courses.

- Four of the motorcycles were Naked Street bikes and two were adventure bikes.
- Engine cc for two was 800cc and 600cc respectively, one 125cc and one 1050cc
- Three of rider riders were travelling at speeds of between 81 to 90 kph, one was travelling at estimated speeds of between 71 to 80 kph and one was travelling at estimated speeds of between 31 to 40 kph and another at estimated speeds of between 31 to 40 miles per hour.
- All motorcycles were equipped with ABS.

- Four of the riders were travelling in the morning (between 8 am and 12 noon) and two in the early afternoon.
- Weather conditions were good – in five cases it was sunny and in one case it was overcast (cloudy).
- In five cases the road conditions were good and in one case there was gravel.

Table 15

Estimated Speed	Type of road	Crashed with	Impact on MC/ Post-crash motion	Injuries, days in hospital/rehab.	Comments
31-40 mph	Rural road right hand bend	Single vehicle	Didn’t separate	Lower limbs 14 (hosp.) 365 (rehab.)	Road had been resurfaced and gravel had built up on the bend. There was a depression on the outside of the bend and gravel had pooled in it. I went into a field and clipped a dike guard. Left leg was smashed back against the bike. Fibula tibia 3 metatarsals were all broken.
31-40 kph	Urban road (straight + Cross road)	Car	Frontal/Topside	Upper limbs/Shoulders 38 (hosp.)	The driver of the car lost his licence for driving recklessly and because he didn't yield.
81-90 kph	Urban road (straight + T junction)	Truck	Frontal/ highside-right	Lower and upper limbs 180 (hosp.)	The truck cut me off at the last moment, so I hit it head on.
81-90 kph	Rural road (Straight + T junction)	Car	Lateral, right side/Topside	9 (hosp.), 90 (rehab.)	A collision of two motorcycles against a car. Two riders seriously injured - my wife and myself, but she died one week later. My wife hit the front, I hit the side (the car was turning square on into our way). Evidently, the person in the car, elderly, 86 years old if I remember correctly, cut us off because he thought he was seeing 'bicycles'.
81-90 kph	Rural Straight road	Car	Frontal/topside	Lower + Upper limbs 22 (hosp.) 600 (rehab.)	I was passing a car which turned left without using the indicators. I was thrown more than 30 meters away while my motorcycle went under the car. I owe my survival in part to the reflex that I had of letting go of the handlebars and standing on my toe clips. I specify that I was an "all weather" biker and experienced. But, one cannot drive in place of the others ...

Table 15 continued

Estimate Speed	**Type of road**	**Crashed with**	**Impact to MC/ Post-crash motion**	**Injuries, days in hospital/rehab.**	**Comments**
71-80 kph	Rural Straight road	Car and motorcycle	Frontal/Topside	Upper limbs, pelvis. 30 (hosp.), 30 (rehab.)	The crash happened just after a left-hand bend on a straight part of the road. Just after the bend, a car was standing still on this 100 kph limit road. No Alarm lights, no indication of car trouble. Not parked with two wheels on the side. Just in the middle of my lane. My wife was on her R1200GS riding in front of me. Just after the left-hand bend, the car - a dark black Porsche was there in the middle of our lane. It took a fraction of a second for my wife to realize that the car was not moving. She had to decide to go around the car or emergency brake. She chose the latter because the "only reason" a car would be standing still on this 100KM road, was that the car was going to make a U-Turn. My wife made an emergency stop. Because of our position on the road (just after the bend) my wife was blocking my view. I could not see the car. I saw her braking lights, but not for what she was braking. It took a split second before I realized that she was not just braking, but emergency braking. I also emergency braked. My position was now "staggered" (not in a straight line behind my wife, but to the left of her). Now I could see the car as well. My wife realized that she could not stand still before she was going to hit the car so at the last moment she moved to the left to pass the car. By doing this, she was coming into "my line". Since I started braking just a bit later than my wife, I was still driving faster and hit my wife in the back of the motorcycle. She went low-side, going across the tarmac ending up in a ditch. She only had a scratch on her elbow because her Rukka protection did not stay in place. I went high-side and ended up on the tarmac. My injuries were: broken collar bone, three broken ribs, broken pelvis front and back on both sides and a pneumothorax. This all happened in two or three seconds. We didn't hit the car.

Annex two: Acknowledgements

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Cover photo:Joachim Sjöström

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Research Team

The research team has wide experience in the study of motorcycle crashes such as those conducted by James Ouellet who co-authored the seminal Hurt Report as well as other ground-breaking studies on motorcycle crash investigations[13]; Elaine Hardy's involvement in EU PTW research projects and studies of motorcycle safety, including reporting crash investigations[14].

Research on infrastructure and training by Martin Winkelbauer[15] and in-depth accident investigation (e.g.MAIDS, SaferWheels, DaCoTA) by Dimitri Margaritis[16].

The latter two researchers collaborated in the OECD/ITF research report, "Improving Safety for Motorcycle, Scooter and Moped Riders[17].

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Avoiding Motorcycle Accidents by Motorcycle Risk Mapping

Klemens Schwieger, Andreas Hula, Peter Saleh; AIT – Austrian Institute of Technology GmbH
Horst Ecker, Manfred Neumann; TU Wien

Abstract:

The risk of suffering a motorcycle accident is still difficult to quantify given the different types of individual riding styles of motorcyclists. Every year, nearly 100 motorcycle accidents occur on Austrian roads [1], but the rare occurrence of accidents at the same spot makes it difficult to locate risky spots. To tackle these challenges, test riders were gathering data while driving on popular motorcycle routes with a motorcycle equipped with the latest sensor technology in order to collect individual driving dynamics data. The test vehicle used (MoProVe, Motorcycle Probe Vehicle) was a modern KTM motorcycle that is equipped with cameras, geo-position antennas (GPS, GLONASS), inertial measurement units (IMUs) and with access to the motorcycle's internal data acquisition (CAN bus).

In order to achieve the identification of risky spots from driving dynamics, the project viaMotorrad (funded by the Austrian Road Safety Fund - VSF) [2] started in 2015 with the aim of developing tools and methods for improving motorcycle safety in the national road network. The test vehicle MoProVe was developed by the Vienna University of Technology and the AIT Austrian Institute of Technology in order to obtain the necessary driving dynamics data. It was the focus of the project to enable a preventive / predictive approach to motorcycle safety based on the dynamic driving data instead of the conventional, reactive approach.

This work presents a central part of the final project results of viaMotorrad: A method for identifying accident hot spots with risky driving dynamics parameters through machine learning. The developed approach uses a combination of unsupervised and supervised learning methods in machine learning to distinguish the dynamics at known accident sites from the most common driving dynamics of every single driver in a pool of 6 drivers. The individual risk estimates are then combined into a common risk estimate for the pool of test drivers in the experiment. Using the joint estimate, maps of risk spots for 6 popular motorcycle routes in the Austrian Alps were derived. The risk spots on these maps were further divided into three groups depending on how high the individual risk warnings were in their vicinity. Therefore, these maps may include a priority checklist for implementing security measures on popular routes.

1. Introduction

As advanced driver assistance systems (ADAS) in cars get ever more sophisticated, devising approaches to improve motorcycle security remains challenging. The more delicate issue of controlling a motorcycle in complex driving situations is difficult, as interventions into the steering process or other automatic adjustments of the driving process are not necessarily welcomed by motorcycle riders. Hence another approach to this may be to recognize patterns among several drivers' dynamics at known accident spots (e.g. a big data approach) and determine dangerous spots via an analysis of (individual) dynamics, combined into to a (population-wise) estimate of local accident risk spots (see earlier work in [3,4,5]). These estimates can in turn be used to address issues of road infrastructure improvements for the safety of motorcyclists or perhaps inform onboard warning systems of upcoming spots of notable dynamics.

2. Measurement Systems

To be able to carry out the measurements, a motorcycle was provided by KTM [6]. This motorcycle was then equipped with high quality sensors (see Fig. 1), to gather the precise movements (e.g. speeds, angular velocities, accelerations) of the KTM 1290 during the test drives. All measurements were undertaken in normal daytime traffic on the routes of interest.
The motorcycle was equipped with additional measurement systems [7,8]. Those were comprised of a separate data logger each, IMUs (Inertial Measurement Unit), other sensors and a connection to the CAN-bus. For a detailed description, see Schwieger et al, 2018 [3].

Figure 1: KTM 1290 Super Adventure equipped and instrumented as a Motorcycle Probe Vehicle (MoProVe)

3. Data

Data collection took place on 6 selected tracks with 6 experienced drivers using the probe vehicle to collect data. If a rider tested on a given tack, they would drive several times on that track, in both directions. Data was annotated to record special events (such as following a slow

vehicle or overtaking). All rides took place during daylight hours and under generally favourable weather conditions.
Measured time series were postprocessed, to obtain “per meter” values of the observed variables, using values at the start of each track meter and providing a means for spatial comparison between the different rides on the same track.
Accident site data on these 6 tracks for single driver accidents and frontal collisions was obtained for the years 2012 to 2015.

4. Data Preparation

For the purpose of analysis, data was only included when 2 criteria were fulfilled: At least four satellite signals were received and we required our test-riders to not be following another vehicle e.g. to drive freely (there was a separate indicator, that specified when the MoProVe was driving behind another vehicle).
Our analysis was based on several measures of driving dynamics: The vehicle speed, X-, Y- and Z- Accelerations, Roll-Rate, Yaw-Rate and Pitch-Rate, measured by more than one system (IMUs and CAN Bus) for additional information. Where meaningful, we separated the positive and negative values of variables (e.g. left-turn or right-turns of the vehicle, accelerations or decelerations) into separate time series, in order to allow for separated statistical weights in our model.
Dynamics variables were smoothed with a rolling average window, (see Fig. 2 below). We used the function “rollmean” found in the package “zoo” of the statistics language “R” [9, 10] and shifted the resulting series of rollmeans in such a way, that each new value would be an average of only values that happened before it. E.g. we chose a rollmean that was “predictable” in the sense of only using available information at the actual point in time. The window used in this study was 60 meters.
The rolling average serves two purposes: Firstly, compared to raw data, changes happen in a more consistent and steady manner. Secondly, since the value at any given time point is an average of several values that happened before, the value of the rollmean at a given meter encodes a kind of autoregressive approach to studying the vehicle dynamics. This was desirable, as we assume the dynamics leading up to a certain point would be highly relevant in whether an accident might be recorded at the investigated location.

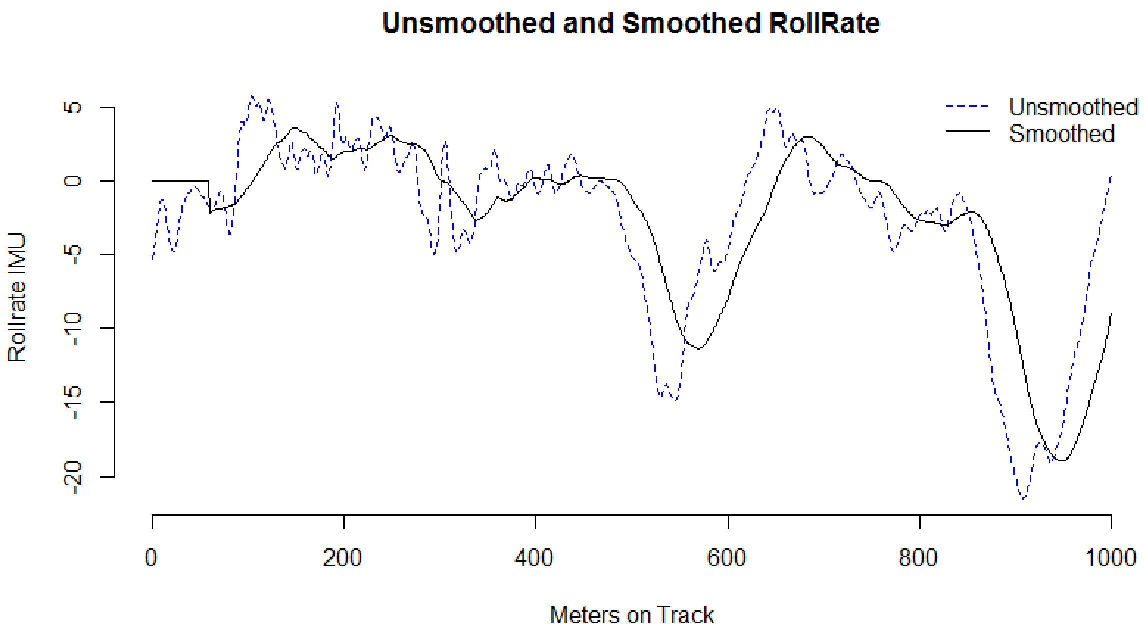

Figure 2: Example of the effect of smoothing and shifting the data (Rollrate in this case) of a single driver. We show only the first 1000 meters of the given ride. The “lag” between the rollmean and the actual data is well visible and this serves to ensure that critical dynamics affect the likelihood of the next few meters after their occurrence still (e.g. the potential recorded accident locations).

Finally, the smoothed curves served as basis to calculate approximate derivatives (namely first differences) between their meter values and those derivatives were smoothed again. In addition to this, we determined the effective curvature of the driven path (defined as the current speed divided by the current Yaw-Rate) as well as accelerations uphill and downhill and treated them as independent variables of interest.

5. Deriving individual Reference Motions from Clustering

A well-established clustering method (k-nearest neighbours, kNN) [11, 12], implemented in the R package “mclust” [13], was used to determine the 8 vectors (cluster centers) of our processed dynamics variables around which the observed data of an individual driver could best be grouped for each single ride, according to the kNN algorithm. These clusters served as the “reference motions” of each driver, assuming them to be non-dangerous, as drivers would on average drive in ways that they could control.
The data of each driver was aggregated into a large time series over all tracks and rides and the dynamics values at each known accident spot were extracted for every single ride.
Finally, we set as target values on the dynamics of the known accident spots the value 1 and for the dynamics of the cluster centers the value 0. Thus, a linear regression was run for each driver, to find the weights (regression coefficients) on the dynamic variables, that would best separate the “reference motions” from the known accident spots (similar to a single layer perceptron [14]). From these separation values, an individual threshold was calculated by taking the average of the linear separation function values on the known accident spots, corresponding to the assumption that the accident spots should be “dangerous on average”.
The weights/coefficients resulting from the linear separation of “reference motions” and accident spots, can then be used to assign a “Dynamical Value” to each meter on the track. These values can then be compared to the individual threshold mentioned above, to determine when the evaluation of the driving dynamics reach the accident-spot-like domain (see Fig. 3 below for an illustration).

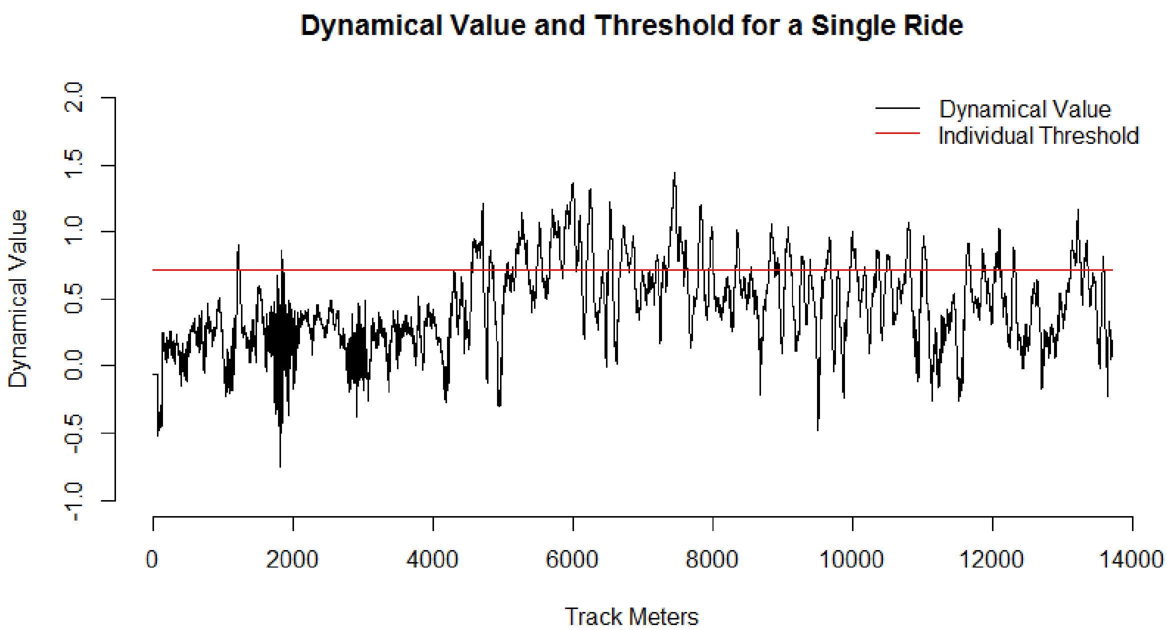

Figure 3: The measured dynamics on each meter of the track can be transformed into a value (“Dynamical Value”) that encodes whether dynamics might be in a similar risk domain as known accident spots. An individual threshold, derived from the Dynamic Values at known accident spots, allows to identify domains of interest for safety studies.

6. Building an Overlay of Threshold Exceedances

Each meter on the track is assigned a value of zero and then incremented by one, for every ride with the dynamical value above the driver's threshold. E.g. by counting how many threshold exceeding events occurred at this spot. This is done jointly for all drivers on the given track e.g. their counts are summed up and on each meter the counts are then divided by the number of valid measurements on that meter (e.g. the maximal number of possible counts), thus giving a proportion of occurred threshold exceeding events to potential threshold exceeding events. Since the dynamical value fluctuates quite a bit, this map of threshold exceeding event proportions is again smoothed (with a window of 60 meters), to provide a consistent structure of potential accident spot like dynamics locations. An illustration can be found in Fig. 4 below.

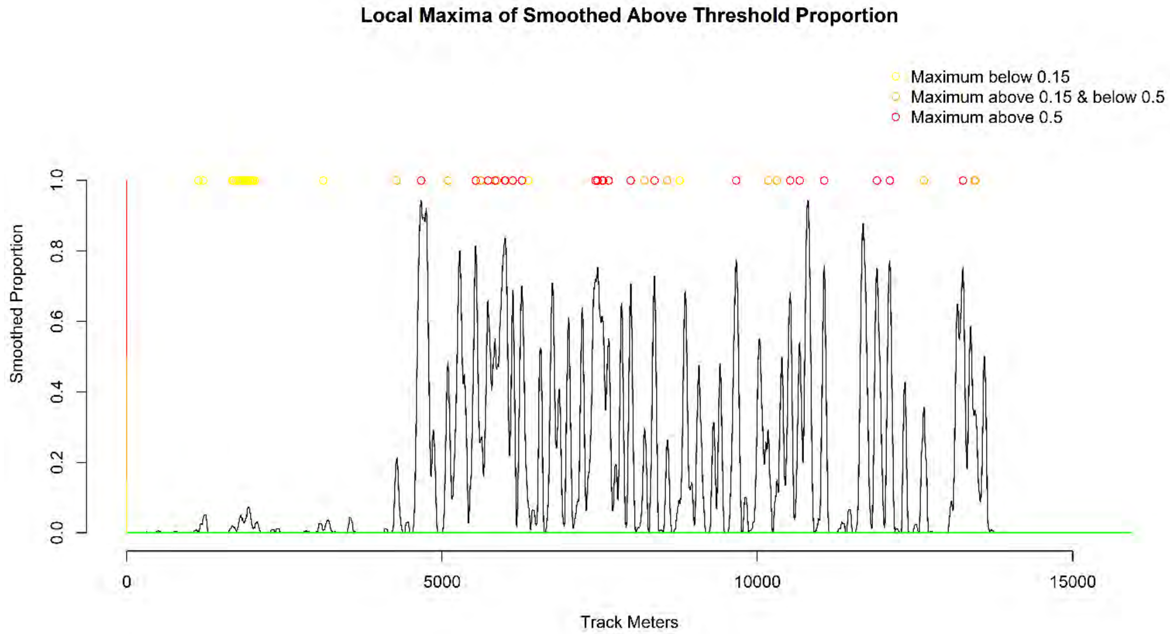

Figure 4: Outline of the smoothed (via rollmean) proportion of threshold exceeding events on the Kalte Kuchl track (over all drivers and rides). Above we marked the local maxima of the resulting curve. Only those local maxima are then used to estimate the potential risk spots and their surrounding area. The maxima are colour coded as "low" (yellow, 0 to 15 percent), "middle" (orange, 15 percent to 50 percent) and "high" (red, 50 percent and above) stress locations. The colour green encodes meters with no local maximum nearby.

The local maxima of the resulting curve serve as the spots of "local dynamical stress" and around them an area of 120 meters before and after them is labelled their "area" of influence (lead up and follow up area, accounting for potential ambiguity of accident spot localization). These maxima and their areas are colour coded, depending on the proportion of above-threshold observations. Yellow maxima reach less than 15 percent of the possible threshold exceeding events and are local maxima of low stress. Orange maxima and areas reach at least 15 percent and up to 50 percent and can provide a serious indication of accident risk. Red maxima and areas reach at least 50 percent and serve as definite indicators of challenging driving dynamics. The focus on maxima was decided in order to have estimates for local peaks within the "yellow" area, without immediately "colouring" the whole track and just focus on the local maxima instead.
Based on the Kalte Kuchl track, we present an exemplary map, as would be the result of this method, in Fig. 5 below.

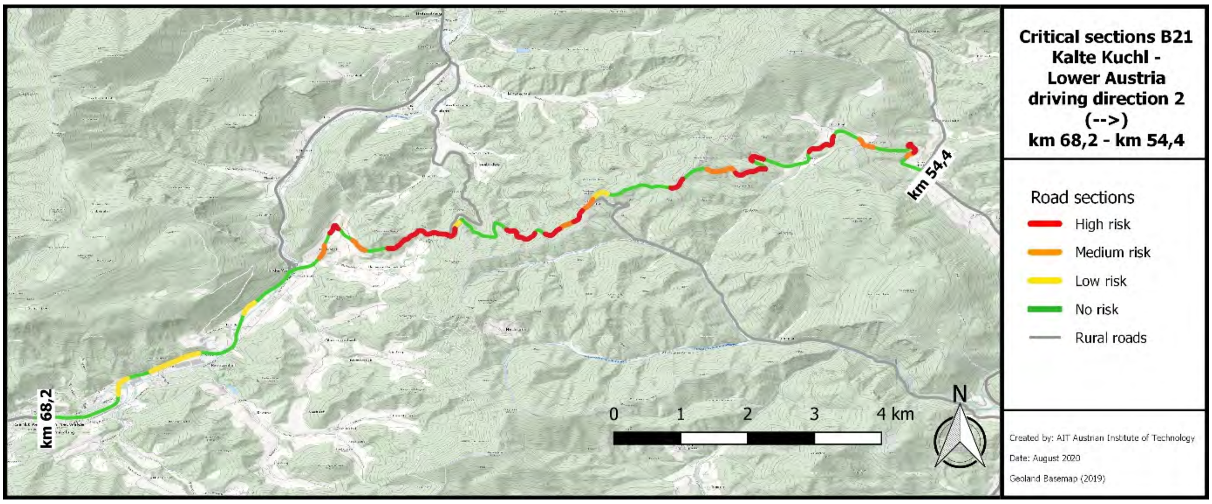

Figure 5: Example of a resulting map for the Kalte Kuchl. Spots in this case are the ones shown in Fig. 4.

We consider an accident to be “hit” by our model, if its location is in one of the coloured areas described above. For the Kalte Kuchl track mentioned here, this yields a “Hit” share of 68 percent, to be compared with a total share of 52 percent of the track being in any of the coloured areas. The Kalte Kuchl is an extreme example, given the high number of known accident spots and the many small curves on the track. On the totality of all 6 tracks we have 38 percent in any coloured area and 66 percent of accidents hit.

7. Discussion and Summary

We have analysed data collected in 2017 by 6 motorcycle drivers on 6 reference tracks, covering a total of approximately 3000 kilometers driven in almost 200 test-rides on the MoProVe. Driving dynamics were quantified in terms of speed, accelerations (X-, Y-, Z-) and angle changes (Roll-Rate, Yaw-Rate, Pitch-Rate) and per-meter values were provided. These dynamics data were postprocessed via smoothing (rolling average), separation by sign and approximate derivatives (first differences). The values at known accident spots were compared to the values around which the dynamical values were most likely to cluster (kNN cluster centers) via a high dimensional linear separation model. The resulting function on the driving dynamics allowed to provide individual estimates, the “dynamic value” for each driver. It also enabled us to define a threshold for when driving dynamics reach a domain of similar individual stress compared to known accident sites. Combining the estimates of multiple drivers, it was possible to define a map of areas around local maxima of the number of threshold exceeding events and these areas contained 66 percent of the considered accident sites.
This methodology combines unsupervised approaches, such as clustering (kNN), with supervised approaches (such as the linear separation) and forms a group effect (the overlay of threshold exceeding events) at points of interest. This has the advantage of stabilizing and summarizing the estimates of the very different individual drivers, while still characterizing drivers individually.

The resultant map may be used to guide road safety efforts and study the highlighted spots in detail to determine, whether actual threats to safety can be noted there and infrastructure improvement might mitigate the effects of crashes in these spots. The colour coded system can serve to prioritize investigations and measures for a road safety inspection on the analysed tracks.
The obtained estimates become generalizable due to the overlay of multiple driver’s estimates and the individual thresholds and clusters, which allow to adjust for personal driving styles. Therefore, a systematic study of motorcycle safety on common tracks based on riding dynamics becomes feasible by this approach.

The current approach of using clustering on the individual riding styles and separations between typical driving dynamics and driving dynamics at known risk spots leading to overlays of multiple limit transgressions for a final estimate of accident spot like dynamics has been filed as a European patent [15] and will be the focus of further work.

8. Limitations and Further Work

The used methods are still quite simple and it may well be that other approaches, such as support vector machines or deep learning, might yield yet better results for the separation.
On the other hand, interpretability is already a challenge, as the combination of individual threshold exceeding events makes it hard to discern the individual causes of threshold exceedance. Further work will focus on creating interpretable criteria for risk spots, based on the described risk map approach.
The individual threshold estimates might be refined further, to define personal safety profiles of drivers that would be interested to use such a functionality and provide online feedback to the drivers.

Finally, the use of only the extrema of the threshold exceeding events overlay may be replaced by types of hazard maps, that would instead colour the whole area above a certain threshold, rather than the areas around extrema. This approach will require a refinement of the used criteria, as the estimates of which points to choose will have to be able to still hit known accident spots, without resorting to colouring large areas around each above-threshold point, since this would otherwise include a far too big proportion of the investigated track.

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Motorcyclist pelvis interaction with the fuel tank in frontal crashes – a laboratory test method

Tom Whyte[1,2,3], Julie Brown[1,2,3]

1. Neuroscience Research Australia, Randwick, NSW, 2031, Australia
2. The George Institute for Global Health, Newtown, NSW, 2042, Australia
3. Faculty of Medicine, The University of New South Wales, Kensington, NSW, 2052, Australia

Abstract

Pelvic injury is common among hospitalised motorcyclists. The primary mechanism is contact with the fuel tank. Injury outcome likely relates to the design of the fuel tank and may also be influenced by the posture of the rider. There is a need to understand the interaction between tank design and initial pelvis posture as this varies by motorcycle type. Currently there is no accepted physical test method for studying this. This study aimed to develop a physical test method for replicating pelvis-fuel tank impacts in frontal motorcycle crashes and to investigate changes in initial pelvic posture.

A mini-sled was affixed to the sled table of a deceleration sled. A frame was attached to the mini-sled, to which a surrogate pelvis was attached. The frame allows the surrogate to rotate and translate upward. A rigid fuel tank surrogate was mounted to the main sled table at 3 different angles. The pelvis surrogate was a THOR dummy pelvis and upper legs. New soft tissue, separating the pelvis and upper legs was molded from silicone rubber. Two triaxial accelerometer arrays were mounted to the surrogate to measure peak acceleration and rotational velocity due to fuel-tank impact.

The pelvis surrogate, clothed in standard jeans was tested in an initial upright posture, a forward, sport-bike posture and a reclined, cruiser posture. In each test condition, the sled table was accelerated to 20 km/h and decelerated. The mini-sled and surrogate frame continued at 20 km/h causing impact between the pelvis surrogate and the fuel tank surrogate

This study indicates both tank angle and rider posture likely play a role in pelvic injury risk in fuel tank impacts that result from frontal motorcycle crashes.

Introduction

Injury to the pelvic region is common among crash involved motorcyclists, occurring to 13% of riders in a large in-depth crash investigation study of 900 accidents [1] and even more common among riders hospitalized after crashing [2]. The more serious of these injuries can have significant long-term health implications such as chronic pain and quality of life impairments [3].

The primary mechanism for crash-related pelvic injuries to motorcyclists is direct contact with the motorcycle fuel tank, occurring in more than 85% of pelvic injury cases [1,2]. This typically occurs when the motorcycle is involved in a frontal impact with another vehicle where the motorcycle abruptly stops and the rider continues forward at the initial travelling speed. The impact between the pelvis of the rider and the motorcycle fuel tank is often clearly evidenced by post-crash damage and markings to the fuel tank. In a previous analysis of hospitalized riders exhibiting this ‘fuel tank syndrome’, injury to the pelvic region was most commonly of moderate or greater severity (AIS 2+) [2]. This type of injury has been shown to relate to impact speed with more severe injuries generally occurring in higher speed crashes [1,2].

Previous work has indicated that pelvic injury risk may also relate to the characteristics of the motorcycle fuel tank. Suggested strategies for reducing injury risk have included that fuel tanks be designed to: minimise the angle of incidence the fuel tank makes with the seat of the motorcycle [1,4–7], distribute the impact over a wider area and longer time [1], promote ejection of the rider [8] and not be wedge shaped [5]. Other researchers have suggested covering the fuel tank with padding or yielding foam [4,5,7]. However, there has been little work confirming whether these suggested strategies would actually mitigate pelvic injury risk.

Rider posture likely also influences pelvic injury mechanism and risk in fuel tank impacts as different rider postures likely alter the initial loading condition. As noted previously by Ouellet & Hurt, different riding postures may also result in different pelvis structures (e.g. pelvic arch vs ischium) contacting the fuel tank [1]. In a collection of hospitalized motorcyclists in Australia, pelvic injury occurred most often among cruiser riders compared to other motorcycle types [9,10], with cruiser type motorcycles shown to position the rider in a more upright, legs forward, relaxed seating position than sports style motorcycles [11]. To date there has been no rigorous examination of the potential impact of different rider postures and/or initial pelvic positions on injury risk and the dynamic interaction between the fuel tank and rider's pelvis.

These current gaps in evidence for how the pelvis interacts with the fuel tank and what fuel tank design strategies might best ameliorate pelvic injury risk need to be addressed. A major barrier to addressing these gaps is the current lack of a physical test method to systematically investigate the effects of rider posture, fuel tank characteristics and potential countermeasures on pelvic injury risk during crash impacts with the fuel tank. The aim of this study was to develop a repeatable physical test method to simulate the interaction between a rider's pelvis and the fuel tank in a frontal crash. A preliminary investigation of the effect of tank angle and rider posture on dynamic interactions between a pelvis surrogate and the fuel tank was undertaken.

Methods

A test apparatus was designed and constructed to simulate pelvis-fuel tank impacts using a mini-sled mounted on a deceleration crash sled (see Figure 1). A steel frame was attached to the mini-sled (the surrogate frame), to which a pelvis surrogate was attached by a steel bar. The surrogate frame was designed to allow the pelvis surrogate to rotate in the sagittal plane and translate upward from the sled table upon impact with the fuel tank. Another steel frame (the tank frame) was fixed to the main deceleration sled table, onto which a wooden fuel tank surrogate was attached at one of three angles of incidence to the sled table (30°, 37.5°, 45°). A wooden fuel tank surrogate was used for this study to provide a repeatable relatively rigid impact surface whereby the tank surrogate would not be damaged in successive impacts.

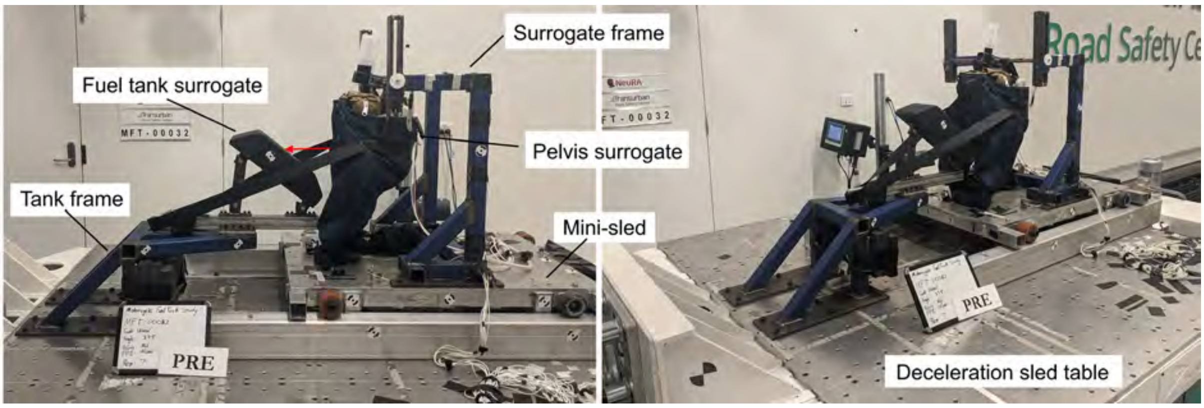

Figure 1 Test apparatus showing mini-sled, pelvis surrogate and surrogate frame, and fuel tank surrogate and tank frame. The red arrow indicates the direction of travel of the pelvis surrogate to impact the fuel tank surrogate.

For the impact tests in this study, the main deceleration sled table was accelerated to an impact speed of 20 km/h and decelerated to a stop. The mini-sled and surrogate frame continued at the impact speed resulting in a 20km/h impact between the pelvis surrogate and the stationary fuel tank surrogate. The mini-sled then impacted energy absorbing foam on the tank frame, stopping the mini-sled.

The pelvis surrogate consistent of the THOR dummy lumbar spine, pelvis and upper leg components with the soft tissue removed. New soft tissue components, separating the pelvis and upper legs were molded from silicon rubber previously used to replicate the impact response of human thigh tissue [12]. The pelvis surrogate was clothed in standard jeans. The initial posture of the pelvis surrogate was varied by changing the anterior-posterior location of the steel bar relative to produce three postures (forward, upright and reclined) intended to represent postures on different motorcycle styles (sports, standard, cruiser).

Two triaxial accelerometer arrays were mounted to the rear of the lumbar spine pelvis surrogate. Data from the accelerometers were used to calculate the peak resultant acceleration of the pelvis surrogate at the lumbar spine and the peak rotational velocity. The pelvis response was analysed from the initial impact with the fuel tank to the time point when the mini-sled contacted the tank frame. High-speed cameras captured a lateral view of each impact at 1000 frames per second.

At least 2 impacts were performed in each test condition. The test matrix is shown in Table 1. The variations in tank angle and rider posture are shown in Figure 2.

Table 1 Test matrix varying fuel tank surrogate angle and pelvis posture.

Test condition	Number of impacts	Impact speed (km/h)	Tank surrogate angle (°)	Pelvis posture
1	2	20	30	Forward
2	3	20	30	Upright
3	2	20	30	Reclined
4	2	20	37.5	Forward
5	7	20	37.5	Upright
6	2	20	37.5	Reclined
7	2	20	45	Forward
8	3	20	45	Upright
9	2	20	45	Reclined

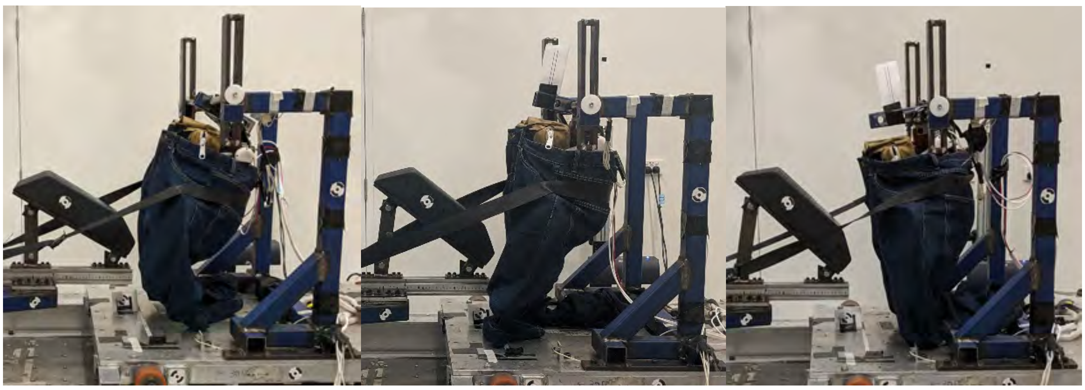

Figure 2 Variations in fuel tank surrogate height (left to right, 30°, 37.5°, 45°) and pelvis surrogate posture (left to right, reclined, upright, forward).

Results

The impact kinematics of the pelvis surrogate in an initially upright posture against a fuel tank with a tank angle of 37.5° are shown in Figure 3.

The peak pelvis surrogate responses are provided in Table 2. Increasing surrogate fuel tank angle saw an increase in peak pelvis acceleration and rotational velocity, see Figure 4 and 5. The reclined posture generally provided the highest pelvis surrogate responses.

The coefficient of variation in each test condition was less than 9% for peak pelvis acceleration and less than 11% for peak pelvis rotational velocity in all test conditions, see Table 2.

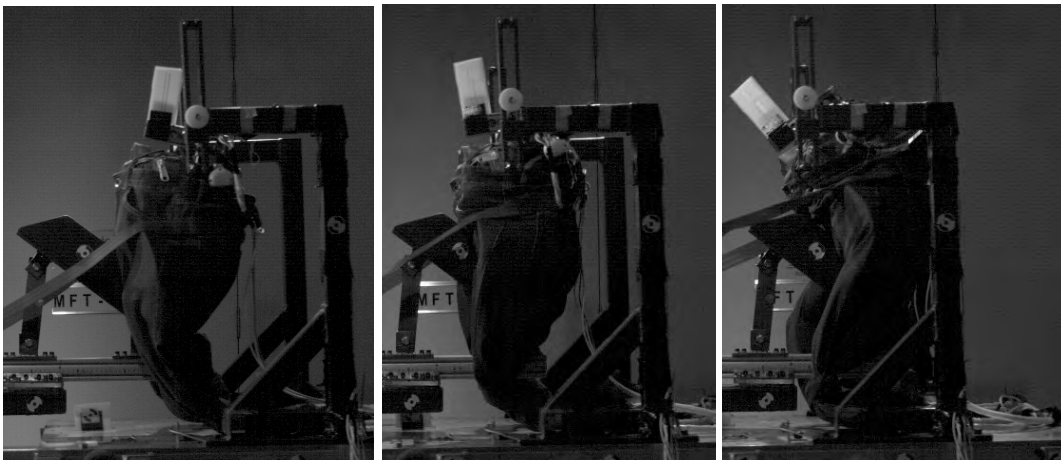

Figure 3 Pelvis surrogate rotating and the lumbar spine translating upward from the sled table as a result of the simulated fuel tank impact.

Table 2 Peak pelvis surrogate responses in each test condition.

Test condition	Tank surrogate angle (°)	Pelvis posture	Peak pelvis acceleration (g)		Peak pelvis rotational velocity (rad/s)	
			Mean	St. dev.	Mean	St. dev.
1	30	Forward	53.8	4.5	1490	163
2	30	Upright	64.9	0.3	1522	107
3	30	Reclined	71.4	0.2	1667	72
4	37.5	Forward	61.6	3.7	1636	24
5	37.5	Upright	80.5	3.3	1709	50
6	37.5	Reclined	99.5	6.8	1885	159
7	45	Forward	76.2	4.3	1825	66
8	45	Upright	87.7	2.4	1791	112
9	45	Reclined	106.2	7.6	1923	186

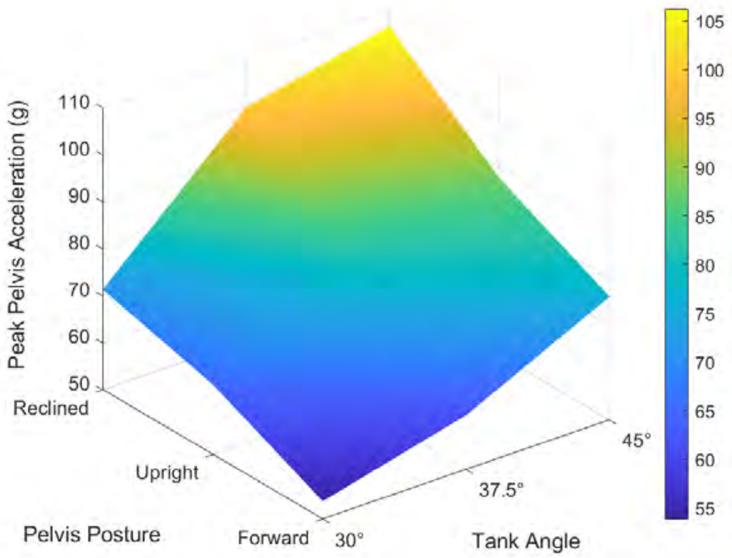

Figure 4 Mean peak pelvis acceleration response for each combination of initial pelvis posture and tank angle.

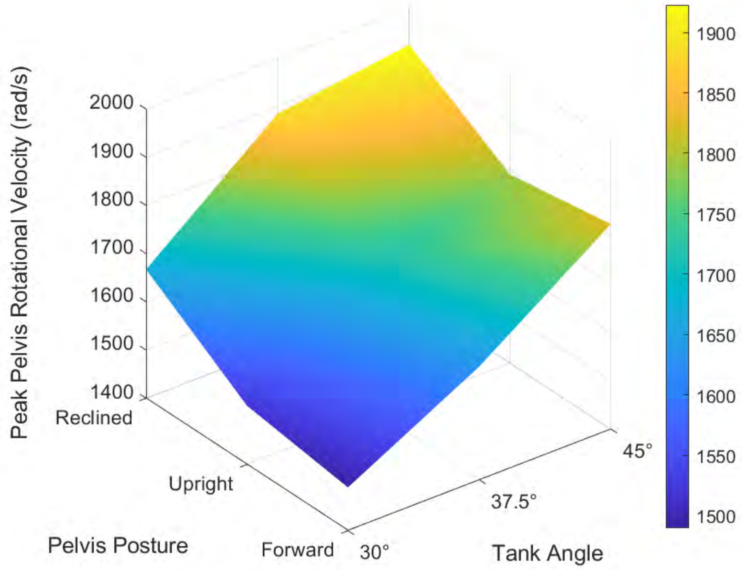

Figure 5 Mean peak pelvis rotational velocity response for each combination of initial pelvis posture and tank angle.

Discussion

The objective of this study was to design a physical test method for simulating impacts between a motorcyclist's pelvis and the fuel tank in a frontal motorcycle crash. The kinematics of the pelvis surrogate (Figure 3) are consistent with that previously described for full scale motorcycle crash tests where the fuel tank impact initiates forward pitching of the dummy [7,8]. Impact test results indicate that the measured response variables of peak acceleration and rotational velocity exhibited an acceptable coefficient of variation (<11%) in repeated tests under the same conditions. These responses were also sensitive to the varied test conditions suggesting the test method is promising for studying potential countermeasures for pelvis injury risk mitigation such as fuel tank design changes or personal protective clothing for riders.

Changes to fuel tank angle and pelvis posture influenced the pelvis surrogate impact response. Increasing tank angle led to larger peak accelerations and rotational velocities, in agreement with a previous computational study which found larger impact forces at higher tank angles [6] and real crash investigations that found tanks with an abrupt rise contribute to pelvic injury [1]. The reclined posture produced the highest pelvis responses at each tank angle, with peak responses generally reducing as the posture moved from upright to forward. This posture effect may explain why cruiser riders had a high incidence of pelvic injury in a collection of Australian cases despite cruiser style motorcycles generally having lower tank angles than other types of motorcycle [9,10]. The peak pelvis acceleration in a reclined posture at a 30° tank angle potentially representative of a cruiser tank and rider posture was similar to the forward posture and a 45° tank angle that might be present on a sports style motorcycle. However, these observations should be viewed as preliminary and further work is required to confirm real world implications.

There are a number of limitations to this study to keep in mind. To our knowledge there is no dynamic biomechanical impact data to ascertain the response and tolerance of the pelvis in anterior-posterior loading like that would occur in a motorcycle fuel tank impact. There are two implications of this lack of data. Firstly, the rider surrogate consisting of a metallic pelvis and silicone rubber soft tissue may not adequately simulate the pelvis impact response in this type of loading. Secondly, the pelvis surrogate impact response variables that were measured at the lumbar spine (peak acceleration and rotational velocity) may not be the parameters that most closely relate to pelvis injury risk. Nevertheless, the results presented here in combination with previous literature suggest the test method developed demonstrates expected responses and aligns with real world observations.

Further limitations include the fact that the fuel tank surrogate in this study was essentially rigid whereas real fuel tanks are often deformed in real crashes [2]. A rigid tank surrogate was chosen in this study for repeatability, however this would produce a more severe impact than a real fuel tank at the same impact velocity. There is also the possibility that different motorcycle styles incorporate different fuel tank construction which was not accounted for in this study. The physical test method developed will allow future work examining the impact of these variables. The impact with the stationary fuel tank simulated in this study also neglects any pitching of the motorcycle that might occur in a frontal collision Further study of pelvic kinematics in full scale crash tests using human cadavers and volunteers would help determine the importance of incorporating this in future developments of the test method. Finally, the variations in initial pelvis posture were not based on real rider postures. While differences in torso and leg angles have been documented for different motorcycle styles [11], more detailed data is needed to accurately determine the pelvis orientation relative to the fuel tank among motorcyclists with varying anthropometry and motorcycle design.

Conclusion

The physical test method developed for this study provides a means of systematically investigating the interaction between the pelvis of a motorcyclist and the fuel tank in a frontal crash. The test showed good repeatability and the ability to monitor the pelvis response which was sensitive to changes in test conditions that have been linked to pelvis injury risk in previous studies. In the future, the test method could be used to aid in improving crashworthiness of motorcycle fuel tanks and in the design of protective equipment for riders.

Acknowledgement

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Fahrversuche und Analyse des Fahrstreifenwechsels mit Motorrädern

Stefan Litschauer, Horst Ecker

Technische Universität Wien

Getreidemarkt 9 / E325, A-1060 Wien, Österreich

Kontakt: horst.ecker@tuwien.ac.at

Kurzfassung

Ein grundlegendes Verständnis des Fahrmanövers „Fahrstreifenwechsel“ ist aus mehreren Gründen wesentlich und wichtig, nicht zuletzt, wenn andere Verkehrsteilnehmer, insbesondere autonom gelenkte Fahrzeuge, ihr Fahrverhalten auf das des einspurigen Fahrzeuges abstimmen müssen. Mit dieser Arbeit soll hierzu ein Beitrag geleistet werden.

Dazu wurden mit einem instrumentierten Motorrad mehr als 100 Fahrstreifenwechselmanöver im öffentlichen Verkehr durchgeführt und fahrzeugdynamische Parameter gemessen und aufgezeichnet. Der Geschwindigkeitsbereich lag zwischen 40km/h und 100km/h, der seitliche Versatz bei den Fahrstreifenwechsel betrug zwischen einer halben und einer Fahrstreifenbreite.

Die Auswertung der Daten der Messfahrten erfolgte primär anhand der Zeitsignale von Rollwinkel und Rollwinkelgeschwindigkeit. Mittels statistischer Datenanalyse konnten Abhängigkeiten der Maximalwerte der genannten Messgrößen erkannt werden. Dadurch war es möglich, zu jedem Manöver einen Parameter „Intensität“ anzugeben, der als skalierter Wert die Vehemenz/Agilität/Ambitioniertheit angibt, mit der der Fahrer das Manöver gefahren ist.

Ein wesentliches Ergebnis der Studie ist, dass die Messkurven durch synthetische Signalverläufe angenähert werden können. Wegen der vergleichsweise hohen Anzahl von Versuchen gelingt mittels Regressionsverfahren die Optimierung der Parameter dieser analytischen Funktionen. Dadurch kann ein mathematisches Modell des Fahrstreifenwechsels angegeben werden, welches in verschiedenen Anwendungen eingesetzt werden kann.

Quasi als Nebenprodukt wurde auch die Zeitdauer bis zum Einsetzen einer Lenkreaktion der Fahrer auf ein visuelles Signal erfasst. Damit kann nunmehr auch die anzunehmende Reaktionszeit für ein Ausweichmanöver eines einspurigen Kraftfahrzeuges genauer angegeben werden als bisher.

Abstract

A basic understanding of the driving maneuver “lane change” is important for several reasons. One of them concerns other road users, especially autonomously driven vehicles, which need to be able to anticipate the next actions of a single-lane vehicle in order to avoid traffic conflicts.

To contribute to the ongoing research, more than 100 lane change maneuvers were carried out in public traffic with an instrumented motorcycle. The dynamic parameters of the motorcycle were measured and recorded. The speed range covered was between 40km/h and 100km/h, the lateral offset when changing lanes was either a half or a full lane width.

The evaluation of the measured data from the test runs was primarily based on the time signals of the roll angle and the roll rate. By statistical data analysis, it was possible to identify relations between the peak values of the measured signals and other parameters. This made it possible to specify a parameter, termed “intensity”, to describe and quantify the vehemence / agility / ambition that the driver used when performing the maneuver.

A key result of the study is that the measured signals can be approximated by using synthetic functions. Because of the comparatively high number of tests, the parameters of these analytical representations can be optimized using regression methods. In this way, a mathematical model of the lane change maneuver can be specified, which can be used in various applications.

The time until the driver started to react to a visual signal was also recorded as a “by-product”. The reaction time for an evasive maneuver that can be assumed was analyzed and better data than before are now available.

1. Einführung

Den Fahrstreifen zu wechseln ist an und für sich ein alltägliches Fahrmanöver, für Lenker von einspurigen wie auch von mehrspurigen Fahrzeugen. Je nach Fahrzeug und Verkehrssituation kann das Manöver von eher langsam bis hoch-dynamisch gefahren werden. Für Fahrer von Motorrädern ist ein zügiger bis schneller Fahrstreifenwechsel auch ein Ausdruck des Fahrvergnügens. Gelegentlich ist aber ein seitliches Ausweichmanöver, welches sehr viele Gemeinsamkeiten mit einem regulären Fahrstreifenwechsel hat, notwendig, um einen Unfall zu vermeiden. Dann geht es natürlich nicht um die Freude am Beherrschen des eigenen Motorrades, sondern primär darum, die schwerwiegenden Konsequenzen einer Kollision mit einem Unfallgegner (auch) für die eigene Person zu vermeiden.

Im Gegensatz zu mehrspurigen Kraftfahrzeugen besteht bei einspurigen Krafträdern nämlich die zumindest theoretische Möglichkeit, durch ein beherztes Auslenken und Umfahren eines Hindernisses eine Kollision zu vermeiden. Diese Option ist mehrspurigen Fahrzeugen meist verwehrt, weil diese wesentlich breiter sind und beim Ausweichen auf die Fahrbahn des gegenläufigen Fahrstreifens ein erhöhtes Unfallrisiko besteht.

Das schnelle Ausweichen zur Unfallvermeidung stellt daher quasi den Extremfall eines Fahrstreifenwechsels dar und ist nur die alternative Möglichkeit der Unfallvermeidung für Motorradfahrer. Die andere und mit allen Fahrzeugen zur Verfügung stehende Möglichkeit ist natürlich die einer entsprechend starken Bremsung. Wegen dieser beiden, grundlegend verschiedenen, Möglichkeiten als Motorradfahrer in einer Gefahrensituation zu reagieren, wurde insbesondere das fahrdynamisch schwieriger auszuführende und auch theoretisch komplexere Ausweichmanöver schon vor etlichen Jahren Gegenstand von Forschungsarbeiten.

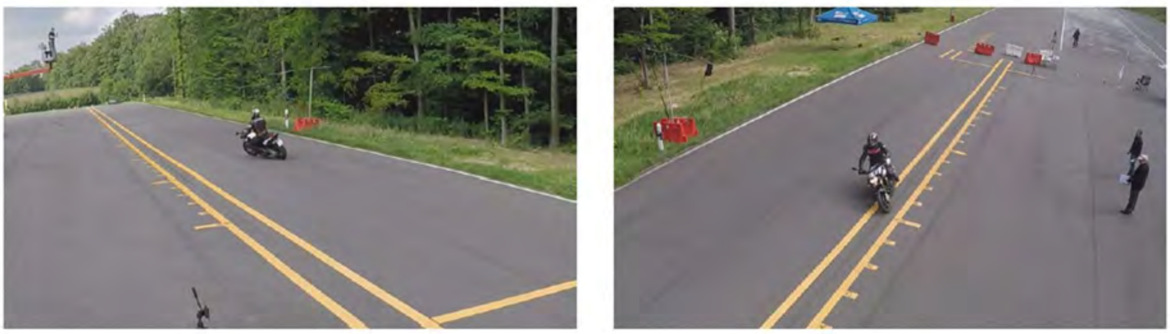

Bild 1: Versuchsanordnung zum Fahrstreifenwechsel (3,5m Spurversatz) auf einem Versuchsgelände wie von Kuschefski et al in [4] verwendet.

Bekannt sind aus dieser Zeit insbesondere die Arbeiten von Watanabe et al. So war zum Beispiel [1] eine der ersten Publikationen, in der Ausweichmanöver zur Kollisionsvermeidung mit einem unbeweglichen Hindernis experimentell untersucht wurden. Dabei stand jedoch der Gewinn an seitlichem Versatz in Relation zur zurückgelegten Fahrstrecke im Vordergrund, und die Fahrlinie nach dem Passieren des Hindernisses wurde nicht berücksichtigt. Wegen dieser fehlenden Ausrichtung der Fahrlinie an den Fahrbahnverlauf nach dem Hindernis sind diese Studien nur bedingt mit einem Fahrstreifenwechsel zu vergleichen. Frühe experimentelle Studien zu einem vollständigen Fahrstreifenwechsel sind in [2] und [3] beschrieben. In jüngerer Zeit führte Kuschefski et al in [4] eine sehr umfassende experimentelle Studie durch, in der auch die bereits in [1] gestellte Frage aufgegriffen wurde, ob Bremsen oder Ausweichen bei der Unfallvermeidung wirksamer ist.

Mittlerweile ist aber auch das wissenschaftliche Interesse an einem „normalen“ Fahrstreifenwechsel ohne Unfallvermeidungsabsicht gestiegen. Dafür gibt es mehrere Gründe. Für die Überprüfung und Validierung von fahrdynamischen Modellen für Fahrer&Motorrad eignet sich dieses hoch-dynamische Fahrmanöver besonders gut. Weiters besteht eine zunehmende Nachfrage nach Modellen für humangelenkte Motorräder zur Anwendung in Simulationsumgebungen. Da im Straßenverkehr der Zukunft ein erheblicher Wandel stattfinden wird, insbesondere durch das Aufkommen des autonomen Fahrens von Personenkraftwagen, müssen wichtige Fragen zu heterogenen Verkehrssystemen beantwortet werden. Für die Regelung eines autonom gelenkten Fahrzeugs muss das Verhalten eines nicht-autonom geführten Fahrzeugs wie es das Motorrad stets sein wird, vorausberechenbar sein. Daher werden validierte Motorrad-Fahrermodelle benötigt, um die Modellierung des gesamten Systems voranzutreiben.

Schließlich ist dieses Fahrmanöver auch für die Unfallforschung bedeutend, wie schon am Beginn dieser Einleitung ausgeführt wurde. Da die Unfallzahlen in der Kategorie „Unfälle mit Motorrädern“ in den letzten Jahren (zumindest in Österreich) auf relativ hohem Niveau liegen, bedarf es weiterer Anstrengungen, einen Abwärtstrend zu initiieren. Nun ist zwar der Fahrstreifenwechsel per se nicht jenes Manöver bei dem Motorradfahrer häufig verunglücken, aber für andere Verkehrsteilnehmer stellen die raschen Positionsänderungen zu welchen ein Motorradfahrer, auch unter Einhaltung der Verkehrsvorschriften, in der Lage ist, eine Herausforderung dar. Insbesondere in Verkehrssituationen, bei denen sich ein Motorrad von hinten einem anderen, langsameren Verkehrsteilnehmer nähert, und dieser die Annäherung nur indirekt über Spiegelsysteme bemerken kann.

Der Umstand, dass in jüngster Zeit keine entsprechenden Forschungsarbeiten durchgeführt wurden, obwohl es dafür einen aktuellen Bedarf gibt, hat die Autoren dieser Studie motiviert, eine Reihe von Fahrstreifenwechselmanöver mit einem Messmotorrad durchzuführen, messtechnisch zu erfassen und auszuwerten.

2. Das Mess-Motorrad

Für diese Studie stand ein in den letzten Jahren aufgebautes Messmotorrad zur Verfügung, welches schon in anderen Forschungsprojekten zum Einsatz kam [10]. Es handelt sich um eine KTM 1290 Super Adventure mit regulärer Straßenzulassung, sodass Fahrten im öffentlichen Verkehr möglich sind. Das Modell ist schon werksseitig mit zahlreichen Sensoren ausgestattet, die von den Fahrerassistenzsystemen (kombiniertes ABS, Traktionskontrolle, Stabilitätskontrolle, Tempomat) benötigt und verwendet werden. Die für diese Funktionen benötigten On-Board-Sensoren umfassen Raddrehzahlsensoren, eine 5-Achsen-Trägheitsmesseinheit (IMU), einen Drosselklappenstellungssensor und vieles mehr. Alle Sensoren kommunizieren über einen CAN-Bus.

Trotz der umfangreichen On-board-Sensorik des serienmäßigen Modells, wurden zusätzliche Messaufnehmer hinzugefügt. Wichtige Ergänzungen waren die Positionsmessung mittels GPS-Antennen und –Empfängers, sowie ein Lenkwinkelsensor der am Vorderradsystem angebracht war. Außerdem wurden zwei Auslöseschalter an den beiden Griffen am Lenker installiert, um den zeitlichen Beginn einer Lenkaktion durch den Fahrer genau zu erfassen. Zusätzliche vollständige 6-Achsen-IMUs wurden aus Qualitätsgründen und aus Gründen der Redundanz eingebaut. Eine CAN-Bus-Schnittstelle ermöglichte den Zugriff auf die Fahrzeugsensoren. Mittels zweier unabhängiger und leistungsstarker Datenlogger wurden die zahlreichen Messsignale aufgezeichnet.

Bild 2: Messfahrzeug KTM 1290 Super Adventure mit zusätzlich eingebauten Messsystemen, siehe [10].

Um auch Video-Aufzeichnungen der Fahrmanöver zu ermöglichen, wurde zwei Video-Cams relativ niedrig links und rechts an den Schutzbügeln montiert. Diese beiden Kameras waren in Fahrtrichtung ausgerichtet und zeigten die Fahrbahn links bzw. rechts des ebenfalls gefilmten Vorderrades, siehe Bild 3. Diese Video-Aufzeichnungen waren sehr wichtig für die Beurteilung des erreichten Fahrspurversatzes, da eine genaue Messung der Seitenposition nicht möglich war. Die GPS-Signale lieferten zwar recht gute Ergebnisse, jedoch war die Positionsgenauigkeit nicht gleichbleibend hoch. Die Verwendung von D-GPS war nicht möglich, da die Messfahrten im öffentlichen Verkehr, insbesondere auch auf Autobahnen erfolgte und daher die Entfernung zu der dabei erforderlichen Basisstation viel zu groß geworden wäre. Das Problem der Messung des Spurwechselversatzes wurde jedoch durch die Beschränkung auf nur zwei verschiedene Versatzabstände überwunden und wird im nächsten Abschnitt erläutert.

Bild 3: Screenshot des Video-Auswerteprogramms mit gleichzeitiger Darstellung der beiden Kamera-Aufnahmen. Weitere Funktionen des Tools erlauben auch die gleichzeitige Ausgabe von Messgrößen.

3. Das Versuchs-Setup

Ein Ziel dieser Studie war es, Fahrstreifenwechsel bei konstanter Geschwindigkeit in einem großen Geschwindigkeitsbereich zu erfassen. Für Geschwindigkeiten bis zu 50 km/h wäre eine geeignete nicht-öffentliche Teststrecke verfügbar gewesen, jedoch nicht für Geschwindigkeiten von 100 km/h oder mehr. Daher wurden anders als in [4] alle Versuche im regulären Verkehr durchgeführt. Für Tests mit niedriger Geschwindigkeit wurden Tage mit schwachem Verkehr und Straßenabschnitte am Stadtrand von Wien ausgewählt. Die Hochgeschwindigkeitstests wurden auf einer Autobahn mit einer Geschwindigkeitsbegrenzung von 130 km/h durchgeführt, siehe die Luftaufnahme eines Abschnitts dieser Autobahn in Bild 4. Bisher lag die maximale Testgeschwindigkeit im Bereich von 120 km/h. Das Testen auf einer Autobahn war etwas schwierig, da der andere Verkehr natürlich nicht gestört werden durfte und der Fahrer auf Situationen warten musste, in denen sich keine anderen Fahrzeuge dem Motorrad von hinten näherten.

Ein generelles Problem bei solchen Versuchsfahrten ist die Messung des Spurversatzes. Dieses Problem wurde umgangen, indem die regulär aufgebrachten Fahrbahnmarkierungen (Leitlinien) auf den Straßen verwendet werden, und die z.B. auf Autobahnen 3,5 m voneinander entfernt waren. Die Testfahrer mussten genau auf einer markierten Linie fahren und dann auf die nächste Linie links oder rechts wechseln. Da der Abstand der Leitlinien direkt gemessen werden konnte, lieferte dieses Verfahren in Verbindung mit der Kontrollmöglichkeit durch die Video-Aufzeichnung einen exakt bekannten seitlichen Versatz der Fahrlinien bei den Versuchen. Auch halbe Spurwechsel wurden durchgeführt. In diesem Fall musste der Fahrer zwar von der nicht markierten Mittellinie eines Fahrstreifens zur nächsten markierten Linie wechseln, was aber für die Versuchsfahrer kein Problem war.

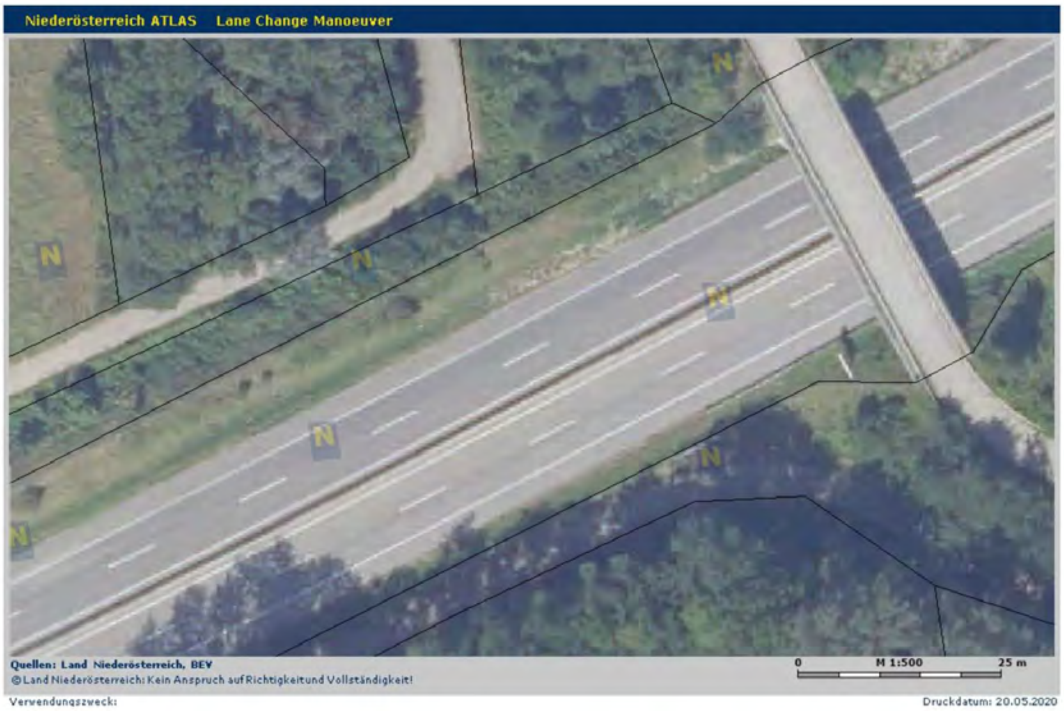

Bild 4: Streckenabschnitt auf einer Schnellstraße in Niederösterreich/Austria, welche bei den Fahrversuchen benutzt wurde.

Bei einem Teil der Versuchsfahrten wurden auch Reaktionstests durchgeführt. Dazu fuhr ein PKW in einem Sicherheitsabstand vor dem Motorrad und signalisierte dem nachfolgenden Motorradfahrer durch das Einschalten einer Signallampe (Warnblinkanlage) die Aufforderung zu einem Fahrstreifenwechsel. Die aufleuchtende Lampe war auf den zeitsynchron mitlaufenden Aufzeichnungen der On-Board-Videokameras zu sehen. Der Beginn der Fahrerreaktion wurde durch die Betätigung der Minischalter an den beiden Lenkergriffen aufgezeichnet. Dadurch konnte der zeitliche Ablauf der Fahrstreifenwechsel ab dem Zeitpunkt einer Reaktionsaufforderung präzise erfasst und aufgezeichnet werden.

Die Spurwechsel- sowie die Reaktionszeitversuche in dieser Studie wurden von nur zwei Fahrern durchgeführt. Diese werden in weiterer Folge mit „HE“ bzw. „SL“ bezeichnet werden. Fahrer HE ist ein 63 Jahre alter Motorradfahrer mit Erfahrung und Fahrpraxis mit Motorrädern bis über 1000 cm³ Hubraum. Sein Fahrverhalten ist als sehr aufmerksam und mit großen Sicherheitsreserven zu beschreiben. Fahrer SL ist 27 Jahre alt. Seine Erfahrung reicht bis hin zu Motorrädern mit über 1000 cm³ Hubraum im Straßenverkehr und auf der Rennstrecke. Das Fahrverhalten von SL ist sportlich, mit größerer Risikobereitschaft und einer Vorliebe für schnelles Fahren. An dieser Stelle ist anzumerken, dass keiner der beiden Fahrer während der Versuche auch nur in die Nähe der Grenzen seiner fahrerischen Fähigkeiten gekommen ist.

4. Das Datenmaterial

Im Folgenden wird ein kurzer Überblick über das Messprogramm und den Umfang der Messdaten gegeben. Insgesamt wurden 167 Fahrstreifenwechsel durchgeführt und aufgezeichnet. Die Anzahl der innerstädtischen Tests bei niedrigen Geschwindigkeiten (<60 km/h) betrug 110, die anderen 57 Tests wurden auf Autobahnen bei höheren Geschwindigkeiten durchgeführt. Die Anzahl der Fahrstreifenwechsel mit voller Breite betrug 120 und die der halbbreiten Spurwechsel betrug 43. Einige Manöver sind misslungen und wurden daher von der Studie ausgeschlossen.

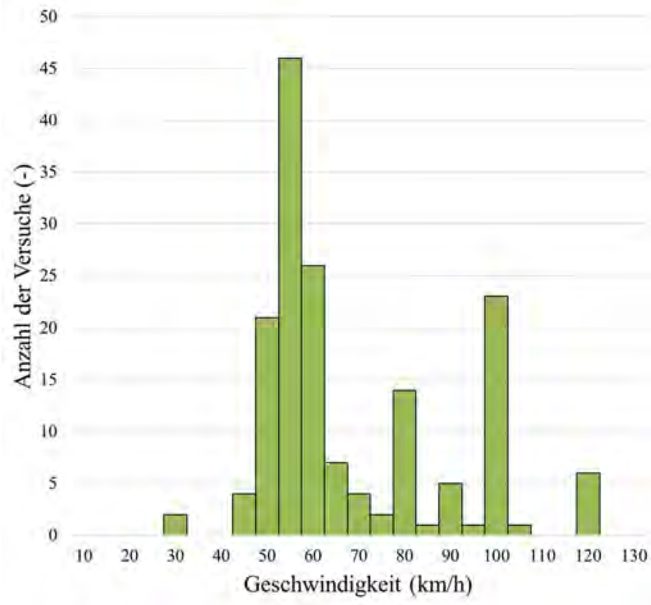

Bild 5: Häufigkeitsverteilung der gefahrenen Geschwindigkeiten

Das Bild 5 zeigt eine Häufigkeitsverteilung der bei den Manövern gefahrenen Geschwindigkeiten. Die meisten Manöver wurden zwischen 45 und 55 km/h durchgeführt. Die Höchstgeschwindigkeit betrug 118 km/h, die Mindestgeschwindigkeit 26 km/h mit einem Durchschnitt von 67 km/h. Es können mehrere Maxima in der Häufigkeitsverteilung erkannt werden und diese können den verschiedenen Testorten zugeordnet werden. Aufgrund der Geschwindigkeitsbegrenzung innerhalb der Stadtgrenzen von 50 km/h gibt es ein Maximum im Bereich dieser Geschwindigkeit. Außerhalb der Stadtgrenzen konnten die Fahrversuche bei höheren Geschwindigkeiten durchgeführt werden, was einen weiteren Spitzenwert bei 80 km/h erklärt.

Auf der Autobahn wurden überwiegend 100 km/h als Testgeschwindigkeit und bei einigen Versuchen auch 120 km/h verwendet. Insbesondere bei den Hochgeschwindigkeitstests stellte sich heraus, dass die Tempomat-Funktion des Motorrads extrem nützlich war. Der Fahrer konnte die Fahrgeschwindigkeit einstellen und musste sich nicht mehr auf das Gas konzentrieren, sondern konnte den Verkehr dahinter beobachten und auf die Ausführung des Spurwechselmanövers achten. Daher war es möglich, etliche Tests mit nahezu exakt der gleichen Geschwindigkeit zu absolvieren.

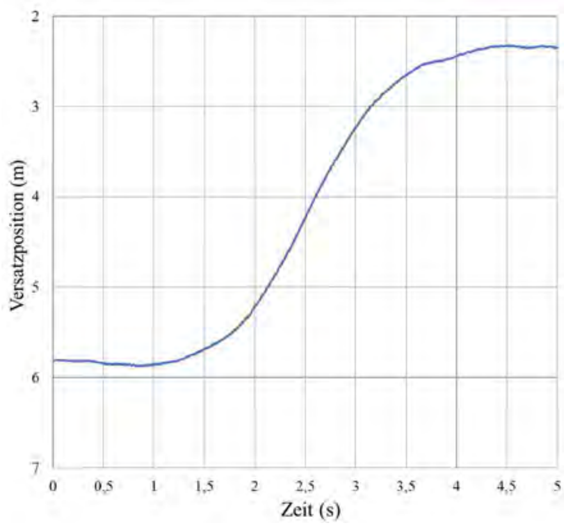

Bild 6: Seitlicher Versatz bei einem Fahrstreifenwechsel (ca. 3,5m nach links) mit ca. 52 km/h gefahren.

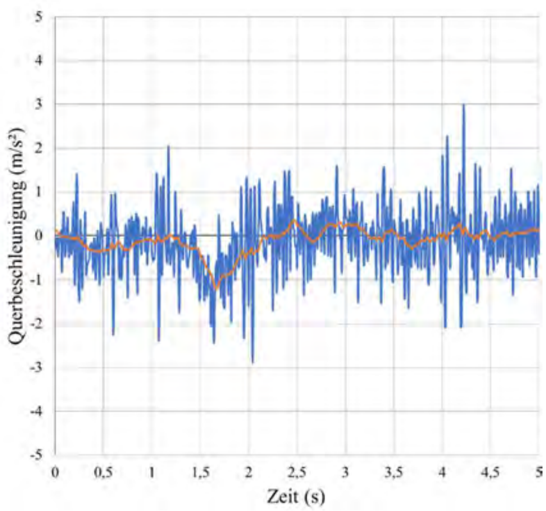

Bild 7: Gemessene Querbeschleunigung (positiv nach links) zu dem Manöver wie in Bild 6 gezeigt.

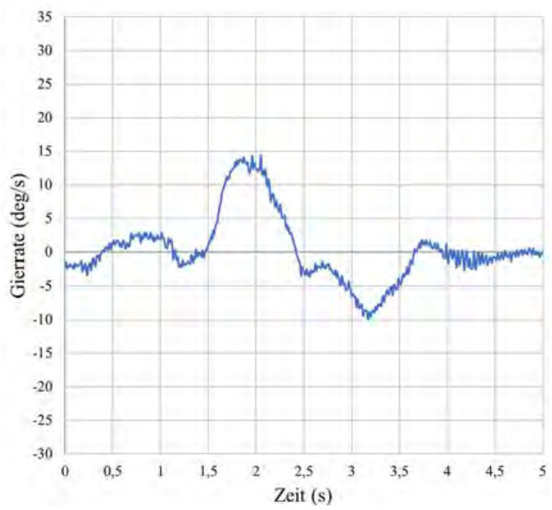

Bild 8: Gierwinkelgeschwindigkeit um die z-Achse (zeigt nach oben) zu dem Manöver in Bild 6..

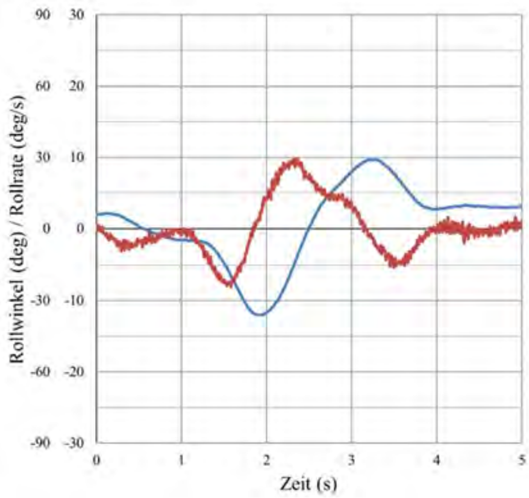

Bild 9: Rollwinkel (blau) und Rollwinkelgeschwindigkeit um die x-Achse (zeigt nach vorne) zu dem Manöver in Bild 6.

Die Diagramme in den Bildern 6-9 zeigen typische zeitliche Verläufe von verschiedenen Messgrößen, welche im Zusammenhang mit dem Fahrstreifenwechsel von Interesse sind. Mit Ausnahme von Bild 6 sind hier die Rohdaten dargestellt, gemessen im Fahrzeugbezugsystem ohne Signalbearbeitung und ohne Koordinatentransformation in das Inertialsystem. Das Bild 6 zeigt den seitlichen Versatz als Zeitfunktion eines Fahrstreifenwechsels nach links mit einer Breite von ca. 3,5m. Die dabei gefahrene Geschwindigkeit ist 52 km/h. Dieser Verlauf konnte direkt aus den GPS-Positionen errechnet werden. In der Regel war die relative Genauigkeit der gewöhnlichen GPS-Daten ausreichend, um die Bahntrajektorie lokal ausreichend genau zu bestimmen. Das Querbeschleunigungssignal (siehe Bild 7) alleine eignet sich nur in Verbindung mit einer rechnerischen Verarbeitung der anderen Beschleunigungs- und Drehratensignale der IMUs zur Bestimmung des Spurversatzes. Dies deshalb, weil alle Bewegungsgrößen im fahrzeugfesten System gemessen werden und nicht im Inertialsystem. Außerdem ist die Querbeschleunigung, wie Bild 7 zeigt, nicht unmittelbar anschaulich mit dem Manöver zu korrelieren und ist auch von geringerer Aussagekraft als die Drehbewegungen um die Gier- und die Rollachse des fahrzeugfesten Koordinatensystems.

Das Diagramm in Bild 8 zeigt die Gierwinkelgeschwindigkeit (Gierrate) im körperfesten Koordinatensystem, wobei die positive z-Achse nach oben zeigt. Im Bild 9 sind die Rollwinkelgeschwindigkeit (Rollrate) und der Rollwinkel dargestellt, bezogen auf die positive x-Achse, welche in die Fahrtrichtung zeigt. Alle zeitlichen Verläufe der Bilder 6-9 zeigen einen Fahrstreifenwechsel von ca. 3,5 Meter Breite bei einer Geschwindigkeit von 52 km/h. Wie die „idealen" Zeitfunktionen dieser fahrdynamischen Größen aussehen würden, wird als bekannt vorausgesetzt, bzw. ist in der Fachliteratur (z.B. [11] oder [Sharp]) ausführlich dokumentiert. An dieser Stelle sollen mehr die Abweichungen und Imperfektionen kurz diskutiert werden, da sie für die spätere Datenanalyse von Bedeutung sind.

Der Zeitverlauf des Seitenversatzes (Bild 6) ist entspricht weitestgehend dem zu erwartenden sinusförmigen Verlauf. Auch das aus der Theorie bekannte kurze Ausweichen in die Gegenrichtung zu Beginn konnte messtechnisch immer wieder bestätigt werden. Das Ausleiten des Fahrstreifenwechsels ist mit kleinen seitlichen Schwankungen verbunden, welche auf Lenkkorrekturen des Fahrers beim Einfahren in die neue Fahrlinie zurückzuführen sind. Das

Lenk- und Regelverhalten des Fahrers wird sich in anderen Signalen noch wesentlich deutlicher zeigen.

Das Zeitsignal der Querbeschleunigung (Bild 9) ist deutlich verrauschter (blaue Linie) und muss daher geglättet werden (rote Linie). Das Betrags-Maximum dieses Signals tritt als negative Größe etwa zum Zeitpunkt 1,6s auf. Das bedeutet eine kurze Phase einer Querbeschleunigung in Richtung gegen den Fahrstreifenwechsel nach links und lässt sich daher mit der Bewegung „im Großen“ nicht vereinbaren. Die Erklärung findet sich darin, dass bei realen Fahrversuchen laufend Störungen auf Fahrzeug und Fahrer einwirken und daher kleinere und größere Lenkkorrekturen laufend stattfinden, die sich insbesondere in den Beschleunigungssignalen bemerkbar machen.

Das Diagramm in Bild 8 zeigt die Gierrate des Manövers und lässt auch die etwas unruhige Phase am Beginn des Spurwechsels erkennen, weil zwischen Sekunde 1,2 -1,5 eine Richtungsänderung nach rechts stattfindet, bevor dann die Gierrate positive Werte bis knapp 15 Grad/s erreicht, entsprechend dem Schwenk nach links. Die markantesten Signale sind jedoch die Rollwinkelgeschwindigkeit und der Rollwinkel. Beide Zeitverläufe sind gemeinsam im Bild 9 dargestellt. Die rot gezeichnete Rollrate erreicht nach anfänglichen negativen Werten bei Sekunde 1 wieder beinahe einen Nullwert und demgemäß verflacht auch der blau dargestellte Rollwinkelverlauf. Im weiteren zeitlichen Verlauf nehmen aber die negativen Werte für beide Signale zu, wie es auch einer Schräglage nach links entspricht. Der Rollwinkel erreicht einen Maximalwert von -32 Grad, beim anschließenden Aufrichten und nach rechts Neigen wird ein Maximalwert von 30 Grad Schräglage erreicht. Anhand des Signals der zeitlichen Änderung der Neigung, also der Rollrate, welche dem Winkelsignal vorauseilt, sind die kleinen Fahrerkorrekturen und Störungen des Ablaufes wie üblich deutlicher zu erkennen.

Zur Auswertung und Beurteilung der Fahrmanövers wurden alle benötigten dynamischen Größen erfasst, jedoch mit einer Ausnahme, nämlich dem Lenkmoment. Über das Lenkmoment könnte die Fahreraktion, also die vom Fahrer eingeleiteten Kräfte und Momente gut erfasst werden, es kann jedoch nicht an dem Messfahrzeug gemessen werden. Da es jedoch von entscheidender Bedeutung ist, ob ein Fahrer das Manöver langsam, zügig oder aggressiv fährt, wurde der Intensitäts-Parameter eingeführt. Durch einen Zahlenwert zwischen 0 und 10 soll zum Ausdruck kommen wie „ambitioniert / sportlich / ehrgeizig“ ein Fahrer den Fahrstreifenwechsel ausführt. Die Definition dieses neuartigen Dynamik-Parameters wird im folgenden Abschnitt erklärt.

5. Die primäre Auswertung der Messsignale

Für die Datenanalyse der Spurwechselmanöver standen primär die sechs konsolidierten dynamischen Zustände der am Hauptrahmen installierten IMUs zur Verfügung: Längsbeschleunigungen und Winkelgeschwindigkeiten in und um die drei Koordinatenachsen, sowie davon abgeleiteten Variablen Längsgeschwindigkeiten und Drehwinkel. Zusätzlich zu diesen Signalen konnten GPS-Koordinaten, Lenkwinkel und Radgeschwindigkeiten analysiert werden. In einem ersten Schritt der Datenanalyse wurden alle relevanten Signale qualitativ analysiert, um nach den aussagekräftigsten zu suchen. Wie schon im vorangegangenen Kapitel angedeutet, zeigte sich, dass das Spurwechselmanöver durch das Signal um die Rollachse, dh.

die Rollrate und davon abgeleitet den Rollwinkel ausreichend beschrieben wird. Andere Signale wie Gierrate und Gierwinkel können als Ergänzung verwendet werden. Da der seitliche Versatz der Manöver durch das Testdesign festgelegt wurde, war es in dieser Studie nicht erforderlich, die seitliche Position zu berechnen.

Zu Beginn der Auswertungen bestand noch die Vermutung, dass auch die Fahrgeschwindigkeit einen wesentlichen Einfluss auf die Ausführung des Manövers haben würde. Ein solcher Einfluss stellte sich jedoch als so gering heraus, dass er am Ende nicht berücksichtigt wurde.

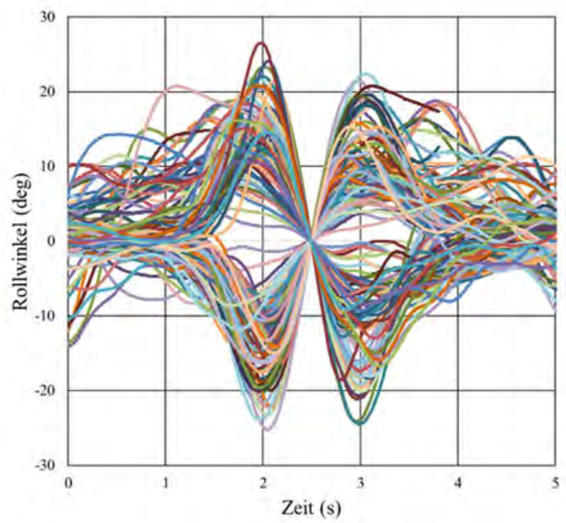

Bild 10: Zeitverlauf aller Rollwinkelverläufe, synchronisiert mit dem Vorzeichenwechsel.

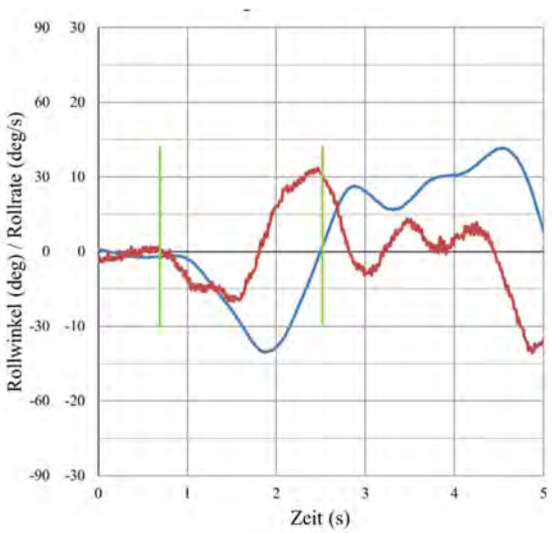

Bild 11: Definition der halben Manöverdauer über Nullstellen der Rollrate (Beginn) und des Rollwinkels (Ende).

Die Datenanalyse basiert daher primär auf den Zeitreihen des Rollwinkels und der Rollrate. Jeder Datensatz eines Tests wurde auf charakteristische Merkmale gescannt. Die wichtigsten Ereignisse waren der Nulldurchgang des Rollwinkels und die Maxima der Rollrate. Für die nicht skalierte (rohe) Zeitreihe wurde eine Zeitverschiebung durchgeführt, so dass der erste Nulldurchgang des Rollwinkels (im Verlauf des Manövers) auf den Zeitpunkt Null gesetzt wurde. Alle anderen Signale wurden ebenfalls entsprechend synchronisiert.

Dieses Verfahren wurde auf alle gültigen Zeitreihen angewendet. Dadurch konnten die Zeitreihen überlagert dargestellt werden. Das Bild 10 zeigt den synchronisierten Rollwinkelverlauf aller Messungen. In dieser Darstellung ist sehr gut zu sehen, dass alle Verläufe eine weitgehend ähnliche Form haben und dass sich die Dauer der Manöver nicht wesentlich unterscheidet, zumindest wenn man den ersten Peak des Verlaufes betrachtet.

Die für ein Spurwechselmanöver charakteristische Zeitdauer wurde nach folgendem Verfahren berechnet. Da der Beginn der Zunahme des Rollwinkels eher schwer zu erkennen ist, wurde stattdessen die Zunahme der Rollrate als Indikator für den Beginn des Manövers verwendet. Als nächstes wurde der Nulldurchgang des Rollwinkels gesucht und lokalisiert. Mit der Zeitspanne zwischen diesen beiden Ereignissen wurde die Dauer des halben Spurwechsels definiert, siehe Bild 11. Da der „Auslauf“ eines Spurwechselmanövers häufig untypisch ist und weniger charakteristisch, finden sich meist keine signifikanten Ereignisse, welche das Ende definieren. Deshalb wurde die Dauer des halben Spurwechsels verdoppelt und als Spurwechselmanöverzeit definiert. Dies ist natürlich eine idealisierte Dauer und definiert die Untergrenze der Zeitspanne, die ein Spurwechselmanöver benötigen kann. Obwohl Bild 10 alle ausgewerteten Fälle zeigt (alle Geschwindigkeiten, alle Fahrer) und daher etwas überladen ist, kann man immer noch sehen, dass die Spurwechselzeit nicht stark variiert, besonders wenn man die „lehrbuchmäßig" gefahrenen Versuche hernimmt. Im nächsten Kapitel wird darauf noch näher eingegangen.

Es ist daher die Dauer des Manövers auch nicht charakteristisch dafür, ob ein Spurwechsel „langsam / durchschnittlich / sportlich" oder gar „aggressiv" ausgeführt wurde. Für die weitere Analyse und die Entwicklung von Fahrermodellen wird jedoch ein Parameter benötigt, der diesen menschlichen Faktor beschreibt. Wie schon erwähnt, wäre vermutlich das vom Fahrer auf den Lenker ausgeübte Lenkmoment der beste mechanische Parameter, um diesen Parameter des Fahrmanövers zu quantifizieren, aber leider war kein Sensor installiert, um das Lenkmoment zu messen. Daher muss ein charakteristischer Parameter aus anderen Größen abgeleitet werden.

Wie bereits weiter oben erwähnt, wird ein neuer Parameter mit der Bezeichnung „Intensität (des Spurwechselmanövers)" eingeführt. Die Definition basiert auf einem rein heuristischen Ansatz. Da ein sehr „intensives" Manöver zu hohen Maximalwerten des Rollwinkels und der Rollrate führt, war es naheliegend, die Definition auf diese beiden Messgrößen zu stützen. Nach dem Ausprobieren mehrerer Ansätze wurde mittels Datenregression eine Definition für den Parameter „Intensität" in Abhängigkeit des Rollwinkels ϕ (Grad) gefunden:

$$I = 5\frac{\sqrt{\phi}}{\sqrt{13}} \quad (dim. los)$$

Das Intensitätsniveau ist für Rollwinkel im Intervall [0° … 52°] definiert und die dimensionslose Ausgabe in diesem Intervall ist [0 … 10]. Die Formel gibt für den Durchschnittswert des gemessenen maximalen Rollwinkels ϕ= 13° einen Intensitätswert von 5 an. Es wird sich später zeigen, dass bei den Testfahrten der Rollwinkel meist im Bereich von 5° bis 26° lag. Die entsprechende Intensität variiert zwischen 3,1 und 7,1. Die degressiv ansteigende Funktion sollte eine angemessene Darstellung der „Ambition" des Fahrers bei der Durchführung eines solchen Spurwechselmanövers sein. Darüber hinaus ist die Skala von 0 bis 10 sehr praktisch. Selbstverständlich handelt es sich hier um einen rein heuristischen Ansatz und man kann auch versuchen, andere Formeln zu finden, die z.B. auch die Rollrate oder andere Messgrößen einbezieht. Wollte man diesen Intensitätsparameter stärker mit dem Lenkmoment in Verbindung bringen, dann wäre es jedenfalls notwendig auch die Fahrgeschwindigkeit einfließen zu lassen, da ja die Kreiselmomente von der Winkelgeschwindigkeit der Räder abhängen.

Um einen besseren Eindruck vom Verlauf des Rollwinkels und der Rollrate zu vermitteln, werden typische Beispiele für Manöver mit unterschiedlicher Geschwindigkeit und unterschiedlich ambitioniert ausgeführtem Spurwechsel gezeigt. Das Bild 12 zeigt die Zeitreihen der Rollrate und des Rollwinkels eines Spurwechselmanövers mit einer relativ hohen Intensität (I=7,1). Der maximale Rollwinkel erreicht 26,5 Grad und die Rollrate beträgt 76 Grad/s. Die Dauer des Spurwechsels beträgt ca. 3 Sekunden. Die Form beider Funktionen ist charakteristisch für ein Spurwechselmanöver, wie es in dieser Versuchsreihe ausgeführt wurde.

Anfangs nehmen Rollwinkel und Rollrate schnell zu. Natürlich folgt der Winkelverlauf dem Verlauf der Winkelgeschwindigkeit mit einer Zeitverzögerung. Wenn das erste Einlenken des Manövers stattgefunden hat, werden beide Signale negativ und erreichen aufgrund der erforderlichen Gegenlenkung eine zweite Spitze. Der folgende letzte Abschnitt der Signale zeigt häufig einen schwingungsähnlichen Verlauf. In diesem Beispiel ist dieses Phänomen weniger ausgeprägt, der Fahrer erreicht ziemlich schnell den Endzustand des Manövers und fährt geradeaus und aufrecht weiter.

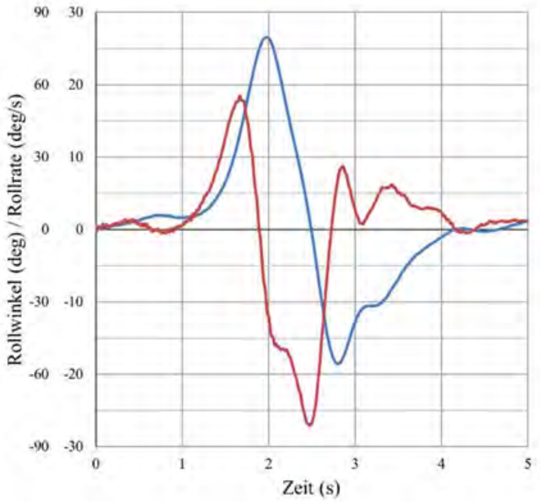

Bild 12: Rollwinkel (blau) und Rollrate (rot) eines Fahrstreifenwechsels nach rechts mit hoher Intensität (I=7,1) bei 79 km/h

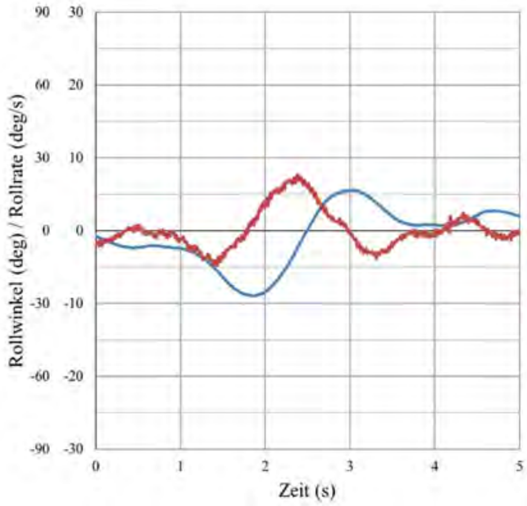

Bild 13: Rollwinkel (blau) und Rollrate (rot) eines Fahrstreifenwechsels nach links mit geringer Intensität (I=4,4) bei 58 km/h

Im Gegensatz dazu zeigt Bild 13 einen Spurwechsel niedriger Intensität (I=4,4). Der maximale Rollwinkel beträgt weniger als 10°, die maximal erreichte Rollrate liegt unter 30°/s. Die Dauer dieses Spurwechsels ist zwar etwas, aber nicht wesentlich länger als im vorangegangenen Versuch. Dieses Beispiel zeigt außerdem recht gut, dass das Ende und manchmal auch der Anfang eines Manövers nicht immer klar definiert ist. Es ist auch anzumerken, dass in beiden Beispielen die erste Spitze des Rollwinkels, aber die zweite Spitze der Rollrate die Höchste ist.

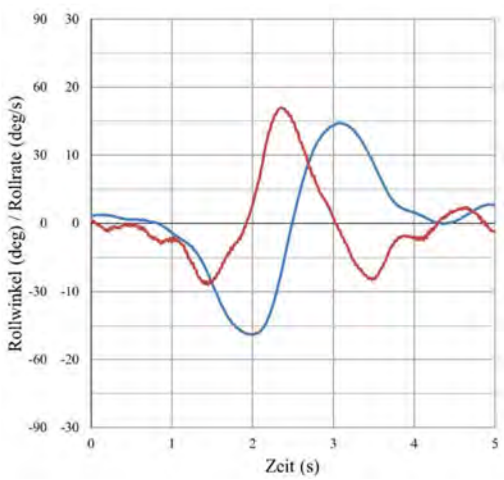

Bild 14: Rollwinkel (blau) und Rollrate (rot) eines Fahrstreifenwechsels nach links mit 97 km/h

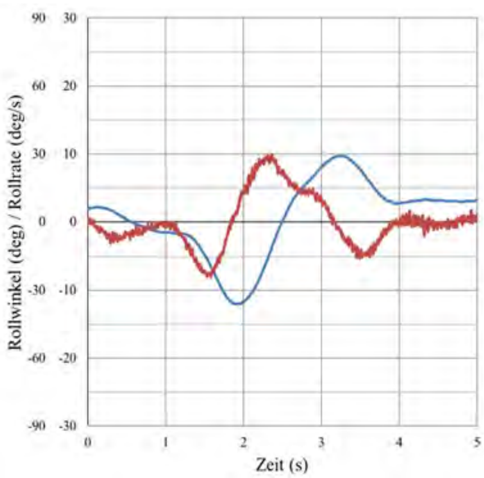

Bild 15: Rollwinkel (blau) und Rollrate (rot) eines Fahrstreifenwechsels nach links mit 52 km/h

Um den Geschwindigkeitseinfluss noch näher zu beleuchten, zeigen die Bilder 14 und 15 je einen gefahrenen Fahrstreifenwechsel mit hoher Geschwindigkeit (97 km/h) und einen mit niedriger Geschwindigkeit (52 km/h). Das langsamer gefahrene Manöver wurde mit fast der Hälfte der Geschwindigkeit ausgeführt, und zwar vom selben Fahrer und mit der gleichen subjektiven Einstellung wie beim vorherigen Test. Die errechneten Intensitätswerte sind trotzdem etwas verschieden, mit I=5,5 (bei 97km/h) und I=4,8 (bei 52km/h), was aber angesichts der unpräzisen subjektiven „Skala" nicht verwundert. Das interessanteste Ergebnis dieser Tests bei den beiden stark unterschiedlichen Geschwindigkeiten ist die Dauer des Manövers. Man kann leicht erkennen, dass beide Tests fast dieselbe Zeit dauern, nämlich ungefähr 3 Sekunden. Der Vollständigkeit halber muss erwähnt werden, dass alle bisher gezeigten Versuche vollständige Fahrstreifenwechsel mit einem Spurbreitenversatz von 3,5 Metern waren.

6. Die statistische Auswertung

Wie in Abschnitt 4 erwähnt, basiert diese Studie auf Messungen von nur zwei Fahrern mit signifikant unterschiedlichem Alter und Fahrerfahrung. Daher ist es durchaus von Interesse, wie unterschiedlich sich diese beiden Fahrer in den Tests verhalten haben. Bild 16 zeigt ein Histogramm der maximalen Rollwinkel, die bei Tests mit niedriger Geschwindigkeit im Bereich von 50 km/h gemessen wurden. Man erkennt eine Zwei-Peak-Verteilung mit Häufungen bei 10-12° und bei 18-20°. Die Farben des Histogramms zeigen, dass der Peak bei niedrigeren Winkeln mit dem Fahrer HE und der andere mit dem Fahrer SL verbunden ist. In der Tat war Fahrer SL in diesen Tests hochmotiviert, und seine Leistung zeigt das obere Ende des Bereichs, während Fahrer HE versuchte, sich wie ein Alltagsfahrer zu verhalten. Da diese Tests bei niedrigen Geschwindigkeiten durchgeführt wurden, kann diese Auswertung eine gute Vorstellung von den maximalen Neigungswinkeln geben, die beim Fahren in einer städtischen Umgebung zu erwarten sind.

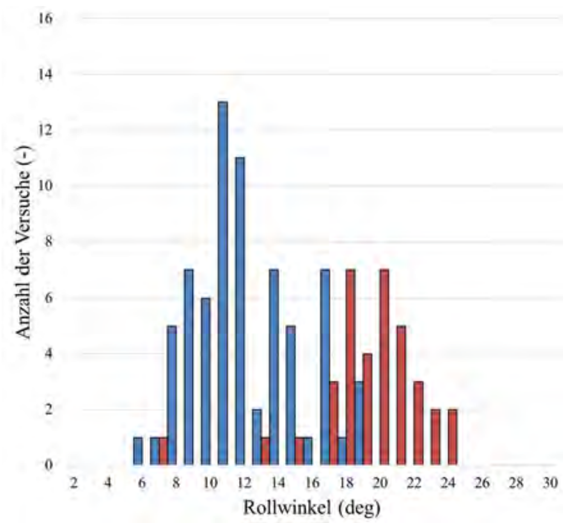

Bild 16: Häufigkeitsverteilung der erreichten maximalen Rollwinkel bei ca. 50km/h. Fahrer: Blau-HE, Rot-SL

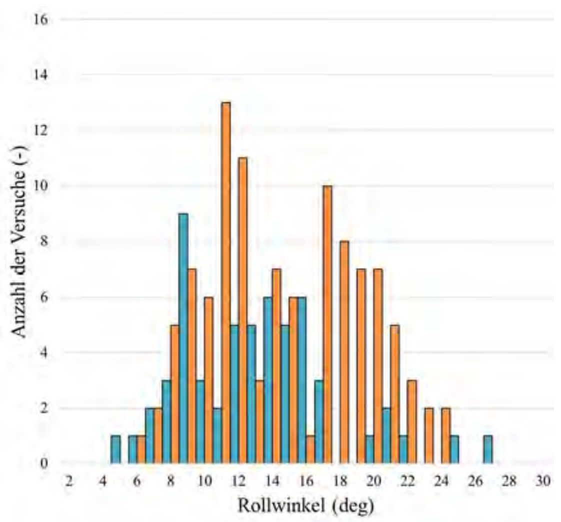

Bild 17: Häufigkeitsverteilung aller erreichten maximalen Rollwinkel. Geschwindigkeit: Gelb < 60km/h, Blau > 70km/h

Das Histogramm in Bild 17 kombiniert gemessene maximale Rollwinkel bei niedrigen Geschwindigkeiten (<60 km / h) und hohen Geschwindigkeiten (> 70 km / h) für beide Fahrer. Die Verteilung bei niedriger Geschwindigkeit (gelb) wiederholt die Ergebnisse von Bild 16 mit der Doppelspitze, die von den zwei verschiedenen Fahrern verursacht wurde. Die Hochgeschwindigkeitsverteilung wurde nur vom Fahrer HE erfasst und hat eine breite Verteilung zwischen 12 und 17 Grad und einen kleinen Peak nahe 9 Grad. Eine gründliche Datenanalyse ergab, dass diese Häufung hauptsächlich durch halbe Spurwechsel verursacht wird. Es ist naheliegend, dass für einen halben Spurwechsel die Fahrzeugneigung zur Seite früher gestoppt werden muss als für den vollen Fahrstreifenwechsel und daher kleiner ausfällt.

Eine ausführlichere Analyse wie und wo sich der Fahrereinfluss in den Messwerten bemerkbar macht findet man in [8] und [9].

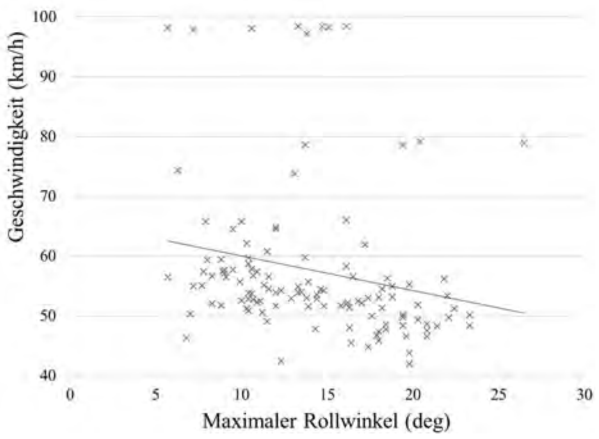

Bild 18: Streudiagramm für Fahrgeschwindigkeit und maximalem Rollwinkel

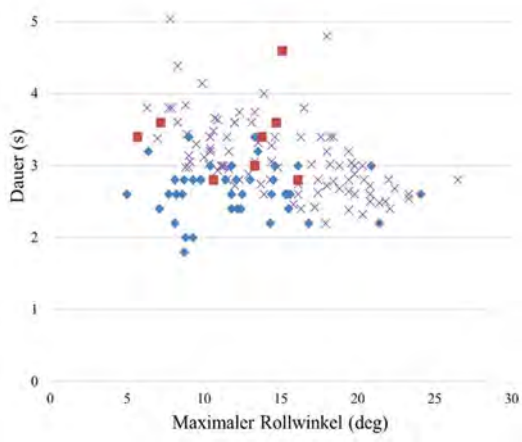

Bild 19: Streudiagramm für die Manöverdauer und den maximalen Rollwinkel. Rot: > 90km/h, Blau: halbe Breite

Ein möglicher Zusammenhang zwischen der Fahrgeschwindigkeit und den maximal gefahrenen Rollwinkeln wird anhand von Bild 18 untersucht. Diese Abbildung zeigt ein Streudiagramm, das Markierungen für jeden auswertbaren Versuch zeigt. Die meisten hochwertigen Manöver wurden mit 50-60 km/h durchgeführt. Es wurden zwar insgesamt mehr Hochgeschwindigkeits-Spurwechselmanöver gefahren, aber eine große Zahl davon waren halber Fahrstreifenwechsel. Diese wurden ausgeschlossen, um sie nicht mit den ganzen Spurwechseltests zu vermischen. Es wurden auch nur „saubere“ Versuche aufgenommen, um „Datenrauschen“ durch weniger gute Ergebnisse zu vermeiden. In Zukunft wird eine alternative Methode zur Datenauswertung verwendet werden müssen, um auch solch unpräzise gefahrenen Versuche auswerten zu können.

Für die Datenwolke wurde eine Trendlinie mit der Methode der kleinsten Quadrate berechnet und eingezeichnet. Diese bestätigt den auch visuell erkennbaren Trend zu kleineren Rollwinkeln bei höheren Geschwindigkeiten. Allerdings ist dieser Trend nicht sonderlich ausgeprägt. Nur die wenigen gelungenen Messungen bei knapp 100 km/h für sich genommen zeigen einen niedrigeren mittleren maximalen Rollwinkel von ca. 17 Grad im Vergleich zu niedrigeren Geschwindigkeiten.

Das wahrscheinlich interessanteste Ergebnis der statistischen Analyse ergab die Suche nach einer vermuteten Korrelation zwischen der Dauer eines Spurwechsels und dem maximalen Rollwinkel. Das Streudiagramm in Bild 19 enthält vollständige Spurwechsel (X) und auch halbbreite Spurwechsel (◊). Die Hochgeschwindigkeitsversuche (v> 90km/h) aus Bild 18 sind ebenfalls eingezeichnet und rot markiert (□). Wenn man nur die vollen Fahrstreifenwechsel analysiert, dann kann ein eher schwacher Trend erkannt werden, nämlich eine Zunahme mit abnehmendem Rollwinkel. Von wenigen Ausreißern abgesehen liegt die Fahrstreifenwechseldauer im Bereich von 2-4 Sekunden mit einem gut abgesicherten Mittelwert bei ca. 3 Sekunden. Wesentlich ist, dass dieser Wert sich auf den idealisierten und bis zum Ende betrachteten Fahrstreifenwechsel bezieht, so wie in Abschnitt 4 erläutert. Die eher wenigen Messungen mit hoher Geschwindigkeit (rote Quadrate) liegen im oberen Bereich dieses Intervalls, nur ein Wert fällt nach oben hinaus.

Es ist zwar plausibel, dass ein aggressiv gefahrener Spurwechsel in kürzerer Zeit durchgeführt werden kann, nach den vorliegenden Messungen ist der Zeitgewinn jedoch geringer als zunächst vermutet wurde. Fast alle Spurwechsel wurden innerhalb von 2-4 Sekunden abgeschlossen. Auch die Hochgeschwindigkeitsergebnisse sind relativ gleichmäßig in der Wolke der Messpunkteverteilt. Betreffend eine tiefergehende Analyse dieser Abhängigkeit wird auf [8] und [9] verwiesen.

Die blauen Datenpunkte in Bild 19 sind die Ergebnisse für die Fahrstreifenwechsel mit halber Breite. Diese Ergebnisse bilden eine lokale Gruppe, die überwiegend zwischen 2 und 3 Sekunden liegt, was darauf hinweist, dass der Spurversatz erwartungsgemäß einen Einfluss auf dieses Ergebnis hat.

7. Ein mathematisches Modell des Manövers

Eines der Ziele dieser Studie war es, mathematische Funktionen abzuleiten, um charakteristische Parameter eines Spurwechselmanövers zu beschreiben. In [8] wurden Regressionsmodelle verwendet, um analytische Ausdrücke für die Spurwechseldauer, die maximale Rollrate und schließlich die Zeitfunktionen von Rollwinkel und Rollrate zu finden.

Dabei wurden verschiedene Ansatzfunktionen untersucht und die Parameter dieser Funktionen durch lineare und nichtlineare Regressionsanalyse für die gemessenen und vorbereiteten fahrdynamischen Daten ermittelt. Es handelt sich dabei um eine weitgehend auf „Data Mining“ basierende Datenanalyse. Das heißt, es findet kein Apriori-Wissen Verwendung, und auch keine auf den üblichen mechanischen Modellen basierenden Annahmen. Der Grund für diese Vorgangsweise ist darin zu suchen, dass diese konsequente Analyse von Messdaten bisher noch nicht versucht wurde und es daher interessant war, zu sehen, wie erfolgreich dieser Ansatz ist. Für diese numerische Vorgangsweise wurden die im Softwarepaket Matlab enthaltenen Datenanalysefunktionen und Toolboxen verwendet.

Die vollständige Herleitung der gesuchten Funktionen wird in [8] ausführlich erläutert. Im Folgenden werden nur die wichtigsten Ergebnisse und Funktionen vorgestellt.

Die Dauer eines Spurwechselmanövers kann mit dem folgenden Ausdruck berechnet werden:

$$t_{sw} = -0.2346\, I + 0.3379\, b + 3.1715$$

wobei t_{sw} (sec) die Zeitdauer des Fahrstreifenwechselmanövers bezeichnet, I (-) die Intensität des Fahrers bei der Ausführung des Manövers, und b (m) die Breite des Spurwechsels. Es fällt auf, dass diese Dauer hier nur mehr von der Fahreraktion und der Spurbreite abhängt, aber nicht von z.B. der Fahrgeschwindigkeit. Im Kapitel 6 wurde kurz gezeigt, dass die Fahrgeschwindigkeit eine eher untergeordnete Rolle bei der Spurwechselzeit spielt. Diese Erkenntnis wurde in [8] gewonnen, wo auch andere, Mehrparameter-Ansätze untersucht wurden. Letztlich hat sich jedoch gezeigt, dass dadurch kaum Verbesserungen in der Approximationsgüte erzielt werden konnten. Es ist aber gut möglich, dass sich diese Einschätzung noch ändert, wenn in Zukunft mehr und stärker gestreute Messungen verfügbar sein werden.

Die maximale Amplitude der Rollrate wird wie folgt angegeben:

$$\dot{\phi}_{max} = 11.5724\, I - 10.5877\, t_{sw} + 13.4428$$

Es bedeutet $\dot{\phi}_{max}$(°/s) die maximale Rollrate, I die Intensität, und t_{sw} (sec) die Zeitdauer des Manövers. Schließlich kann die Roll-Winkelgeschwindigkeit (Rollrate) als Zeitfunktion angeschrieben werden

$$\dot{\phi}(t) = \dot{\phi}_{max}\, e^{\frac{-3.14\ ^{2}}{{t_{sw}}^{2}}} \cos\left(\frac{3\pi}{d}\,|t|^{1.21}\right)$$

Der zeitliche Verlauf des Rollwinkels $\phi(t)$ kann dann numerisch durch Integration der Rollrate $\dot{\phi}(t)$ erhalten werden.

Mit den vorgestellten Funktionen können synthetische Zeitverläufe der wesentlichen Parameter eines Spurwechselmanövers erstellt werden. Daher ist der ultimative Test für die Qualität dieser analytischen Ausdrücke ein Vergleich mit tatsächlich gemessenen Signalverläufen. Ein solcher Vergleich ist in den Diagrammen der folgenden Bilder 20 -23 gezeigt. Es sind dies im Wesentlichen die Diagramme der Bilder 12-15, aber es wurden die synthetischen Funktionen hinzugefügt und können mit den gemessenen Signalen verglichen werden.

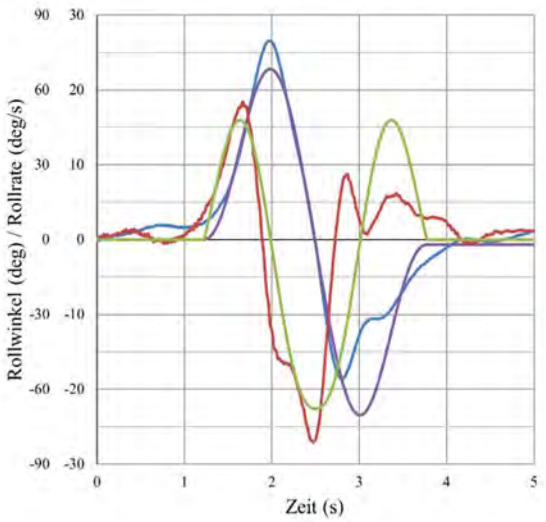

Bild 20: Signalverläufe von Bild 12 ergänzt um die synthetischen Signale Rollwinkel (violett) und Rollrate (grün) eines Fahrstreifenwechsels nach rechts mit hoher Intensität (I=7,1) bei 79 km/h

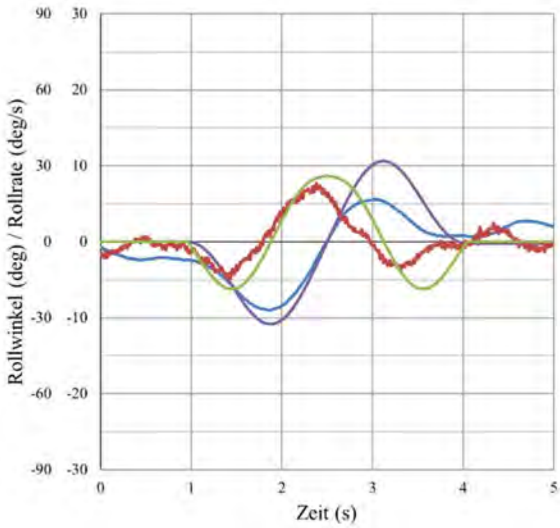

Bild 21: Signalverläufe von Bild 13 ergänzt um die synthetischen Signale Rollwinkel (violett) und Rollrate (grün) eines Fahrstreifenwechsels nach links mit geringer Intensität (I=4,4) bei 58 km/h

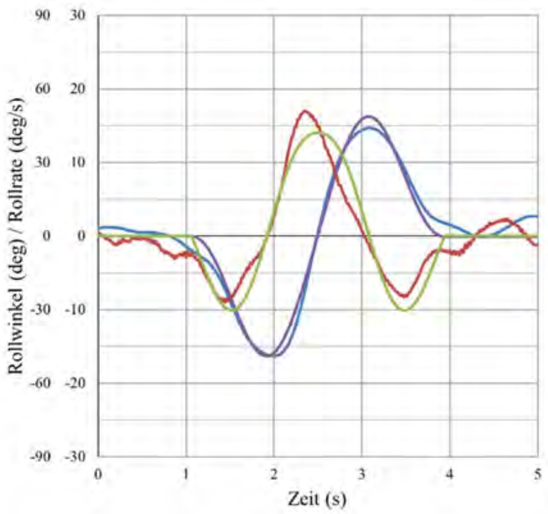

Bild 22: Signalverläufe von Bild 14 ergänzt um die synthetischen Signale Rollwinkel (violett) und Rollrate (grün) eines Fahrstreifenwechsels nach links mit 97 km/h

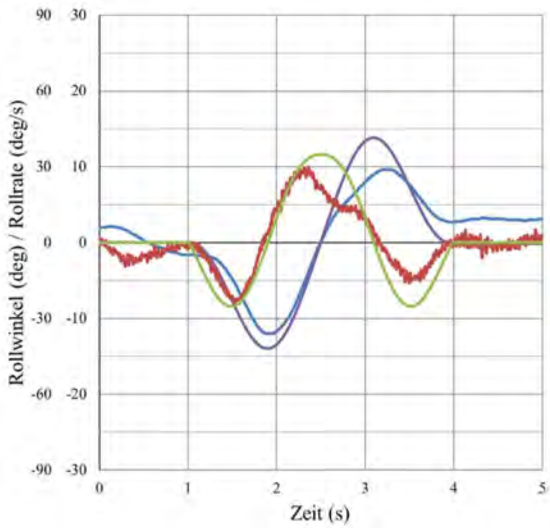

Bild 23: Signalverläufe von Bild 15 ergänzt um die synthetischen Signale Rollwinkel (violett) und Rollrate (grün) eines Fahrstreifenwechsels nach links mit 52 km/h

Wie man sehen kann, stimmen gemessene und synthetische Funktionen sehr gut überein. Natürlich sind die synthetischen Funktionen glatter, da kein Messrauschen vorhanden ist und auch die Einflussnahme des Fahrers ist in der synthetischen Lösung nicht vorhanden. Gelegentlich wird auch die zweite Spitze des Rollwinkels überschätzt. Dieses Problem tritt insbesondere dann auf, wenn die Originaldaten weniger glatt sind und die Anpassung an die Rollrate noch nicht perfekt ist. Aber insgesamt konnte ein sehr befriedigendes Ergebnis erreicht werden, besonders bei der Einleitung des Fahrstreifenwechselmanövers. Das Manöverende wurde in den Versuchen wegen der durchaus anspruchsvollen regelungstechnischen Fahraufgabe, nämlich in einem Zug auf die neue Fahrlinie einzulenken, oftmals nicht sehr „sauber“ gefahren und entzieht sich daher einer guten analytischen Beschreibung.

8. Die Reaktionszeitmessungen

Wie schon in Kapitel 3 ausgeführt, wurden die Fahrstreifenwechsel zum Teil mit freier Wahl des Zeitpunktes gefahren, und zum Teil nach einer Reaktionsaufforderung. Außerdem wurden auch reine Reaktionszeitmessungen ohne Fahrstreifenwechsel durchgeführt.

Fahrstreifenwechsel ohne Aufforderung (und daher ohne Zeitmessung) waren all jene auf der Autobahn bzw. Schnellstraße, da sich die Verkehrssituation auf diesen Straßen in der Regel nicht für diese Versuche eignete. Daher wurden die Versuche mit Zeitmessung auf stadtnahen Landstraßen (mit Fahrstreifenwechsel) und im städtischen Verkehr (ohne Fahrstreifenwechsel) durchgeführt.

Die Versuchsanordnung war derart, dass ein vorausfahrendes Fahrzeug dem nachfolgenden Motorradfahrer durch das Einschalten einer Signallampe (Warnblinkanlage) die Aufforderung zu einem Fahrstreifenwechsel signalisierte. Die aufleuchtende Lampe war auf den zeitsynchron mitlaufenden Aufzeichnungen der On-Board-Videokameras zu sehen. Der Beginn der Fahrerreaktion wurde durch die Betätigung von zwei Minischaltern an den beiden Lenkergriffen aufgezeichnet. Diese Betätigung erfolgte unbewusst durch die für den Fahrstreifenwechsel erforderlichen Lenkbewegungen. Bei den Versuchen ohne Fahrstreifenwechsel genügte es, den Lenkergriff fester zu umfassen, um die Minischalter zu betätigen.

Die Auswertung erfolgte auf zweierlei Arten. Der Beginn der Reaktionszeit war immer durch das Videosignal definiert. Für die Fahrerreaktion wurde einerseits das Schaltersignal verwendet, aber auch der zeitliche Verlauf der Rollrate. Es zeigte sich nämlich, dass dieses Signal auch sehr sensibel die Fahrerreaktionen erfasst. Natürlich wurden die Ergebnisse verglichen und es zeigte sich, dass die visuelle Identifikation des Reaktionsbeginns anhand des Rollratenverlaufes häufig zeitlich sehr nahe am Triggersignal lag. Diese doppelte Auswertung hatte zudem den Vorteil, dass Fehlauslösungen oder auch verzögerte Auslösungen der Triggerschalter zweifelsfrei erkannt und in den Daten berücksichtigt werden konnten.

In der nachstehenden Tabelle sind nur Versuche mit Fahrstreifenwechsel berücksichtigt, und die Auswertung erfolgte auf Basis der Signale der Triggerschalter. Die einzelnen Parameter sind die üblichen statistischen Kenngrößen Stichprobenanzahl n, Mittelwert $\bar{x}$, Median $\tilde{x}$, Standardabweichung σ, sowie Minimal- und Maximalwert.

Versuchsreihe	n	$\bar{x}$	$\tilde{x}$	σ	MIN	MAX
HE1	16	0,83	0,77	0,35	0,27	1,58
HE2	20	0,74	0,58	0,32	0,46	1,47
SL1	16	0,53	0,50	0,16	0,34	0,85
HE	36	0,78	0,69	0,33	0,27	1,58
SL	16	0,53	0,50	0,16	0,34	0,85
Gesamt	52	0,70	0,61	0,31	0,27	1,58

Tabelle 1: Statistische Parameter der ausgewerteten Versuchsreihen. (Zeitangaben in Sek.)

Von primärem Interesse ist natürlich der Mittelwert der Lenk-Reaktionszeit und dieser ergibt sich für die hier ausgewerteten Fahrstreifenwechselmanöver mit optischer Aufforderung zu 0,70 Sekunden. Der Fahrervergleich anhand dieser Messungen zeigt, dass Fahrer HE mit einem Mittelwert von 0,78 Sek langsamer reagierte als Fahrer SL mit 0,53 Sek. Auch die Standardabweichung war bei Fahrer HE höher. Allerdings waren die Unterschiede zwischen den beiden Fahrern deutlich geringer bei den Reaktionszeitversuchen ohne Fahrstreifen-wechsel. Weitere Ergebnisse und Auswertungen findet der interessierte Leser in [8].

Auch für diese Versuche gilt, dass zwar der gesamte Umfang mit 175 ausgewerteten Reaktionszeitversuchen durchaus repräsentativ ist, jedoch nur zwei Testpersonen zur Verfügung standen und daher die Ergebnisse eine eingeschränkte Aussagekraft haben.

9. Schlussfolgerungen

Die mit einem Messmotorrad durchgeführten zahlreichen Fahrstreifenwechsel-Manöver im öffentlichen Verkehr auf Basis eines innovativen Versuchsdesigns haben mehrere sehr interessante Erkenntnisse geliefert.

Zunächst konnte festgestellt werden, dass zwar die Phase der Einleitung und das erste Einlenken in das Manöver gut reproduzierbar und weitgehend einheitlich verläuft. Das Zurück- und Einlenken auf die neue Fahrspur gelingt jedoch oft nicht beim ersten Ansteuern und erfordert mehrfache Lenkkorrekturen des Fahrers. Dies wurde bisher bei der mathematischen Beschreibung eines Fahrstreifenwechsels nicht beachtet und berücksichtigt. Allerdings zeigt sich dieses Verhalten nur dann, wenn die Fahrer versuchen, sehr präzise die neue Fahrlinie einzuhalten. Für die tägliche Praxis spielt es in der Regel keine Rolle, ob eine Fahrlinie auf 10cm genau eingehalten wird.

Mittels des instrumentierten Motorrades konnten sehr viele fahrdynamische Parameter gemessen werden. Das Fahrzeug war jedoch nicht mit einem Lenkmomentsensor ausgerüstet. Es wird jedoch vermutet, dass die „Intensität“ der Ausführung des Manövers durch den Fahrer, am besten durch das Lenkmoment erfasst werden könnte, weil dieses in direktem Zusammenhang mit der Höhe der Kraftanstrengung gesehen werden kann. In Ermangelung dieser Messgröße, wurde der maximale Rollwinkel des Manövers als Ersatzgröße herangezogen und ein nichtlinearer Zusammenhang zwischen dem maximalen Rollwinkel und der als „Intensität“ definierten charakteristischen Größe zur Beschreibung der Fahreraktion gefunden. Die Brauchbarkeit dieses neu geschaffenen Parameters hat sich bestätigt. Eine erweiterte Basis zur Parameteridentifikation, bzw. zur Überprüfung möglicher zusätzlicher Einflussgrößen wäre wünschenswert. Eine höhere Anzahl von Testfahrern ist das nächste Ziel im Rahmen dieser Studien.

Etwas überraschend war die Erkenntnis, dass die Dauer eines Fahrstreifenwechsels zwar vom Spurversatz abhängt und auch von der Intensität der Ausführung durch den Fahrer, aber kaum von der Fahrgeschwindigkeit. Diese Erkenntnis gipfelt in einer analytischen Formulierung für die Dauer des Fahrmanövers, welche nur von den beiden obgenannten Größen abhängt. Im weiteren wurden mittels statistischer Methoden und im Sinne eines Black-Box Modells analytische Formulierungen für das Fahrstreifenwechselmanövers gefunden mit denen schon sehr gute Ergebnisse erzielt werden konnten. Diese Formulierungen bedürfen zwar noch einer weiteren Absicherung durch Messungen mit einem größeren Probandenpool, sind aber ein vielversprechender Ausgangspunkt für weitere Studien.

Als Nebenprodukt der Fahrstreifenwechselversuche kann auch die Messung der Antwortzeiten der Fahrer durch eine Lenkreaktion auf einen visuellen Reiz gesehen werden. Jedenfalls konnten weit mehr als 100 Reaktionszeit-Versuche durchgeführt werden. Die Ergebnisse liegen nun in Tabellenform vor. Die Tatsache, dass nur zwei Fahrer all diese Experimente ausgeführt haben, ist aus statistischer Sicht zwar bedauerlich und schränkt die Allgemeinheit der Aussagen auch ein, aber die Autoren arbeiten an einem neuerlichen Testprogramm mit mehr Teilnehmer_innen. Im Hinblick auf die generische und analytische Beschreibung eines Motorradfahrers der ein Fahrstreifenwechselmanövers konnten aber jedenfalls Fortschritte erzielt werden.

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Weiters gebührt unserem Kollegen Ing. Manfred Neumann besonderer Dank für seine wertvolle Hilfe bei der Vorbereitung und Durchführung der Messungen.

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Steering Torque Measurement on Motorcycles

Anja Wahl*, Felix Kaut, Erdogan Dikmenli*, Matthias Klews*

*Robert Bosch GmbH, Germany

Abstract

The essential control variable for riders to influence the lateral dynamics of a motorbike is the steering torque. In contrast to passenger cars, it is so far not common to measure this quantity. However, for scientific investigations that deal with the derivation of handling measures, steering torque has to be known. In single studies, different approaches to measure the steering torque are realized.
The target of the presented work is to realize a robust steering torque measurement setup for bike dynamics investigations. This setup should influence the geometry of the steering system and the driving behavior of the motorbike as little as possible. It also should be easily mountable and removable without repeated calibration.
Because a motorcycle has no steering column as in a car, the steering torque cannot be measured directly in an easy manner. Motorcyclists generate the steering torque by applying different forces to the right and left handlebar grips. These handlebar forces generate reaction forces in the connection blocks of the handlebar with the upper triple tree clamp. The measurement setup is realized in a way that these reaction forces are measured. For this purpose two force measuring bolts from a former weight sensing system for advanced passenger safety are mounted with adapter plates between the handlebar and the upper triple tree clamp. The handlebar thereby increases by 8 mm with otherwise unchanged components and steering geometry. The used force measuring bolts have a uniaxial sensitivity and measure to a good approximation only the force perpendicular to the steering axle. Given the defined mounting position, the steering torque can be directly evaluated. The described setup is calibrated on a test bench. First rides on the test bike show that the measurement setup fulfils the requirements. Further test rides will be carried out to analyze the measured steering torque in dynamic riding situations.

1 Introduction

To control the lateral bike dynamics, the rider applies different left and right handlebar forces which produce a steering torque. This steering torque T is the input variable, which manipulates the lateral bike states, like lateral acceleration a_y, yaw rate $\dot{\Psi}$ and roll angle λ as illustrated in Figure 1.

Figure 1: Input variable steering torque for lateral bike dynamics

From a system dynamics point of view in contrast to passenger cars, the steering system of a motorcycle cannot be separated and the steering angle δ has to be seen as bike state. Despite the much more complex transfer behavior of motorcycles they are not equipped with steering torque and steering angle sensors like cars.

But when studying the handling of bikes knowledge of the steering torque is required. Kooijman and Schwab [1] give a detailed overview of handling aspects for motorcycles. All listed indices to rate handling describe in some way the relation between steering torque and a lateral bike state. For example, good handling is achieved in steady turning when the roll factor T/λ has a low value with small negative steering torque [2]. When the time lag between the steering torque T and the yaw rate $\dot{\Psi}$ is small the bike has good handling for avoiding an obstacle [2]. Further examples of handling indices can be found in [1].

Since a motorcycle has no steering column like a car, the steering torque cannot be measured directly in an easy manner. In literature only single studies measuring the steering torque can be found, which use different measurement approaches. In [3, 4] special torque sensing assemblies integrating torque measurement shafts have been constructed. Also Figure 2 shows such a realization of direct torque measuring by a measurement shaft.

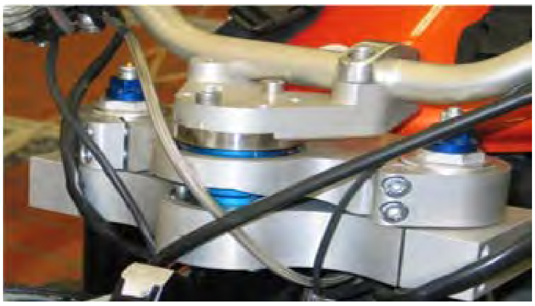

Figure 2: Steering torque measurement with torque measurement shaft

With the advantage of direct measuring of the steering torque there come the disadvantages of a complex construction and a changed steering feeling. Another approach is to measure the steering torque indirectly. For example [5] applies bi axial load arms at the handlebar grips and calculates the steering torque with the measured handlebar grip forces. In [6] a special realization is described where a custom build transducer with strain gauges on a cantilever is constructed for steering torque measurement. More common is pasting strain gauges directly onto the handlebar and to calculate forces and the steering torque from the measured deformations. This approach, for example used in [7,8], does not require any bike modifications. The application of strain gauges needs corresponding expertise and an extensive calibration of quite sensitive measuring elements.

Since no general steering torque measurement setup for bike dynamic investigations is available, the goal of this work is to put forward a robust measurement setup for a test bike to handle easily. This setup should influence the geometry of the steering system and the driving behavior of the motorbike as little as possible. It also should be easily mountable and removable without repeated calibration.

2 Measurement concept and realization

2. 1 Concept

To steer a bike, motorcyclists apply different handlebar forces F_{HB} at the right and left handlebar grips. These forces generate reaction forces in the connection blocks between the handlebar and the upper triple tree clamp. With the part F_S of the reaction forces acting perpendicular to the steering axis at the well-defined distance l_i from the connection blocks to the rotation point, the steering torque T can be evaluated. The torque equilibrium at the handlebar yields:

$$T = \left(F_{HB,R} - F_{HB,L}\right) * l_a = \left(F_{s,L} - F_{s,R}\right) * l_i$$

Figure 3 depicts a simplified handlebar model introducing the used notation.

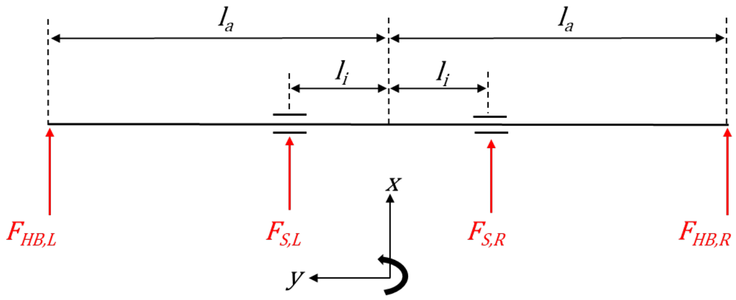

Figure 3: Simplified handlebar model. T steering torque, F_{HB} rider force at handlebar grip in longitudinal direction, F_S reaction force in connection block

An advantage of this indirect way to measure the steering torque is that beside the steering torque the handlebar grip forces acting in longitudinal direction can be approximated.

$$F_{HB,L} = -\frac{1}{2} * \left[F_{S,L} * \left(1 + \frac{l_i}{l_a}\right) + F_{S,R} * \left(1 - \frac{l_i}{l_a}\right)\right]$$

$$F_{HB,R} = -\frac{1}{2} * \left[F_{S,L} * \left(1 - \frac{l_i}{l_a}\right) + F_{S,R} * \left(1 + \frac{l_i}{l_a}\right)\right]$$

2.2 Sensor principle

The described concept needs a force sensor with uniaxial sensor sensitivity to only measure the reaction force perpendicular to the rotation axis of the steering system. For this purpose a force measuring bolt from a former weight sensing system, originally developed for passenger classification in cars [9] but no longer produced, has been chosen. This force sensor has a uniaxial measuring direction as displayed in Figure 4.

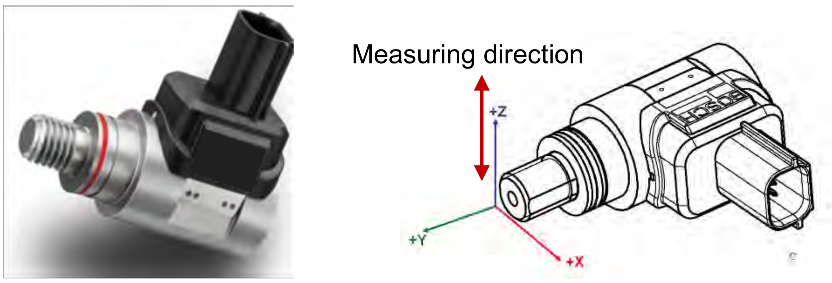

Figure 4: Force measuring bolt with its measuring direction

The working principle of the force sensor, as illustrated in Figure 5, is based on measuring the deflection of a bending beam caused by the applied force F. This deflection is monitored by measuring the change of a static magnetic field with a Hall-sensor. The sensor provides analog output data (voltage value), which is linear to the applied force.

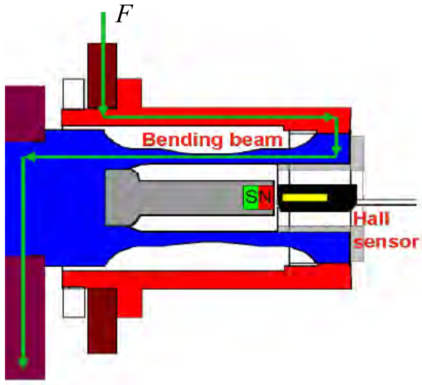

Figure 5: Scheme of the used force sensor

Additionally the force sensor features a mechanical limitation of the maximum strain on the bending beam. The mechanical design of the force sensor is developed to ensure a minimum sensitivity against forces and moments lateral to the main measuring direction.

2.3 Construction

A model of the finally assembled steering torque measurement setup is displayed in Figure 6.

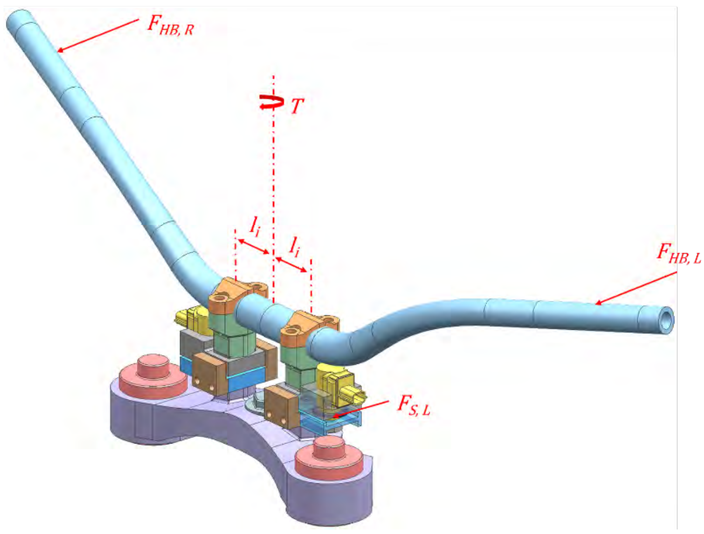

Figure 6: Model of the measurement setup integrating two force measuring bolts force sensor (yellow), adapter plate I (grey), adapter plate II (blue), overload protection (brown)

The two force measuring bolts (yellow) are integrated with opposite mounting directions between the handlebar connection blocks (green) and the upper triple tree clamp (purple). For this purpose two adapter plates (grey and blue) respectively have been constructed. They are attached to the connection blocks or the triple tree clamp using the existing screw fittings. The two adapter plates themselves are connected by the measuring bolt of the force sensor. In addition to the overload protection of the force sensor, the construction includes overload stops (brown).

Figure 7 shows the final realization of the steering torque measurement setup. This setup does not require any changes of components of the steering system. Only the height of the handlebar is increased by 8mm. The modular design allows for easy mounting and dismounting.

Figure 7: Steering torque measurement setup

4 Calibration

For calibration measurements under constant and repeatable conditions, a test bench has been built up. A design drawing is shown in Figure 8.

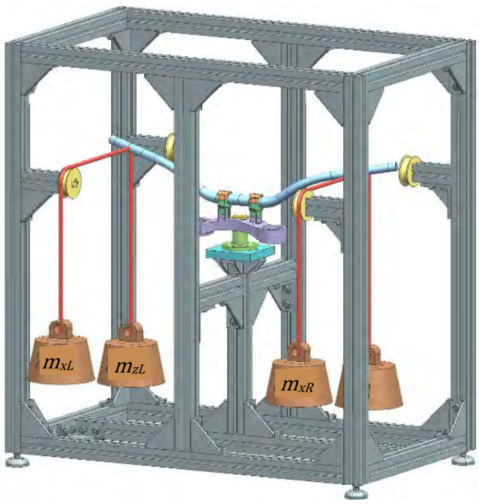

Figure 8: Test bench for calibration. Weights at pulleys in the front → pulling force (negative), weights at pulleys in the back → pushing forces (positive)

The upper triple tree clamp is stiffly fixed with the test bench. By hanging weights in the x-direction, pulling or pushing forces can be applied, which produces a steering torque dependent on their difference. The weights m_x in Figure 8 produce pulling forces. For pushing forces, the pulleys in the back have to be used. With these forces at their exactly defined positions, a reference value T_{ref} for the steering torque to measure T_{meas} is evaluated.

$$T_{ref} = \left(F_{HB,R} - F_{HB,L}\right) * l_a \qquad T_{meas} = \left(F_{S,L} - F_{S,R}\right) * l_i$$

By hanging weights in the z-direction, the influence of the rider's supporting force in normal direction is taken into account. These forces are parasitic forces concerning steering torque measurement.

To consider all load cases, different weights are applied as pulling and pushing forces at the left and right of the handlebar. This results in a matrix of measured steering torques as illustrated in Figure 9. The diagonal from top left to bottom right corresponds to the straight ride with zero steering torque. The green marked fields, where one of both weights is zero, correspond to the one-handed ride.

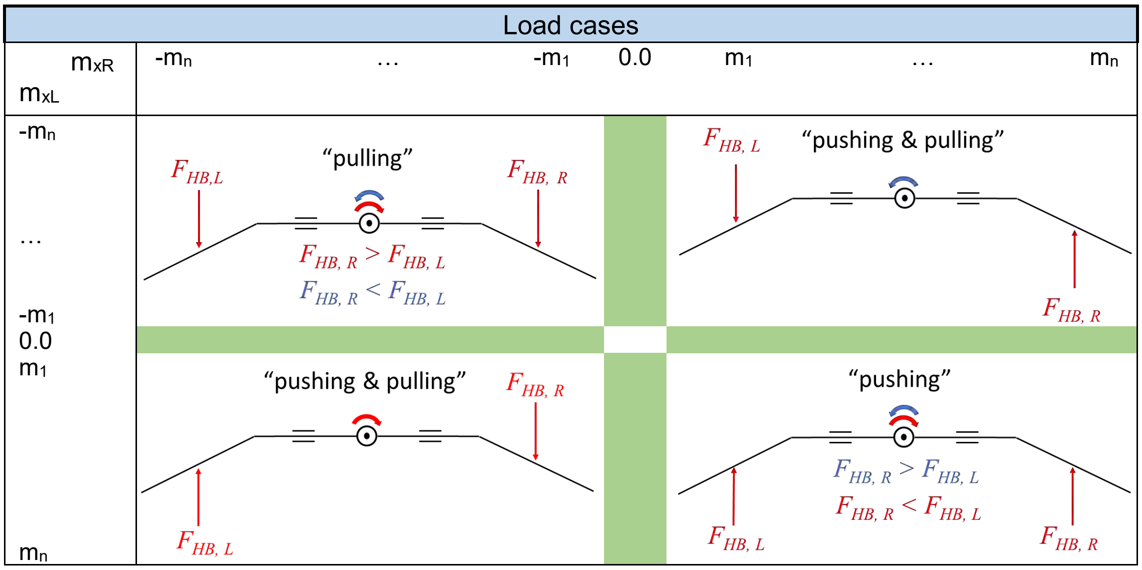

Figure 9: Load cases for calibration by applying different left/right weights ("negative" weights correspond to pulling)

Figure 10 shows the results of the calibration measurements plotting the value pairs (T_{ref}, T_{meas}). Theoretically these points lie on a line through the origin with a gradient of one. Of course there are disturbing effects like mounting inaccuracies (e.g. small error in sensor direction), sensor hysteresis or parasitic loads which lead to measurement errors. By means of a correction factor, which is determined with help of the regression line, the influence of systematic errors is reduced. This static calibration results in a mean absolute measurement accuracy of ±1,24 Nm of the developed measurement setup.

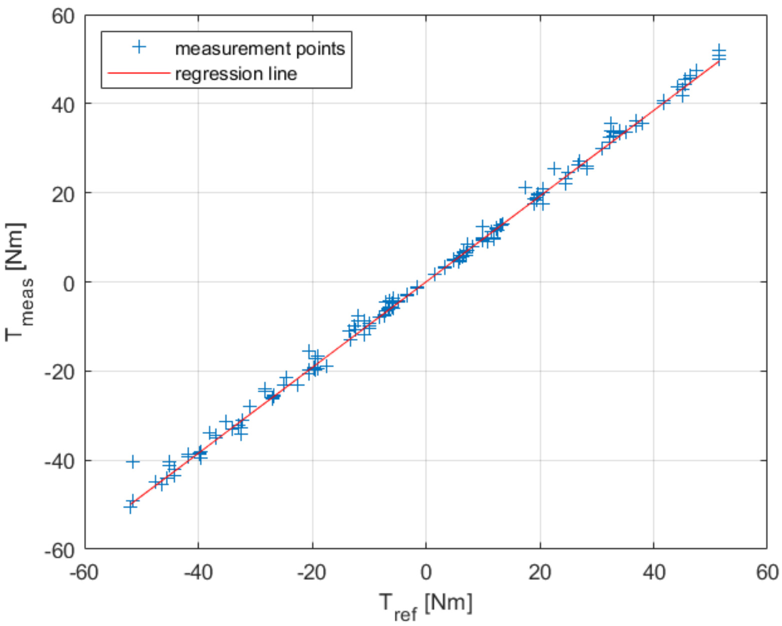

Figure 10: Scatter plot of measured points (T_{ref}, T_{meas}) and linear regression line

Although the used force sensor is able to measure positive and negative forces in its sensitive measuring direction, it has been designed for passenger classification in cars, where only positive or negative forces occur dependent on mounting. In the sensor design no focus was put on change of force direction (positive to negative and vice versa). For small forces with changing sign, the used force measuring bolt probably is not the optimal sensor.

5 Measurements

The steering torque measurement setup is built to perform deeper bike dynamics investigations especially concerning the input/output transfer behavior. Primary test rides to check the functionality of the measurement setup have been carried out. Different riding maneuvers, smooth ones and also extreme ones, yield no change in steering feeling. Thus the construction does not introduce significant elasticity in the steering system.

An example measurement of curve braking with Motorcycle Stability Control [10] is displayed in Figure 11.

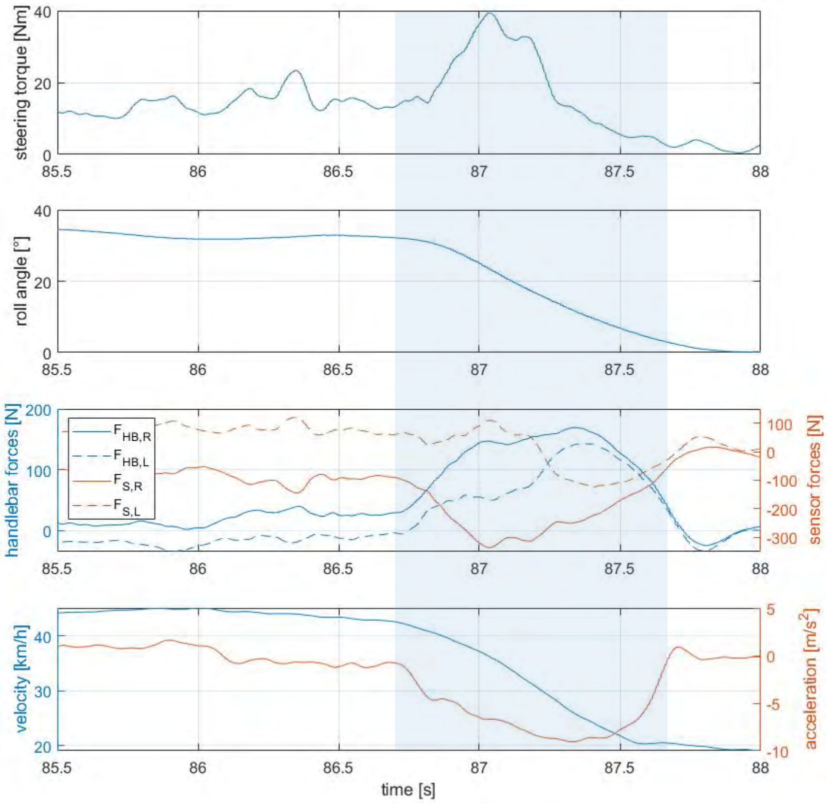

Figure 11: Example measurement of curve braking. Steady cornering at beginning, braking in blue area

The maneuver begins with steady cornering (right turning) at a velocity of 45 km/h (blue line, 4. diagram) and a roll angle around 35° (2. diagram). To steer the bike on the circular ride the rider applies a steering torque around 15 Nm contrary to the curve direction (1. diagram). The rider creates the steering torque by slightly pulling at the outer and pushing at the inner handlebar grip, which can be seen in the handlebar forces (blue lines, 3. diagram). At 86.7s the rider initiates ABS braking down to a deceleration of approximately 9 m/s^2 (4. diagram, orange). Motorcycle Stability Control limits the deceleration gradient to keep the bike stable. To stay on the circular ride the rider counteracts the brake steer torque by applying a steering torque up to 40 Nm contrary to the curve direction. Looking at the handlebar forces in the time span of braking (blue area) one can see that the rider first pushes at the at inner handlebar grip to compensate the brake steer torque. Delayed also a pushing force is measured at the outer handlebar grip since the rider has to support the upper body during deceleration.
The measurement setup has been checked with more maneuvers like slalom, evasion, straight braking and steady cornering. All analyzed measurements are plausible and give a good insight how the rider steers the bike. The measurement setup is now available for further bike dynamics studies.

6 Summary and outlook

In the paper a robust setup for steering torque measurement is presented, taking advantage of the defined force transmission at the connections between the handlebar and the triple tree clamp, which is a good position to place force sensors. Requirements with no modification of bike components, no change in steering feeling and a construction easy to mount and remove are fulfilled by this setup. The steering torque is measured with a sufficient accuracy for the extensive vehicle dynamics studies planned next. With the steering torque the handling and the transfer behavior can be evaluated. The steering torque gives insights into how a rider steers a bike and can also be used to validate and improve simulation studies. Furthermore, the steering torque may be used to enhance existing motorcycle safety and assistance functions or to support new functions.

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Keywords

motorcycle safety, steering torque, force measurement bolt, bike dynamics

Possibilities and Benefits of Event Data Recorders (EDR) for Motorcycles

Authors:
ir. C.R. (Kees) Duivestein: vehicle dynamics engineer & management consultant. Current position (ao): concept developer for EUDARTS/MODARTS.
Dimitri Margarits, PhD cd, FIM CAP / EUDARTS
ing. Jan Paul Peters: legislation specialist, trainer EDR EUDARTS.

Institution:
EUDARTS: The EUDARTS Group (European Data Analysis Research Training & Service) is an association of experts and trainers in more than 30 countries and cooperates with 23 European police forces and 500+ private enterprises.
Within EUDARTS the MODARTS division focuses at EDR for PTW's. MODARTS aims to facilitate and encourage the development and usage of EDR in PTW's and will offer services in the field of diagnosis and analyses, training & service in respect to EDR for PTW's. This is our contribution to safety of motorcycles and other PTW's.

Introduction:
Implementation of advanced electronics in road vehicles, has given the possibility to record events like accidents, defaults or anomalies. An EDR records a set of parameters, such as speed, acceleration/ deceleration, position of throttle and brakes etc. after an event occurs that meet predefined criteria.
EDR became mandatory in the US for new passenger car models in 2006; in the EU from 2022. Motorcycle accidents are complicated incidents to analyse in comparison to car accidents: the trajectory of the motorcycle is usually not just longitudinal, impacts zones are not easily visible and the rider often has a separated trajectory.

Research question:
Three questions will be answered:
1. What's the state of art, what has been published.
2. Can a motorcycle EDR provide useful data to analyse an accident.
3. What are the benefits of motorcycles equipped with EDRs for traffic safety.

Method:
Desk study was conducted to obtain insight in the state of art.
A sample of registered motorcycle accidents was evaluated on the benefit of using eventual additional data from an EDR systems.

Results:
The results show that EDR data can deliver accident and vehicle dynamics information that lead to a better understanding of motorcycle accidents or near accidents.
It is recommended that further extensive research on this topic will be conducted for validation reasons and to point out areas of further improvement. Technical solutions for EDR in motorcycles are within reach or available, and a matter of making agreements with the PTW industry.

Impact:
Similarly to EDR in cars, motorcycle EDR is an objective data recording method to analyse motorcycle accidents. The deeper knowledge in motorcycle accidents will lead to countermeasures and contribute to safety of motorcycling.

Contents

1. General outline
2. State of the art
3. Accident Analyses
4. Conclusions and Recommendations
5. Appendix: regulations

1. General

Event Data Recorder (EDR)

EDR is a device or function that records the measurements, in chronological order before, during, and after an event happens, such as significant reduction in speed. For passenger cars the EDR is triggered at a delta-V of 8 km/h within a 150 ms interval. To have the EDR ready at the moment the trigger level is reached, a “wake-up call” is given at a cumulative delta-V of over 0,8 km/h within a 20 ms time period [1].
Event Data Recorders are essentially different from a Flight Recorder in an Airplane A Flight recorder registers data and cockpit voice during the whole flight whereas an Event Data Recorder registers data only in case a pre-determined event occurs.
Information obtained from EDR can contribute to understand the causation of an accident. This will allow researchers to better assess the effectiveness of countermeasures, manufacturers to improve future vehicle design and it will allow to determine the liability for the accident more accurately and objectively determined, therefore reducing time and legal costs and providing road users and society with access to justice.

Powered Two-Wheelers (PTW)

The term ‘Powered Two-Wheeler’ (PTW) covers a wide diversity of vehicles. The products are divided into different segments such as moped, scooter, street, classic, super-sport, touring, custom, supermoto and off-road motorcycles.
PTW’s are one of the most affordable forms of personal transport in many parts of the world. In various regions, PTW’s are also the most common type of motor vehicle.
In the international regulatory environment, in particular UNECE, PTW’s are referred to with the term: ‘vehicles of category L’. At first, in this initiative we focus at the category L3, motorcycles: a two-wheeled vehicle with an engine cylinder capacity in the case of a thermic engine exceeding 50 cm3 or whatever the means of propulsion a maximum design speed exceeding 50 km/h. See the UNECE Consolidated Resolution on the Construction of Vehicles [2] for further information.

Urge

Progress in reducing EU-wide road fatality rates has stagnated in recent years. It appears highly unlikely that the EU's current medium-term target, to halve the number of road deaths between 2010 and 2020, will be reached. Even less progress has been made in preventing serious injuries. A prerequisite for reducing the number of road accidents is to have a good understanding how accidents happen.
The introduction of various Advanced Driver Assistance Systems (ADAS) has improved road-safety but made it often even more complicated to determine the causation an accident.
The EU will require for new type of cars, together with the mandatory fitment of a number of ADAS systems an Event Data Recorder from 2022 onwards (EU Regulation 2019/2144 of 27 November 2019). The expected large-scale implementation of EDR in cars together with the on-going miniaturization of electronic components will make the easier to implement EDR on motorcycles too.
Compared to car-car accidents, motorcycle accidents are more complicated to analyse due to the lack of clear impact zones and the movement in three dimensions by the motorcycle.
A large-scale fitment of EDR on motorcycles would help to analyse the causation of motorcycle accidents and at the end to take the appropriate measures to improve road-safety.

2. State of the art

Scientific papers

In 2015 Murugesh Gorajanal eo [3] mounted an embedded system on two wheelers which records the events like brake, gear, speed, stand and congestion. The results of analysis showed that the recorders can report real world crash data and therefore be a powerful tool by providing useful information to crash reconstruction experts.
In 2016 A.H. Alasiry eo [4] presented a preliminary design of a simple low cost EDR prototype which utilize only external sensors, i.e. IMU, GPS and Compass information, therefore, this EDR can be banded easily and cheap to be used even on a motorcycle. This research was to be continued in the near future by researching new features such as data compression, security, low energy, signal behaviour and also advance testing of this EDR performance and reliability.
Co-writer E.S. Ningrum [5] presented 3D reconstruction tools to accessing real-time data in the Event Data Recorder (EDR) loaded in a motorcycle. The aim is to facilitate investigators for analysing the chronology of motorcycles accident as well as being one of authentic forensic evidence.

The US-researcher and collision-analyst Edward Fatzinger and Landerville [6] [7] published in 2017 and 2018 about the testing of Electronic control units (ECU) from Kawasaki Ninja motorcycles in order to examine the capabilities and behaviour of the event data recorders (EDR).

According to Montalbano eo [8] a number of methods have been presented previously in the literature for determination of the impact speed of a motorcycle or scooter at its point of contact with another, typically larger and heavier, vehicle or object. However, all introduced methods to date have known limitations, especially as there are often significant challenges in gathering the needed data after a collision. Unlike passenger vehicles and commercial vehicles, most motorcycles and scooters carry no on-board electronic data recorders to provide insight into the impact phase of the collision. Recent research into automobile speedometers has shown that certain types of modern stepper motor-based speedometers and tachometers can provide useful data for a collision reconstruction analysis if the instrument cluster loses electrical power during the impact, resulting in a “frozen” needle indication.
Filliger ea [9] already in 2013 computed information from measurements of a commercially available, low-cost 6-axes MEMS-IMU (3 specific force and 3 angular rates sensors), in order to avoid privacy issues related to GPS-based EDR-functionality.

Patents

Scanning Google patents* shows not much of research has been protected by patents so far. Whether this is also a sign of comprehensive R&D on this subject or not, is still unknown.
*https://patents.google.com/patent/EP2026287B1/en?q=event&q=data&q=recording&q=motorcycles&oq=event+data+recording+motorcycles EDR is in classification G07C5/085.

Current application in motorcycles

About Kawasaki it is known from the user manual that EDR functionality is present in at least a number of Ninja- and recent models. The same is for Honda’s US Gold Wing model. About cars in general there is a relation between airbags and EDR. Kawasaki shows it doesn’t have to be the case, because the Kawasaki patent is about triggering events without an airbag sensor. BMW through its E-Call functionality [10] shows to have the technical solutions to trigger the major events: ‘The consequences of the collision and the state of the motorcycle are transmitted via sensors on the motorcycle so that accidents can be reliably recognised and differentiated from typical motorcycle driving situations.’
No official statements about EDR for motorcycles have been published so far. A survey along European Head Quarters of major OEMs showed EDR is not top of mind yet, although the subject attracts attention. Most OEM's have it or will have it 'under investigation'. A common remark is about the costs issue. It is relatively and absolutely more expensive in motorcycles than in cars because of the different production numbers.

3. Accident Analyses

Case A
The following has been anonymised for this publication. It is an intersection accident, between a motorcycle and a car.

Image 2: Overview of the collision scene case A

The investigation report of the scene describes: 'Intersection accident: The *car* came from the *road number 1* (vertical on the picture above) and intended to turn left onto the *road number 2* (horizontal) in the direction of *city name 1* (to the right side from this picture). The cyclist drove on the *road number 2* in the direction of *city name 2* (to the left side). When the *car* turned left onto the *road number 2*, it overlooked the motorcyclist who had the right of way. According to the car driver, the cyclist drove too fast. The *road number 2* has a speed limit of 100 km/h, and 70 km/h at the crossing.'

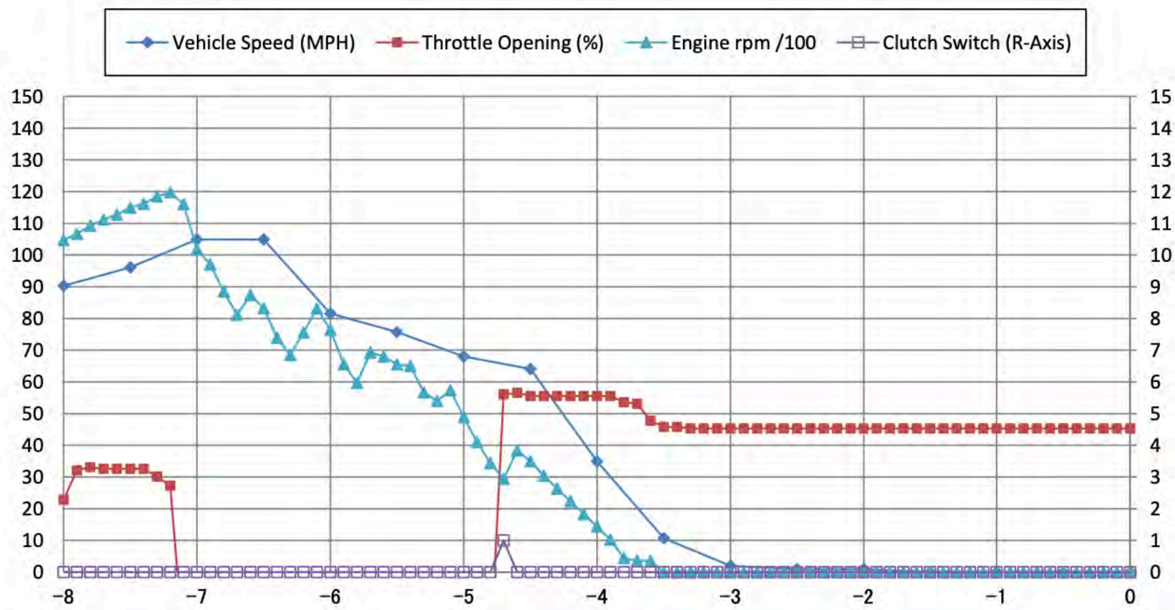

Diagram 2: Event data recordings (correction in legenda: MPH = km/h)

Explanation to the recorded variables: time of impact is between -4.5 and -4 seconds. At -7.5 seconds the motorcyclist releases the throttle and reduces speed to 80 km/h in 1 second, a deceleration of 6 m/s^2. The next second speed is reduced to 70 km/h (speedlimit at the crossing), at before the moment of impact speed further to 65.
The car came from the right and turned left, but the driver overlooked the motorcycle. The motorcycle approaching reflexively dodged to the left. The collision analysis confirmed exactly the value from the EDR.

Case B

The accident has been anonymised, all information that can lead to time, place, people has been omitted.

In this case, the vehicles initially drove in a column, the combination of car and trailer turned left at the very same moment as the motorcycle overtook the white van behind car and trailer. The motorcycle is thrown to the left after the impact, the motorcyclist is thrown straight ahead over the turning car and lands further down the street.

The job for the expert involved was to determine whether the driver of the car-trailer combination could have seen the motorcycle or determine how long the motorcycle had been driving in the left lane. It turned out that the driver of the car-trailer combination could not see the motorcycle at the moment of the turn because it was obscured by the following white van. The motorcycle did not go too fast (speedlimit 100 km/h).

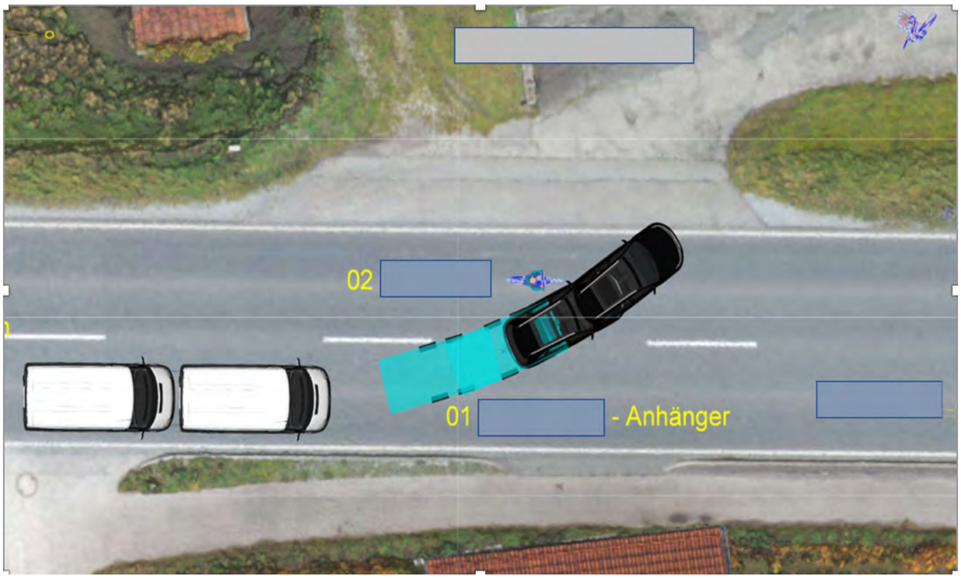

Image 3: collision situation case B

Reconstruction using skidmarks etc. shows the displacement of the motorcycle as a function of time. For this case we focus at only one quantity, speed. Among other items, speeds and deceleration at different moments in time were calculated. This analysis does not point at extraordinary speed directly right before impact, from 21 m/s (75 km/h) to 3.6 m/s less (63 km/h), after one second.

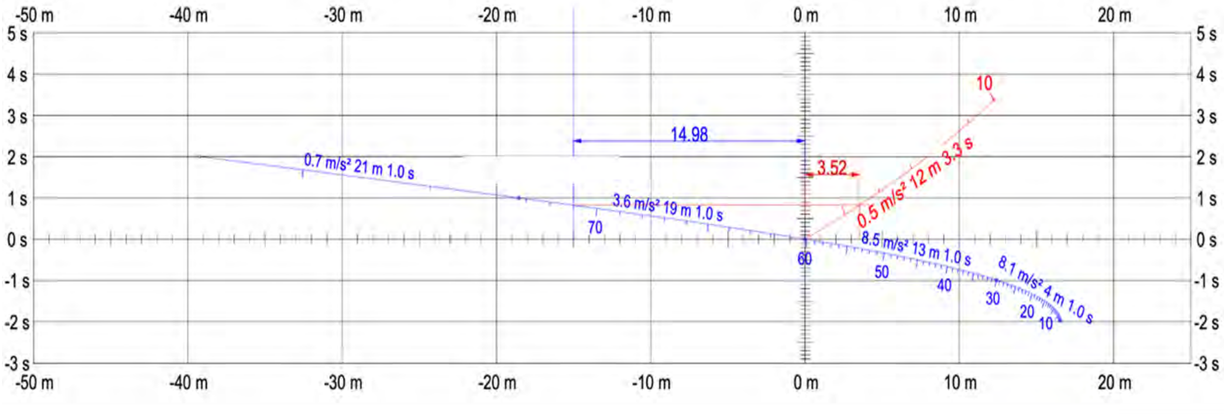

Diagram 3: displacement-time diagram case B

Also in this case, EDR data was available from the motorcycle. An extract of a number of sensors is shown here in diagram 4. This provides insight into the actual speeds and actions of the rider and thus provides valuable information.

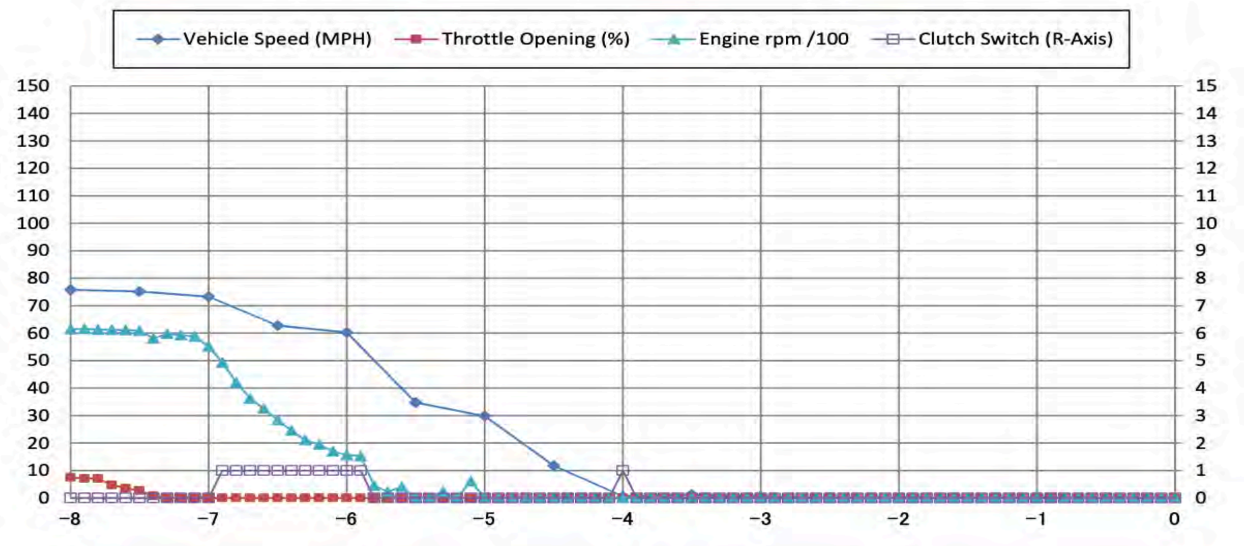

Diagram 4: Event data recordings (correction in legenda: MPH = km/h)

As we can see in diagram 4, approximately 2 seconds (t = - 8) before impact (between t = - 6 and t = - 5,5) the speed of the motorcycle as stored by the EDR was 75 km/hour. This is a plausible speed: at that moment there still wasn't any slip of the rear wheel.

4. Conclusions and recommendations

Motorcycles are considered as vulnerable road users. The fatalities per million driven kilometers are relatively high. It is likely assumed that new technologies can contribute to enhanced safety, for example directly with ADA-systems.
Our experience in legislation issues, the desk study and survey along European Head Quarters of motorcycle OEM's show EDR on motorcycles is not on the agenda's yet, although technical solutions for EDR in motorcycles are within reach or available and ready for large scale implementation.

Conclusions

1. Our studies show EDR-data can enhance and enrich analyses on accident causation and vehicle behavior in case of impactful events. These experiences with analyses on EDR of motorcycle accidents show promising results, not a priori against the interest of the motorcyclist. The results show that EDR data can deliver accident and vehicle dynamics information that lead to a better understanding of motorcycle accidents or near accidents.
2. Technical solutions for EDR in motorcycles are within available and in reach and ready for large scale implementation.
3. EDR on Motorcycles will help to understand how and why accidents happen and can contribute to the development of a safer motorcycling.

Recommendations

1. We wish all stakeholders to adopt these new technologies to enhance safety of motorcycling. Therefore, it is recommended that further extensive research on this topic will be conducted: the development of a minimum set of parameters that has to be recorded by the EDR in case of an event, a validation program to ensure the reliability and the standardization of the data protocols to allow a single reader for all motorcycle models.
2. We recommend the European Commission together with the industry takes an active role on the development and standardization and validation of EDR.
3. MODARTS is ready to assist manufacturers and regulators with the implementation of EDR in Motorcycles.

5. Appendix: regulations

Drivers for EDR

Regulation is a strong driver for development and implementation of EDR, by regional regulation or anticipation on this. Nevertheless, recent history has shown that OEM's might take the initiative to offer EDR functionality for various reasons, others than regulation. Although the fitment of EDR is not mandatory in the US, all cars need to satisfy a number of requirements if data is recorded. De facto all cars sold in the US are equipped with EDR. How the data is stored is not standardized, but the manufacturer has to make available equipment to read the data.
In Europe some large manufacturers have done the same as in the US (e.g. Volvo, VW) but others have encrypted the software or haven't installed an EDR.

General Safety Regulation

Event Data Recorders (EDR) will become mandatory in the EU for new cars, vans, heavy goods vehicles and buses, as a part of a package of safety measures in the revised General Safety Regulation (GSR), approved by European Parliament on the 16th of April 2019 and published and therefore entered into force in the EU on January 5th 2020. It means that all new vehicle models introduced on the market from July 2022 will have to comply. The new regulation requires new vehicles to be fitted with a large number of Advanced Driver Assistance Systems (ADAS) and Event Data Recorder (EDR).
PTW's haven't been taken in account yet, but is most likely to believe this will come in the future. This will take time. Even if there's a Publication of a Regulation, the entry into force is 20 days after the date of publication. New type approvals have to comply after a certain time after the entry in to force (eg. for cars and vans 30 months, for the latest GSR Juliy 2022) and new registrations have to comply after a longer period of time (cars and vans 54 months).
Powered Two-Wheelers (Category L) are not part of the recent GSR, which means Rl. 2002/24/EC ofVo. (EU) Nr. 168/2013 is leading.

Regulations and directives on motorcycles

In Europe there is on-going development of regulation concerning safety and sustainability, especially by application of modern techniques in data sensoring and communication.
Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles contain the current legislation. Following the Lisbon Treaty in 2007, regulations in this area are determined by regulations that were previously directives. From 2013 up to and including 2018, a number of Implementing and Delegated appeared [3]. Most recent is Regulation (EU) 2019/129 of the European Parliament and of the Council of 16 January 2019 amending Regulation (EU) No 168/2013 as regards the application of the Euro 5 step to the type-approval of two- or three-wheel vehicles and quadricycles. NB: it shows that European Parliament and Council don't delegate the environmental and sustainability issues to the Commission.
Of the Regulations on Powered2Wheelers published since 2013, none is aimed at the application of electronics and data for the direct or indirect improvement of active safety, apart from ABS and monitoring functions via an OBD. This contrasts with the GSR of April 2019, which describes a range of ADAS features for other motor vehicles, and EDR.

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Kees Duivestein, Jan Paul Peters; Delft/Rotterdam, August 2020

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DEVELOPMENT OF AN ASSESSMENT METHOD FOR POWERED TWO-WHEELER HUMAN-MACHINE INTERFACES

Presenter and Author **Dr. Sebastian Will**
Würzburger Institut für Verkehrswissenschaften (WIVW GmbH)
Robert-Bosch-Str. 4, 97209 Veitshöchheim
Email: will@wivw.de
Tel.: +49 (0) 931 / 78009 203

Co-authors: Thomas Hammer (WIVW GmbH), Nico Rothe (KTM AG), Gerald Matschl (KTM AG)

Recent advancements and technological developments pose new challenges to Powered Two-Wheeler (PTW) Human-Machine Interfaces (HMI). For instance, digital dashboards, which are widely spread nowadays, need to cover more and more functions. To date, PTW-specific standards and guidelines neither exist for HMI design nor HMI assessment in terms of safety.

Therefore, this paper presents an HMI assessment method that was specifically developed for PTWs. The focus lies on the assessment of distraction caused by interaction with the HMI. Starting point were established methods (e.g., use of driving simulators) and measures (e.g., parameters for longitudinal and lateral vehicle behavior as indicator for distraction from the primary riding task) from the automotive sector. From a scientific point of view, the method is based on a so called resource model (Wickens, 2008). This model postulates a limited amount of cognitive or rather attentional resources to handle the primary riding task as well as possible secondary tasks. If the required workload to master the interaction with the HMI is too high, the performance in the primary riding task decreases. If it is possible to validly replicate the workload, resulting from the real riding task, in any test environment, such as a motorcycle riding simulator, this test environment can be used to assess HMI concepts in terms of safety.
As a first step, the workload resulting from motorcycling on public roads was estimated by measuring the performance in the Peripheral Detection Task (PDT) while riding. Then, proper riding tasks for the assessment of HMI interactions on the simulator and the test track were derived. The workload resulting from the riding tasks was adjusted to meet the level of workload resulting from motorcycling on public roads.

Finally, the application of a visual-manual reference task is proposed (Surrogate Reference Task, SuRT). This reference will help to classify potential distraction coming from the completion of HMI use cases while riding.

The results gained from a pilot study verify the general applicability of the proposed method to assess PTW HMI concepts. As a next step a participant study with a larger panel will follow. This paper proposes one scientifically based solution to assess the distraction level of an HMI. It shall serve as a proper basis to pursue the debate on assessment standards for PTW HMI concepts.

ENTWICKLUNG EINER ABSICHERUNGSMETHODIK FÜR MOTORRAD HMI-KONZEPTE

Die Fortschritte und Entwicklungen der letzten Jahre stellen Human-Machine Interfaces (HMI) an Motorrädern vor immer neue Herausforderungen. Auf den inzwischen weit verbreiteten digitalen Displays im Cockpit müssen bspw. kontinuierlich mehr Funktionen abgebildet werden. Motorradspezifische Standards und Richtlinien zum Vorgehen bei der HMI-Konzeption sowie deren Absicherung liegen bislang nicht vor.

Um diesen Entwicklungen gerecht zu werden, soll im Folgenden eine Absicherungsmethodik, die speziell für Motorrad-HMI-Konzepte entwickelt wurde, vorgestellt werden. Es geht dabei primär um die Bewertung von Ablenkung. Es erfolgte eine Orientierung an den im Automobilsektor etablierten Methoden (bspw. Einsatz von Fahrsimulation) und Metriken (bspw. Maße für Quer- und Längsführung in der Fahraufgabe als Indikatoren für Ablenkung). Im Fokus steht ein Ressourcenmodell, welches die begrenzte Verfügbarkeit von Aufmerksamkeitsressourcen zur Bewältigung der Fahraufgabe und etwaiger Nebenaufgaben postuliert (Wickens, 2008). Bei zu hoher Beanspruchung von Aufmerksamkeit für die Interaktion mit dem HMI-Konzept, leidet die Leistung in der Fahraufgabe. Gelingt es die Beanspruchung der realen Fahraufgabe hinsichtlich Modalität und Ausmaß in einer Prüfumgebung wie der Fahrsimulation valide abzubilden, kann diese Prüfumgebung zur Absicherung von HMI-Konzepten herangezogen werden.

In einem ersten Schritt wurde dazu die Fahrerbeanspruchung bei Fahrten im öffentlichen Straßenverkehr abgeschätzt, indem die Beanspruchung mit Hilfe des sog. Peripheral Detection Tasks (PDT) gemessen wurde. Anschließend erfolgte die Ableitung von Fahraufgaben für die Betrachtung von Interaktionen mit dem HMI in der Fahrsimulation sowie auf der Teststrecke. In beiden Prüfumgebungen wurden die Fahraufgaben hinsichtlich ihrer erzeugten Beanspruchung auf das Niveau der im ersten Schritt erfolgten Realfahruntersuchung parametriert. Zur Betrachtung der relativen Validität erfolgte im Rahmen einer Probandenstudie ein Vergleich der in beiden Prüfumgebungen gewonnenen Erkenntnisse zur Bedienung einer standardisierten Nebenaufgabe. Hierfür wurden unterschiedlich schwierige Parametrierungen des visuell-manuell fordernden Surrogate Reference Tasks (SuRT) untersucht.

Die Ergebnisse einer Pilotstudie belegen die grundsätzliche Anwendbarkeit der erarbeiteten Prüfmethode zur Absicherung von HMI-Konzepten. Ein nächster Schritt sieht die Durchführung einer größeren Probandenstudie vor. Das vorliegende Paper präsentiert eine wissenschaftlich fundierte Möglichkeit zur Bewertung von HMI-Konzepten, welche als Grundlage weiterer Diskussionen für die Erarbeitung eines Absicherungsstandards für Motorrad HMI-Konzepte dienen kann.

1 Introduction

Generally, assessing HMI solutions as to their potential to distract a driver while driving is nothing new. Decreasing the level of distraction to a minimum is also a fixed aim to achieve in other transport domains, such as the passenger car or truck sector. The recent circumstances for PTWs (rise of functionalities, limited space for controls, availability of TFT displays etc.) have been an issue for decades in the passenger car domain. Consequently, standard procedures and recommendations on how to assess HMIs have been developed and are established as state-of-the-art today. Therefore, it was decided to base the PTW HMI assessment method on already established methods from the passenger car domain. Even if there are different possible procedures, mainly two test environments are used to assess HMIs throughout the whole development cycle: driving simulators and prototype vehicles on test tracks. HMI assessment in a simulator has the advantage that no working prototype vehicle is necessary (incl. communication between all control units etc.) and new functions, designs and concepts can easily be simulated. It creates an experience for developers as well as potential end users in participant studies that allows to shape the HMI concept towards a highly usable and safe design. HMI assessment with a prototype vehicle on a test track is typically used at a later stage in the development process and provides an approval for the distraction level of an HMI solution while real riding (incl. ergonomic boundary conditions, such as how easily every control button can be reached etc.). Consequently, test procedures for these two environments have been developed.

This paper proposes one scientifically based concept to assess the distraction level of an HMI. It shall trigger a discussion to an increasingly safety relevant topic. The presented HMI assessment method is theoretically based on so called resource models, which are pervasive when it comes to the description of driver behavior as well as the prediction of driver workload (e.g., Kahneman, 1973; Wickens, 1980, 2008). Further, resource models are highly valuable to explain dual-task overload situations. Generally, these models postulate that human beings have a certain limited amount of resources that may be used to fulfil certain tasks. If one has to complete more tasks at a time, the resources must be divided. Different publications separate resources into rather independent clusters, e.g., divided by modality (i.e. visual resources, auditory resources etc.). If one task requires a lot of resources, the performance in any secondary task will suffer.

The use of resource models to explain rider behavior during secondary task engagement, i.e. solving tasks through the HMI while riding, is obvious. In these scenarios, the rider has to fulfil the most important primary task of riding. This is already a rather complex task in terms of perception of the environment and action to stabilize and navigate the PTW in longitudinal and lateral dimensions (e.g., Donges, 1978; Spoerer, 1979). Additionally, the rider is engaged in a secondary task, which is the completion of an HMI use case. Both tasks rely on the same pool of resources. If either riding task or HMI use case completion becomes too challenging, the performance in either riding task or HMI use case completion or even both will suffer. The main aim in terms of HMI design should therefore be, to establish the necessary tasks for any HMI use case while riding on a low level to leave as much resources as possible for the riding task. Furthermore, any HMI use case that lead to an overload must be avoided (see also Figure 1).

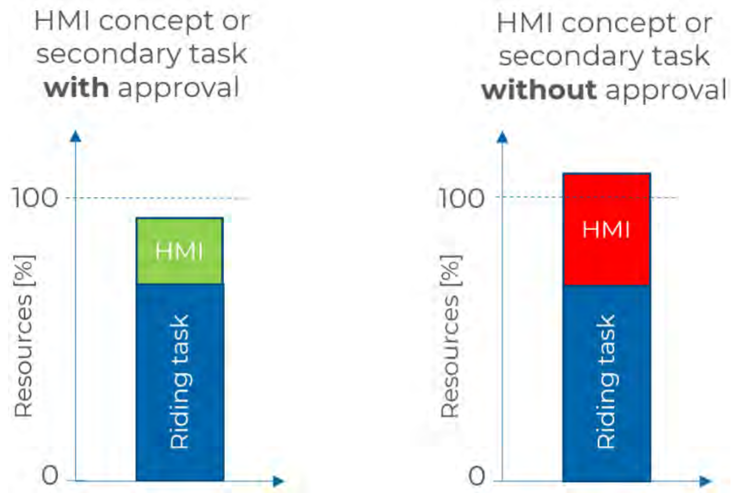

Figure 1: Simplified representation of a resource model applied to the context of riding while completing an HMI use case.

2 HMI assessment concept

As motorcycle riding simulator and test track assessment were set - in line with state-of-the-art HMI assessment procedures - the first and very important step was to assess the external validity for both test environments. In order to be able to draw conclusions gained in a more or less artificial test scenario it must be assured that the riding task is comparably challenging in all test environments. Only then, potential performance losses in the riding task may be attributed to challenging secondary tasks (HMI) rather than difficulties with the riding itself.

In a first step, a panel of $N = 3$ HMI experts rode on public roads while completing the Peripheral Detection Task (PDT, related to ISO/TS, 2016), which quantifies rider workload as a measure for used resources. The focus lay on rural roads as this is the most representative type of road for leisure motorcycle riding. Additionally, it is assumed to be more challenging than riding on highways, where HMI use cases are possibly completed as well. This decision was made to make the HMI assessment more conservative. Riding in bigger cities or urban areas typically requires high attention (e.g., due to crossing pedestrians, junctions, obstacles) so that it is not a road type, where HMI use cases are completed regularly. Operating an HMI in these areas depends massively on the specific circumstances, which cannot be covered encompassing by an HMI assessment method. In a subsequent video analysis, the riders assessed segments in which completing HMI use cases would have been possible. The average PDT performance across segments and riders delivered a workload baseline level as benchmark for the riding tasks in the simulator and on the test track. This step shall assure to have a reliable and fair baseline for the difficulty of the riding tasks in all test environments.

In a second step, riding tasks for the simulator and test track have been developed and optimized to represent the same level of difficulty as riding on public roads. The test scenarios were created in a workshop with PTW experts coming from different fields of activities, such as traffic psychology, HMI design, engineering, or law. The different potential scenarios were iteratively tested and optimized to fit the required workload baseline. During

this series of simulator and test track studies different measures that quantify primary and secondary task performance were compared.
As a last step a reference task performance had to be defined. At the end of the day, this reference shall clarify which amount of performance loss due to distraction coming from the HMI task is still acceptable.

2.1 Simulator assessment

The simulator assessment was done on the static motorcycle riding simulator at WIVW (see Figure 2 left). It provides the possibility to change the motorcycle mockup, add new controls and switch cubes as well as an interface to integrate the HMI prototype dashboard. The riding task follows the NHTSA respectively AAM procedure (National Highway Traffic Safety Administration, 2012), which proposed a dynamic car following task. Opposed to the NHTSA setup, a rural scenario was chosen (see Figure 2 right). Characteristics of the road (height profile, curvature, velocity profile of the lead vehicle etc.) have been investigated in a series of experiments to provide a difficulty for the riding task which resembles the previously defined baseline workload from real riding. Longitudinal measures describing the car following performance are used as well as lateral vehicle dynamics measures.

Figure 2: Static motorcycle riding simulator for the HMI assessment (left). Screenshot of the riding task in the motorcycle simulator (right).

2.2 Test track assessment

Regarding the HMI assessment on test tracks a new task was designed, in order to replicate the demands, which are posed to the rider by the primary riding task in real traffic. Further, the aim was to develop a task that is adaptable to different test tracks (e.g., regarding spatial dimensions). Therefore, pylons were used to define different riding tasks on a plain test field (Figure 3 left).
Following a series of tests, a test track setup was chosen that consists of a number of gates in a row. Every gate marked with pylons leaves two options to pass (left entrance and right entrance). The riders’ task is, to choose the gate that is doubled with a second pair of pylons (Figure 3 right). The so called double-gates are arranged in a way that makes them hard to detect and therefore needs regular control gazes. This simulates the visual demand while riding in public traffic. During the adaptation of the task different pylon colors, gate widths,

and longitudinal distances between gates were tested, in order to manipulate the necessary resources on a visual and manual level.
Riders' behavior can be analyzed by their success in choosing the accurate gate (e.g., number of wrong decisions, number of maneuvers with high yaw rates, number of collisions with pylons) and deviations from the instructed velocity. To avoid series effects, the position of the double-gates is arranged in a way that avoids periodic patterns and is regularly altered.

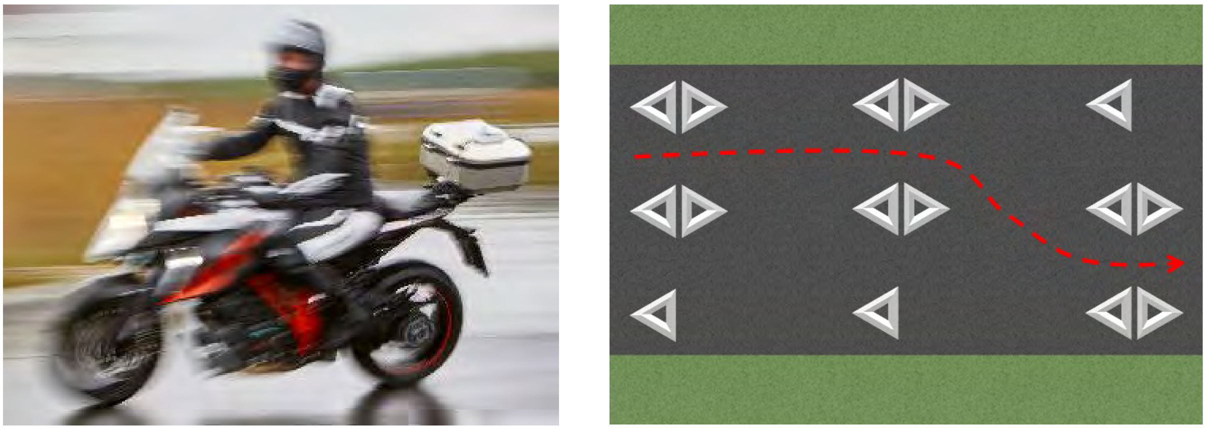

Figure 3: Measurement motorcycle for the HMI assessment on the test track (left). Bird's eye view on the schematic test track riding task (right). The dashed line marks the correct trajectory through the double gates.

2.3 Reference task

In the passenger car domain, the manual radio tuning task was chosen as reference task, when the development of assessment methods for HMIs began (National Highway Traffic Safety Administration, 2012). Setting a certain frequency on a car radio had been regarded as an acceptable level of distraction while driving, before more stable criteria based on drivers' glance behavior in naturalistic driving studies were established. Any distraction coming from the interaction with an HMI should be below this reference level of distraction. Unfortunately, there was no comparable reference task for PTWs, which could have been used as a starting point. For instance, regularly performed secondary tasks such as reading a map mounted on top of the fuel tank would be a purely cognitive – visual task, but lacks a manual component, which HMI tasks usually have. Therefore, it was chosen to rely on an artificial but standardized reference task, which has been used in the motorcycle domain before (Guth, 2017).

The Surrogate Reference Task (SuRT) is a visual-manual task that is specified in ISO 14198:2019 (ISO/TS, 2019). The SuRT is illustrated in Figure 4. The task is to identify and select a target (circle with bigger diameter) among distractors (circles with smaller diameter). Therefore, the SuRT contains a visual component (i.e. searching and recognizing the target stimulus that needs to be selected) and a manual component (i.e. selecting the target with a cursor which can be moved with button presses left/ right and confirmed). Both components can be modified as to their difficulty (visual: e.g., target – distractor diameter ratio; manual: size of the cursor). The displayed image changes as soon as the rider has hit the confirm button. A further advantage of this task is that the rider can freely decide when and how long to engage in that secondary task. Both, the combination of visual and manual components, as well as the self-paced work on the task is representative for the completion of HMI use cases while riding.

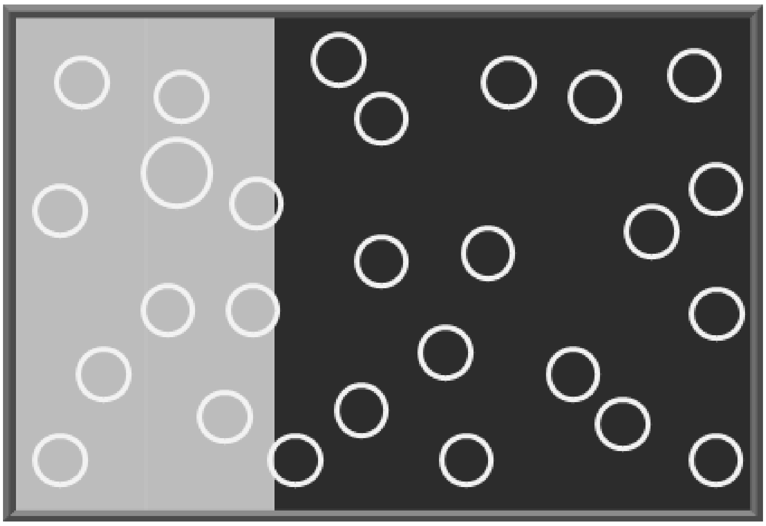

Figure 4: Surrogate Reference Task (SuRT) with grey bar as cursor correctly marking the target circle.

3 Conclusion & Outlook

This paper proposes one scientifically based solution to assess the distraction level of a PTW HMI. It shall trigger a discussion to an increasingly safety relevant topic, which could benefit from further research.

Next steps to be taken could be the following. Instead of relying on a rather small panel of expert riders, a bigger participant study would be interesting to consolidate the workload baseline levels, to ensure that the parametrizations for simulated riding task and the test track riding task are suitable. Also, a participant study could contribute to the generation of first threshold values for the reference task. Threshold values might be found on different levels such as longitudinal and lateral vehicle behavior, duration, and number of glances away from the forward roadway and / or subjective ratings regarding workload. With these threshold values, evaluations of current and future HMIs become possible by comparing their effects to the reference task's threshold values. Therefore, any approved HMI use case has to be less critical than this threshold value (binary approval in acceptable or not acceptable). Hence, the definition of these thresholds is difficult and was only achieved by large naturalistic driving observations in the passenger car domain. Independent of thresholds, the proposed simulator and test track methods already allow for the comparison between different HMI solutions (e.g., HMI A is less distractive than HMI B).

The integration of HMI assessment methods in the development process of PTWs will avoid liability issues due to rider distraction and most importantly contribute to rider safety.

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Thema:	**Überblick über ehemalige und aktuelle Grundfahraufgaben für den Motorradführerschein.**
	Overview of former and current basic driving tasks for the motorcycle license.
Autor:	Thomas Ihle, seit 1985 Motorrad-Fahrlehrer, Polizeibeamter in der Unfallermittlung a.D., DVR Moderator
Redner:	Thomas Ihle, 41747 Viersen, Landwehrstraße 16
Problem:	Aktuell scheint in der Motorradausbildung ein Stillstand erreicht, der sich auch in der Unfallstatistik niederzulegen scheint. In den letzten 7 Jahren ist die Anzahl der jährlich schwer verletzten oder getöteten Motorradfahrer nicht gesunken. Entweder ist es gefährlicher geworden Motorrad zu fahren, Stichwort Fremdverschulden, oder die Fahrfähigkeiten stagnieren. Eine Studie des Instituts für Zweiradsicherheit kritisiert die Fahrschulausbildung. Verschiedene Hypothesen sollen hierzu in den Raum gestellt werden: Die höherwertige Technik im Motorrad hat in den letzten Jahren nicht zu einer adäquat gestiegenen Ausbildung geführt. Die Entwicklung zu immer breiteren Reifen – insbesondere am Hinterrad – führt in der Praxis zu immer weniger effektiver Schräglage bei „normalen“ Motorradfahrschülern. Das „Bremsgefühl“ scheint durch den Einsatz von ABS zu verkümmern.
Darstellung:	Die Mindestausbildung und die verschiedenen Grundfahraufgaben sollen ein Bild der geforderten Fahrfertigkeiten des Motorradschülers in den letzten 30 Jahren aufgezeigen.
Konsequenzen:	Grundfahrübungen und deren Anforderungen sollen diskutiert und neue Aufgaben zur Verbesserung der Fahrfähigkeiten angedacht werden.

Overview of former and current basic driving tasks for the motorcycle license.

Problem: Currently there seems to be a standstill in motorcycle training, which also seems to be reflected in the accident statistics. In the past 7 years, the number of motorcyclists seriously injured or killed annually has not decreased. Either it has become more dangerous to drive a motorcycle, keyword external debt, or the driving skills stagnate.

A study by the ifz criticizes driving school education. Various hypotheses should be put into this: The higher-quality technology in the motorcycle has not led to an adequate increase in training in recent years. In practice, the development of ever wider tires, especially on the rear wheel, leads to less and less effective leaning for normal motorcycle riders. The braking feeling seems to be atrophied through the use of anti-lock braking system.

Presentation: The minimum training and the various basic driving tasks should show a picture of the required driving skills of the motorcycle student in the last 30 years in germany.

Consequences: Basic driving exercises and their requirements should be discussed and new tasks to improve driving skills should be considererd.

Ehemalige und aktuelle praktische Grundfahraufgaben für den Motorradführerschein, Stand und Ausblick aus der Praxis.

1. Einführung
2. Entwicklung der Mindestfahrstunden (1958 –)
   [Tabelle I]
3. Entwicklung der Grundfahraufgaben (1958 –)
4. Der Stufenführerschein (1986 –)
   [Tabelle II]
5. Bewertung der Grundfahraufgaben
6. Überarbeitung der Grundfahraufgaben (1998 –)
   [Tabelle III]
7. Änderung der Grundfahraufgaben (2014 –)
   [Tabelle IV]
8. Ausblick und Vorschläge zu Grundfahraufgaben

1. Einführung

Aktuell scheint in der Motorradausbildung ein Stillstand erreicht, der sich auch in der Unfallstatistik niederzulegen scheint. In den letzten 7 Jahren ist die Anzahl der jährlich schwer verletzten oder getöteten Motorradfahrer nicht gesunken. [1] Entweder ist es gefährlicher geworden Motorrad zu fahren (Fremdverschulden) oder die Fahrfähigkeiten stagnieren. Eine Studie des Instituts für Zweiradsicherheit kritisiert die Fahrschulausbildung. [2] Verschiedene Hypothesen sollen dazu in den Raum gestellt werden, darunter besonders drei Punkte:
* Die höherwertige Technik hat in den letzten Jahren im Motorradsektor nicht zu einer adäquat gestiegenen Ausbildung geführt.
* Die Entwicklung zu immer breiteren Reifen (insbesondere Hinterrad) führt in der Praxis zu immer weniger effektiver Schräglage bei „normalen“ Motorradfahrschülern.
* Das „Bremsgefühl“ scheint durch das ABS verkümmert zu werden.

2. Entwicklung der Mindestfahrstunden

Vor 60 Jahren wurden 8 Fahrstunden im Bereich Motorradausbildung vorgeschrieben, Anfang der 1970er Jahre keine. 1980 erfolgte eine erste Aufteilung der Motorradklassen und 1986 eine Verbesserung der Verkehrssicherheit durch die Einführung des Stufenführerscheins mit umfangreichen Vorgaben zur Mindestausbildung.

Die Vorgaben zu den gesetzlich geforderten Mindestfahrstunden sind seit der Einführung des EU-Führerscheins, 1999, unverändert.

Im Aufstiegsverfahren seit 2014 (von A1 auf A2 oder von A2 auf A) und nach einem Vorbesitz von mindestens zwei Jahren entfallen wieder Mindestfahrstunden.

Beim neuerdings möglichen Einschluss von A1 in Klasse B (Schlüsselziffer 196) schreibt das nationale Recht 10 Fahrstunden, jedoch keine praktische Prüfung vor.

Tabelle I: Entwicklung der gesetzlichen Mindestvorgaben für Fahrstunden im Bereich Motorrad von 1958 bis heute: [3,4,5,6,8,26]

seit	Klasse	Besondere Fahrstunden	Anzahl a´ 45 Minuten
28.01.1958	1	8 Fahrstunden an 8 verschiedenen Tagen	8
20.09.1971	1	*keine*	
31.05.1976	1	– mindestens 50 km Überlandfahrt	1 – 2
01.04.1980	1 1b (neu)	– mindestens 50 km Überlandfahrt – 90 Minuten Autobahnfahrt *keine*	1 – 2 2
01.04.1986 (Stufenführerschein)	1, 1a 1b 1a auf 1	– 225 Minuten Überlandfahrt – 135 Minuten Autobahnfahrt – 90 Minuten Beleuchtungsfahrt – 225 Minuten Überlandfahrt – 90 Minuten Beleuchtungsfahrt – 135 Minuten Überlandfahrt – 45 Minuten Autobahnfahrt – 45 Minuten Beleuchtungsfahrt	5 3 2 5 2 3 1 1
01.04.1993	1a auf 1	– 2 Jahre Vorbesitz, 4000 km Fahrpraxis *keine Fahrprüfung*	
01.01.1997	1b	– 225 Minuten Überlandfahrt – 135 Minuten Autobahnfahrt – 90 Minuten Beleuchtungsfahrt	5 3 2
01.01.1999 (EU-Führerschein)	A, A(b), A1 A(b) auf A	– 225 Minuten Überlandfahrt – 180 Minuten Autobahnfahrt – 135 Minuten Beleuchtungsfahrt – 135 Minuten Überlandfahrt – 90 Minuten Autobahnfahrt – 45 Minuten Beleuchtungsfahrt	5 4 3 3 2 1
01.01.2014	A1 auf A2 A2 auf A *(vor Ablauf von 2 Jahren)*	– 135 Minuten Überlandfahrt – 90 Minuten Autobahnfahrt – 45 Minuten Beleuchtungsfahrt	3 2 1
31.12.2019	A1 in B Schlüsselziffer 196	– 5 x 90 Minuten *(zur Hälfte Autobahn und Überlandfahrt)* *keine Fahrprüfung* *Mindestalter 25 Jahre, 5 Jahre Klasse B*	10

3. Entwicklung der Grundfahraufgaben

„Die Grundfahraufgaben dienen dem Nachweis, dass der Bewerber das Kraftrad selbstständig handhaben kann, die Grundbegriffe der Fahrphysik kennt und sie richtig anwenden kann", so die Prüfungsrichtlinie. [4,5,6] Sie erlauben dem Fahrprüfer in der Fahrprüfung festzustellen, ob der Führerscheinkandidat das Motorradfahren und das Motorrad beherrscht.

Bereits 1958 gab es erste Regelungen, die Grundfahraufgaben betreffend. In der Fahrprüfung wurden damals nur die „*Vollbremsung*" und das „*Verhalten mit Soziusfahrer*" geprüft. [3]

In der Prüfungsrichtlinie von 1971 gab es erste Beobachtungskriterien für den Fahrprüfer. 1976 wurde für die Klasse 1, „*die Beherrschung der Fahrtechnik in der Kurve, Besonderheiten beim Betätigen der Bremse und Bremsprobe*" in der praktischen Prüfung gefordert. Neben der „*Vollbremsung*" wurden „*Acht fahren*", sowie „*Kreis fahren*" geprüft. [3,4] Dem Prüfer wurde ein weitgehender Ermessensspielraum bei der Beurteilung der Prüfung eingeräumt.

Der Wegfall der alten Klasse 4 (50 cm³ ohne Geschwindigkeitsbegrenzung) und die Etablierung der Klasse 1b (80 cm³, 80 km/h) zum 01.04.1980 brachten für diese zwar eine praktische Prüfung jedoch keine gesetzlichen Mindestfahrstunden. Die damals für die Ausbildung von Fahrschülern benötigte Zeit lag im Mittel zwischen 6 und 10 Fahrstunden.

4. Der Stufenführerschein

Der Stufenführerschein – eine Begrenzung des Führerscheins nach Leistung – der zum 01.04.1986 eingeführt wurde, brachte umfangreiche Neuerungen. Die Ausbildung musste ab dem 01.10.1986 mit einem Funkgerät erfolgen, zum 01.01.1987 wurde der Funk auch in der Fahrprüfung obligatorisch. Nun fuhr der Prüfling in der Fahrprüfung voraus und konnte weitaus mehr Fehler machen als beim „einfachen Hinterherfahren". [8] Dennoch liegt die Nichtbestehensquote in der praktischen Fahrprüfung seit dieser Zeit bundesweit im einstelligen Bereich – 2018 bei 8,77 % , und damit an der Spitze aller Führerscheinklassen. Für Fahrschüler kamen 1987 neue Grundfahraufgaben in den Klassen 1 und 1a hinzu.

1988 – 1993
Der Direkteinstieg auf Klasse 1 entfiel zum 01. April 1988. Ab dem 01. April 1993 konnte nach zwei Jahren Klasse 1a und nachgewiesener Fahrpraxis von 4000 km, die (offene) Klasse 1 ohne praktische Prüfung beantragt werden. [9] In der Folge ging die Aufstiegsprüfung völlig zurück, und damit ein Baustein des Stufenführerscheins verloren.

1996
Zum 23.02.1996 wurde die Klasse 1b von 80 cm³ auf 125 cm³ Hubraum angehoben. Durch die Leistungssteigerung (max. 11 kW) wurde die Fahrausbildung auf der Autobahn (01.01.1997) möglich und vorgeschrieben sowie die Prüfdauer (01.02.1997) erhöht.

Tabelle II: Regelung vom 01.10.**1987** bis 01.06.**1998** [3,8,13]

		Klasse 1b 16 Jahre	**Klasse 1a** 18 Jahre	**Klasse 1** 20 Jahre
	Prüfungsdauer	30 Minuten 45 Minuten ab 1.2.1997	45 Minuten	60 Minuten
	Prüfungsfahrzeug	bis 80 cm³ bis 80 km/h ….............................. ab 23.02.1996 mindestens 95 cm³ mindestens 100 km/h [Anm. 1]	maximal 20 kW/27 PS mindestens 140 kg Leergewicht ….............................. ab 01.04.1993 maximal 25 kW/34 PS	mindestens 37 kW/50 PS mindestens 200 kg Leergewicht
	Grundfahraufgaben			
1	Schrittgeschwindigkeit geradeaus	A	O	
2	Stop + Go	A		
3	Trial-Stop			A
4	Bordsteinklettern 12 cm Höhe		A	
5	Kreisfahren 4,5 m Radius	O	O	
6	Schneckenkurve 20 m Durchmesser			O
7	Anfahren in einer Steigung 8-10 %	A	A	
8	Abbremsen aus 50 km/h	O	O	
9	Beschleunigen und Abbremsen			A
10	Bremsen in Schräglage 20 m Durchmesser			O
11	Abbremsen und Ausweichen	O	O	
12	Ausweichen aus 50 km/h			O
Summe	O = obligatorisch A = alternativ	4	5	4

5. Bewertung der Grundfahraufgaben

Anspruchsvoll und problematisch waren die drei folgenden neuen Grundfahraufgaben der (offenen) Klasse 1:

1. „**Trial-Stop**“. Der Proband fährt langsam im 1. Gang, bremst das Motorrad bis zum Stillstand ab, verharrt einen kurzen Augenblick und fährt wieder an, ohne die Füße von den Rasten zu nehmen.
2. „**Schneckenkurve**“. An einer markierten Stelle einer Kreisbahn von ca. 20 m Durchmesser verlässt der Proband die Kreisbahn um ca. 4 m nach innen, ohne dabei die Geschwindigkeit von mehr als 25 km/h zu verringern.
3. „**Bremsen in Schräglage**“. Der Proband fährt eine Kreisbahn von ca. 20 m Durchmesser mit ca. 30 km/h und bringt das Motorrad spätestens nach 12 m zum Stillstand, ohne von der Fahrlinie wesentlich abzuweichen. Bereits bei der Präsentation kam dabei zum Sturz. [10]

Die „ungeliebten Drei“ wurden nicht regelmäßig geprüft. Trial-Stop war „alternativ“ und mangels Fläche (mehr als 20 m Durchmesser) konnten „Bremsen in Schräglage“ und „Schneckenkurve“ nur auf größeren Plätzen geübt und geprüft werden. Antiblockiersysteme lagen zu diesem Zeitpunkt bei Fahrschulmaschinen in weiter Ferne, der Überraschungseffekt in der Prüfung war dementsprechend groß. Bereits im Erlass vom 21.03.1988 ging das Bundesland Hessen einen Sonderweg und prüfte diese drei Grundfahraufgaben nicht mehr. Einige Jahre danach verschwanden diese Übungen lautlos, der Nachruf hielt sich in Grenzen.

<u>Weitere neue Übungen waren</u>:

4. **Beschleunigen und Abbremsen**: Innerhalb von ca. 35 m (Schalten in den 2. Gang) sollte das Kraftrad auf 50 km/h beschleunigt werden, um danach mit höchstmöglicher Verzögerung das Motorrad zum Stillstand zu bringen. [11,12] Die Frage nach der Anwendung im öffentlichen Straßenverkehr ist vor dem Hintergrund des vorausschauenden Fahrens unbeantwortet.
Vgl. Punkt 8.1

5. „**Bordsteinklettern**“ (langsames Auffahren auf ein Hindernis) kam unglücklicherweise für die Klasse 1a hinzu. Hier wurde das Auffahren auf einem mindestens 12 cm hohen Bordstein geübt, das Abwürgen des Motors war zweimal zulässig. [12] Bereits nach wenigen Jahren wurde dies – da alternativ – nicht mehr geprüft. Nicht nur Kupplungen sondern auch kleine Prüflinge haben es gedankt.

Tabelle III: Regelung vom 01.06.**1998** bis 01.06.**2014** [13]

		Klasse A1 16 Jahre	Klasse A(b) 18 Jahre	Klasse A *Direkteinstieg* 25 Jahre
	Prüfungsdauer	45 Minuten	60 Minuten	60 Minuten
	Prüfungsfahrzeug	mindestens 95 cm³ mindestens 100 km/h [Anm. 1]	mindestens 250 cm³ mindestens 20–25 kW *(27–34 PS)*	mindestens 44 kW *(60 PS)*
	Grundfahraufgaben			
1	Schrittgeschwindigkeit geradeaus	x		
2	Slalom Schrittgeschwindigkeit		x	x
3	Stop + Go	x	x	x
4	Kreisfahren	x	x	x
5	Anfahren in einer Steigung 8-10 %	x	x	x
6	Abbremsen aus 50 km/h mit höchstmöglicher Verzögerung	x	x	x
7	Slalom 4 x 7 m	x		
8	Slalom 4 x 9/2 x 7 m		x	x
9	Abbremsen und Ausweichen	x	x	x
10	Ausweichen aus 50 km/h	x	x	x
	Summe	**4**	**5**	**5**

6. Überarbeitung der Grundfahraufgaben

In jeder Prüfung musste mindestens die Bremsaufgabe (6), eine Slalomaufgabe (7 oder 8) und eine Ausweichaufgabe (9 oder 10) durchgeführt werden.

Von den neuen Aufgaben ab **1998** fiel relativ schnell „Slalom mit Schrittgeschwindigkeit“ auf, da hierbei ein langer Radstand und hohes Gewicht der Prüfungsmaschine von Nachteil waren. Bis zur Einführung von ABS im Fahrschulsektor (2002 mit der BMW F 650 CS, 2004 mit Honda CBF 500, 2006 mit Kawasaki ER-6n, Yamaha FZ6 Faser usw.) waren die Übungen „Bremsung mit höchstmöglicher Verzögerung“ und „Abbremsen und Ausweichen“ bei nasser Fahrbahn für Fahranfänger die schwierigsten Fahraufgaben. Welche Fahrschulmaschine hatte keine Sturzspuren?

Tabelle IV: Regelung seit 01.06.**2014** [14,23]

		Klasse A1 16 Jahre	Klasse A2 18 Jahre	Klasse A *Direkteinstieg* 24 Jahre
	Prüfungsdauer	45 Minuten	60 Minuten	60 Minuten
	Prüfungsfahrzeug	mindestens 120 cm³ *(5cm³ weniger zulässig)* maximal 11 kW *(15 PS)* mindestens 90 km/h Leistung/Leermasse: ≤ 0,1 kW/kg	mindestens 400 cm³ *(5cm³ weniger zulässig)* mindestens 20–35 kW *(27–48 PS)* Leistung/Leermasse: ≤ 0,2 kW/kg	mindestens 600 cm³ *(5cm³ weniger zulässig)* mindestens 50 kW *(68 PS)* mindestens 180 kg Leergewicht *(5 kg weniger zulässig)*
	Grundfahraufgaben			
1	– Schrittgeschwindigkeit geradeaus – Stop + Go – Kreis fahren *(jeweils eine Aufgabe)*	A	A	A
2	Slalom Schrittgeschwindigkeit	O	O	O
3	Abbremsen aus 50 km/h mit höchstmöglicher Verzögerung	O	O	O
4	Slalom 4 x 7 m Slalom 4 x 9 / 2 x 7 *(jeweils eine Aufgabe)*	A	A	A
5	Abbremsen und Ausweichen	O	O	O
6	Ausweichen aus 50 km/h	O	O	O
	O = obligatorisch A = alternativ			
	Summe	**6**	**6**	**6**

7. Änderung der Grundfahraufgaben

Die bisherigen Grundfahraufgaben wurden **2014** in ihrer Wichtigkeit überarbeitet, das „Anfahren in einer Steigung“ entfiel. Seitdem ist die Übung „Slalom-Schrittgeschwindigkeit“ der Knackpunkt in der praktischen Führerscheinprüfung, insbesondere vor dem Hintergrund der länger gewordenen Endübersetzung bei allen Motorrädern. Hier entscheidet sich, wer mit dem Motorrad umgehen kann.
Der Bewerber hat dabei eine Slalomstrecke von 6 Leitkegel im Abstand von 3,5 m mit Schrittgeschwindigkeit (ca. 5 km/h) unter Beibehaltung des Gleichgewichts und mit richtiger Handhabung von Kupplung, Gas und Bremse zu durchfahren. Als amtliche Fehler gelten „Überschreiten der Schrittgeschwindigkeit, Auslassen eines Feldes, Umwerfen eines Leitkegels oder Absetzen eines Fußes auf die Fahrbahn.“
In der Prüfung gibt es dazu eine einfache Regel: Ist der Proband zu schnell, kommt er nicht fehlerfrei durch den Parcour, ist er zu langsam, kippt er um.

Die Übung „Stop and Go“ (mehrfaches Anfahren und Anhalten, mindestens 4 mal) hatte in der ersten Verordnung (1987) bei der Fehlerbewertung u.a. nur „Füße nicht auf den Fußrasten“. Ob ein Fuß oder beide Füße am Boden waren, wurde nicht explizit gefordert. In einer späteren Umsetzung wurde das wechselseitige Absetzen gefordert und in der neuen Richtlinie (2014) wird zweimal der eine, zweimal der andere Fuß zur Seite verlangt. [23] Das wechselseitige Absetzen eines Fußes stellt den Probanden in der Praxis vor höheren Anforderungen, gerade weil die Sitzhöhe bei neueren Motorrädern immer größer wurde.

8. Ausblick und Vorschläge zu Grundfahraufgaben

In jüngerer Zeit wurden neue Übungen vorgeschlagen und diskutiert. [7] Die Übungen „Fahren einer Acht“ – in Hessen in allen Motorradklassen bis 1998 geprüft, sowie „Bordsteinklettern“ – bis 1998 – waren bereits Grundfahraufgaben. Diese sind aus wohlüberlegten Gründen – rechtliche und technische – entfallen. Es gibt Prüfbezirke des TÜV, wo mangels Freifläche die Grundfahraufgaben nur im öffentlichen Straßenverkehr geprüft werden können. „Fahren einer Acht“ führt die Fahrlinie im öffentlichen Straßenverkehr in den Gegenverkehr und verstößt damit im Prinzip gegen die Prüfungsrichtlinie. Das „Bordsteinklettern“ schädigt die Kupplung des Motorrads und hat im Realverkehr keinen Mehrwert.

8.1. **Bremsen und Weiterfahren**

Gegen „Bremsen und Weiterfahren“ – ein umgekehrtes „Beschleunigen und Abbremsen“ – bestehen keine Bedenken. Die Übung zielt in Richtung motorische Geschicklichkeit des Probanden, und ist praxisbezogen. Beispielsweise schlägt die Ampel kurz vor dem Anhalten auf grün um, der Fahrer soll herunterschalten und sofort weiterfahren ohne die Füße von den Rasten zu nehmen.

8.2. **Bremsung mit Spurversatz**

Die „Bremsung mit gleichzeitigem Spurversatz“ wurde durch das Institut für Zweiradsicherheit in einer umfangreichen Studie von 2016 durchgeführt [15] und wird vorrangig für Fahrsicherheitstrainings empfohlen. [16] Diese Übung könnte mit der Durchdringung der leistungsfähigen Technik des Kurven-ABS (u.a. *Bosch MSC, Conti MK100)* durchaus im Rahmen der Klasse A (Auf – oder Direkteinstieg) als Prüfungsaufgabe eingeführt werden. Dass bei der aktuellen Prüfungsaufgabe „Bremsen und Ausweichen“ die Bremse vor dem Ausweichen – nach links um etwa 1 bis 1,5 m – völlig gelöst werden muss, ist nicht praxisbezogen und hinsichtlich der Priorität „Verringerung der kinetischen Energie vor einem Aufprall“ kontraproduktiv. [15,16,17] Warum sollte in dieser Situation versucht werden, an einem Hindernis vorbeizufahren, wenn man etwa 4,3 m davor halten kann? [Anm. 2]
Des Weiteren wird in der Prüfungsrichtlinie immer noch das „Herumlenken des Kraftrads um die Leitkegel“ bei dieser Übung als Fehler gewertet. Wenn das Institut für Zweiradsicherheit in seiner Studie von einer defizitären Fahrschulausbildung spricht [2], kann dies auch auf die aktuelle Prüfungsrichtlinie erweitert werden.[Anm. 3].

Mit der Übung „Bremsung mit Spurversatz“ könnte ansatzweise die **Kurvenbremsung** in die Ausbildung eingeführt werden.

Die Ausgangsgeschwindigkeit sollte bei 50 km/h liegen, wie alle Grundfahraufgaben dieses Limit haben, um innerhalb geschlossener Ortschaften durchgeführt werden zu können. Dann müsste man festlegen mit welcher Bremsverzögerung der Spurversatz durchgeführt werden sollte. Als Anhaltspunkt könnte die bereits erwähnte ifz-Studie mit einer mittleren Bremsverzögerung von 5,9 m/s² [15] gelten. Ähnliche Werte ergeben sich aus der HU-Bremsenrichtlinie [18] mit der Mindestabbremsung von 58 % sowie eine ältere Studie von Vavryn [19], die von einer durchschnittlichen Bremsverzögerung der Probanden von 5,8 m/s² ausgeht.

Demnach müsste der Bremsweg nach der Bremswegformel ($S= v^2/2a$) bei 50 km/h mit Spurversatz bei 16,35 m liegen. Durch zwei Markierungen 7 + 9 m, die jetzt schon bei den Slalomaufgaben markiert vorhanden sind, ist die Wegstrecke schnell ermittelt. Der Spurversatz könnte etwa ein Meter (die Studie des ifz hatte bei 50 km/h einen Spurversatz im Mittel von 2,1 m) betragen. Weiteres nach empirischen Messungen mit Fahrschülern.

8.3. **Abbremsen aus 50 km/h**

Bei der Grundfahraufgaben „Abbremsen aus 50 km/h mit höchstmöglicher Verzögerung“ wird seit der Durchdringung von Prüfungsmotorrädern mit ABS die Übung überwiegend so geschult, dass der Proband den Bremshebel und das Bremspedal sofort mit voller Kraft betätigt. Hinsichtlich der dynamischen Vorderradüberbremsung führt dies mit ABS zwar nicht zum Sturz, jedoch zu einer Verlängerung des Bremswegs, da die Bremse systembedingt wieder geöffnet und nach der Stabilisierung wieder mit einer neuen Bremsung begonnen wird. [20,21] Damit widerspricht diese Schulung im Prinzip der Prüfungsrichtlinie, die eine höchstmögliche Verzögerung fordert. Darüber hinaus führt diese Fahrtechnik bei dem eigenen Motorrad ohne ABS unweigerlich zum Sturz. Auch zeigt eine Studie, dass die Technik „Bremsrampe“ für den Fahrer weitaus zumutbarer und mit höherer Verzögerung vonstatten geht als die „Blockbremsung“. [22]

8.4. **Slalom 4 x 9/2 x 7 m**

Bei dieser Übung konnte in den letzten Jahren eine Verringerung der Wechselgeschwindigkeit bedingt u.a. auch durch die Zunahme der Reifenbreite (Hinterrad) beobachtet werden. Beispielsweise soll hier die Verdoppelung bei Yamaha erwähnt werden. Die Yamaha RD 250, eine klassische Fahrschulmaschine in den 1980er Jahren mit 3.50 Zoll (89 mm) und Yamaha MT-07, der Bestseller von 2019, mit 180 mm am Hinterrad. Die Unterschiede in der Schräglagenwilligkeit sind mit bloßem Auge zu erkennen. Durch eine Verlängerung der Zwischenräume der Pylonenstrecke könnte ein flüssigerer Richtungswechsel erzielt werden.

8.5. **Schräglagenangst**

Die technisch mögliche Schräglage beim modernen Motorrad sollte nicht durch Schräglagenangst derart behindert werden, dass weitestgehend nur mit 20 Grad Rollwinkel gefahren werden kann. [24,25] Ansätze zur Überwindung sollten bereits in der Fahrschulausbildung stattfinden. Als sichere Übung, zumindest für Rechtskurven, hat sich das Fahren mit gleichen Kurvenradien am Autobahnkreuz erwiesen, um die Fahrlinie zu korrigieren und die Schräglage zu steigern. Ein obligatorisches Schräglagentraining sollte m.E. nach einer gewissen Fahrpraxis vorgeschrieben werden, die Fahrschulausbildung stößt hierbei an ihre technischen Möglichkeiten.

8.6. **Elektromotor**

Die neue Prüfungsrichtlinie lässt Raum für Elektromotorräder in der Fahrprüfung, wobei die Leistungsdaten im Gegensatz zum Verbrennungsmotor geändert wurden. Das Elektromotorrad ist dadurch prinzipiell schwerer.

	Klasse A1	Klasse A2	Klasse A
Prüfungsfahrzeug (zum Vergleich Verbrenner)	maximal 11 kW Leistung/Leermasse: $\leq$ 0,08 kW/kg $\leq$ 0,1 kW/kg	20–35 kW Leistung/Leermasse: $\leq$ 0,15 kW/kg $\leq$ 0,2 kW/kg	mindestens 50 kW Leistung/Leermasse: $\leq$ 0,25 kW/kg
Mindestgewicht bei definiter Leistung (zum Vergleich Verbrenner)	137,5 kg (110 kg)	133–233 kg (100–175 kg)	200 kg (175 kg)

Für die Klasse A1 erfüllen (Stand 2020) nur drei Elektromotorräder die Prüfungsnorm u.a. wegen 90 km/h Höchstgeschwindigkeit, der (schwere) BMW Roller C erfüllt die Prüfungsnorm für Klasse A2. In der Klasse A sind die Premium-Anbieter Energica, Harley-Davidson und Zero vertreten. [27] Neben dem exorbitanten Preisgefälle sprechen die geringere Reichweite (mehrere Fahrstunden hintereinander?) und die lange Ladedauer der Batterien für den Verbrennungsmotor. Darüber hinaus müsste für Abbremsen und Ausweichen sowie Ausweichen ohne Abbremsen die Rekuperation abschaltbar sein.
Die Elektromobilität wird m.M.n. zumindest im Motorradsektor noch einige Jahre benötigen, für die Klasse AM (bis 45 km/h) eher kommen.

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Anmerkungen

1. Für die Fahrerlaubnisprüfung wurde die Höchstgeschwindigkeit des Prüfungsmotorrads auf mindestens 100 km/h festgelegt, das Fahren mit der Führerscheinklasse A1 war jedoch bis zur Vollendung des 18. Lebensjahrs auf 80 km/h begrenzt. Bis zur Neufassung der FeV vom 17. Januar 2013 galt dieser Widerspruch.

2. Das Lösen der Bremse, ca. 0,2 Sek vor dem Leitkegel entsprechen 1,8 m (bei 30 km/h)
Der Bremsweg bei 30 km/h nach der Gefahrbremsformel $S = \frac{km}{10} \times \frac{km}{10} : 2 = 4{,}5$ m.
7 m Entfernung von der ersten Pylone bis zum fiktiven Hindernis plus 1,8 m (Bremsbeginn davor), ergeben 8,8 m, minus 4,5 m (Bremsweg) = 4,3 m Entfernung zum Hindernis.

3. Vgl. https://ifz.de/wordpress/wp-content/uploads/2013/04/ifz-Studie_Motorrad-Fahrschulausbildung_20121.pdf S. 41 ff. „*62,0 Prozent der befragten Motorradfahrer [wissen] nicht, wie eine Kurvenfahrt bzw. ein Richtungswechsel eingeleitet wird.*“
Es ist davon auszugehen, dass dieser Anteil bei uninteressierten Motorradfahrern wesentlich höher ist.

Autoren: Klaus Schwabe (KTM RIDERS ACADEMY)
Dr. Sebastian Will (WIVW GmbH)
Dr. Klaus Bauer (LMU München)

Thema:

Motorcycle Motor Skill Level System – Definition von Fahrerfähigkeiten und Ausbildungsinhalten auf Basis von Realunfalldaten

Zusammenfassung

In mehreren Studien wurde gezeigt, dass ein Unfall in der Entstehung häufig auf das mangelnde Fahrkönnen des Einzelnen zurückzuführen ist (bspw. Bauer et al. 2014, Kuschefski et al., 2012). Basierend auf den Analysen von Realunfällen werden die Fähigkeiten verunfallter Motorradfahrer in Hinblick auf die Unfallursachen eingeschätzt. Auf Grundlage dieser Erkenntnisse wird ein Levelsystem zur Beurteilung motorischer und kognitiver Fähigkeiten von Motorradfahrern entwickelt. Weiter erfolgt eine Definition von Fahrerfähigkeits-Mindestlevels (motorisch und/ oder kognitiv) zur Vermeidung der als relevant ermittelten Unfallsituationen. Mit diesem Vorgehen soll auch eine Grundlage zur Bewertung bzw. Anpassung von Ausbildungsinhalten für Motorradfahrer geschaffen werden. Auch wenn der Fokus auf motorischen Fähigkeiten liegt, soll die kognitive Verankerung dieser Fähigkeiten durch die Unterstützung der korrekten Selbsteinschätzung erfolgen.

Die wesentlichen Kernbereiche dieses Levelsystems basieren auf der permanenten Anpassung folgender drei Säulen:

A) Aus Unfalldaten ermittelte, fehlende Fahrerfähigkeiten dienen im Levelsystem zur Festlegung notwendiger Mindestlevels.
B) Das Levelsystem soll die Motivation von Motorradfahrern zum Trainieren steigern. Es bietet einen Ausblick auf erreichbare Fähigkeitslevels sowie Unterstützung bei der Selbsteinschätzung der Hobbyfahrer.
C) Die Überprüfung und Festlegung von Mindeststandards bei der Aus- und Weiterbildung.

Motorcycle Motor Skill Level System – Definition of rider skills and training content based on accident data

Abstract

Different studies showed that a lack of skills of the individual motorcyclist is regularly recognized as main contributing factor to accidents (e.g., Bauer et al. 2014, Kuschefski et al., 2012). Rider skills that contributed to the accidents are defined founded on real accident data. Based on these findings, a level system for the assessment of rider motor and cognitive skills is developed. Further, a set of minimal rider skill requirements is defined, which would be necessary to avoid the analyzed types of accidents. This approach shall provide a basis for the evaluation respectively optimization of motorcycle training content. Even if focusing on motor skills a cognitive anchoring of different skills, levels and training content is necessary. Riders shall receive support for improving their self-assessment capabilities.

The motor skill level system is based on three main pillars that undergo regular adaptation:

A) Necessary rider skills that are defined based on accident data serve as input for the definition of minimally required skills.
B) The level system shall motivate riders to train their skills. It provides an outlook on what is achievable and supports a correct self-assessment of the riders.
C) The review and definition of standards for initial and post-license rider training.

One may assume that human beings aim at mastering situations that relate directly to their physical wellbeing as well as their experienced pleasure the best they can. Motorcycling as means of transport or as leisure activity can be regarded as one activity that is related to physical wellbeing due to the costs of an accident and pleasure due to the fact that at least in mid-European countries, motorcycling is mainly a leisure activity (Broughton & Stradling, 2005; Chesham, Rutter, & Quine, 1993; Will et al., in press).
Comparable leisure activities such as climbing or windsurfing have grades that define either skills of a person or challenges posted by a certain activity (e.g., climbing route). These grades and levels provide an orientation on achievable skills and allow every person to assess their own skill level. Typically, these scales refer to motor skills involved in the activity.

As there are similarities between the mentioned activities and motorcycling, this paper proposes a motorcycle motor skill level system to allow motorcyclists to classify their skills (guideline for self-assessment) and provide a collection of skills one may aim to accomplish (motivation to train).

It is important to see that cognitive skills provide the necessary framework on how to deal with motor skills. Every riders should benefit from a wide range of - ideally automated - motor skills that he or she is aware of, while at the same time only situations are pursued that leave a safety margin to master possible critical scenarios.
Further, it is obvious that it is not necessary for every rider to aim at the highest level. Same as for climbing, some riders may settle on a motor skill level that is sufficient to cover situations they seek. Hence, for any unexpected critical situation riders may benefit from automated action patterns gained in higher motor skill levels.

Different studies showed that a lack of skills of the individual motorcyclist is regularly recognized as main contributing factor to accidents (e.g., Bauer et al. 2014, Kuschefski et al., 2012). Rider skills that contributed to the accidents should ideally be defined founded on real accident data. Based on these findings a set of minimal rider skill requirements is defined, which would be necessary to avoid the analyzed types of accidents. This approach shall provide an empirically funded basis for the creation of different skills and consequently for the evaluation respectively optimization of motorcycle training content (e.g., define a start velocity for emergency brake maneuvers). Where appropriate, the motor skills coming from accident data are augmented with maneuvers that increase the riders' anticipation of motorcycle behavior given a certain input (optimized rider-motorcycle interaction).

As the motorcycle motor skill level system shall be used by every rider, the motor skills are typically defined as maneuvers, which are rather easy to understand for motorcyclists (e.g., emergency braking on a straight road from 100 km/h to standstill). The different skills should furthermore be clustered in actions that are easy to understand and that contain comparable maneuvers (e.g., braking, steering).

The proposed motorcycle motor skill level system may potentially be one classification among others that follow the same aim. For instance, depending on typical regional or national characteristics, the development of different motorcycle motor skill level systems might be useful (e.g., USA might have different accident types and consequently necessary skills than India). Also, the definition of five levels seems to be useful, but there is no strict reason for other classifications to create five levels themselves.

Table 1 provides an example about what the motorcycle motor skill level system could look like. It focuses on braking with a motorcycle equipped with ABS while going straight (no significant lean angle).

Table 1: Motorcycle motor skill level system for the domain "braking with ABS without lean angle (straight)".

Level	Skills
Level 1	Braking with the highest possible deceleration from 50 km/h
Level 2	Braking with the highest possible deceleration from 70 km/h
	Braking over a patch with reduced friction (e.g., dirt, gravel) from 50 km/h
Level 3	Braking with the highest possible deceleration from 100 km/h
	Braking over a patch with reduced friction (e.g., dirt, gravel) from 70 km/h
	Braking with a locked front-wheel for 0.3 m from 50 km/h (vehicle control in case of ABS malfunction)
Level 4	Braking over a patch with reduced friction (e.g., dirt, gravel) from 100 km/h
	Braking with a locked front-wheel for 0.5 m from 70 km/h (vehicle control in case of ABS malfunction)
	Trial stop (braking and stopping - without taking feet from footrests - and accelerating again)
	Stoppie from 50 km/h (controlled elevation of rear wheel)
Level 5	Braking with a locked front-wheel for 1.0 m from 100 km/h (vehicle control in case of ABS malfunction)
	Stoppie from 100 km/h (controlled elevation of rear wheel)
	Testing tire grip while riding
	Braking with the rear wheel in hair pin curves (no relevant lean angle) to stabilize the motorcycle (to standstill and accelerate again)

As noted before, the given threshold values do ideally come from accident data where available. It is not the aim to check whether a rider can handle a locked front wheel for 0.48 m or 0.50 m in order to "achieve" level 4. It is more about the general training of motor skills that allow to control the situation instead of showing a startle response that limits actions in hazardous situations. Same hoods true for maneuvers such as a controlled Stoppie. This motor skill is nothing to be used in public traffic for fun. It is about the general capability to handle a elevated rear wheel for instance in emergency situations instead of releasing the brakes due to shock.

It is clear that the self-assessment might differ from any external assessment of rider skills. Furthermore, some criteria such as highest possible deceleration can not simply be assessed or measured by every rider. This demonstrates the importance of professional rider trainings. These trainings can provide substantiated feedback for the riders due to their experience respectively the availability of measurement technique.

Currently, a motorcycle skill level system gets developed and will be shaped throughout the time with fruitful discussions among riders and experts as well as experiences with its applicability.

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A Comparison of Motorcycle Instructor Candidate Selection Practices In the United States

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Donald L. Green, Ed.D. M.Ed., B.S.C.S.

Rider Choices - Rider Education Consulting, Chester, New York, United States

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Abstract

An essential aspect of motorcycle rider education is how the instructor selection process impacts student learning, sometimes referred to as the human element, as it is a significant factor influencing curriculum success. Student and program achievements are partially contingent on instructors who understand the curriculum and facilitate student learning during instruction. Previous research on motorcycle rider education has emphasized a need for the examination of instructor selection and development, stating that quality education is reliant on instructors who are competent and qualified.

By applying an exploratory study method, state and military Motorcycle Safety Education Program Managers and Instructor Trainers were examined through telephonic interviews to develop a greater understanding of instructor candidate selection criteria and vetting processes.

The results suggest that changes in instructor candidate selection systems may improve decisions about a candidate's job and organizational fit.

Study conclusions indicate that use of multiple and thorough assessments to determine a candidate's motivation, social disposition, and emotional intelligence before preparation courses may better identify candidates and align potential job and organization fit within the discipline.

Applications of the findings would include a standardized selection process with improved interviews and pre-course auditing, and candidate expectation management before the selection to attend preparation or certification courses. The efforts potentially decrease long-term costs and deficiencies when candidates have an inconsistent job or organizational fit, departing from organizations after short periods or by not providing consistent quality instruction to students. The study recommendations, when implemented, can improve most educational disciplines where instructors are selected for technical instructional positions where students risk injury or harm.

Keywords: behavior; coaching; education; emotional intelligence; organization; job; fit; human resources; rider; safety; sports; training; transportation.

Introduction

An essential aspect of rider education is how instructor selection impacts student learning, a factor significantly influencing curriculum success (Daniello, Gabler, & Mehta, 2009; Senserrick, McRae, Wallace, de Rome, Rees, & Williamson, 2016/2017). Student and program achievement are dependent on instructors who understand the curriculum and facilitate student learning during formalized instruction. Baldi, Baer, and Cook's (2005) seminal research on motorcycle rider education emphasized a need for adequate supervision and training consumable by students, stating the quality is reliant on instructors who are competent and qualified. Moreover, a qualified instructor presents a defining model for students, placing value on increased consciousness, and good judgment while riding motorcycles to reduce risk and prevent harm (Arthur & Doverspike, 2001; Sensenrick et al., 2016). Therefore, this exploratory study used interviews to attain how instructor selection is considered by state program administrators and instructor trainers during candidate selection to inform the rider education discipline.

Problem. A problem in formal motorcycle rider education is the thoughtful selection of instructor candidates who demonstrate a good job and organizational fit to support the quality delivery of well researched and effective curricula in training programs. Kardamanidis, Martiniuk, Ivers, Stevenson, and Thistlethwaite (2010) recommend the need for more rider education research based on previous methodological weaknesses. Baldi et al. (2005) note there is a sizeable gap in knowledge about the impact of instructors who are selected as a critical mechanism to facilitate student learning, potentially decreasing crashes (Daniello et al., 2009; Horswill, 2016; Sensenrick et al., 2016).

Context and Literature Review. Studies on motorcycle rider education effectiveness have historically used motorcycle crash data in correlation with vehicle miles driven as a primary measure of efficacy. In doing so, researchers do not define the various factors, including instructor quality, which influence the delivery and retention of course content. Rarely considered in statistical analysis is whether the rider received any rider education at all, measuring the possible effects of inappropriate judgment and behavior, no educational exposure, or poor knowledge transfer during a rider education course (Aupetit, Riff, Butelli, & Espie, 2013; Haworth, & Mulvihill, 2005). As in all modes of safety instruction, it is challenging to research and document non-events caused by the effects of proper education. These events are sometimes referred to as lead events, as discussed by Loosemore, Reftery, Reilly, and Higgon (2006) as opposed to lag events currently used to measure crash causation. While collecting evidence is considered problematic, an assumption in rider education is accidents and fatalities do decrease with proper education, although to what extent is unknown (NHTSA, 2009). Regardless, without an exploration of instructor candidate selection, meaningful consideration of instructors as a catalyst for knowledge transfer remains a gap in understanding efforts to improve rider education instruction as a prophylactic countermeasure to motorcycle crashes.

Daniella et al. (2009) advise the wrong instructor can lead to ineffectiveness for formal education. Supporting this in a study on teacher self-efficacy, Feldstein (2017) submits the effectiveness of quality teachers, improves the instruction, improves student achievement, and reduces teacher shortages. While measuring effectiveness is problematic, it is equally challenging measuring positive outcomes when an instructor with the wrong fit or quality employs a curriculum improperly.

Saskia de Craen (personal communication, June 12, 2018), the senior researcher at Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV), The Netherlands Institute for Road Safety Research, explained that the quality of instructor is a crucial element for successful motorcycle rider training. Moreover, research on young driver training viewing identical curricula at different sites showed a negative impact by instructors who did not display job fit or trust in an organization or the curriculum's educational methods. By not preparing to give the course wholeheartedly, using the curriculum as intended or designed, the student outcomes became negatively impacted (de Craen, Vissers, Houtenbost, & Visk, 2005).

Instructor competence is an essential cornerstone of driver education, as described by Gregersen (2005). The knowledge to employ curricular lesson plans is necessary for creating a situation where instructors must not only understand the content but be able to explain all aspects of what the student should know and why that information is crucial. Moreover, quality instructors display the skill of pedagogical self-efficacy, best defined by a person's belief about being able to complete a specific task as described by Uhl-Bien, Schermerhorn, and Osborn (2014). Qualified and knowledgeable instructors use whatever tool is necessary to help individual students incorporate curricular material into their long-term memory and behavioral actions for continual use (Bandura, 1997; Danielson, 2007; Feldstein, 2017).

Guidance on instructor selection from the U.S. National Highway Traffic Safety Administration (NHTSA, 2014) recommends a national standard that includes qualification criteria, which are purposefully vague and flexible to accommodate the many different programs and curricula choices. However, state programs use the NHTSA recommended criteria for instructor selection in a manner that may have little to do with an instructor's ability to use pedagogical methods for relaying content. The recommendations may focus more on social compliance criteria than an ability to share information on wide-ranging topics and interacting well with others. As a result, Haworth and Mulvihill (2005) submit the matters associated with rider judgment, assessing risk, and developing motor skills are delivered differently from place to place, often affecting the curricular intent and the safe operation of motorcycles.

Another cogent problem is instructor quality and the impact on rider education to employ focused curriculum components effectively to individual students. Instructor ability necessitates consistency with an educational method to successfully facilitate student learning in an accelerated manner without losing a group or individual's attention (Akhmetova, Kim, & Harnish., 2014; Senserrick et al., 2016/2017). An instructor is a conduit for successful knowledge transfer between curriculum and students; an inappropriate or off-topic emphasis by the instructor may well affect the retainment of desired course content. When an instructor does not have the knowledge or ability to present the curricular material as intended, the student may leave with a piece of limited knowledge or worse - an inappropriate understanding of the content (Bandura, 1997; Senserrick et al. 2016/2017). Dewey (1938/2015) made an essential clarification to this point when he explained that experience and education are not synonymous; not all experience is educational, and inappropriate experiences are counterproductive.

Purpose. Beyond the sphere of instructor influence, the novice rider course has historically been the main opportunity for formal education to enhance rider survivability since graduated motorcycle licensing or tiered training is not consistently used with motorcycling in the United States. Instructor selection and appropriate use of pedagogy then become the main factors for student learning and skill development provided during the educational process.

Haworth and Mulvihill (2005) describe the emphasis on motorcycle roadcraft control as a skill essential for students, yet also suggest other behavioral aspects of rider education emphasized haphazardly or not enough. Many consider judgment and risk management underrepresented in the teaching of course content (Aupetit et al., 2013; Dorn, 2005; Dorn & Brown, 2003; Rowden, Watson, & Haworth, 2012; Vidotto, Tagliabue, & Tira, 2015). The connection between content and sustainable knowledge transfer in rider education resides with a competent instructor able to analyze the learning environment and provide the appropriate direction to a student (Bandura, 1997; Danielson, 2007; Feldstein, 2017).

In a study by Bramley, Rodriquez, Chen, Desta, Weir, DePaul, and Patterson (2018), a parallel is formed with Motor Learning Principles (MLPs) of Physical Therapy students in Canada. Findings suggest a knowledge-practice gap from programs where student learning is not fully supportive of the needs of a student MLP needs, focusing more on the neurological curriculum. If instructors do not understand or teach all relevant material, the student will only receive what the instructor relays. In rider education, MLPs are important and emphasized excessively; however, behavior and rider judgment typically is not accentuated enough where many experts in traffic safety believe it is a primary cause for crashes (Evans & Schwing, 1985; Evans, 1991, 2004; Dorn, 2005; Breakwell, 2014).

Person organizational fit is desirable in teaching endeavors, and behavior specialists Uhl-Bien et al. (2014) suggest the combination of values, behaviors, and interests match well with the culture and professional requirements of an organization. An instructor with poor organizational fit can undermine the value of the culture and curricular material. Uhl-Bien et al. (2014) also define employee job fit as the interests, skills, and characteristics necessary to deliver the requirements associated with a position. If the improper instructor is selected, it may be considered antithetical to quality rider education. Either issue of fit could potentially endanger the well being, health, and safety of students. Both organizational and job fit also relate to the competence of instructors, which helps to define what is considered a good employee or instructor fit. Oliveira (2015) describes employee [instructor] fit best as consistent with what the selector knows are the characteristics and attributes needed for the job and organization, as evidenced by a manager's extensive experience.

Although research on the efficacy of driver/rider education continues to produce mixed results, as previously stated, inquiries cite the variables of instructor impact as the topic leaving a gap in understanding (Aupetit et al., 2013; Baldi et al., 2005; Tagliabue, Gianfranchi, & Sarlo, 2017). A universal assumption is that a more knowledgeable motorcyclist can make better riding decisions. Quality entry-level motorcycle rider curriculum contains well-researched life-saving information, but the accurate relay of the lesson plans are contingent on instructors having the appropriate skills, characteristics, attributes, values, behaviors, and interests for facilitating knowledge transfer. Additionally, the instructor must match well with the culture and environment of the organization, modeling appropriate and safe riding behaviors as role models for students, demonstrating the need for a quality selection process to identify good candidate fit.

Before the risk of life or limb becomes a consequence of instructor guidance, programs that accurately assesses candidate fit could enhance the future educational process, improving preparation and certification course outcomes making the findings of this research beneficial.

Research Questions. In the examination of the significant issues, three questions guided the qualitative interviews:

RQ1: How do motorcycle education program administrators and instructor trainers describe the criteria and vetting processes used to identify potential instructor candidates?

RQ2: How do motorcycle education program administrators and instructor trainers describe the quality characteristics and attributes of candidates?

RQ3: How do motorcycle education program administrators and instructor trainers describe the measure of candidates at the completion of the selection process?

The research questions provided an exploratory line of inquiry for understanding instructor candidate selection in motorcycle rider education in the United States. The results of this study establish a foundational perspective for future studies in rider education and other educational disciplines where instructors are integral to program and student success.

Method

An exploratory research method offered a more in-depth understanding of the views belonging to the more experienced and most informed program managers and instructor trainers in the profession. A 30-minute telephonic semi-structured interview used probing open-ended queries to answer the three research questions. By analyzing the thoughts and perceptions of multiple managers and trainers, the intent was to compare insights of the sample on the selection processes to identify useful selection models.

The transcribed interviews were verified by participants to ensure accuracy and trustworthiness through member checking. The sample was analyzed multiple times manually and by using NVIVO software to obtain a holistic sense of the information. Text segments were identified, annotated, and then divided into codes and end themes developed through the collective grouping of terms. In the absence of one exemplar selection model to extract from the interviews, the information developed into a list of individual practices best reflected by programs and trainers, further confirmed and supported by contemporaneous organizational behavior and human resource literature.

Participants. Recruiting of study participants was accomplished through emails garnered through state government agencies and public announcements on formal and informal social media websites. Limitations included program managers and instructor trainers between 30 and 65 years of age, with at least five years of motorcycle instructor trainer experience. Those who replied signed consent documents, verified they met the inclusion criteria, scheduled meetings, and participated in telephonic interviews. A total of 13 volunteer respondents were vetted and met the criteria included in the research, differentiated as eight Instructor Trainers (IT) and five Program Managers (PM) in the final sample.

Of the potential 60 states, military, and organizational PMs in the United States, 20 validated to have met the research inclusion criteria, with five opting to participate in the study. It is important to note that two-thirds of the PMs have little experience instructing motorcycle rider education and-or have limited exposure to the necessary characteristics and attributes for instructing riders or for training instructors to instruct riders. Each of the 60 contacted PMs are paid by the government or the motorcycle industry for their positions to make decisions impacting instructor selection to ensure the success of motorcycle rider education programs.

184 ITs received direct contact emails in the known IT population of over 214. Nine accepted invitations and did not follow through, 12 declined for various other reasons, and eight consented to participate. It is difficult to determine the activity and status of all ITs since personal data is maintained under privacy rules making them publicly inaccessible. Pay is a variable difficult to determine based on program structure but is generally attributable to the amount of work and geographical location of the organization having oversight. ITs serve the limited needs of sponsor organizations depending on the population, and dispersion is from two to five per organization or program.

Some contactable ITs did not meet the selection criteria, either with too little experience or presented as older than the IT selection criteria. The limitation based on research criteria highlighted the many ITs serving in the trade beyond the age of 65. Future studies should account for the possibility ITs serving well beyond normal retirement age.

The average age of participants in this research was 58 years old, with the youngest being 39 years old and the oldest 65 years old. Based on the selection criteria, experience averaged 23 years with the least being nine years, and the most 37 years. Collectively, experience in Motorcycle Rider's Education was 301 years. Represented within the participants were two distinct curriculums, representatives from three different industry manufacturers, and trainers with experiences from 24 different states.

Results

The interview transcripts were analyzed by the researcher to develop themes providing an understanding of the participants' perceptions. The themes were determined primarily by the three research questions aligning with RQ1: instructor candidate selection and vetting process, RQ2: characteristics and attributes of instructor candidates, and RQ3: measure of candidates after the selection process (pre-certification). The noted representative comments exemplify the collective respondents' views, using the pseudonyms of Program Manager (PM##) and Instructor Trainer (IT##) to differentiate the multiple participants in their own words.

RQ1: Candidate selection and vetting processes. Qualitative interviews of State Motorcycle Safety Education Program Managers (PM) and Instructor Trainers (IT) provided an understanding of instructor candidate selection criteria and vetting processes. A broad range of answers and methodologies signified the use of the consistent, yet minimal guidance proposed by NHTSA (2014). One state program administrator expressed:

> My role in [candidate] selection in the state is very much one of leadership…The state accepts applications for any and all wishing to teach… All applications are routed through my office. Myself, [with] the support of my administrative team, we first vet the application to make sure the candidate at a minimum, passes the requirements set forth in the state program rules (PM01, 2019).

In states without formal programs, instructor trainers may act on behalf of private sites, the motorcycle industry, or U.S. military sites to handle the screening process. Three of five program managers and one in eight instructor trainers spoke of formal written standards for candidate recruitment and selection. Typically, programs use or build upon NHTSA's (2014) written recommendations and curricular material:

> The state has no requirements at all… [industry company] actually has no requirements other than they recommend [instructor] candidates are interviewed, and they meet some loose recommendations for a source of the candidates…but they make no recommendations beyond that. I do interview them [candidates], and it largely is based on [my] experience for having poorly selected candidates in the past. I've gradually learned what things I need to look for. In things actually than look for, things to listen for (IT01, 2019).

All respondents discussed interviews citing at least a short phone conversation by state program managers or instructor trainers. In other cases, informal collective information sessions or levels of interviews with multiple program team members was the policy. The candidate interview process was most commonly handled informally and inconsistently through day-to-day interactions, with some research participants questioning how useful they were.

Typical vetting questions were about general topics like "why do you want to become an instructor?" While others used information from written or electronic applications to discuss the applicant's motivations through probing, open-ended questions. More structured programs used multiple interviews by state program managers, instructor trainers, instructors, site providers, or site managers to develop stronger profiles of their candidates. While in at least some less structured programs, individuals were accepted merely upon meeting the NHTSA recommendations:

> I wouldn't call it really a formal interview process. The requirements we have are, they're not super heavy… it's very rare that anybody does not qualify for the basic things, so we've never, I've never really done any one-on-one [interviews]. … we've never called candidates in for a face to face interview. … there's nothing else that we can do to eliminate a candidate. We have to go by the letter of [the] regulation (PM04, 2019).

> I contact every one of those folks who are interested in becoming instructors, I interview them. We spend quite a bit of time on the phone…once referred to the [training] site and the site decides to sponsor that instructor candidate… I'll have a second interview with them (PM05, 2019).

> It's almost a warm body theory out there to get them in the front door, and then you try to weed out who may not be the best candidate [during the instructor preparation course] (IT02, 2019).

> We joke about if you can fog a mirror, you can do that [be a candidate] (IT04, 2019).

> I get the honest impression that 99 percent of it was, in the beginning, a good ole boy type of thing. …the only real interviews that you got was what we did during the [instructor preparation course] (IT08, 2019).

In some programs to explain the job requirements and expectations involved in being an instructor, information sessions or discussions informed candidates of the position. In some cases, program managers and instructor trainers used the opportunity to discourage less motivated candidates by exposing the less glamorous side of the profession:

> We are sometimes, to our own detriment, …dissuade anyone from actually carrying forward… We remind them that it does require a lot of upfront preparation, there is a financial investment, …as well as a considerable time investment. … it's not a lucrative profession, but rather one that is very gratifying emotionally (PM04, 2019).
>
> I am upfront and honest [to candidates] about what I think [their] liability might be (PM04, 2019).
>
> I make sure that they understand how much time they're committing and how it's going to affect them. Not only during the training program, but during the off days when they go home, and they've been working for 10 days in a row … between their personal jobs and this training just to see if they're willing to make some of those sacrifices. I will state to everyone how labor-intensive it is. I explain early on the time commitment (IT06, 2019).

Some respondents discussed vetting a candidate through action as a method to assess the candidate's interest. If the candidate volunteered to observe or participate in courses as range aides before selection, they reasoned the candidate showed motivation, interest, and an inherent desire to be an instructor:

> [Candidates] complete an online application. So that initiates the process…our applicant liaison will contact that person to set up a time to talk to them on the phone…signing [candidates] up for their audit assignment. …[candidates] do their audit

> assignment out in the field, the instructors that they audit also evaluate the applicant. …after the audit is complete when we have evaluation forms, and they're on assignment, then the training manager determines whether or not they're going to interview the candidate (PM02, 2019).

> Prior to them actually getting to [the] training they are encouraged to actually get out and interact with some of our team in a class environment. Observing and interacting with other instructors. So, that tends to give us some insight. …a lot of it is just gut impression during the interview process (IT03, 2019).

The term most often used for this type of vetting was "auditing" a course as a student or range aide, to further develop an understanding of the requirements as an instructor. The task helped to vet those who were interested, potentially dissuading some candidates, yet identifying their desire and willingness to participate in the educational process. In some programs, the audit requirement is outlined in policy documents and expected of all candidates, whereas other programs merely suggested participation as a recommended way to prepare. Some programs did not have an audit process at all.

RQ2: Characteristics and attributes for candidates. Respondents used similar terms when describing the features and qualities of potential candidates. Although not always articulated concisely, the construct of Emotional Intelligence (EI), defined as the ability to manage oneself and one's relationships with others, was mentioned in varying ways by all respondents (Goleman, 2005; Mortiboys, 2011; Uhl-Bien et al., 2014). A high level of EI is considered an active component in being able to facilitate learning by creating bridges of understanding and using empathy as a tool to interact with others in adult learning:

> The qualities that we look for, having the soft skills, people skills, to interact with students and represent the program in a positive light. You know, the kind of intangible things like integrity, honesty, and just being able to generally interact well with others…(PM03, 2019).

> I want a role model both, I want a boy scout or a girl scout. I want someone who has impeccable character, patience, and who can be a mentor to our students the same way the quality assurance specialist is a mentor to the [instructors] (PM05, 2019).
>
> Within the first five minutes, gauging their experience as far as teaching, mentoring, coaching, identifying the self-motivation, seeing where all that sits. …see if you can get emotional intelligence out of it, and that's you know, a conversation with them about things to see what their emotional intelligence is (IT02, 2019).

Also mentioned, was the ability for potential candidates to be life-long learners capable and willing to seek new knowledge and continued growth as an individual and educator:

> You can kind of get a general idea, is this something [they're] interested in? Do they have a positive attitude toward the whole thing? Their attitude and motivation [are] a big part, you know their willingness to come out and learn. …what extra work can they do to make them a better instructor down the road (PM03, 2019)?
>
> I listen for enthusiasm, I listen for curiosity, I listen for willingness to learn. …how readily they will reconsider a position based on something they've seen or something they've been told. …I look for flexibility (IT01, 2019).

All respondents suggested that motorcycle riding skills and knowledge were necessary for being an instructor, but also acknowledged that they were secondary to high EI. Some respondents mentioned a necessity for candidates to have observation skills and provide proper guidance to students as highly desired characteristics and attributes of a model candidate.

RQ3: Measure of candidates at the completion of selection. Varying degrees of selection activities affect the determination of employability at the end of the candidate selection. Some programs use more thorough processes to vet potential candidates, while others by policy or choice, allow anyone who aspires to be an instructor to go directly to the instructor preparation course where formal certification uses a pedagogical vetting process. After the selection process, participant's expressions were consistent with the characteristics and abilities section of the study, even for those not having a selection and vetting process going beyond the NHTSA recommendations for instructor selection. Again, NHTSA recommendations have little to do with candidate quality or the ability to use pedagogical methods for delivering course content.

> Selection is hard…It's choosing the right people. There is a qualitative factor. …the team perspective and if the group believes that this candidate is strong…we follow the group mentality. …someone who is seeking a job will say what they think you want to hear to get the job. So, the trick of it is to kind of listen to what's not being said. … it's an art and skill (PM04, 2019).
>
> [I want] an emotional commitment to both the training program, riding, riding safety in general, and to the team [before sending to prep] (IT03, 2019).
>
> So that's what I am talking about fit, somebody that's totally up-front and honest with you right off the get-go and they are who they say they are. Motivation and desire…to do that type of work…to be that help agent, to help somebody reach their goals (IT05, 2019).
>
> …to clarify, we don't ever compromise the end goal or the end of completion requirements, but we will keep weaker candidates through the training process when we have low numbers (IT06, 2019).

The responses from participants provided an initial understanding of instructor candidate-job and organizational fit perceptions in the motorcycle education community. Once again, as discussed by Oliveira (2015), the manager's extensive experience is key to recognizing the characteristics and attributes necessary for a job and organizational fit. What was not definitively expressed by participants was a true measure of what a quality candidate should be, potentially opening the selection process to mismatches in personnel to a job and organizational fit.

Discussion

With the varying sizes of programs and differing regulatory or policy constraints among the states, it is difficult to use a one-size-fits-all approach for candidate selection. There are, however, best practices that, when implemented, show promise in selecting better candidates who are more suitable to represent program goals. The results identified areas of significant emphasis for improvement, given programmatic implementation of known best practices. Areas include 1) enhanced recruiting efforts, 2) conducting multiple interviews with multiple team members, 3) more robust screening activities like auditing of courses for candidates, 4) comprehensive assessment of candidate EI, 5) detailed documentation of processes, and 6) further research within the field to fully measure selection outcomes.

The study results highlighted differences of opinion and knowledge between program managers and instructor trainers where answers were incongruent regarding how screening processes were employed and the degree of success. Specifically, the use of selection interviews was a point of contention for instructor trainers not thoroughly included in candidate selection vetting activities with program managers before certification courses. Written policies or requirements, often considered as common knowledge in the field, may not have been effectively documented or communicated to organizational levels below that of PMs, creating potential tensions. A strong recommendation is for programs to verify and detail all processes thoroughly, distribute the findings widely to prevent knowledge silos, ensure all personnel can understand the program's intent, and facilitate consistent usage by teams (Hannon, Hocking, Legge, & Lugg, 2018). Lemke (1995) supports the assertion by recommending well designed and implemented plans of induction raise retention rates from 50% to 85%.

The most thorough vetting systems included written or online applications as part of or immediately after recruitment. After recruitment, multiple levels of formal and informal interviews, requisite audits, evaluations, and preliminary written assignments display the potential of candidate efforts before preparation or certification courses. The least restrictive programs relied wholly on curriculum preparation and certification courses using assessment and qualitative selection criteria embedded in a minimal and often time-constrained process. By having a more robust system of screening candidates with multiple interviews, audits, and assignments, programs decrease the potential of selective screening bias as described by Uhl-Bien et al. (2014) and Oliveira (2015), where a limited portion of available candidate information enters the perception of a single candidate selector. A recommendation is to research further the differences between the most thorough and least restrictive methods of selection and quantifiably compare the outcome of selected candidates.

Respondents expressed a more developed EI as a desired attribute. The building blocks of EI, as defined by Goleman (2005), include self-awareness, self-regulation, motivation, empathy, and social skill, all characteristics described as desired in candidates by all participants in the interviews (Uhl-Bien et al., 2014). A recommendation is to increase the vetting and screening of applicants to assess candidate EI before admittance into expensive and time-consuming preparation courses. The practice could potentially decrease training costs, decrease the amount of turnover, decrease human resource management costs, and decrease instructor organizational fit tensions — the human factor.

Similarly, it is a consideration of longevity when a candidate minimally passes the preparation course or does not fit the culture necessary for adult learning, departing the program shortly after significant time and investment. A recommendation to achieve a better screening process includes multiple interviews or assessments by different levels of organizational members (Oliveira, 2015). By monitoring for inconsistencies in responses and actions, a complete valuation of the candidates EI, either through the interview process, formal assessments, or auditing, may be achievable before preparation course acceptance to clarify and help determine job and organizational fit.

Some respondents identified the need for accepting all candidates ostensibly to participate and act as filler candidates for courses to have enough participants. Although this practice may foster some success, a recommendation would be to recruit more viable candidates with stronger EI to enhance and accelerate learning in preparation courses. Interestingly, the characteristics and abilities most sought are those best fulfilled by professionals in the teaching, coaching, and education fields. When asked about the value of having an educational or teaching background, most participants downplayed the significance.

This study exposed multiple variances in instructor candidate selection methods in motorcycle rider education in the United States, which can affect the quality of student and program outcomes. Previous research recommended future study based on previous methodological weaknesses, this research considers the impact of candidates and hence instructors selected as a critical mechanism to facilitate student learning and also recommends deeper exploration of the topic (Baldi et al., 2005; Daniello et al., 2009; Kardamanidis et al., 2010; Horswill, 2016; Sensenrick et al., 2016).

Conclusion

Individual programs must determine the advantages of additional selection requirements to improve quality. The effort and time spent on candidates who do not have the desired characteristics and abilities to fit with current culture or to complete a preparation course is a significant consideration. Recruitment and screening practices commonly used in human resource domains, as reinforced by organizational behavior research, could be invaluable for determining strong candidates as the need for competent instructors continues.

The results of this study identified basic practices for the improvement of instructor selection processes, suggesting early candidate assessment might identify stronger emotional intelligence as a primary way to differentiate better instructor fit. By using basic interviewing techniques and auditing to assess candidates before preparation courses, emotional intelligence determination and motivations could substantially increase candidate quality, translating to quality of student learning in motorcycle rider educational environments.

Practical application

Application of this research in motorcycle rider education and other instructor-led educational disciplines may potentially decrease the long-term effort and cost of sending candidates through preparation courses or overly extensive onboarding processes, ultimately resulting in poor outcomes. The practices, when implemented upfront, could improve an instructor and organizational quality when selection addresses a holistic fit instead of meeting the minimal conventional compliance-based hiring criteria. A subsequent investigation could further this study by analyzing the impact of the candidate selection on the longevity of instructor employment and instructor efficacy by monitoring student outcomes in a longitudinal study.

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Vitae

Donald L. Green was born in Fort Wayne, Indiana, serving over 21 years in the military as both enlisted and officer. As a helicopter pilot he specialized in training and development, leadership, and operations continuously seeking education including attendance at the U. S. Army Command and General Staff College at Leavenworth, Kansas.

Don has a Doctorate of Education from Maryville, University of Saint Louis, Missouri, a Masters of adult education from Troy University, Troy Alabama and a Bachelor's of Science in Computer Science from Central State University, Wilberforce, Ohio.

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Corresponding Author

Donald L. Green
60 Pewter Circle
Chester, NY 10918
dgreen5@live.maryville.edu
Mobile: (US 001) (270) 945-1903

SAFE STRIP: Hardware in the Loop motorcycle simulator experiment for C-ITS applications

Ioannis Symeonidis[1], Nikos Dimokas[1], Ioannis Gragkopoulos[1], Ioannis Tsetsinas[1], Evangelia Chrysochoou[1], Katerina Touliou[1], Giammarco Valenti[2], Francesco Biral[2], Maria Gkemou[1], Evangelos Bekiaris[1]
[1]Hellenic Institute of Transport, Centre for Research and Technology Hellas, Greece
[2]Department of Industrial Engineering, University of Trento, Italy

Abstract

The SAFE STRIP project (SAFE and green Sensor Technologies for self-explaining and forgiving Road Interactive aPplications) introduces an electronic road strip technology that can provide C-ITS functionality to existing road infrastructure. The SAFE STRIP technology among other vehicles has application also to motorcycles. SAFE STRIP can detect critical events such as vehicles traveling in the wrong direction on the highway, adverse weather conditions, deteriorated road surface and inform the rider with intuitive personalized messages in his language. Experiments took place before field tests in order to verify the correct functionality of the V2I communications (Road Side Unit), the decision logic (Co-driver and DSS) and to assess the HMI (smartphone app) of the SAFE STRIP prototype technology. The CERTH-HIT motorcycle simulator was used to test the system in Hardware in the Loop configuration. Communication, decision logic, HMI and simulator deficiencies were tuned and corrected during the experiment. No virtual accident happened while the system received mainly positive feedback from the riders.

1. Introduction

The SAFE STRIP project (SAFE and green Sensor Technologies for self-explaining and forgiving Road Interactive aPplications) introduces a road solution, the so-called "strip", that can provide C-ITS functionality exploiting the existing road infrastructure aiming at a more consistent and in-time warning with regard static and dynamic environmental, traffic and road conditions in order to prevent critical traffic incidents. The SAFE STRIP technology among other vehicles has application also to motorcycles. SAFE STRIP, through its multisensorial platform and built driver and rider applications, can detect various critical events such as vehicles traveling in the wrong direction on the highway, adverse weather conditions, deteriorated road surface and inform/warn the driver/rider with intuitive personalized messages in their language. The relevant information arrives far earlier before visual contact so the rider has enough time to adapt his/her speed and overall driving behaviour.

Experiments took place prior the field tests in order to verify the correct functionality of the Infrastructure-to-Vehicle (I2V) and V2I communications enabled through a custom Road Side Unit (called Road Side Bridge - RSB), the decision logic (co-driver and Decision Support System (DSS)) and secondly, to assess the Human Machine Interface (HMI) of the SAFE STRIP prototype solution. Users experienced the solution through a smartphone application. Hardware-in-the-Loop (HiL) methodology was used for the experiments.

In HiL simulation a part of the real hardware is included in the simulation loop during system development. Rather than testing the control algorithm on a purely mathematical model of the system the real hardware is used in a simulated environment that can provide the appropriate signals. HiL simulation is used for the design of anti-lock braking systems (ABS), traction control systems (TCS), suspension systems and others (Bacic 2005). In our case the real hardware was the cloud infrastructure and the smartphone while the simulated environment was the motorcycle simulator the road strips and the RSB. The virtual implementations communicated with the cloud implementation, while warning messages were sent to the smartphone from the cloud.
The objectives of the experiments were:

2. to test and tune the function and communication of the SAFE STRIP components,
3. to study the reaction of the volunteers to the warning messages, and
4. to collect feedback from the volunteers concerning the system and its application for motorcycles.

All the above objectives were addressed before the field experiments.

5. Materials and Methods

The experiments were performed with the CERTH motorcycle simulator (Fig 1) (Nehaoua 2007, Symeonidis 2018). The motorcycle simulator represented a non-equipped with V2x and IVIS (In Vehicle Information System) vehicle.

Figure 1: CERTH Motorcycle simulator, the app running on the smartphone and a warning message.

The volunteer rode the simulator and during the ride warning messages (Fig 1) appeared on the smartphone attached with a grip to the handlebar while audio warnings were sent to the rider's headset to prepare the volunteers for a critical event in their course.
Two simulator setups and two scenarios were tested (Table 1).

Table 1 Motorcycle simulator scenarios

	Setup 1		Setup 2	
Road condition	Dry road		Wet road	
Scenario	Pedestrian	Wrong way driving	Pedestrian	Wrong way driving

The difference between the two setups concerned the road traction available for braking and acceleration. In Setup 1, the maximum traction allowed a braking deceleration of 7 m/s^2, while in the wet road conditions the maximum deceleration was 3.6 m/s^2.
The two different scenarios concerned the critical event. One was a vehicle entering the highway from a highway exit (Fig. 2) and the other a pedestrian crossing the road (Fig. 3). Virtual road strips were simulated on the simulator on the road of the highway exit and on the pedestrian crossing.

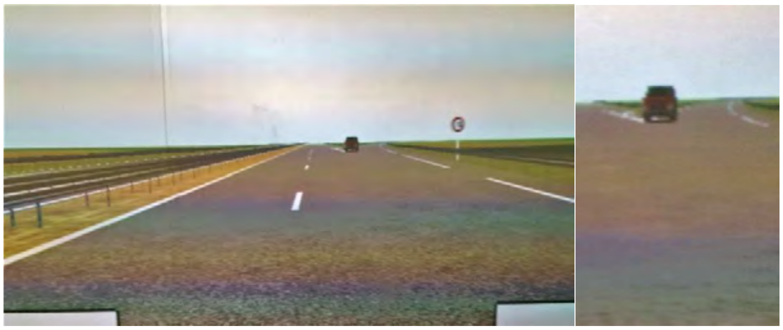

Figure 2: The wrong way driving scenario with the car entering the highway from a highway exit (view from the motorcycle rider and zoomed view)

Figure 3: A pedestrian crossing the road on a crossing (view from the motorcycle rider and zoomed view)

For the realization of the scenarios apart from the motorcycle simulator, the Hardware, in the Loop, was a cloud server and a smartphone. The cloud server was running an MQTT broker, the critical event detection logic (Co-driver) and a warning message prioritization system (DSS). The smartphone functioned also as the virtual RSB for the road strips.

In more detail the Co-Driver module implements a virtual agent used to understand what the driver is doing with respect to the potential incoming danger (i.e. pedestrian on cross walk or wrong way driving vehicle) and issuing a warning if a safe manoeuvre is available to achieve the goal required by the driving scenario (e.g. stopping at a cross-walk). The Co-Driver module receives the potential danger via DENM message it calculates all the feasible and human like (smooth and optimal) manoeuvres to stop the vehicle before the danger given the actual vehicle state (i.e. velocity, acceleration and distance to the danger) (Da Lio 2018). The manoeuvres also consider the potential traction available in the specific portion of road.

The Co-Driver rates all the computed manoeuvres based on the effort necessary to change the longitudinal dynamics (i.e. acceleration and speed) in order to enter in the safe state (i.e. stop before the danger).

The following paradigm explains the line of communication. The motorcycle emits its position with the smartphone application while information from the road strips is sent to the cloud server through the RSB. The cloud server detects critical events with the Co- driver component and prioritizes warning messages with the DSS before emitting them. The warning messages are received from the app preparing the rider for the event.

The communication protocols, implemented via MQTT, followed the ETSI ITS- G5 standard (Table 2 and 3).

Table 2 Virtual actors and SAFE STRIP components running in different computing systems

Simulator	Smartphone	Cloud server
Ego vehicle	RSB	MQTT broker
Road Strip (for vehicles and pedestrians)	SAFE STRIP app	Co-driver
Other vehicle		DSS
Pedestrian		

Table 3 Wireless communications between the different computing systems

Communication direction	Type of information	Communication technology standard
From ego vehicle to SAFE STRIP app	Ego vehicle speed, acceleration, geodetic coordinates	Bluetooth
From SAFE STRIP app to MQTT broker	Vehicle CAM	WiFi
From virtual road strip to RSB	Strip id when activated	Bluetooth
From RSB to MQTT broker	DENM	WiFi
From DSS to SAFE STRIP app	HMI Input by App Active message	WiFi

Two log files were used in order to collect the simulation data. Since the motorcycle rider did not have direct interaction with the cloud server the traffic of the messages in the Cloud server was not relevant, only the time duration between sending the strip id from the smartphone and receiving the warning message to the smartphone was logged for synchronization purposes.

Table 4 Log files

Simulator	Smartphone
Simulator controls	DENM message
Ego vehicle, other vehicle and pedestrian kinematics and vehicle dynamics parameters	HMI Input by App Active message
Strip id when activated	Strip id when activated

In order to synchronise the two log files, the message sent from the simulator to the smartphone with the strip identifier, when the strip was activated, was recorded in both files.

The motorcycle simulator vehicle dynamics, motorcycle controls and actuator motor control are running on a Real Time Operating System (RTOS) with a frequency of 100Hz while the simulator's visual environment the smartphone and the cloud server are running in General Purpose Operating Systems (GPOS). Most of the SAFE STRIP components had very small delays in the order of a couple milliseconds. Only the communications to the cloud and the smartphone display of the audio and visual warning had significant delays. These delays were subtracted from the measurement in order to have the reaction time of the volunteer from the moment they receive the warning.

Since smartphones are not following real time constraints and Android and iOS are GPOSs they have variable response times based on the process scheduling. Because these delays were not recorded in the smartphone or the simulator log file, an ad-hoc experiment was performed to measure these app delays (delay for visual message and delay for audio message).

The app was running on an Android mobile phone (Samsung S9+, SM-G965F, Android v.9). A Light Dependent Resistor (LDR) was attached on the screen of the smartphone and headphones were plugged on the 3.5 mm headphone jack of the smartphone. An oscilloscope (Rohde & Schwarz RTB2004) with four channels was used for the measurement. At one channel of the oscilloscope the device that sends the "Strip identifier when activated" message through Bluetooth from the simulator to the smartphone was connected and at the two other channels the headphones and the LDR sensor were attached. The delay between the simulator message and the reception of the warning message was also recorded (Fig 4).

Figure 4: Smartphone delays measurement with an oscilloscope the timing delays of the audio and visual warning

From this experiment an average delay of around 400ms was measured for the audio message and additionally around 100ms for the visual display. The delay was different if different smartphones were used. During the experiment the specific smartphone was used.

The recruited volunteers were informed about the purpose of the experiment and signed a GDPR compliant informed consent form. Acceptance and usability questionnaires were completed post-test.

6. Results

Ten male volunteers, experienced motorcycle riders participated in the experiment. The volunteers that were not familiar with the CERTH motorcycle simulator had a free ride for 5 min before the experiment to familiarise themselves with the simulator. All volunteers completed the experiments.

After synchronization and subtraction of the communication and processing delays the first and second reaction of the volunteers were calculated as depicted in the figure below (red vertical line is the HMI stimuli, green line is the first reaction and blue the second reaction).

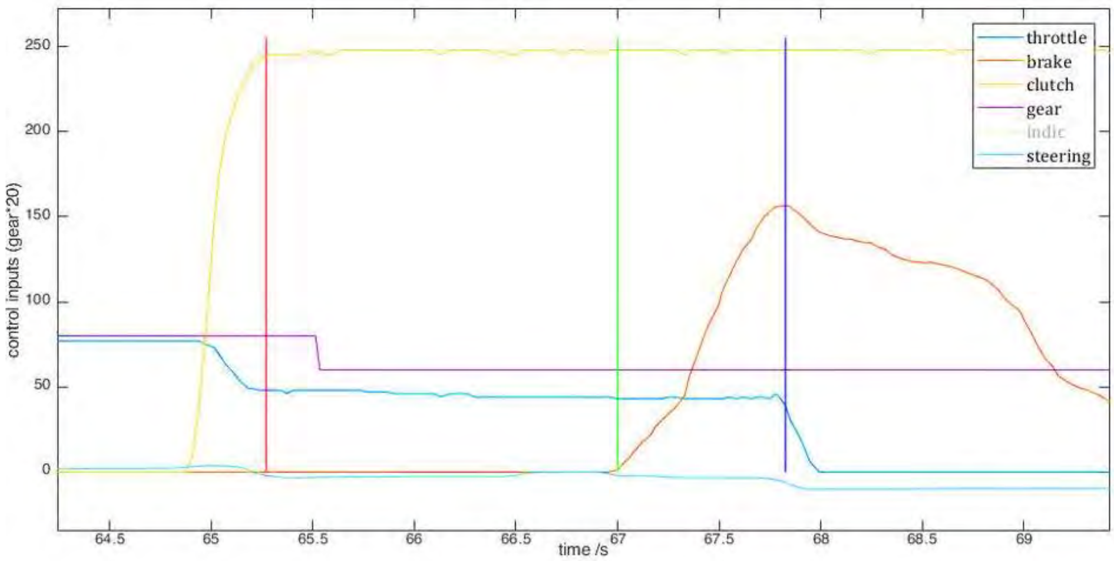

Figure 5 HMI stimulus (red vertical bar) and first (green) and second (blue) reaction of the volunteers with the motorcycle controls

The type of reaction type for each volunteer was more or less the same across the tests with most common being the throttle reduction.

In the table below the measured reaction times are presented. Reaction times above 3s were not considered as reaction to HMI input (Table 5).

Table 5 Reaction times (mean and standard deviation)

	Setup 1		**Setup 2**	
Road condition	Dry road		Wet road	
Scenario	Pedestrian	Wrong way driving	Pedestrian	Wrong way driving
Average reaction time/ s (with SD)	1.560 (0.758)	1.453(0.712)	1.654 (0.675)	1.269 (0.785)

The speed adaptation 5s after the HMI warning was issued, was analysed for all scenarios and all volunteers. The highest speed reduction was recorded at the Dry road. The steering angle after the warning had no important variation mainly due to being in a straight road scenario and not having need to avoid the obstacle/pedestrian due to early reaction.

Table 5 Speed adaptation per scenario

	Setup 1		Setup 2	
Road condition	Dry road		Wet road	
Scenario	Pedestrian	Wrong way driving	Pedestrian	Wrong way driving
Speed adaptation/ km/h (with SD)	-22.29 (13.43)	-22.89 (7.63)	-16.20 (12.36)	-21.67 (8.76)

7. Discussion and Conclusion

Several parameters of the decision logic were tuned mainly concerning the timing of the warnings and the persistence of the message on the screen. The DSS was better integrated to the cloud server and the smartphone delays were optimized. The volunteers adapted their speed in time and no virtual accident happened during the experiments. The system received mainly positive feedback from the riders. The volunteers found the audio warning more useful than the visual warning on the screen of the smartphone, and they mainly used the screen to better understand the situation.

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Authors: Giovanni Savino, Lorenzo Berzi, Simone Piantini, Marco Pierini
Institution: DIEF - Department of Industrial Engineering, University of Florence, Italy

Addressing the availability and reliability of satellite-based vehicle positioning methods in a future connected-vehicle environment for the purposes of riding assistance systems

Abstract

Research question / Starting point for investigation:
The application of Autonomous Emergency Braking on Motorcycles (MAEB) relies on the solution of a number of open research questions. The collision represents a dangerous and safety critical event to be avoided with high priority. However, focusing on the triggering methods, the recommendation from literature is to deploy automated braking only when the collision becomes inevitable, the priority in this initial phase of development being the avoidance of false positive activation. The identification of Inevitable Collision States (ICS) adopting existing car technologies is particularly challenging though, due to the tilting and nimble nature of powered two wheelers.
Due to injury and even fatality risks in case of wrong activation when no collision takes place and in case of missing activation when collision takes place, according to transportation and standardization community MAEB has to be considered a "safety of life" application. Safety requirements therefore imply the use of accurate but above all reliable positioning system - a characteristics called “integrity”. Satellite navigation systems are an interesting mean to provide accurate, reliable and safe positioning service to transportation systems. Satellite navigation faults need to be accurately monitored and mitigated since they can cause both wrong activation in case of no collision and missed activation in case of collision. A safety analysis identify the risk to be associated to each safety critical events in terms of maximum probability of occurrence. Given these conditions, the MAEB, the satellite navigation receiver and each part of the system need to be designed to satisfy the associated risk.
In this paper we analysed the possible application of satellite technologies as resource for the identification of accurate and safe relative position of vehicles in emergency situations to support the MAEB system.
Methods:
We combined the knowledge on MAEB with recent updates on global positioning and performed a review of state of the art and future methodologies for reliable and safe geo-localization in transportation. The problem of safety was addressed considering that the positioning is obtained with a certain accuracy and a given uncertainty: the user is located within a given region and with a given probability. There is then a risk for the user to be

outside the high-likelihood region. This risk needs to be properly quantified, controlled and mitigated in a safety application such that of MAEB.
Results:
The outcome of the review was a set of technologies and methods suitable for MAEB application, including localisation based on satellite navigation systems augmented with high accuracy and integrity services. Last frontier of GNSS pushing the boundaries of this technology is the use and integration with 5G communications to exploit the mutual positioning, in which each entity assesses its position relative to the others.
Impacts / Effects / Consequences:
Our results showed that a proper combination of current technologies may be used to build a cooperative transportation system suitable for MAEB applications.
Keywords: Active safety, Autonomous emergency braking, GNSS, system integrity, cooperative transportation.

Introduction

Road crash statistics in Europe clearly show that in the last decade a substantial plateau has been reached in terms of motorcycle and moped fatalities [1]. Further improvements are strongly warranted. These may be obtained introducing safety systems, including novel technologies for powered two wheelers that have not been feasible so far and that may benefit from the availability of high accuracy data such those derived from newly available global satellite systems.
Among the possible list of safety systems, autonomous emergency braking was predicted to be effectively applicable for motorcycle safety [2]. The analysis of real world motorcycle crashes suggests that MAEB may be relevant to a percentage of cases that ranges from approximately a fourth, up to more than a third of the cases [3], [4], with an estimated speed reduction at impact of up to 10 km/h. Such values are obtained assuming an activation time of approximately 600 ms and using a target automatic deceleration of 3 m/s2 (in case of no braking action from the rider).

The application of Autonomous Emergency Braking on Motorcycles (MAEB) relies on the solution of a number of open research questions that include the feasibility of an accurate detection of the triggering conditions [5], the feasibility of the automatic decelerations in realistic riding conditions [6], the threshold deceleration and jerk that can be safely applied [7], the quantitative assessment of the potential injury reduction that slowing down the PTW may have prior to crash [8], just to name a few.

Focusing on the triggering methods, the recommendation from the literature in the field of motorcycle safety systems is to deploy automated braking when the collision becomes physically inevitable, i.e. the point in time at which no combination of manoeuvres from the ego motorcycle and the opponent vehicle may prevent the crash anymore, assuming vehicle accelerations of up to 1 g. It was shown that this criterion is typically fulfilled less than 600 ms ahead from actual collision, thus posing a tight limit in the time available for the automatic system to take an action and produce an effect. One motivation of such approach was to maximise the user acceptability for MAEB: it was shown that motorcycle riders hardly accept a system that takes over the control of the vehicle [9], but in this case the system intervenes only when the complete crash avoidance is beyond the possibilities of the rider/driver's avoidance actions. A slight relaxation of this criterion was proposed in [8], by considering a lower threshold for the extreme accelerations used to compute the set of possible avoidance manoeuvres. Another reason for adopting this triggering approach is related to the liability of manufacturers, as with different approaches system developers may hardly prove that MAEB was not a contributing factor of any crash event involving MAEB activation.

The triggering criterion is clearly a critical aspect of MAEB. A correct MAEB intervention may reduce the likelihood for the rider to sustain fatal injuries [8], whereas with a missed activation (misdetection) the system fails to deliver its safety contribution, and any wrong activation (false alarm) in non-critical riding situations may introduce an undesirable crash risk with a probability of causing harm to the user.

Notwithstanding the possible different thresholds set for the avoidance manoeuvres, the identification of Inevitable Collision States (ICS) on a motorcycle via existing passenger car sensors is particularly challenging, as it was well documented from previous research [10].

In this paper we analysed the possible application of satellite technologies as resource for the identification of accurate relative pose of vehicles in emergency situations for the purposes of MAEB. We combined the latest knowledge on MAEB with recent updates on global positioning and performed a review of state-of-the-art and future methodologies for reliable and safe geo-localization in transportation.

First, a state of art overview of satellite navigation systems will be provided focusing on the wide range of new services and systems offered by Europe, China, Japan, Russia and other countries in addition to the well-known Global Positioning System (GPS) of the United States. Then, the technical characteristics and driving performance factors for supporting MAEB applications will be presented, including deterministic versus probabilistic positioning, the discretization and resolution of the collision region, the refresh rate of the positioning and finally the integrity of the service.

Global Navigation Satellite Systems

The scenario of satellite navigation has rapidly evolved in the last years. After 25 years of monopoly of Global Positioning System (GPS), a military American system, several countries decided to become independent from US government for their civil transportation service (in particular aviation) and started developing autonomous and independent systems. In particular, the European Commission developed Galileo, Russia modernized its existing system GLONASS, and China developed BeiDou. Nowadays ground users have signals from more than hundreds of satellites to be used to locate themselves on the earth. This new worldwide service is called Global Navigation Satellite System (GNSS).

Advantages with respect to other positioning systems are the availability of the signals free of charge since the services are provided for civil use and protected by public institutions. Besides thanks to the miniaturization of the hardware, the cost of one chip and one antenna reduced so drastically that GNSS chips are integrated in all smartphones nowadays.
The development of new constellations of satellites implied the use of additional signals, a frequency diversity and a widening of the bandwidth. This characteristic is of essential

importance, since navigation signals are affected by several error sources which need to be modelled and corrected before assessing the user position. One of these sources is related to the propagation through the ionosphere which introduces a signal delay. In reality the dispersion through the ionosphere has a deterministic dependency on the frequency and if the user can measure signals from at least two different frequencies, is able to correct completely the ionospheric errors. This characteristic led a significant improvement in the accuracy obtained with novel GNSS receivers with respect to GPS ones. Thanks to this approach the accuracy evolved from tens of meters to below one meter. However, this achievement may not be sufficient for applications such as MAEB, as it will be explained later in this paper.

To push further the performance and reach higher accuracy, recent systems provide additional augmentation or high accuracy services, that is additional service providing corrections of signals, the so-called differential systems (DGNSS). These services are provided by reference stations on ground in the proximity of the receiver (Real Time Kinematic, RTK, or Precise Point Positioning, PPP) or geostationary satellites (Satellite Based Augmentation, SBAS). Galileo for example will transmit a High Accuracy service, completely free of charge, through the satellite signals [11]. This service, currently under operational testing phase, will provide users with ranging corrections, similar to PPP service, allowing to reach decimetre- and centimetre-level accuracies. In addition, multisensory solutions are exploited and needed when GNSS signals are masked, as for example in urban canyons. The receiver uses additional local sensors to “coast”, that is to compute temporary solutions until the next satellite signals are tracked again. The position obtained in this case degrades during the coasting interval, usually linearly over time and proportionally to the drift characteristic of the inertial sensor. Over few minutes the degradation is often considered acceptable and the solution still accurate and reliable for applications such as navigation systems. For MAEB applications, the time span in which coasting may offer acceptable results should be further studied, however it could be estimated in the order of a few dozens of seconds assuming the adoption of high quality and expensive sensors or high-accuracy sensor fusion techniques.

Last frontier of GNSS pushing the boundaries of this technology is the use and integration with 5G communications to exploit the mutual positioning, in which each entity assesses its position relative to the others. This allows to have a cooperative transportation system. In an automatic braking system, a minimum exchange of information is needed, such as position of the opponent vehicle and its velocity. In such collaborative system where vehicles exchange raw or processed GNSS data, the dataflow architecture and the allocation of the processing burden should be established in advance.

If the receivers are mounted on the same vehicle, the novel approach can provide an attitude estimation of the motorcycle and enhance the braking system. It is in fact important to consider the dimension of the motorcycle, its orientation and its attitude.

Deterministic vs. Probabilistic approach for positioning

In [12] a method was proposed to assess the fulfilment of the “inevitable collision state” condition, adopting a deterministic approach to solve the complex problem of the identification of the triggering event. As said, the proposed condition for the activation of MAEB (or any other intrusive “last-resort” safety function) stated that no combination of feasible manoeuvres perfomed by the host motorcycle and the opponent vehicle could lead to avoid the imminent collision. The deterministic approach consisted in pre-computing a set of combined manoeuvres at the physical limit of adherence for a set of initial states and check whether or not the collision can be avoided. The initial state assumed that the motorcycle traveled along a straight path with a given speed, and the opponent vehicle was located at a given relative position travelling with a given relative vectorial speed. Such initial state was described via five scalar values: host vehicle forward speed v_{ptw}, opponent vehicle position x_{ov}, y_{ov}, and relative speed components v_{x_ov}, v_{y_ov}. The pre-computing process leads to the identification of a dataset of initial states associated with the binary variable “inevitable collision” assuming the values of either true or false. By simply checking whether the current state is associated with a pre-computed inevitable collision state, the problem of the identification of the triggering event was solved in a deterministic way. Such approach was inspired by the one proposed for passenger cars in [13]. However, this approach is a simplification of a probabilistic problem. In particular, the current state can only be identified with approximation. In other words, the given position and speed of both host and opponent vehicles corrensponding to the initial state is affected by uncertainty that can be well handled in probabilistic terms. Second, it is reasonable to think that some avoidance manoeuvres are less likely to be performed than others. Furthermore, it was shown that a non-professional rider is less likely to perform an optimal braking manoeuvre at the limit of adherence than just braking at lower decelerations in emergency situations [14]. However, this latter aspect goes beyond the scope of the present paper and will be discussed in a future work.

A simple way to move from the deterministic to a probabilistic solution, is to consider more than one state at each time step. In other words, instead of assuming that the computed state describes the actual state with probability 1, the state of each time step is described as a set of possibile states, each one having a probability below 1, the sum of which is not greater than 1. The probability of being in an inevitable collision state is the sum of the probabilities of those states that were associated with ICS using the same method of the deterministic approach as described above.

Discretisation issues

In [12], the initial state was discretized in terms of space, speed, and heading. A spatial grid of 20x20 cm was proposed to locate the geometrical centre of the opponent vehicle. The vehicle speed was discretised with steps of 3 m/s and the relative heading was divided in steps of 5 deg.

Given these assumptions and the fact that these represent the solution of the problem imposes to have this minimum resolution, the GNSS service need to reach centimetre level accuracy, that is include Precise Point Positioning. Such approach may provide adequate accuracy for the identification of both the relative positioning and also the relative attitude. In fact, the heading of the motorcycle may be obtained with one sensor located in the front and one sensor located in the rear of the vehicle. The 5 deg accuracy can be obtained via accurate positioning of each sensor. Considering that a 5 deg rotation of a 2 m long motorcycle corresponds to a lateral displacement of 1 m * sin (5 deg) for each sensor (equivalent to approximately 8.7 cm from the geometrical centre of the vehicle), the localisation accuracy should be again within a few centimetres.

In addition, the situation of the motorcycle imposes strict requirement in terms of continuity of the service. It is in fact not acceptable to have interruption due to satellite masking in urban canyon or tunnels. In this case, multisensory solutions or other solutions (see for example the so called clock coasting [15]) enhance the continuity and availability performance and bridge gaps of the positioning services.

Refresh rate

The minimum operating refresh rate of an inevitable collision state estimation for MAEB can be defined considering a number of parameters, including the pre-crash speeds of the host motorcycle in the pre-crash phase, the typical working frequencies of state-of-the-art braking systems, and the constraints of the vehicle data acquisition system. Previous studies show that the typical pre-crash speed of the motorcycle where MAEB may contribute is in the range between 10 and 30 m/s [3], [8]. State-of-the-art braking systems operate with working cycles in the range between 4 and 10 Hz. When considering for example a host motorcycle speed of 20 m/s and stationary obstacle, together with the recommended spacial grid with 0.20 m of extension, a single step in the grid is covered in 10 ms, which translates in an ideal refresh rate of the state estimation device of 100 Hz. When considering that a typical triggering timing is 600 ms ahead of crash, a refresh rate of 20 Hz in the inevitable state detection would result in a loss of 7% of impact speed reduction at a deceleration of 5 m/s2: from a theoretical value of 11.5 km/h to 10.7 km/h. A refresh rate of 10 Hz or 5 Hz would result in a loss of respectively 17% and 34%.

When the position is not deterministic and the accuracy is taken into account, the user is located in a certain region with a certain probability. The velocity in a GNSS receiver can be estimated through time difference of consecutive positions or throught the doppler shift of the received signals. In both cases also the velocity has a certain probability associated to it. Given these uncertainties, the position and velocities cannot be updated too frequently to avoid that the measurements are degraded and impacted by the inaccuracies of the sensors. The regions in which the users are located must be much smaller than the distance between consecutive positions. Let us image for example to measure the GNSS of a static user. Due to the mentioned uncertainty, the positions will be each epoch different, but within a certain region. If the user starts moving the receiver will be able to provide information on the shift only if it is significantly larger than the uncertainty region. The distance, position and velocity refresh rates must therefore take into account the receiver accuracy uncertainty. Again, if we assume a speed of 20 m/s for the host motorcycle, high accuracy of 3 cm (in terms of radius) is feasible at 100 Hz when High Accuracy PPP is available, as the actual displacement of the GNSS receiever mounted on the motorcycle exceeds twice the radius of accuracy (6 cm) in less than a third of the desider refresh time step of 0.01 s. For a slow opponent vehicle instead, for example with an assumed speed of 3 m/s, this condition is not fulfulled, as the GNSS received mounted in the vehicle takes twice the refresh time step to cover twice the 3 cm accuracy radius. However, in this condition the 100 Hz refresh frequency for the GNSS is not required, as Kalman filter techniques guarantee the required accuracy of the positioning at the desired refresh rate.

Integrity

Due to the risks associated to missing and wrong activations, according to transportation and standardization community MAEB has to be considered a "safety of life" application. Safety requirements therefore imply the use of accurate but above all reliable positioning system - a characteristics called “integrity”. Satellite navigation systems are an interesting mean to provide accurate, reliable and safe positioning service to transportation systems, since the constellation of satellites provides information on the probability of faults within the system and allows the user to assess the risk of having a wrong positioning service and to monitor the constellation itself.
In simple terms, the probability that an initial state in a given riding scenario may lead to a given level of injuries for the rider, say for example, severe injuries represented by MAIS (maximum abbreviated injury score) equal to 3 and above including fatal injuries, is the product of the probability that such state may lead to a crash, multiplied by the probability that in case of such crash the rider may sustain the given level of injuries.

$$P_{MAIS3+F}=P_{crash}*P_{inj\_crash} \qquad (1)$$

In case of MAEB correct intervention (ideal triggering), assuming a $P_{crash}=1$, the likelihood for the rider to sustain severe injuries is reduced, according to the effectiveness of the system η_{MAEB}:

$$P(\text{crash with ideal trigg})_{MAIS3+F}=1*P_{inj\_crash}*(1-\eta_{MAEB}) \qquad (2)$$

When expressing the probability of a correct intervention of MAEB as P_{MAEB} (probability that MAEB actually triggers in an ICS, missed detection probability being $1-_{PMAEB}$) and the probability of a wrong activation (false alarm) P_{FA}, the probability of sustaining severe injuries for the rider in a generic state is expressed by the following:

$$P(MAEB)_{MAIS3+F}=P_{crash}*P_{inj\_crash}*P_{MAEB}*(1-\eta_{MAEB})+(1-P_{crash})*P_{inj\_MAEB}*P_{FA} \qquad (3)$$

where P_{inj_MAEB} is the probability to sustain injuries as a consequence of a wrong activation of MAEB. We may expect that $P_{inj\_crash}>>P_{inj\_MAEB}$, as the former is always associated with a collision with an opponent vehicle, whereas the latter is not necessarily linked with a fall or collision, as MAEB wrong activation by design should be correctly handled by the user in almost every condition [6].
On one side, MAEB introduces the risk of causing a crash in a situation in which the crash probability is low or even approximately zero. However, MAEB is beneficial for the rider in case of a crash as it reduces the likelihood of sustaining severe injuries. When the probability of false alarms is low, together with a high probability of deploying when needed and high effectiveness in reducing injuries, the system is beneficial and worth the development efforts. In this perspective, the characteristic of integrity of GNSS approach for the detection of triggering events is an added value that contributes to achieve the strict requirements of “safety of life” applications.
In the automotive field, the implementation of MAEB would be subjected to ISO 26262. The standard includes a declination specifically designed for motorcycles indicating the main steps (e.g. HAZOP – Hazard and Operability – Analysis) to be performed to identify potentially critical failures and to quantify their consequences in the MSIL (Motorcycle Safety Integrity

Level, derived from Automotive ASIL) risk scale. In particular, the risk level depends on Severity, Exposure and Controllability of the event. Depending on the MSIL, an estimation of the maximum acceptable probability of failure (for example identified as a loss of integrity of the positioning signal) can be obtained and compared with the probability achievable via GNSS.

Conclusions

In this paper we discussed the possibilities offered by satellite-based vehicle positioning methods for supporting the implementation of riding assistance systems and in particular MAEB. Our results showed that a proper combination of current technologies may be used to build a cooperative transportation system suitable for MAEB applications. One interesting advantage of GNSS use for the detection of the relative positions of conflicting vehicles is the characteristic of integrity, which is fundamental for "safety of life" applications such as MAEB.

Open issues relate to the definition of a system architecture with corresponding allocation of the computation burdens and dataflow among vehicles. Another challenging follow up will be field testing the theoretical availability and reliability of the satellite-based geo-localisation in real world settings. For that purposes, special testing protocols will be required, such as the one proposed in the ABRAM project [16] allowing for data collection during the pre-collision phase of emulated real-world motorcycle crashes .

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Untersuchung der Existenz einer Schräglagenschwelle bei Motorradfahrern*innen

Investigation of the existence of a leaning threshold among motorcyclists

Raphael Pleß, Sebastian Will, Alexandra Neukum

Würzburger Institut für Verkehrswissenschaften (WIVW GmbH),
Veitshöchheim, Germany

Florian Scherer

TU Darmstadt Fachgebiet Fahrzeugtechnik (FZD),
Darmstadt, Germany

Zusammenfassung

Schwere Motorradunfälle in Kurvensituationen und ohne Einfluss anderer Verkehrsteilnehmer sind in der Statistik auffällig häufig. Aus Rekonstruktionen dieser Unfälle ist bekannt, dass das maximal mögliche Schräglagenpotential nicht ausgenutzt wurde. Bestandteil des durch die Bundesanstalt für Straßenwesen (BASt) geförderten Forschungsprojekts „Schräglagenangst“ (Projekt FE 82.0710/2018) ist daher die Untersuchung, ob eine Schräglagenschwelle Fahrende daran hindert, dieses Potential auszunutzen. Das Auftreten einer solchen Schräglagenschwelle wird dabei insbesondere in Situationen erwartet, welche vom Fahrenden als gefährlich wahrgenommen werden – selbst, wenn oftmals keine reale Gefährdung (z.B. nahende Kollision oder Reibwertsprung) existiert.

Zur Untersuchung der Existenz einer Schräglagenschwelle werden zwei Versuchsreihen durchgeführt. Zum einen dient eine Realfahrstudie zur Erfassung alltäglich gefahrener Schräglagen. Zum anderen werden auf abgesperrtem Testgelände subjektiv kritische, jedoch real unkritische („pseudokritische“) Fahrmanöver provoziert. Diese zwingen die Fahrenden z.B. zum unvorhergesehenen Ausweichen oder Anpassen von Geschwindigkeit oder Rollwinkel. Die in beiden Untersuchungen erfassten Messdaten werden mit Subjektivbewertungen der Probanden verglichen. Ein hierzu entwickelter Fragebogen ermöglicht zudem Aussagen zur interindividuellen Risikobereitschaft und dem Komfortbereich der Fahrenden hinsichtlich der gefahrenen Schräglagen.

Eine kollektive Schräglagenschwelle wird nicht beobachtet. Die individuellen Schräglagenschwellen variieren stark in ihren Maxima. Ein Vergleich der im Straßenverkehr gemessenen Rollwinkelverläufe mit theoretischen Verläufen unter Annahme quasistationärer Fahrt ermöglicht eine Clusterbildung, welche gute Übereinstimmung mit den subjektiv erfassten Schräglagenangstbewertungen der Probanden zeigt. In den künstlichen Fahraufgaben auf abgesperrtem Gelände treten je nach Fahrertyp charakteristische Einbrüche in der Rollrate beim Erreichen einer bestimmten Schräglage auf, was für ein situationsabhängiges Verharren in der Rollwinkelaufbauphase spricht. Zudem werden teils unnötig starke Reaktionen auf das Auftreten pseudokritischer Situationen in Form von Brems- oder Lenkeingriffen bei den Probanden beobachtet. Weder ein Unter- noch ein Überschreiten der persönlichen Schräglagenschwelle ist in den Fahrversuchen zu beobachten. Dies führt zu der Annahme, dass insbesondere Fahrtrainings mit starkem Bezug zu Voraussicht, Gefahrenwahrnehmung und dem Steigern der individuellen Schräglagenschwelle eine Besserung des Unfallgeschehens bewirken können.

Die vorgestellte Methodik zur Kombination von Subjektiv- und Objektivdaten aus verschiedenen Erhebungsquellen zur Untersuchung einer Schräglagenschwelle bei Motorradfahrenden zeigt sich insbesondere in Kombination mit neuen Messmethoden (siehe: „Stanglmayr, M. et al.: *Towards Safer Rides: Measuring Motorcycle Dynamics with Smartphones*“), sowie innerhalb des Projektes prototypisch entwickelter, stationärer Messtechnik, tauglich zur Erfassung einer größeren Datenbasis. Diese könnte zukünftig genauere Aussagen zur Existenz einer Schräglagenangst ermöglichen.

Abstract

Severe motorcycle accidents in cornering situations and without the influence of other road users are conspicuously frequent in the statistics. From reconstructions of these accidents it is known that the maximum possible lean angle potential was not exploited. As part of the BASt research project "Corner-Fear" (project FE 82.0710/2018), it is therefore being investigated whether a lean angle threshold prevents riders from exploiting this potential. The occurrence of such a lean angle threshold is expected especially in situations which are perceived as dangerous by the rider - even if often no real danger exists (e.g. approaching collision or µ-jump).

To investigate the existence of a lean angle threshold, two test series are carried out. On the one hand, a naturalistic riding study is used to record roll angles used in everyday riding. On the other hand, subjectively critical, but really uncritical ("pseudo-critical") riding maneuvers are performed on a closed-off test area. These force the riders to e.g. perform unexpected evasion maneuvers or adjust speed or roll angle. The measured data recorded in both investigations are compared with subjective evaluations of the study participants. In addition, the questionnaire developed for this purpose enables statements to be made on the inter-individual willingness to take risks and the comfort range of the rider with regard to their typical use of lean angles.

A collective leaning threshold is not observed. The individual leaning thresholds vary greatly in their maxima. A comparison of the roll angle date measured in road traffic with theoretical curves assuming quasi-stationary riding allows a cluster formation, which shows good agreement with the subjectively assessed fear of lean angles of the participants. In the pseudo-critical riding maneuvers on closed-off terrain, characteristic drops in the roll rate occur when a certain angle is reached, depending of the rider type, which speaks for a situation-dependent persistence in the roll angle build-up phase. In addition, sometimes unnecessarily strong reactions in the form of braking or steering interventions to the occurrence of pseudo-critical situations are observed among some study participants. This leads to the assumption that especially rider trainings with a strong reference to foresight, risk perception and increasing the individual lean angle threshold can improve the occurrence of accidents.

The presented methodology for the combination of subjective and objective data from different survey sources for the investigation of a lean angle threshold of motorcyclists is particularly suitable for the acquisition of a larger database in combination with new measuring methods (see: „Stanglmayr, M. et al.: *Towards Safer Rides: Measuring Motorcycle Dynamics with Smartphones*“), as well as within the project prototypically developed stationary measuring technology. In the future, this could enable more precise statements to be made about the existence of cornering fear.

Investigation of the existence of a leaning threshold among motorcyclists

1 Introduction

In honoration of one of the most renown researchers in the field of motorcyclists' behavior, Professor Bernt Spiegel, we motivate this paper by citing from his book "The Upper Half of the Motorcycle"[1]

> *"Man is […] not "built" to ride motorcycles, but at least he is "pre-adapted" for riding a two-wheeler. That is, he has been adapted in advance (by evolutionary changes) to his original habitat – most notably, starting to walk upright on two legs – and this **pre-adaption** comes in very handy when he gets on a two-wheeler. Over the course of his evolution, man has had to develop intricate, genetically transmitted behavior programs which have made possible an ever more perfected two-legged existence, and which prepare him well for riding a motorcycle. The programs that give him the ability to balance appear as smaller components or building blocks integrated into the program for motorcycle riding. If man had not, over the past millions of years, already been dealing with the biomechanical challenges of an extremely high center of mass, combined with a very small footprint, neither bicycles nor motorcycles would exist in their current form.*
>
> *Similar explanations apply to lean angle and tire stickiness. **Owing to millions of years of experience walking on various surfaces, the available static friction (stiction) under his feet spontaneously leaps into his conscious attention and becomes clearly and directly evident.** […] Man can take the ancient building blocks of behavior affecting sensory and motor activities and incorporate them into the programs that he is acquiring today. In this way, once he has attained perfect command of a high-level program (such as riding a motorcycle), the motorcyclist can extend the so-called evidence experience all the way into the contact patch of the tires.*
>
> *With regard to lean angle, there is another useful pre-adaption, or ancient program stub, that can be used as a building block. **As a fast runner, man is already fully able to handle lean angle but only to about 20 degrees.** It is exactly the same lean angle that arise everywhere from fast locomotion, where relatively natural conditions exist with respect to stiction (that is, no knobbies, spikes, fixed track surfaces, etc.) As soon as a person has more or less learned to ride a two-wheeler, he will immediately make use of the "naturally" available 20 degrees of lean angle, but he will not go beyond those 20 degrees. This has applied for millions of years to all fast runners – horses, dogs, ostriches. Beyond 20 degrees, on a natural surface, the danger of losing traction increases quickly.*
>
> *In order to exceed the 20 degrees, particular technical conditions are not the only requirement. Another key requirement is a long period of continuous practice. This is the time that is needed to **build up a new behavior-controlling program that allows the pre-set limits (based on our genetic heritage) to be exceeded.**"*

Motorcylists belong to the most vulnerable road users. Due to their specific riding dynamics and the preferably curvy, rural roads they ride on, the severity of their accidents is exceptionally high. In 2014, Bauer[2] showed that 45% of the killed motorcyclists in his sample have crashed while cornering without any obvious external cause. Apparently, these accidents all follow an equal pattern:

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[1] Spiegel, B.: *The Upper Halt of the Motorcycle,* p.35-36
[2] Bauer, K. et al.: *Retrospective analysis of fatal motorcycle accidents*

The rider tangentially exits the turn as he might not feel confident with his actual velocity and roll angle or due to badly executed braking until he eventually hits opposing traffic or other hard objects (e.g. trees, posts, signs). Only 30% of those riders tried to reduce the velocity that they have subjectively perceived as too high, while the other 70% didn't show any reaction before exiting their line. As anticipated by Prof. Bernt Spiegel, the study shows that no rider exceeded the threshold of 20 degrees of roll angle. It is also shown, that none of the accidents would have happened if the rider increased the roll angle to 35 degrees or even less.

Even not so modern motorcycles (both in terms of chassis and tires) are easily capable of performing lean angles way above 35 degrees as long as the friction coefficient between tire and road exceeds not more than μ = 0,7. Therefore, the reason for such crashes must rather be sought in the rider's than his vehicle's performance or environmental factors. This leads towards three main questions:

- Can we find relevant data to support the thesis of the existence of a common roll angle threshold among a broad number of motorcyclists?
- Is this threshold omnipresent or rather only immanent in critical scenarios?
- Are there subjective or objective measurements correlating to a possibly individual threshold value?

To the knowledge of the authors, almost no representative study is published, dealing with statistical distributions of roll angles of everyday riders in everyday riding and – possibly even more important – during critical events. Investigating potential limitations in rider's lean angle performances requires a vast effort in data collection. This is especially true for data of critical events, as there is no simple and ethical way of exposing study participants to real critical situations.

This paper concentrates on the data acquisition methods used to investigate the abovementioned questions and shows first results of a pilot study. It is split in four following chapters: Firstly, we discuss different approaches to acquire the data needed to support – or falsify – the thesis that a roll angle threshold value exists. In chapter 3 we describe a method to collect such data without needing equipped motorcycles that has been prototypically tested in this study. Chapter 4 discusses the possibility of testing "pseudo critical maneuvers" on a closed track. Finally, we show first results from a participant study that was performed within the project BASt FE 82.0710/2018 "Schräglagenangst" ("Cornering Fear"). The paper will then end with chapter 6, a summary and outlook.

2 Data acquisition

Following Bernt Spiegel's hypothesis, only training enables us to ride a motorcycle with roll angles exceeding 20 degrees. However, measurements show, that even beginners may quickly be confident with riding at higher values of roll angle, sometimes even up to 40 degrees under normal conditions[3]. At the same time, the abovementioned accident reconstructions obviously point towards such low values as 20 degrees. Therefore, we assume, that such a threshold might not manifest in everyday riding, but rather in critical events, or – more specific – such events that are perceived as critical by the rider, even if they aren't from a technical point of view. As the rider loses his trust and comfort during maneuvering, e.g. due to an unexpected change in curvature, oncoming traffic or other disturbances and distractions, he might fall back to an "emergency mode", or in terms of Bernt Spiegel a "program" that he can access under any circumstances, whenever supposed emergencies force him to rely on it.

[3] Magiera, N. et al.: *An Approach for Automatic Riding Skill Identification*

Luckily for any study participant of an on-road experiment, such critical events are rather rare. Thus, if we want to investigate them, we have different options:

1) Increase the individual duration of observation and wait for rarely happening critical events.
2) Concentrate the observation to where statistics show an aggregation of critical events.
3) Provoke critically perceived events in a safe environment without real danger.

Obviously, these options differ in the achievable data volume, data quality and efficiency.

The first method relies on many measurements of many riders over a long period of time. In this study, we prototypically use an equipped motorcycle for on road testing with N=24 participants. However, it is rather inefficient to provide expensive high-fidelity measurement equipment or even a fully instrumented vehicle to every study participant. Stanglmayr[4] therefore developed the smartphone application *MotoLogger*, that allows to collect data from a broad range of voluntary users in everyday riding. This technology was used for additional N=15 participants of on road testing in this study.

The second method decreases the individual measurement duration and therefore increases efficiency by concentrating the data acquisition locally e.g. towards accident hotspots. As this is only possible by observing everyday riders on their own (unequipped) motorcycles, a tool is needed that allows to observe e.g. the rider's trajectory, velocity, lean angle, etc. externally. While such a technology lacks of precision compared to onboard measurement equipment, it promises to observe the most natural behavior of riders on their own accustomed vehicles in their natural habitat. In comparison to the first method, it is easy to collect detailed information about road- and environmental conditions. On the contrary, only little to none information about the individual rider can be collected.

The third method excels in data quality levels regarding the environment and rider information as well as vehicle dynamics. On a closed track, single study participants can perform tests with a high-fidelity measurement motorcycle allowing for the largest amount and highest quality of data per rider/experiment. At the same time, it is the most "unnatural" environment for study participants and needs the highest invest regarding the measurement equipment, test-track and personnel. With proper design of the riding task it is even possible to generate a perception of criticality without risking real danger, as shown in chapter 4.

Table 1 shows empirical ratings of the different data acquisition methods.

Table 1: Rating of different data acquisition methods

Method	**Data Quality**			**Possible number of participants**	**Individual observation duration**	**Naturalistic behavior**	**Cost per observation**
	Vehicle	**Environ-ment**	**Rider**				
Widely spread lowcost measurements	Low	Low	Medium	Very High	Very Long	High	Low
Stationary measurements	Low	High	Very Low	High	Very Short	Very High	Medium
Closed track experiments	High	Very High	Very High	Very Low	Medium	Low	Very High

[4] Stanglmayr M. et al.: *Measuring Motorcycle Dynamics with Smartphones*

While Stanglmayr[4] describes in detail, how a low-cost measurement system can be set up, the following chapter of this paper presents the concept of a stationary measurement technique that might be used for testing on public roads in the future.

3 Stationary Measurement Technique

Investigations of specific accident hotspots and the measurement of trajectories, roll angles, etc. of passing riders in such hotspots has been the interest of several researchers in the recent years, e.g. Winkelbauer [5,6]. However, gathering continuous measurements of the rider or vehicle states has not yet been implemented successfully and therefore only discrete states were analyzed. (e.g. the roll angle estimated from a single picture, made in perpendicular projection of the motorcycle, or its lane position on such a picture.)

One goal of the project at hand was to develop a prototype measurement technology that allows automated, continuous measurements of at least velocity, roll angle and path of a motorcycle entering, passing and leaving a turn in typical rural corners.

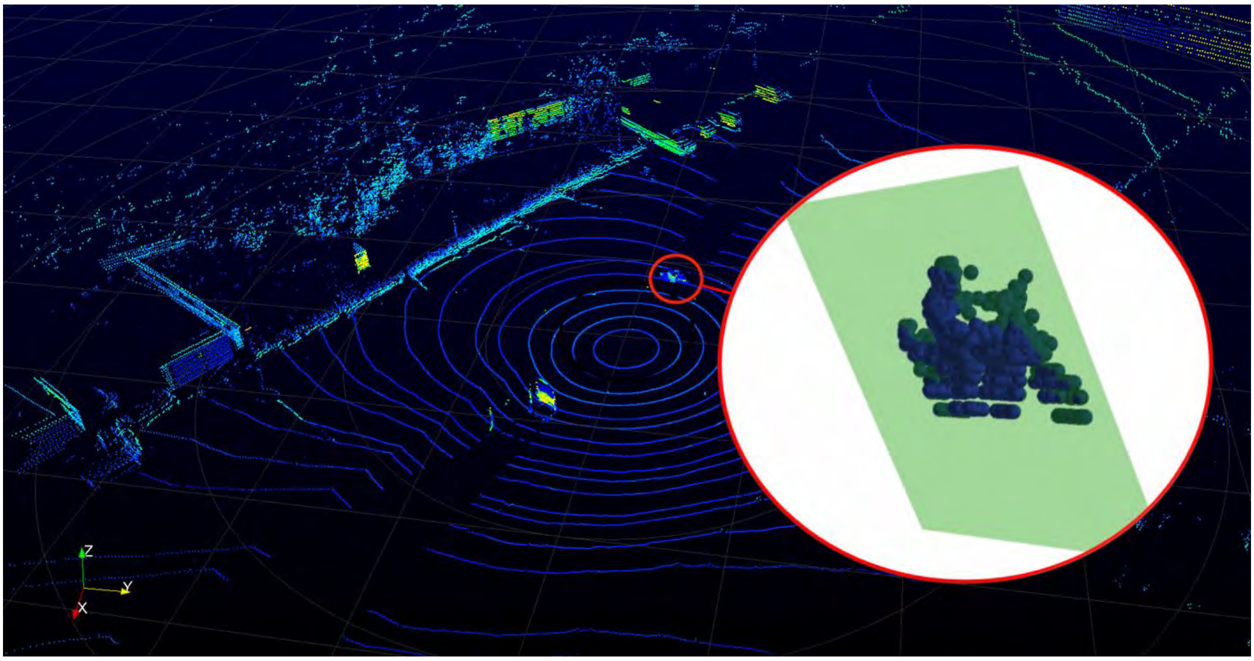

Figure 1: Exemplary point cloud resulting from a LIDAR measurement

A first approach to compare different stationary measurement systems is provided by the work of Häffner[7]. Herein different concepts like RADAR or LIDAR, as well as mono- and stereo camera systems are prototypically built up and tested for their suitability for the use in road traffic.

The advantage of the direct measurability of vehicle speeds with RADAR sensors is opposed to the problem of the bad assignability of single measuring points to the corresponding point on the vehicle. The use of LIDAR sensor technology, on the other hand, offers the great advantage of a data protection compliant measurement (Figure 1), but the error in determining the roll angle is large due to the lack of information about the plane of symmetry of the vehicle. Together with the high price of the sensors utilizing this measurement technology, the decision is made against using LIDAR for this purpose.

[5] Winkelbauer, M.: *Riding Left Hand Corners*

[6] Winkelbauer, M. et al.: *Lean Angles and Lane Positions of Motorcyclists*

[7] Häffner, N.: *Entwurf einer stationären Messtechnik zur Bewertung des Kurvenfahrverhaltens*

Due to the disadvantages mentioned above and the advantage of mono and stereo camera systems in terms of acquisition costs, as well as the possibility of carrying out detailed, automated evaluations of the image material using machine learning algorithms, this technology is used as the basis of the following development.

3.1 License Plate Tracking

As firstly implemented by Anton[8], the system used in this study utilizes mono-camera signals, preferably from an array of cameras lined up along the perimeter of a curve for measuring the roll angle. Therefore, a motorcycle's license plate is identified by modern image processing methods followed by an evaluation of its orientation.

The problem of estimating the position and orientation of an object from image information has existed for many years and is a core problem of machine vision. Basically, the three-dimensional position of an object in world coordinates must be determined from two-dimensional image information in pixel coordinates.

A special case of position estimation is the prediction of the relative position of a planar object. It is called "Plane-based Pose Estimation (PPE)", which is also used in camera calibration, where the position of a flat chessboard has to be estimated in relation to the camera. In calibration, it is used to estimate the extrinsic values of the camera.

One possibility to determine the position is to exploit point correspondences and is called the PnP problem. PnP stands for Perspective-n-Points, where n represents the number of points from which the orientation of the object is to be estimated. In the case of the license plate, four model points describing the plate are assigned to the four projected vertices in the image plane.

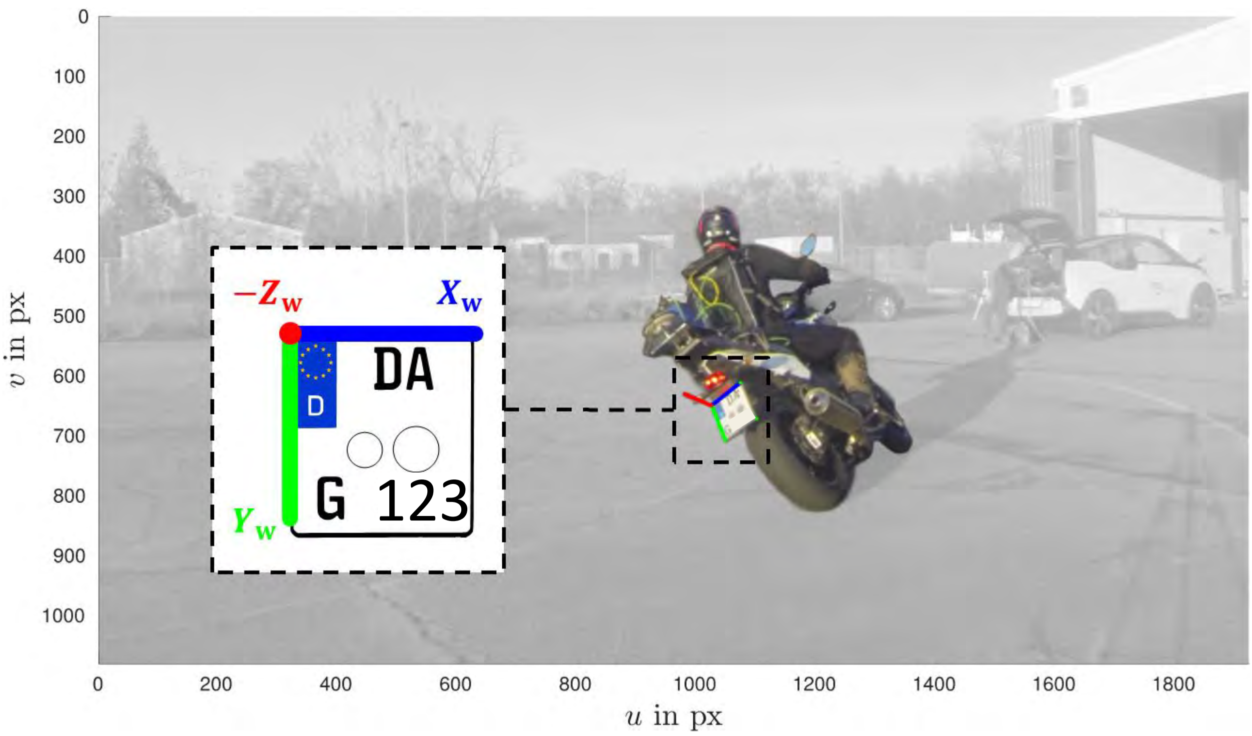

Figure 2: Recognized coordinate system of the license plate from the machine learning algorithm

[8] Anton,M.: *Untersuchung und Bewertung stationärer Messtechnikkonzepte*

The algorithm used is called Infinitesimal Plane-based Pose Estimation (IPPE), after Collins[9]. The underlying idea of IPPE is that some locations on the surface can be estimated more accurately than others. This point is sought and used to determine the position of the surface. Collins and Bartoli have found that the center point within the four model points is the most suitable for this purpose, as it is the point on which the influence of noisy point correspondences is the lowest.

The calculation is carried out using a first-order partial differential equation. The analytical approach makes IPPE particularly fast compared to other PnP methods based on numerical solution algorithms. Collins also shows that the IPPE algorithm provides better results than common PnP methods and is faster.

The IPPE algorithm is implemented in OpenCV. The result of the algorithm is three rotation and three translation values that describe the rotation and translation of the camera coordinate system into the world coordinate system. Figure 2 shows an example of the corresponding coordinate system as it is transferred to a license plate recognized in the image.

Figure 3 shows a comparison between the raw data acquired with the newly developed system with high fidelity IMU signals. It can be seen, that already the magnitude of the roll angle is determined quite well. High frequency deviations might be compensated in the future e.g. by adding appropriate filtering or by increasing the number of cameras along the perimeter.

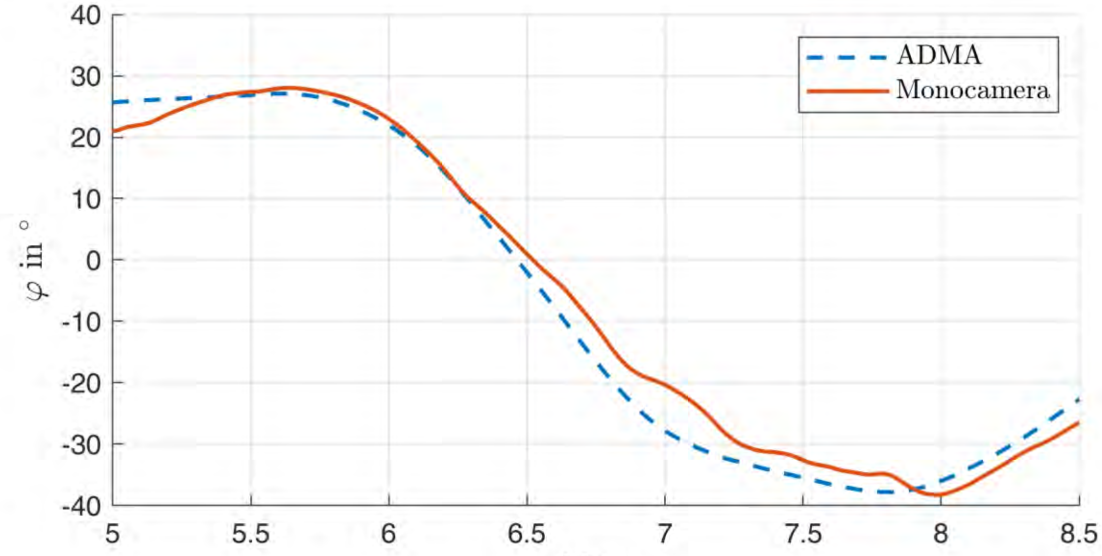

Figure 3: Comparison of a Mono-Camera roll angle estimation with ADMA measurements

During the presented study, the technology was only used in a closed, controlled environment. One reason for this is about legally being able to perform such automated measurements on public roads. Once, these issues are dealt with, we expect this technology to be able to generate highly relevant data for the investigation of critical events.

4 Pseudo-Critical Maneuvers

As discussed in chapter 1, experiments on a closed track might be able to help understanding a potentially existing roll angle threshold. Such testing with an equipped motorcycle in artificial scenarios bears the risk of not showing the naturalistic behavior of the study participants, as it is by all means not commonplace for them. They have to get used to both the environment and test vehicle and must follow specific paths and instructions. Also, they might tend to be overly cautious as they most certainly

[9] Collins, T.; Bartoli, A.: *Infinitesimal plane-based pose estimation*

expect something to happen at some point. Despite all of this, we don't see any alternative solution enabling us to expose motorcyclists to scenarios that they might experience as dangerous. As the reactions of a motorcyclist to an unexpected event may vary extremely (from braking to accelerating, from rush evasion maneuvers to no reaction at all) it is mandatory that each experiment is designed in a way that

- There is always enough evasion space available in every direction behind the event
- There are no hard obstacles around that might be hit by the rider or cause him to crash
- The risk of riding through any configuration of the experiment must not exceed the risk of riding on a typical road by means of visibility, friction, distraction, etc.

A full list of design parameters and demands for such an experiment design can be found in Walther[10]. All maneuvers performed in the study have been tested by professionals and each criticality was subjectively rated by them. As an objective criterion for criticality, the friction coefficient needed to perform each maneuver was evaluated, by measuring the motorcycle's acceleration in all three dimensions. If the subjective criticality was rated high while the friction demand did not exceed a critical value and if all abovementioned demands were fulfilled, the scenario was rated as "pseudo critical". The following maneuvers were performed in this study:

- Multiple rides through a U-turn with constant radius, with the radius changing after several runs, without informing the rider.
- Riding through a corner, after some passes, the corner's exit is rebuilt to steadily increase its curvature.
- Riding through a corner with obstructed view, after some passes, a soft obstacle is placed on the trajectory.

4.1 Results of the track test

The experiments have been performed by N=10 participants with different experience in terms of mileage and daily use. Firstly, no collective leaning threshold could be observed. During the U-turn maneuvers with no dictated speed (all participants were allowed to freely choose a velocity they saw fit for performing the turn), all participants except one showed a median of more than 30 degrees of roll angle both going left and right during the U-turn maneuvers. This part of the track tests was used to determine the personal comfort roll angle range.

As shown in Figure 4, some riders approach different roll angle maxima depending on the direction of the curve, whereas others ride through left and right-hand curves in a very similar way, such as rider number 2. A very large difference between the two curve directions is particularly noticeable for rider number 5. A possible explanation is a recent accident of this rider in a left-hand corner.

[10] Walther, L.: *Entwurf Pseudokritischer Testmanöver für den Motorradfahrversuch*

In addition, there are differences in the absolute, maximum roll angle per turn, as well as the variance of this feature, respectively the interquartile distance. The interquartile distance indicates how evenly the rider passes through the same curve each time. A large inter-quartile distance typically indicates a more inconsistent riding style, whereas a small bar indicates that a similar maximum roll angle is ridden again and again from the first pass to the last. This can often be found for more experienced riders, such as rider number 8, who is the participant in the study with the longest experience. In addition, there are clearly different comfort roll angles, as can be seen between riders 4 and 6.

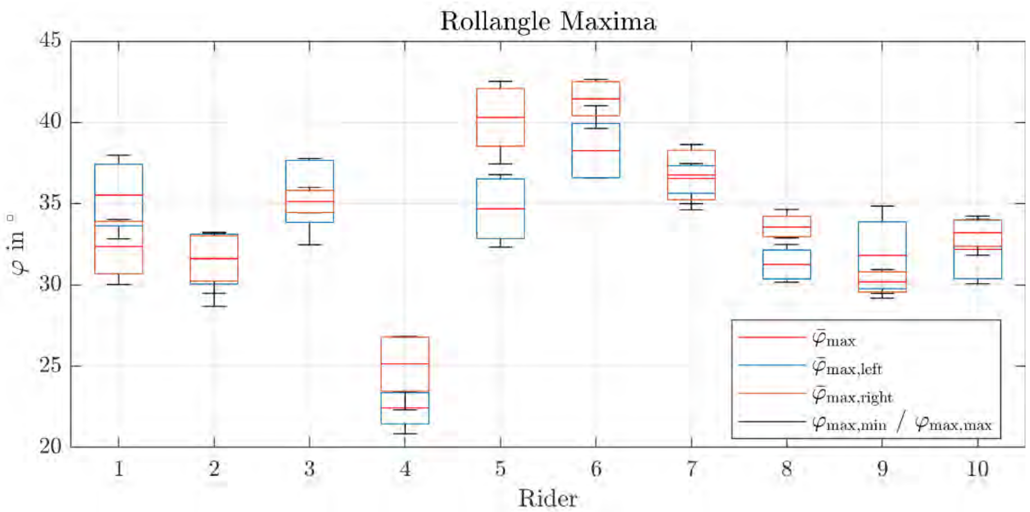

Figure 4: Roll angle distribution in closed track experiment

In order to investigate the existence of a lean angle threshold in potentially critical situations, the reactions of the riders during the pseudo-critical maneuver were compared with the data from the normal riding situations. The most frequent reaction is the reduction of the velocity, both by changing the throttle position and partly by brake interventions. It is interesting to note that all three female test subjects showed similar reactions and intervened more moderately than the male test subjects. For example, in none of the maneuvers a braking intervention was carried out by the female riders, in contrast to the male subjects. Here, however, the small sample size and thus lacking statistical relevance must be pointed out.

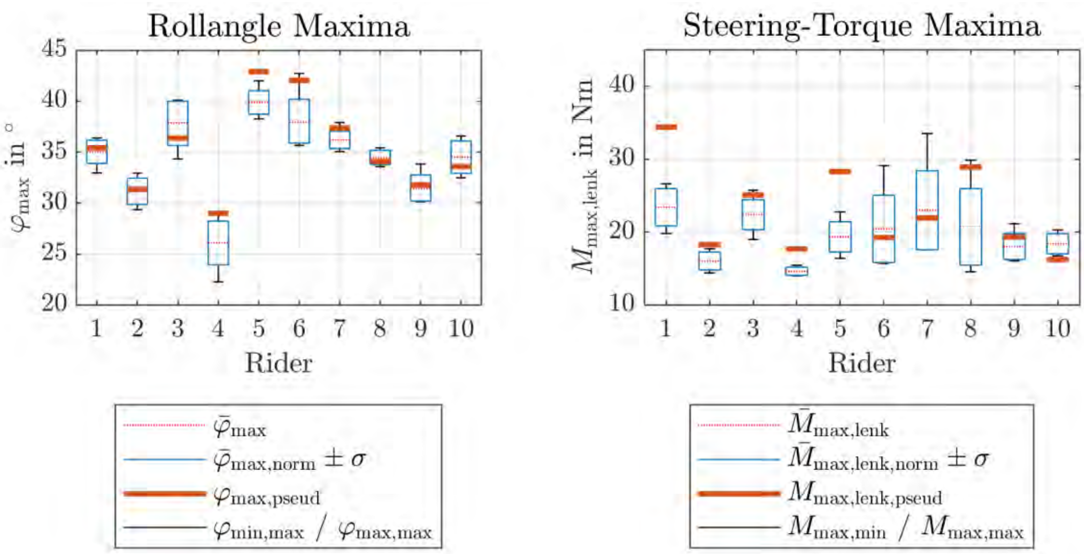

Figure 5: Maximum roll angle and steering torque during pseudocritical maneuver

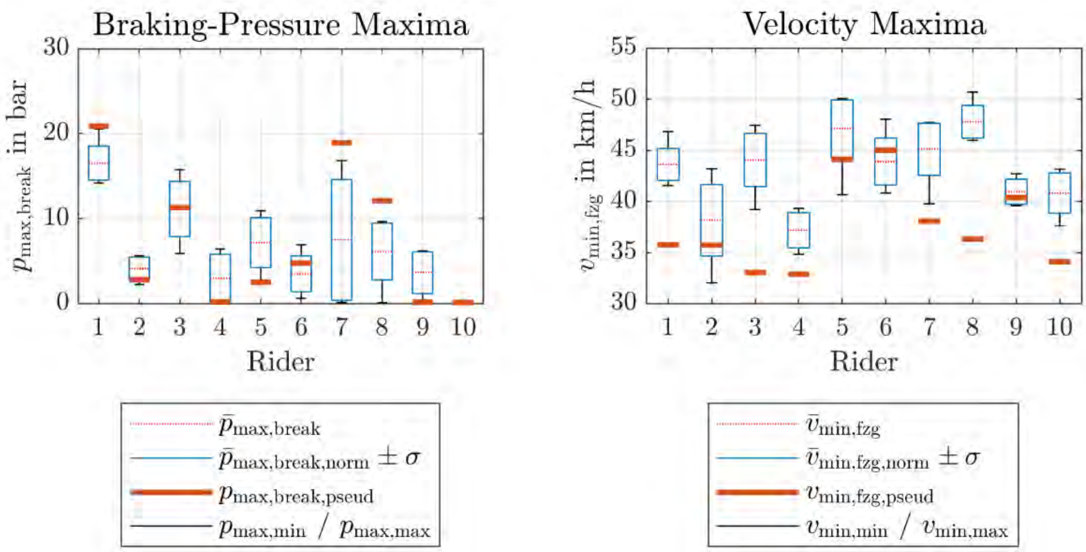

Figure 6:Maximum brake pressure and steering Torque during pseudocritical maneuver

The interventions of all riders are shown exemplarily in Figures 5 and 6, where the distribution of the maximum roll angle or braking pressure respectively are plotted in blue boxes during the cornering without an event and in orange during the pseudo-critical obstacle avoidance maneuver. It should be emphasized that during the entire curve including the pseudo-critical maneuver no less inclined roll angle maxima than during normal maneuvers can be observed. There is a clear difference in the maximum steering torque during the pseudocritical maneuver. Here, high deflections can be observed. Likewise, all the riders reduced speed significantly. This happened partly in parallel with a brake intervention, which also makes the change in the steering torque due to the brake steering torque to be compensated plausible.

The changed behavior also becomes visible when the roll angle distribution of the vehicles is plotted using a cumulative distribution function, like shown in Figure 7. Here a clear change to the otherwise very even distribution of the roll angle becomes visible. In addition, a kink in the distribution at a roll angle of 20 degrees is noticeable during the pseudo-critical maneuver.

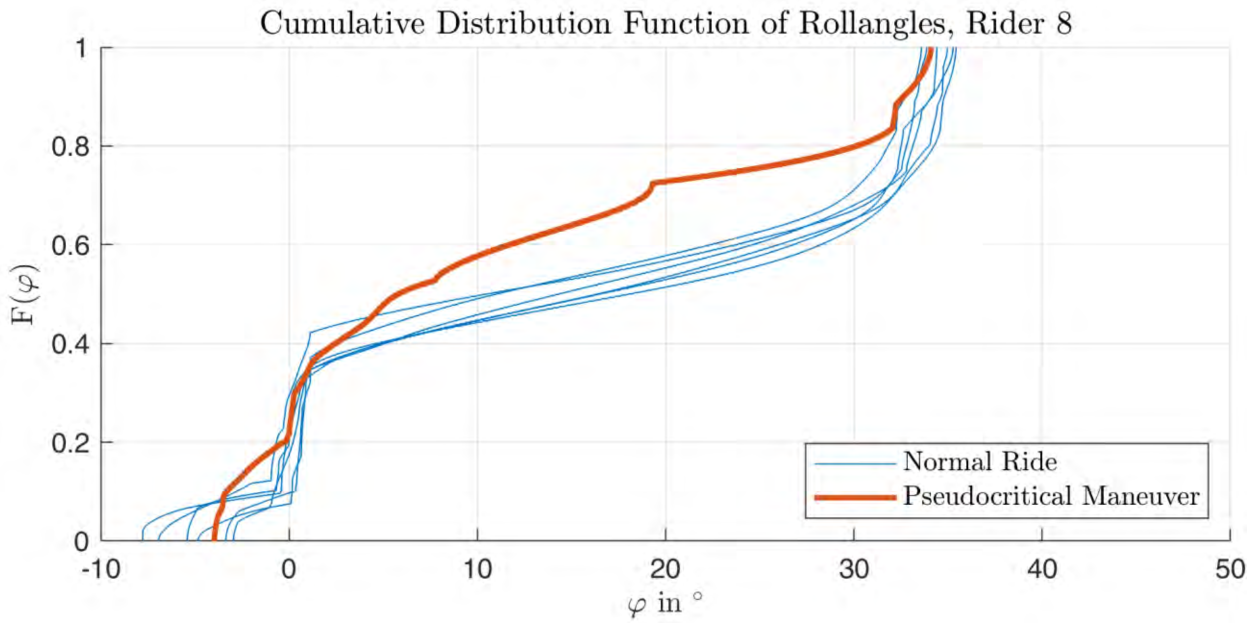

Figure 7: Empirical Cumulative Distribution Function of the Roll angles during cornering

This indicates that the rider remains in this position for a short time. This stopping point with subsequent correction during the roll angle build-up is possibly a useful characteristic value for the investigation of leaning thresholds. A similar behavior can be observed at 8 out of 10 riders.

To get a better understanding of the happening during such an event it is recommended to have a look at the phase diagram of roll angle and roll rates as shown in Figure 8. In comparison to the blue depicted courses of a roll-in and roll-out movement in the right-hand curve without pseudo-critical maneuver, the course of a suddenly appearing obstacle looks very different. The course of such a passage of the pseudo-critical maneuver is marked by arrows in Figure 8.

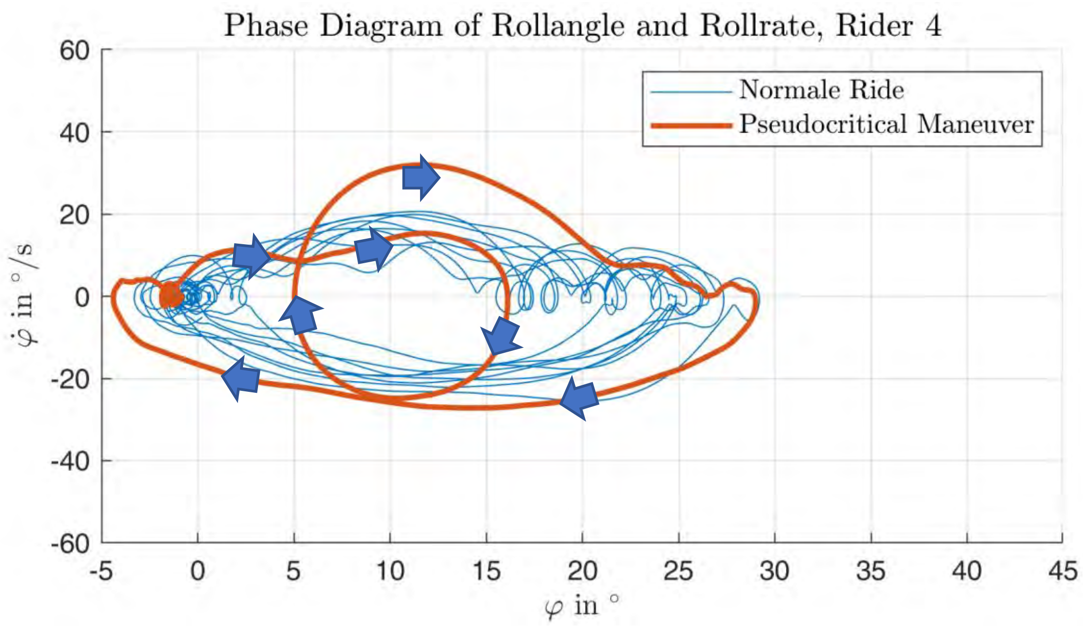

Figure 8: Obstacle & obstructed view

Especially the roll angle build-up to the personal comfort roll angle (positive roll angle in a right-hand bend) is carried out with major stops and restarts of the roll motion. This can be observed through points where the roll rate decreases strongly or approaches zero. 9 of 10 riders, showed a similar behavior. This allows a first interpretation of the existence of a kind of situation-dependent lean angle threshold. The reactions to a pseudo-critical maneuver are not directly related to the personal comfort zone or the way the rider handles in normal situations and again speaks for a situation-dependent threshold. An undershooting below the personal lean angle threshold directly after a pseudo-critical maneuver is not observed in any situation, but vice versa. Thus, the hypothesis of the existence of a situation-dependent lean angle threshold cannot be clearly proven by the investigations.

5 On-road testing

From the previous chapter, it can be seen, that the artificially designed scenarios and the limited number of study participants can only serve for few, descriptive results. Concerning the questions stated in chapter 1 and considering the small number of samples, we can only conclude the following:

- There seems to be no common roll angle threshold among the participants.
- Even during (pseudo-)critical events, each rider manages to reach his (individual) threshold value.
- The small sample number does not allow for correlations between the threshold values and other subjective / objective characteristic values.

Trying to find generalizable results necessitates a larger number of samples. Therefore, an on-road participant study was performed that is described in the following chapter.

5.1 Study design

The aim of the study is to evaluate the usability of low-cost measurement technology and to find evidence for the potential existence of a common roll angle threshold, i.e. analyze the roll angle distributions among a larger sample number during typical rural rides.

Courses

The two-part study was executed in parallel. In the first part, N=15 participants were riding on a specified course (led by satellite navigation) south of Dresden, using the abovementioned smartphone measurement technology on their private motorcycles. In the second part, N=23 participants were riding on a specified course north of Würzburg, using an equipped measurement motorcycle (KTM 790 Duke). Both routes were designed to show typical characteristics of an everyday motorcyclist's route, including curvy roads, inclination, better and worse asphalt quality, etc.

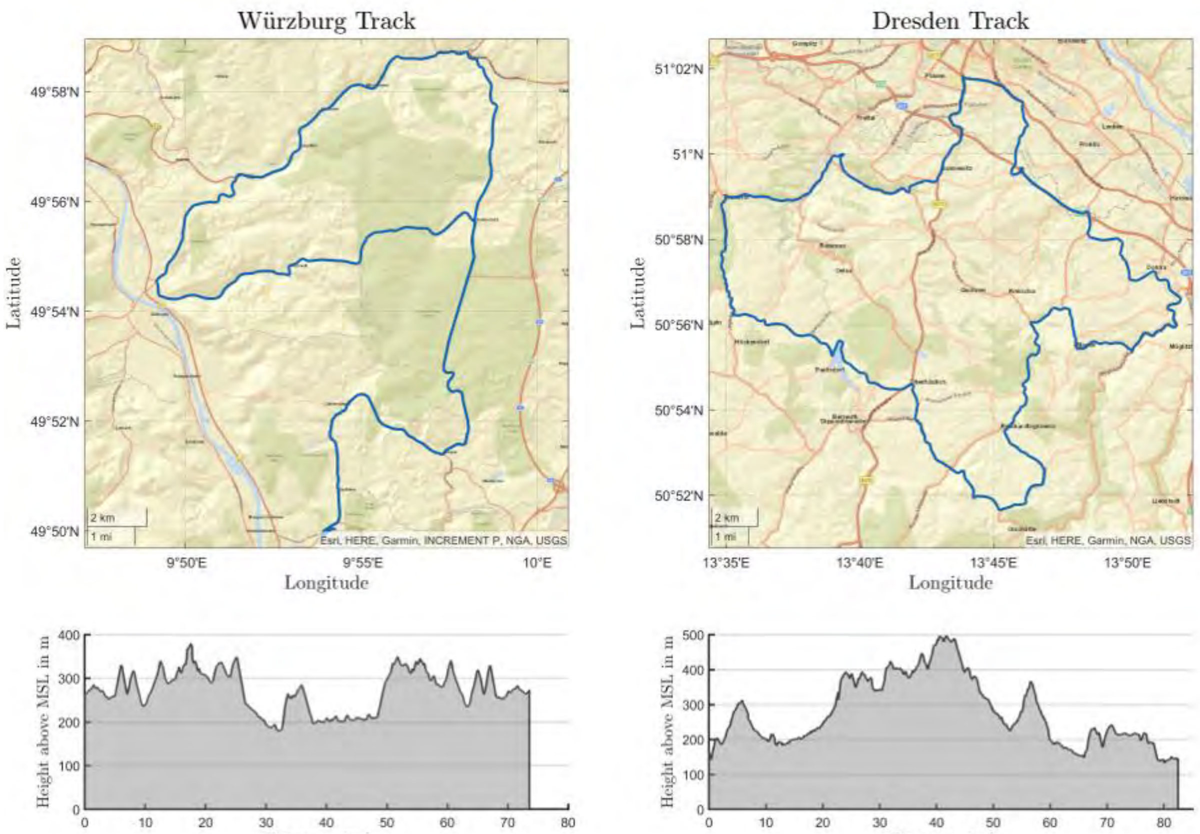

Figure 9: Routes specified for road testing. Left: Würzburg Area, Right: Dresden Area

A length of 83 km or 74 km respectively resulted in a duration of 80-100 minutes, depending on traffic and rider's speed. All participants were told – but not controlled – to stay within the public speed limits and to just ride "normal".

Rider Panel

In preparation to the road testing, all participants were asked to fill in a questionnaire.

Firstly, it included questions about personal details (gender, age, etc.) and their motorcycle use (year-mileage, type of bike, typical use, etc.).

Secondly, 24 items of the questionnaire were aiming to define a rider-type. These Items were rated on a 5 score scale (1-does not appy → 5-does fully apply) and exemplarily included:

- *"I try to ride my bike as economical as possible"*
- *"I brake late and deliberately into turns"*
- *"If possible, I use the opposing lane to ride more dynamically"*

Factorial testing of all given answers then allowed to cluster the items into three representative groups: *sportive, defensive* and *constant*. We assigned every participant into that group, where his mean rating was highest, as depicted in Figure 10:

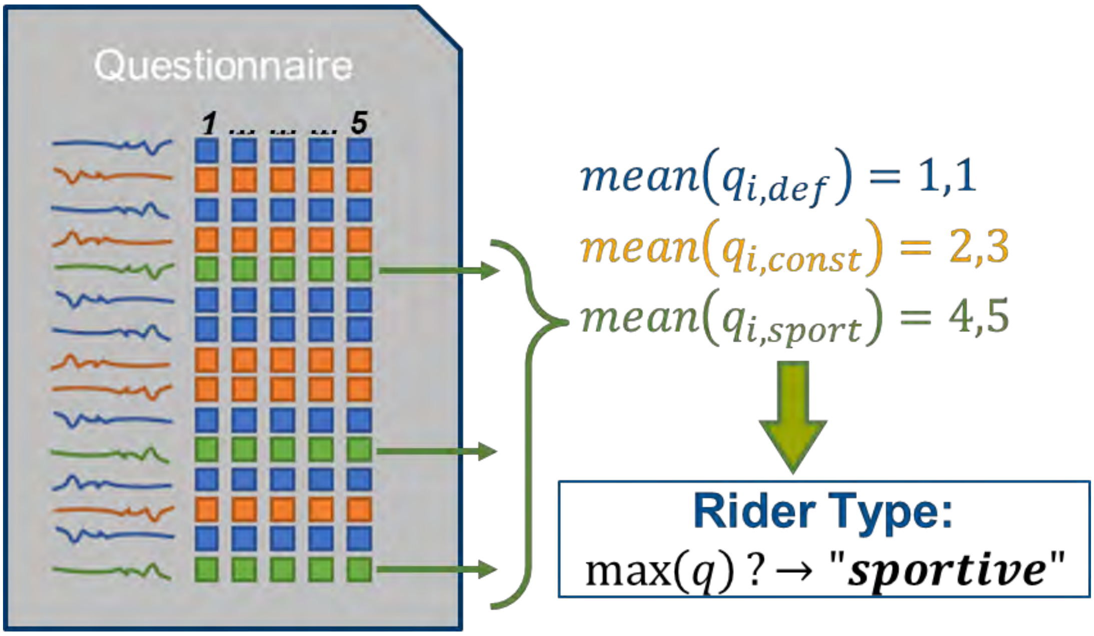

Figure 10: Assigning the rider type

Thirdly, the questionnaire included five items aiming to identify the cornering fear of the participants:

- "I have concerns to exceed a certain lean angle, even though my motorcycle would be capable of it"
- "I feel insecure as soon as I reach a certain lean angle"
- "I am afraid to lose control over my motorcycle while cornering"
- "I try to avoid riding with high lean angles"
- "I think, high lean angles are perilous"

All ratings of these five items were summed up, resulting in a combined "cornering-fear-indication" with values between 5 and 25 for each study participant.

5.2 Data evaluation

In total, more than 13.000 single corners were recorded, including timelines of GPS data and inertial measurements and – on the equipped motorcycle – additional timelines of multiple vehicle states (e.g. throttle, brake pressures, wheel speeds, etc.). In order to generate usable characteristic values for this number of cornering events, an automated data evaluation process is implemented. Firstly, the rider's trajectory is segmented, based on its curvature. As a simple method, we split the data at every sign change of the measured curvature and erase every interval, where the course angle change is less than 10 degrees.

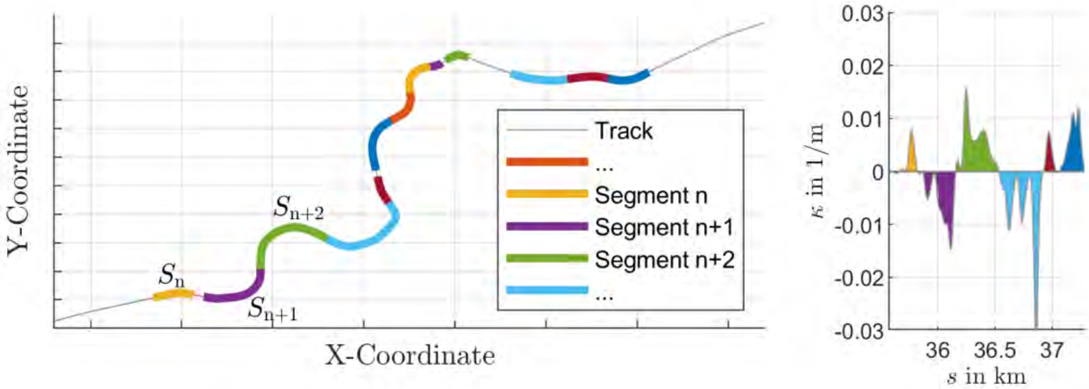

Figure 11: Track segmentation

While this method proves to be quite robust and simple to use, it is often not capable of discriminating between e.g. a single left turn or a multiple left turn, as can be seen in the bright blue segment in Figure 11. For each segment, a set of characteristic values is acquired that includes the maximum curvature, the maximum roll angle, the minimal velocity and other statistical values (means, deviations, etc.) also from further dynamic values (roll rates, longitudinal acceleration, etc.)

The next Figure shows the curvature distribution of the measured sample. It can be seen, that left and right corners occur at almost equal frequency. Furthermore, it shows, that the Dresden route contains a higher number of tighter turns compared to the Würzburg route.

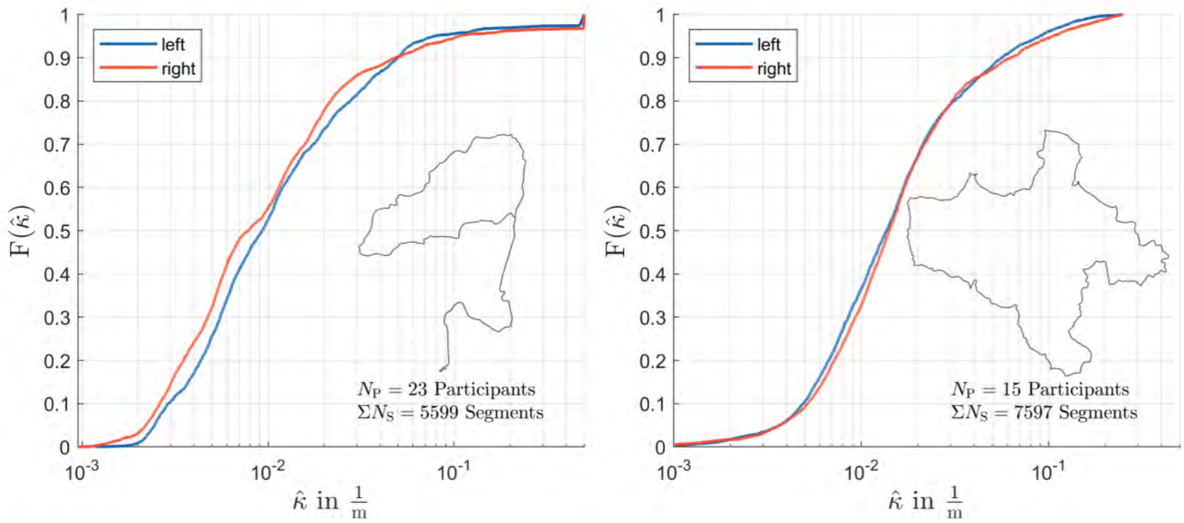

Figure 12: Frequency distribution of minimal curvatures per segment

5.3 Results

At first, we look at the frequency distribution of the maximum roll angles in left and right turns. Figure 13 shows the Würzburg and Dresden (dashed) samples of left (red) and right (blue) corners. The empirical cumulative distribution plot shows, which percentage of the total sample lies within a certain range of the characteristic value – here: the maximum of the absolute roll angle $|\hat{\varphi}|$.

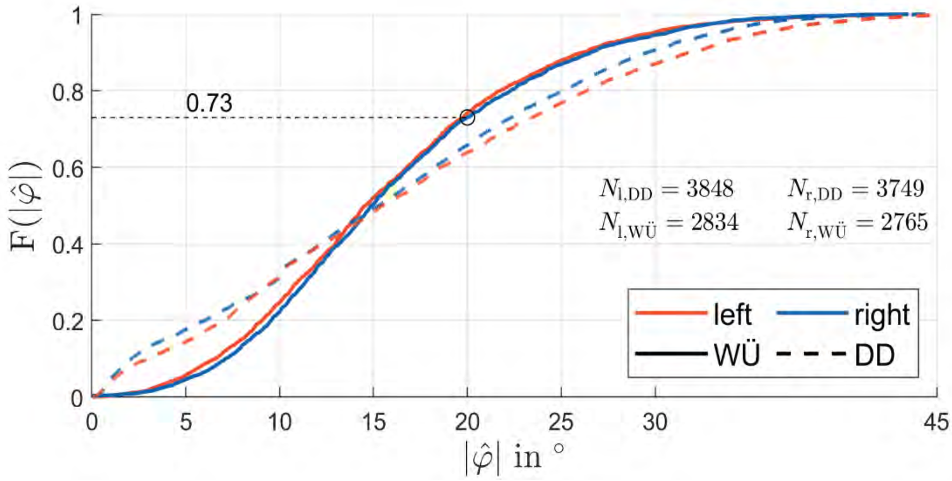

Figure 13: CDF-Plot of roll angle maximum

It can be seen that in 73% of the Würzburg sample and about 65% of the Dresden sample a roll angle of 20 degrees is not exceeded. This data includes all riders and all segments and therefore it is obvious, that also large amounts of lower roll angle maxima are observed. Nevertheless, it shows that at least one fourth to one third of the whole dataset exceeds the 20 degrees limit value that has been anticipated by Bernt Spiegel.

We continue the analysis with more individual data. As stated previously, the roll angle threshold – if existent – doesn't seem to be a common value for all riders but has individual differences. Figure 14 shows the distribution of the roll angle maxima of each study participant by means of a boxplot. The boxes are sorted by their median value. Additional information is given by coloration of the data.

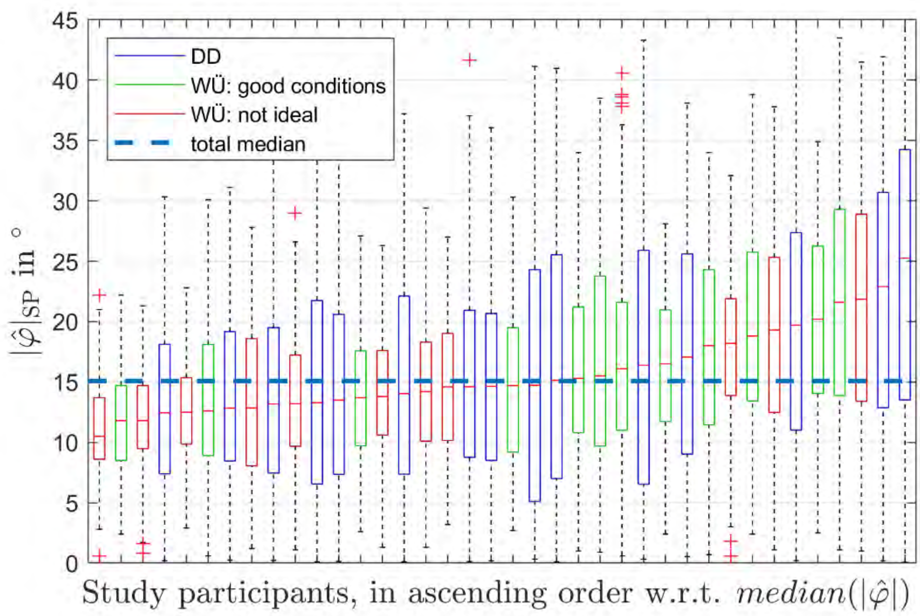

Figure 14: Roll angle distribution of each participant

Influence of environmental Conditions

The blue boxes of Figure 14 have been measured in the Dresden sample, all of them at perfect weather conditions. The red and green boxes result from the Würzburg sample, red indicating not ideal weather conditions. The data shows, that not ideal environmental conditions cause an accumulation of data at lower roll angles as expected. However, we also observe very low values without environmental conditions being an issue as well as very high values at bad environmental conditions.

If we compare the 95 percentile of the attained roll angles with the abovementioned cornering fear rating and discriminate between the environmental conditions, we find in Figure 15, that riders with low indications of cornering fear are able to retain more of their roll angle potential as conditions become worse, while such riders with high indications towards cornering fear lose much more of their roll angle potential.

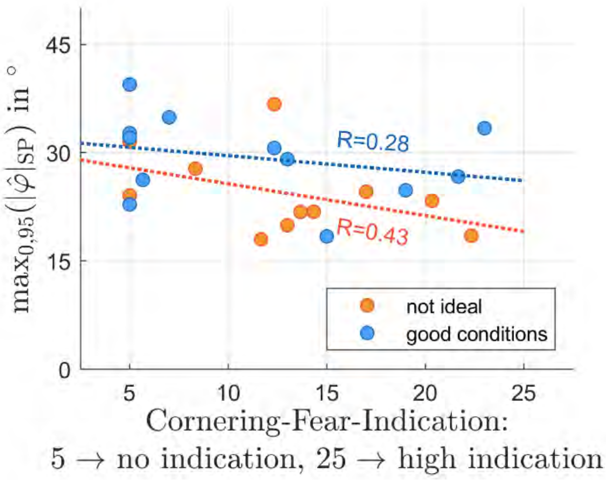

Figure 15: Decreasing roll angle potential under different environmental conditions

As this comparison is only possible with the Würzburg sample, the sample size for each condition becomes quite low and the linear regression may only be seen as a vague trend.

Comparison to cornering-fear-indication

To analyze the connection between the subjective cornering fear ratings of the questionnaire and the individually attained roll angles, we pick just those segments from our dataset that enable – or might even encourage – the study participants to ride at higher lean angles. Therefore, we filter the data for such segments, where the mean velocity was above 50 km/h and the course angle differed more than 90 degrees between entering and leaving the segment.

As this method decreases the sample size, we combine all samples with equal fear ratings (in steps of 5) into single boxes in Figure 16. Each sample point that is an element to a certain box is depicted in the same color. I.e. the box of the Dresden sample with a subjective Rating of about 15 contains all yellow scattered data points that have been collected from multiple study participants with fear ratings between 12.5 and 17.4. While this method results in different numbers of samples per box, it is well suited to show trends emerging from the data.

It can be seen, that in both participant groups the subjectively rated indications to cornering fear correlate well with the observed roll angles during on-road riding.

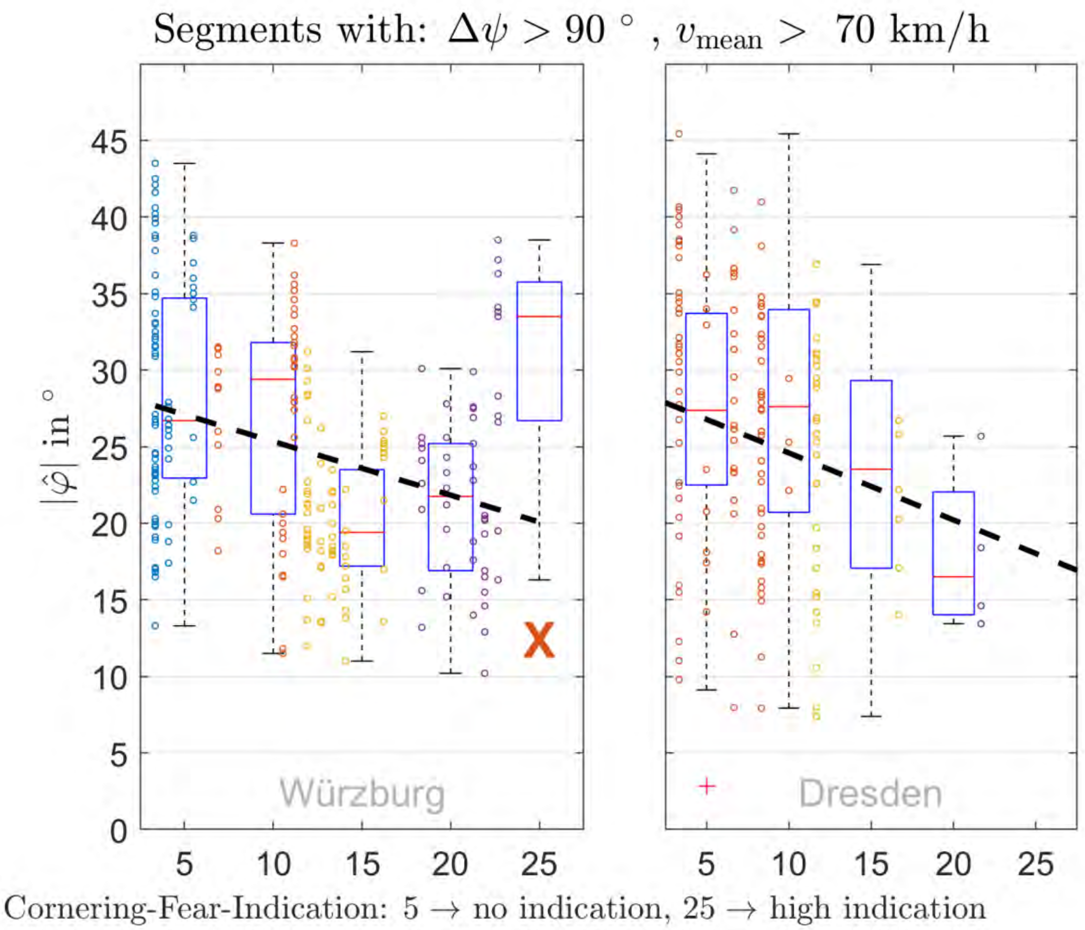

Figure 16: Roll angle maxima over subjective cornering fear ratings

Only one study participant of the Würzburg sample clearly stands out from this trend. With the highest cornering-fear-indication among all study participants, he is the sole member of the box marked with the red “x”, with no other participant contributing to the same box (i.e. having a subjective rating of more than 22,4).

While he is – according to his answers of the questionnaire – the most fearsome study participant, he is counter-intuitively also attaining very high roll angle values. Assuming that he is not purposely giving false answers, this might have two reasons. Either he underestimates his roll angles and attains these high values anyway – despite his concerns to exceed certain lean angles, him being insecure at high lean angles, his fear of losing control while cornering, his avoidance of high lean angles and perceiving high lean angles as perilous. Or he may be aware of his high roll angles but attains them anyway for reasons of thrill and excitement. A last hypothesis might be that he was falsely answering the questionnaire in order to be judged as an especially cautious and calm rider.

To further investigate the connection between the cornering-fear-indication and measured vehicle dynamics, multiple characteristic values have been equally assessed. All typical values like roll rates, velocities, etc. show equal behavior and correlation to the cornering-fear-indication values. Also, we find correlation in our data linking higher age to lower roll angles and higher yearly mileage to higher roll angles.

Steady-State-Deviation

The analysis of roll angle maxima, or similar values for roll rates, velocities, etc. cannot further explain the strange behavior observed with rider "x". Assumed, that he really suffers from great cornering fear, we develop the hypothesis, that this fear might not manifest in the absence of high roll angles but that the roll angles – while eventually reaching high values – are approached rather timidly and cautiously. To further investigate this hypothesis, we compare, how each rider approaches a specific turn. As a baseline, we use the timeline of a theoretic, steady state roll angle that can be calculated from the given curvature κ and velocity v following the equation

$$\varphi_{th} = \arctan\left(\frac{\kappa v^2}{g}\right)$$

This is the roll angle, that a motorcycle would need to build up if the speed and curvature would stay constant. For changing speed and curvature, this amount of roll angle ensures equilibrium between vertical and lateral accelerations at any point in time while neglecting dynamic state transitions. φ_{th} can therefore be seen as the smoothest possible way to ride over a defined trajectory with a defined velocity. It can be calculated for each segment of the dataset. As a single characteristic value, we define the root-mean-square (RMS) of the difference between the actual roll angle and the steady state estimation of the roll angle. This method is depicted in the middle plot of Figure 17.

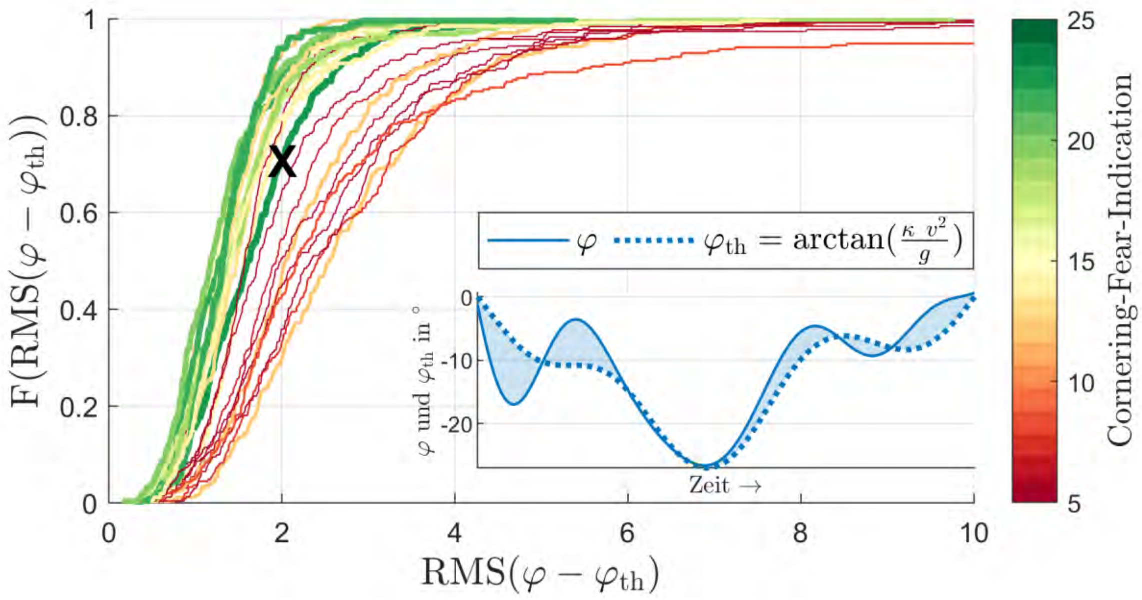

Figure 17: CDF Plot of the RMS of the Steady-State-Deviation

Low RMS values stand for a smooth rolling dynamic. The actual roll angle then tends to match the steady state assumption very well. High RMS values stand for rather dynamic rides. E.g. a rider might utilize body motion a lot or riding a rather edged trajectory.

From the dataset we find one RMS value per every segment. The CDF-plot in Figure 17 shows one line per rider with the color and thickness of the lines discriminating between each's subjective cornering fear rating. Thin, red lines are those riders with small ratings, while thick, green lines point towards higher fear ratings.

Evidently, the steady-state-deviation allows to build two clusters. One cluster with the participants that are less subject to cornering fear and generate higher steady-state-deviations and one cluster with those participants whose subjective ratings indicate towards high amounts of cornering fear.

Again, rider “x” (thick, darkest green line in the middle of the set of curves) plays a special role, as he basically separates the two clusters of either red or green lines from another. It shows, that he really is riding rather smoothly compared to the other riders that are achieving high roll angles and are less subject to cornering fear. It might be worth noting, that following the rider type definition in section 5.1 he is assigned to the small group of “constant” riders.

Summary

The on-road participant study generated huge amounts of data. For now, a simple segmentation method was applied and typical characteristic values were analyzed. They were able to show individual differences in how much roll angle is attained in everyday riding. The newly developed steady-state-deviation value also showed, that not only the individually observed maximum roll angles are of interest, but the way how this maximum is attained.

6 Conclusion and Outlook

The study at hand shows the high potential of the analysis of large naturalistic datasets for the investigation of riders’ cornering behavior. The use of modern smartphone technology can produce convincing results even compared to those acquired with an instrumented measurement motorcycle, but is accessible to a much broader range of riders. A promising addition to vehicle bound measurements are stationary measurements. These might in the future allow to gather continuous data at accident hotspots or any other location to understand the cornering behavior of motorcyclists during critical events even if no direct measurements of the motorcycle dynamics are available.

While the data collected in this study doesn’t show evidence for the existence of a common roll angle threshold, it does however find individual limits that correlate well to personal subjective ratings on items relating to cornering fear. This might e.g. allow to identify riders with a higher risk of becoming a casualty due to under-exploitation of roll angle potential. Also, it was shown, that the maximally achieved roll angle alone does not allow for a characterization of the rider. Therefore, future research should not further concentrate on the existence of a collective threshold value but rather on the robustness of and confidence in the individually attained roll angles. It doesn’t help if a – trained or untrained – rider is capable of riding with 45 degrees of roll angle, as long as he does it without confidence in his capabilities and is capable to robustly maintain such values even in possibly critical events.

Disclaimer

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Die Verantwortung für den Inhalt liegt allein beim Autor.

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The author is solely responsible for the content.

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Towards Safer Rides: Measuring Motorcycle Dynamics with Smartphones

M. Stanglmayr[1]*, M. Bäumler[1], K. Büttner[1], G. Prokop[1]

Abstract
Motorcyclists are among the most vulnerable road users in road traffic. Often, the cause of accidents is a loss of control on rural roads which could be averted by making use of the physical potential in terms of larger lean angles. At the same time, in reality driven lean angles over a larger group of riders and a longer route are unknown which is mainly due to the special measuring technology required. The focus is therefore on the development of a low-cost measurement method for measuring the lean angles of motorcycles. Smartphones are usually characterized by integrated inertial sensors, which are suitable for the acquisition of motorcycle driving dynamics. Employing a smartphone app tailored to the requirements for collecting measurement data on the motorcycle, the data of the sensors are recorded. During the offline evaluation, the rotation angles between the smartphone and the motorcycle coordinate system are determined, the inertial measurement data are transformed and the roll angle is calculated. An essential part is the alignment of the developed measurement chain with a high-precision measurement system. This was carried out on different routes and thus the data quality was determined. As a feasibility study, a test person study with several participants was carried out, which confirmed the practical suitability of the measurement chain. Hence, the study outcomes are briefly shown and discussed. The successful validation on different routes, the practical suitability of the data acquisition and the accuracy of the measurement system encourage to roll out the smartphone app to a larger panel of test persons and thus to collect data on a larger driver collective.

Keywords
Motorcycle Dynamics — Smartphone — Motorcyle Safety — Data Aquisition — Coordinate Transformation — Kalman Filter — Roll Angle Estimation

[1] *Chair of Automobile Engineering, Technische Universität Dresden, Dresden, Germany*
***Corresponding author**: maximilian.stanglmayr@tu-dresden.de

Introduction

As unprotected road users, motorcyclists are among the most vulnerable groups of road users [1]. Due to their naturally unstable driving dynamics, a high power-to-mass ratio and the roads to be travelled, their accident severity is above average. Additionally, motorcyclists are particularly likely to suffer serious injuries in accidents due to their small protection zone. Compared to car drivers, motorcyclists are [2, 3]:

- 3,9 times more often involved in a traffic accident,
- 6,7 times more often injured in a traffic accident,
- 20,6 times more often killed in a traffic accident.

Hereby, over 45% of all killed motorcyclists crash in curves, mostly caused by subjectively too high perceived speed [4]. However, the speed and thus the number of accidents could often be reduced by increasing the corresponding lean angle.

In general, the reasons for driven lean angles seem to be diverse. Bauer et al. motivate that motorcyclists do not take advantage of the physical limit of their vehicles [4]. Spiegel [5] anticipates that a natural lean angle limit of 20° exists. Others correlate driven lean angles with rider characteristics: Winkelbauer et al. with annual mileage [6], Hädrich with driving experience in years [7] and Praschl et al. with rider type (e.g. from sporty to comfort-oriented) [8]. Nevertheless, there exists no systematic review on the reasons for specific lean angle behavior of motorcyclists, despite research methods exist.

In addition to motorcycle riding simulators (e.g. [9]), naturalistic riding studies (NRS) are one way of investigating driven lean angles (e.g. [10]). Up to now, the latter is mainly based on motorcycles equipped with special measurement technology. While measurement-motorcycle-studies ensure high data quality, the rider collective to be addressed is normally quite small due to high efforts in terms of cost and administration. In contrast, smartphones are a low-cost alternative, which is both inexpensive and widely available. With over 57.7 million (69% of the population) smartphone users in Germany and a user share of 95% in the motorcycle relevant target group up to 49 years [11], they seem to be an interesting research tool. This is also proven by a steadily increasing amount of research studies demonstrating the suitability of smartphone sensors for research purposes [12–23].

The closest research to ours was done by Kamimura et al. [24] who developed first single elements towards a complete measurement chain: A smartphone application and data filtering / data analysis components.

With focus to the measurement of driven lean angles, there are also smartphone applications such as calimoto®[1] or EatSleepRide®[2]. However, they do not provide insight into the exact lean angle and calibration methods and thus may not be used for our research purposes.

Therefore, this paper focuses on developing a performant and low-cost smartphone-measurement-toolchain for the investigation of driven lean angles of large rider collectives.

1. State of Research

Regarding the state of research, we briefly go into the basics of motorcycle lateral dynamics (1.1) and applied coordinate systems (1.2), give an overview over smartphone sensors (1.3) and how the motorcycle roll angle can be estimated from sensor data (1.4).

1.1 Motorcycle Lateral Dynamics

In contrast to a two-track vehicle, a motorcycle requires a lean angle to be able to negotiate a curve with the curvature $\kappa = 1/r$. While a car rolls to the outside of the curve when cornering, a motorcycle requires a roll angle towards the centre of the curve to support the centrifugal force. In the case of stationary cornering, the resultant of centrifugal force $F_C = mv^2\kappa$ and weight force $F_G = mg$ points through the tyre contact line where m being the mass of the vehicle, v the forward speed and g the earth gravity constant.

An equation for the roll angle φ_{th} can be derived from the vectorial forces, resulting in the following relationship.

$$F_G \cdot sin\varphi_{th} = F_C \cdot cos\varphi_{th} \Leftrightarrow \varphi_{th} = arctan\frac{v^2 \cdot \kappa}{g} \quad (1)$$

Equation 1 shows that at higher lateral acceleration $v^2\kappa$ or higher speed, a larger roll angle is necessary to pass the curve. Due to the tire width, which is finite in reality, the tire contact point on the tire surface moves towards the center of the curve during cornering. Therefore, a larger roll angle must be set, which is composed of the physically effective rolling angle φ_{th} and an additional angle φ'. Figure 1 illustrates both the theoretical and geometric total roll angle.

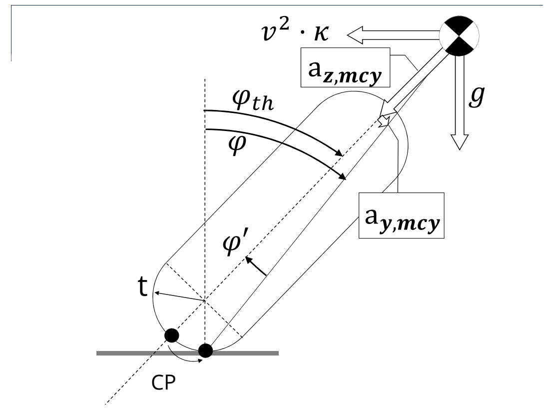


Illustration of Eq. 1 under the assumption of infinitely narrow, undeformed tyres (therefore φ_{th}) and the neglect of gyroscopic forces. The effective roll angle φ is the result when taking into account the tirewidth t.

Figure 1. Ideal and real roll angle; inspired by [25]

The geometric total roll angle φ is therefore calculated by adding the physically effective roll angle φ_{th} and the additional roll angle φ'. While Cossalter [25] gives an equation that takes into account the additional roll angle due to tire width (Eq. 3), the additional roll angle could on average be simplified to approx. 10 % [26] - see Eq. 3.

$$\varphi = \varphi_{th} + \varphi' = \varphi_{th} + arcsin\frac{t \cdot sin\left(arctan\frac{v^2 \cdot \kappa}{g}\right)}{h - t} \quad (2)$$

$$\varphi = \varphi_{th} + \varphi' \approx 1,1\varphi_{th} \quad (3)$$

Due to the relationship between centrifugal and weight forces already presented, a maximum possible drivable roll angle of $50°$ can be achieved for dry road conditions and the assumption of a coefficient of friction of $\mu = 1$. Additional components of the motorcycle like luggage, exhaust parts or footrests can lower this theoretically possible roll angle.

1.2 Coordinate Systems

The coordinate system used is based on DIN ISO 8855 [27]. The coordinate origin of the vehicle-related system is located in the centre of gravity of the vehicle. The axes are described with $[(X_{mcy}, Y_{mcy}, Z_{mcy})]^T$. X_{mcy} is located in the longitudinal median plane of the vehicle and points horizontally to the front, while Y_{mcy} points to the left and is vertical to this plane. Following the right-hand convention, Z_{mcy} points upwards. Rotations around the axes X_{mcy} and Y_{mcy} are called rolling and pitching, and a rotation around the vertical axis Z_{mcy} is called yawing. The roll angle is designated φ. The time derivation of the roll angle is called roll rate $\dot{\varphi}$.

[1] calimoto GmbH, Potsdam, Germany
[2] Kissaki Red Inc. of Toronto, Ontario, Canada

1.3 Smartphone Sensors

Modern smartphones typically integrate an accelerometer, gyroscope and magnetometer as "hardware" sensors which are accompanied by a GPS receiver. Additionally, luxmeters, microphones, proximity sensors and barometers are also often available. Within the operating system, an application can retrieve sensor data over well documented APIs.

The accuracy of the sensors built into current smartphone models is something that most smartphone manufacturers provide little information about. A comparison of high-precision measurement technology and different smartphone sensors by Schelewsky et al. [12] comes to the conclusion that the variance of smartphone sensor technology has decreased considerably (71%) over time, for example from iPhone[3] 4 to iPhone[3] 5. Nevertheless, there is a significant difference between precision measurement technology and the best smartphone that is compared.

A further comparison to the commercial available inertial measurement platforms from GeneSys Elektronik [28] shows that the variance of acceleration and gyro sensors between iPhone[3] 5 and ADMA G differ by a factor of 2000 and 6000. Comparing the data from Schelewsky et al. and Genesys, we find that the noise density, which describes the lower resolution limit of a sensor, is also many times higher for smartphone sensors than for high-precision sensors.

Ma et al. [29] evaluate sensor quality of mobile phone sensors and conclude that accelerometer and gyroscope sensors are rather stable and GPS deviation is not more than $10m$ from the actual value.

Kos et al. [30] use a cloud-based data collection environment to gain more insight into sensor performance for cross-platform smartphone developers. Among other details, they state that the sensor quality between platforms varies considerably and even within the same model. That motivates the question if smartphone sensors are suitable for capturing the dynamics of motorcycle riding.

1.4 Roll angle Estimation Methods

The authors identified four roll angle estimation method clusters. These are 1) the frequency separation principle, 2) optical sensors, 3) Kalman Filter sensor fusion and 4) others. For now, we deliberately exclude algorithms to estimate the pose and position of bodies which are developed in the field of inertial navigation. To determine the impact of the existing methods on the methods to be developed, the findings are concluded shortly at the end of this section.

[3]Trademark of Apple Inc.

Frequency Separation Taking into account the characteristics of motorcycle maneuvers, the frequency separation principle features the fusion of the integrated roll rate (high frequency) with a somehow calculated stationary roll angle (low frequency) values. The accordingly low- and highpass filtered channels are then added up to give a roll angle estimation.

Boniolo et al. [31] use different datasets of inertial sensors to estimate the low-frequency part with the use of a neural network. Also, through optimisation, the separating frequency is determined. The best combination of inertial data was a set of the lateral acceleration, yaw rate and forward velocity. Later, Boniolo and Savaresi [32] find that angular rates measurements also provide sufficient accuracy regarding the low-frequency component. In their patent, Ambruzs et al. [33] describe the calculation of the stationary roll angle mainly based on the lateral and vertical acceleration. This also takes into account the additional roll angle due to tire width.

Optical Sensors Two or more optical sensors which measure the distance to the ground are used. The sensors are e.g. mounted on the left and right foot peg. Through trigonometry calculations, the roll angle can be calculated. This method is often used to deliver ground-truth data in the development stage. Boniolo et al. [34] state that the optical sensor method is a cost-effective method to provide a valid roll angle signal despite that rough asphalt or solar light can reduce the accuracy of the measuring system. Additional uncertainty analysis and change of the sensor principle in [35] reveals that the weak points of the method could be eliminated. However, Lot et al. [36] still mention some problems with the optical sensor method when comparing the results to a roll angle estimation method.

Kalman Filtering Regarding roll angle estimation, Kalman filters are used to fuse signals from different sensors. Like in the frequency separation method, usually stationary and dynamic measurement channels are separately fed into the filter. The filter outputs an optimal estimation value. Corbetta et al. [37] compare Extended (EKF) and Unscented Kalman (UKF) filters and state that the UKF is more robust regarding to initialisation value uncertainties. Also Schlipsing et al. [38] use an EKF with an estimation of the additional roll angle due to tire width by setting $\varphi' = 1,11$. By deriving the state-space formulation out of a multibody system for the core of an EKF, Lot et al. [36] estimate the roll angle based on simulations with errors. Often, the Root Mean Square Error ($RMSE$) is used for a comparison of different time signals. Here, the error is about 4° and $RMSE = 1.5^\circ$. Validation on a real race track yields roll angle errors with peaks above 10° and $RMSE = 4^\circ$.

Others Different methods for roll angle estimation are the pure calculation by GPS data only [7] or the use of image processing algorithms to estimate the roll angle from a video camera [38].

Conclusion It can be concluded that the clusters ”Others” and ”Optical Sensors” can be omitted since no useful sensors exist on a smartphone to apply these methods. Usually, smartphones are equipped with cameras but those might in practice be occluded while riding a motorcycle. Also, GPS data from smartphones can be rather inaccurate. In a preliminary study, we identify a max. sampling frequency of 1Hz, which also excludes a calculation of the roll angle with GPS data only. With the ”Frequency Separation Principle” and ”Kalman Filters” leftover we conclude that the key feature of a successful method is a good estimation of the stationary roll angle. Regarding the dynamic part, the integration of the roll rate $\dot{\varphi}$ is well established.

To fuse both the dynamic and stationary parts, the frequency separation principle is often used. Usually, the separation frequency is set empirically or through optimisation which is one error contributor to the whole method. The authors, therefore, propose to use a simple linear Kalman Filter which itself outputs an optimal estimation of the roll angle.

2. Methods

The measurement chain is separated between (online) data measurement and (offline) postprocessing as can be seen in Figure 2. This means that the tailor - cut smartphone app ”MotoLogger” is optimized for reliably recording raw data on the motorcycle which is then transferred via USB to a computer. The subsequent transformation, filtering, calculation and event- filtering tasks happen within a stationary MATLAB® environment

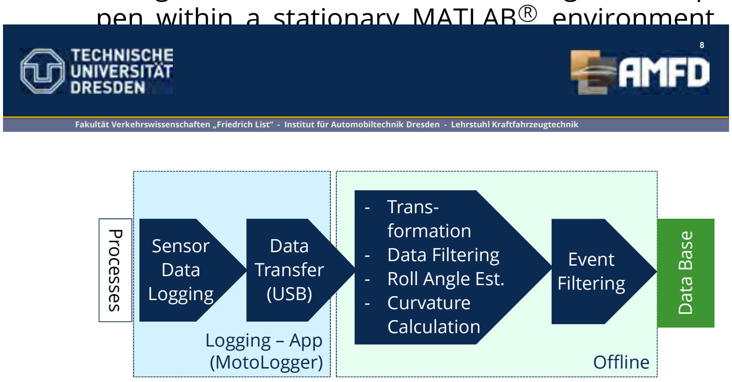
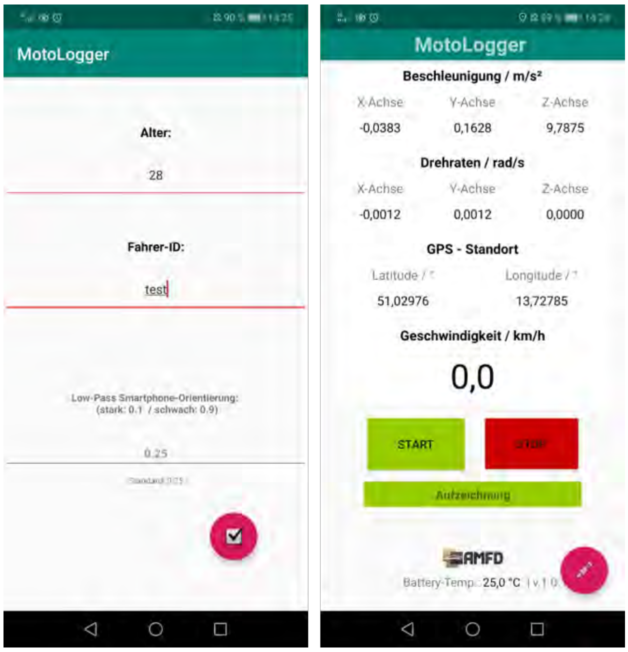


Figure 2. Topology of the measurement chain with a smartphone app and offline processing environment

2.1 Smartphone Application

Despite Staaks et al. [39] present a smartphone application ”phyphox” for conducting educational physics experiments, the authors decided to develop a tailored Android[4] application, called “MotoLogger”, due to several reasons. Firstly, the MotoLogger application is designed for high usability. Study-specific parameters, like age and rider-ID, can be directly retrieved from the users (see Figure 3). Moreover, the user interface was kept as simple as possible avoiding mishandling. Secondly, the measurement data are continuously written in ASCII readable files (*.csv) at each time step for each sensor preventing data loss due to interruptions (e.g. overheating). Thirdly, the sampling rates can be set to the corresponding requirement (Gyroscope, Accelerometer = 100Hz, GPS = 1Hz). Fourthly, the start of each sensor recording can be aligned. This is highly relevant since the start of GPS recording depends on the GPS-signal being available. Fifthly, the user-specific data are only saved in the internal memory to ensure data privacy. Finally, energy requirements can be set to a maximum as usually apps are required to be battery-saving and therefore restricted by the operating system. Tests with the mid-class smartphone “LG G7fit” proofed a maximum recording time of 4 hours due to battery life and a storage-consumption of 100MB per recording hour. By connecting the smartphone with the motorcycle’s electric system and considering the built-in storage capacity of 32GB, the recording of a whole day-trip is possible.



Overview of the MotoLogger app’s user interface, which consists of two different windows. **Left:** Form for filling in rider data (age, rider code). **Right:** Instantaneous values, two buttons to start and stop data logging and valuable system information.

Figure 3. User interface of the ”MotoLogger” application

[4]Android is a trademark of Google LLC.

2.2 Smartphone Coordinate Transformation

By definition, the typical orientation of an Android smartphone (short: SP) coordinate system points with the Y-axis towards the top edge of the screen, the X-axis points towards the right edge of the screen and the Z-axis points out of the screen towards the viewer. For example, a smartphone which is mounted on the motorcycle with the top edge pointing in the direction of travel and the display aiming towards the rider is therefore rotated by a yaw angle of $\psi_{SP} = 90°$ and e.g. a roll angle $\varphi_{SP} = 33°$ to the vehicle coordinate system (see Figure 4).

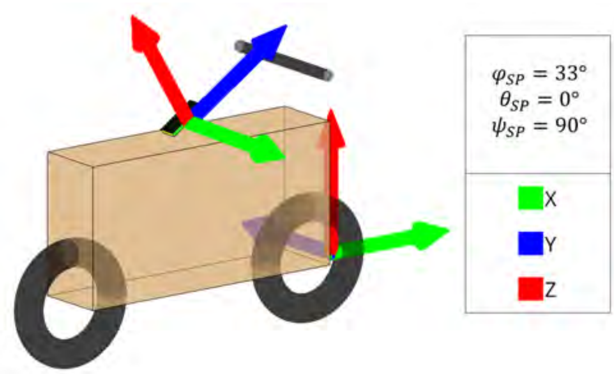


Figure 4. Rotation of coordinate systems

However, different mounting methods imply that the orientation of the smartphone coordinate system to the coordinate system of the motorcycle may be different for each ride. A measurement of the respective angles to the motorcycle coordinate system would be very complex and is not practicable, especially for future test rides where the test person should also have the possibility to carry out the test independently. Consequently, a method was developed that automatically transforms the measurement data related to the smartphone coordinate system (see Figure 5) into the motorcycle coordinate system. The method is separated into three major steps described below.

Step 1 Tests with various test persons have shown that an automated determination of the roll and pitch angles cannot be reliably carried out when the vehicle is standing still, as in this case it must be assumed that the vehicle is as upright as possible. As soon as the motorcycle is standing on the side stand or there is a roll angle when stationary due to a too-short leg length, the above requirement is not met and the transformation is faulty. Therefore, a datapoint selection has to be applied to find "straight maneuvers without accelerating".

The first data point selection applies if a minimum speed of $v_{min} = 30km/h$ is reached, the acceleration of $a_{thresh} = 0,3m/s^2$ is not exceeded and the sum of the three rotation rates does not exceed a calculated threshold value. Looking at the sum of rotation rates is admissible, since at least the pitch and roll rate would be present in the motorcycle coordinate system while stationary cornering. The following Eqs. 4 - 6 are used for a calculation to determine the speed-dependent threshold value of the rotation rates:

$$\dot{\psi}_{glob} = v \cdot \kappa = \frac{tan\varphi_{thresh} \cdot g}{v} \quad (4)$$

$$\dot{\theta}_{mcy} = sin\varphi_{thresh} \cdot \dot{\psi}_{glob} \quad (5)$$

$$\dot{\psi}_{mcy} = cos\varphi_{thresh} \cdot \dot{\psi}_{glob} \quad (6)$$

$$\dot{\omega}_{thresh,mcy} = \dot{\theta}_{mcy} + \dot{\psi}_{mcy} \quad (7)$$

In the above equations, the yaw rate $\dot{\psi}_{glob}$ describes the rotation rate about a global inertial system whereas $\dot{\theta}_{mcy}$ and $\dot{\psi}_{mcy}$ describe the rotation rates within the motorcycle coordinate system.

Only one threshold value for the desired roll angle and the measured (GPS) speed is needed within the equations 4 - 6. With a maximum threshold roll angle of $\varphi_{thresh} = 3°$, the curve for the sum of the rotation rates follows in Figure 6.

Combining the rotation rate criterion with the speed and acceleration criterion, maneuvers for running straight without accelerating or decelerating can be selected. Figure 7 shows the result of the data point selection.

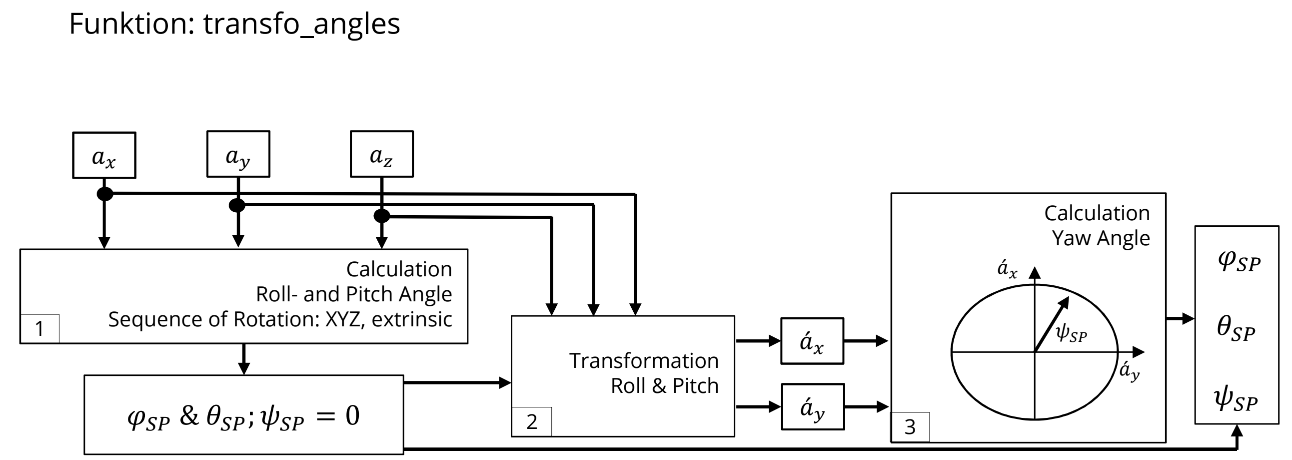
The calculation of the pitch and roll angle from the triaxial acceleration data follows the convention of a rotation sequence X-Y-Z, which corresponds to the extrinsic rotation sequence for the Z-Y-X sequence prescribed in DIN 8855 [27]. The following equations apply to the calculation of the smartphone pitch and roll angles:

$$\varphi_{SP} = atan\left(\frac{a_y}{a_z}\right) \quad (8)$$

$$\theta_{SP} = atan\left(\frac{-a_x}{\sqrt{a_y^2 + a_z^2}}\right) \quad (9)$$

Due to the permitted threshold values for the selection of the data points, a scattered range for the angles of rotation results. The actual rotation angle is determined from the median of the data points, which can be e.g. read graphically or selected automatically from a representation of the cumulative frequency function (CDF) of a data set - see Figure 8.

Step 2 In the second step (see Figure 5), the accelerations and rotation rates are transformed into a horizontal coordinate system in a first transformation with the assumption $\psi_{SP} = 0$. This means that the Z-axes of smartphone and motorcycle coordinate system already match, so that the transformed yaw rate matches the yaw rate in the motorcycle coordinate system.



The determination of the rotation angles between the smartphone and the motorcycle coordinate system is divided into three steps. First, the roll and pitch angles are determined from the acceleration due to gravity which is always effective. Then, the inertial measurement data is pre-transformed into the horizonted coordinate system. In the third step, the yaw angle can be determined from the effective acceleration during braking maneuvers when driving straight ahead.

Figure 5. Method for coordinate transformation

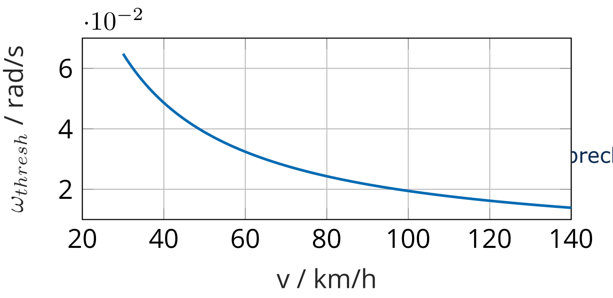
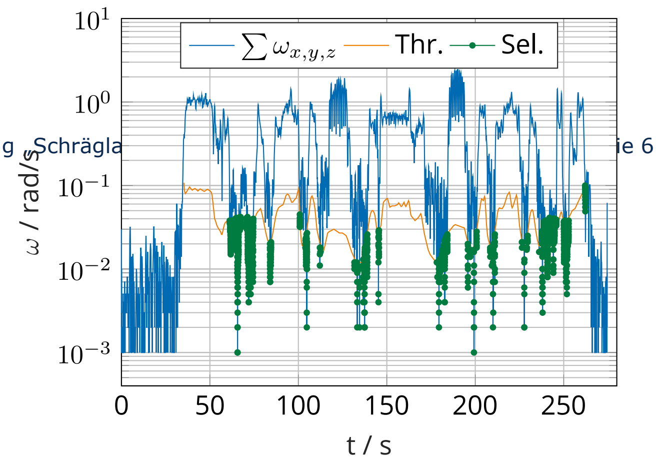


Figure 6. Velocity dependent rotational rate threshold value for running straight; $\varphi_{thresh} = 3°$



The threshold value from Eq. 7 is applied to the sum of all smartphone rotation rates. The data points from the rotational velocity criterion are then overlaid with the criterion of constant speed. The selected data points (in green) are used for the calculation of the pitch and roll angle of the smartphone.

Figure 7. Selection of datapoints for running straight

Step 3 In the third step, the selection of valid data points, which are used to determine the yaw angle, is based on the criterion "braking straight ahead". A straight-ahead ride is determined by comparing the threshold value from Eq. 6 only and the now transformed yaw rate $\dot{\psi}'$. To determine sections while braking, the sum of accelerations is formed from the transformed accelerations a_x and a_y. The sign missing due to the squaring of the terms is determined from the filtered time derivative of the GPS velocity v_{GPS}. Finally, the data points with a braking acceleration of at least $a_{x,mcy} = 2,5 m/s^2$ and a minimum speed of $v_{min} = 30 km/h$ are provided for further evaluation. Then, the missing yaw angle can be calculated from the horizonted selected data (Eq. 10):

$$\psi_{SP} = sign(a_{GPS}) \cdot cos\left(\frac{a'_x}{\sqrt{a'^2_x + a'^2_y}}\right) \quad (10)$$

Similar to the above procedure, the yaw angle is also defined by the median of the calculated angles ψ_{SP} (see Figure 8).

Data Transformation With the now known angles of rotation of the smartphone to the motorcycle, all inertial raw data are transformed into the motorcycle coordinate system by transformation using the transformation matrices $R_{X,Y,Z}$ (Eqs. 11-13) which result in R_{XYZ} (Eq. 14):

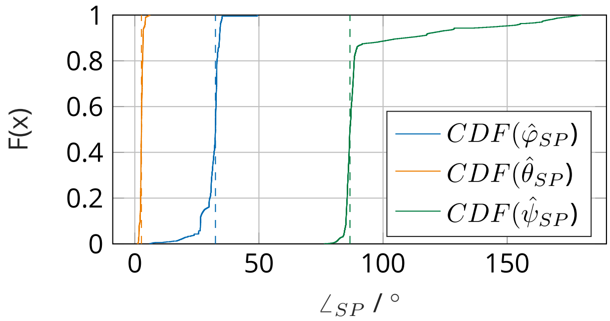
$$R_X = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(\hat{\varphi}_{SP}) & -sin(\hat{\varphi}_{SP}) \\ 0 & sin(\hat{\varphi}_{SP}) & cos(\hat{\varphi}_{SP}) \end{pmatrix} \quad (11)$$

$$R_Y = \begin{pmatrix} cos(\hat{\theta}_{SP}) & 0 & sin(\hat{\theta}_{SP}) \\ 0 & 1 & 0 \\ -sin(\hat{\theta}_{SP}) & 0 & cos(\hat{\theta}_{SP}) \end{pmatrix} \quad (12)$$

$$R_Z = \begin{pmatrix} cos(\hat{\psi}_{SP}) & -sin(\hat{\psi}_{SP}) & 0 \\ sin(\hat{\psi}_{SP}) & cos(\hat{\psi}_{SP}) & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (13)$$

$$R_{XYZ} = R_X \times R_Y \times R_Z \quad (14)$$

After the transformation all inertial data are available in the motorcycle coordinate system and are



Plot of the CDF and the selected values for smartphone roll angle $\hat{\varphi}_{SP} = 2.7°$ and pitch angle $\hat{\theta}_{SP} = 32.5°$ (additionally the yaw angle $\hat{\psi}_{SP} = 86.7°$, see below)

Figure 8. Selection of transformation angle values

stored next to the raw data in the measurement dataset.

2.3 Data Filtering

The recorded raw measurement data from the smartphone on the motorcycle is characterized by a high proportion of unwanted vibration components, which are due on the one hand to the vehicle's own vibrations of the combustion engine drive train and on the other hand to external excitation such as road or air excitation. These vibration components must be filtered out for data evaluation to investigate the actual behavior of the riders. In comparison to the driving dynamics of the rider and the whole vehicle, these additional influences are higher-frequency vibration components. This characteristic makes a low-pass filter suitable for removing these components.

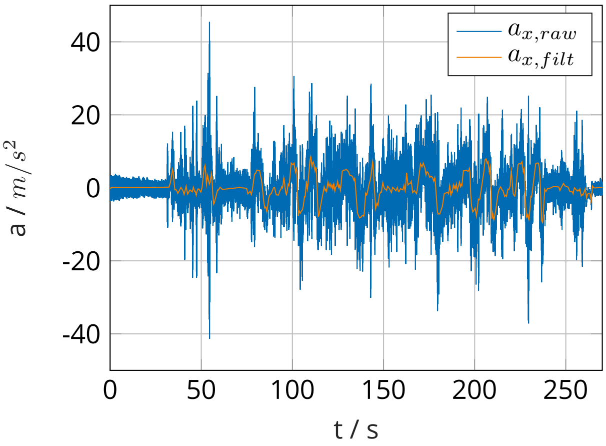
According to [31], the bandwidth of the roll dynamics is about 3Hz. The rotational rates are therefore filtered with a frequency lying above that value. In [24], the cutoff frequency is 1Hz for accelerations. Following cut-off frequencies result for the various data channels, see table 1:

Table 1. Lowpass Filter frequencies

parameter	f_c / Hz
accelerations	1 Hz
rotational rates	5 Hz
forward velocity	0,3 Hz

Specifically, a low-pass filter with Butterworth characteristics is used. Besides, the offline evaluation includes forward and backward filtering, since no real-time calculation is necessary and the phase shift between channels that would otherwise result can be eliminated. Finally, Figure 9 shows an example of the post-processing of a longitudinal acceleration signal a_x with raw data and filtered data.

In this example, the cause of the high-frequency disturbance is the fixture of the smartphone which has an eigenfrequency of about $18Hz$. Through fixing the smartphone to fairing parts or the rear seat, these disturbances can be eliminated partially "mechanically" while data acquisition (see Figures 11 and 17).



The high-frequency disturbance components of the signal can be effectively filtered out with the cut-off frequency used, resulting in a smoothed and physically plausible signal which is used for further investigations.

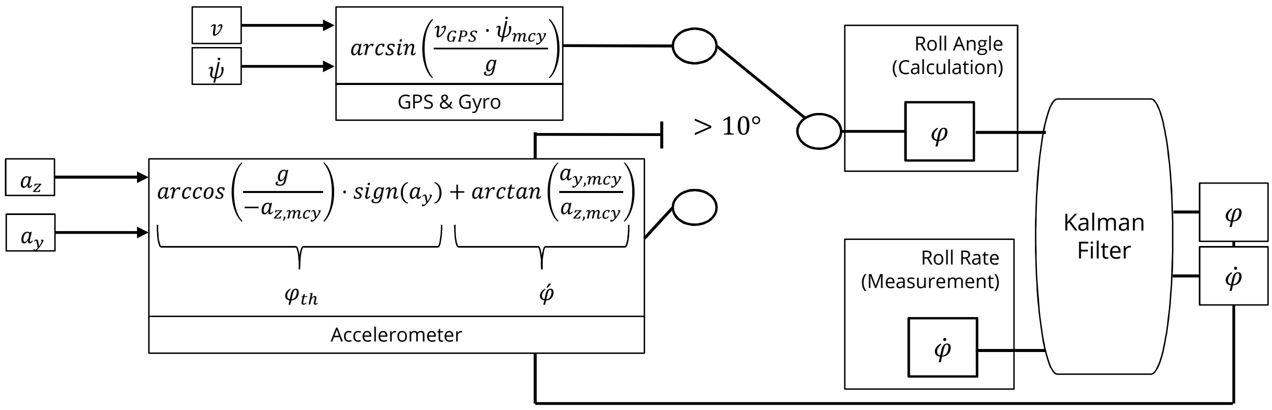
Figure 9. Example for data filtering

2.4 Roll Angle Estimation

Due to the recording of measurement data using a smartphone, there are some limitations for the roll angle calculation. Thus, a method has to be implemented providing the most precise calculation results for the roll angle despite negative properties of the data signals. Since a calculation of the roll angle by GPS position or GPS speed does not yield sufficiently accurate results (low sampling rate & accuracy), the calculation of the roll angle should preferably be based on the measurement data of the inertial sensor system of the smartphone rather than relying on GPS data only.

To minimize the number of necessary calculation data, the additional roll angle is calculated directly from the available measurement data. The lateral $a_{y,mcy}$ and vertical $a_{z,mcy}$ acceleration acting in the motorcycle coordinate system can be used for this purpose, meaning that e.g. measurement of the tire width or estimation of the additional roll angle due to tire width is not necessary. Therefore, we propose the methodology for roll angle estimation depicted in Figure 10.

Switching between the stationary roll angle channels is introduced because accelerometers that are not calibrated exactly can cause deviations of the roll angle around the upright position. The effort of a sensor calibration (e.g. [40]) was deliberately omitted, because it might not be possible to perform it reliably in case of a distribution of the smartphone app over a larger rider collective. For small roll angles predicted in the Kalman filter $\varphi < 10°$, the roll angle is calculated from the longitudinal speed and



Schematic structure of the lean angle estimation algorithm used with a linear Kalman filter. In the Kalman filter, three measurement data channels are merged. The actual roll angle is supplied as a calculated channel, whereby a distinction is made between an approximate straight-ahead travel and curve travel by switching at a limit roll angle of $\varphi_{lim} = 10°$. The calculated stationary lean angle is then fused with the measured roll rate $\dot{\varphi}$ by a linear Kalman Filter.

Figure 10. Algorithm for roll angle estimation

yaw rate (see Eq. 15). Especially on straight sections of the track, the GPS speed is sufficiently accurate so that the longitudinal speed can be used here.

$$\varphi_{meas,GPS} = asin\left(\frac{v_{GPS} \cdot \dot{\psi}_{mcy}}{g}\right) \tag{15}$$

For large roll angles $abs(\varphi) > 10°$ the Kalman filter switches to the calculated signal from the acceleration sensors. Since the theoretical roll angle is calculated purely from the vertical acceleration in the motorcycle plane, this value is not signed, which is why the sign is taken from the lateral acceleration (Eq. 16). The additional roll angle due to tire width is calculated from the quotient of the lateral acceleration and vertical acceleration (Eq. 17). The sum (Eq. 18) of the two calculated values gives the stationary roll angle.

$$\varphi_{az} = sign(a_{y,mcy}) \cdot acos\left(\frac{g}{-a_{z,mcy}}\right) \tag{16}$$

$$\varphi_{ay} = atan\left(\frac{a_{y,mcy}}{a_{z,mcy}}\right) \tag{17}$$

$$\varphi_{meas,acc} = \varphi_{az} + \varphi_{ay} \tag{18}$$

Since the calculated roll angle channels are only valid for stationary cornering and a pure integration of the roll rate does not deliver a sufficient result (see [32]), the suitability of the algorithm for dynamic driving maneuvers is achieved by fusion with the roll rate with the use of a linear Kalman Filter (for details, see e.g. [41]).

The following state vector is used where φ_{meas} refers to the calculated roll angles in Eqs. 15 and 18. The roll rate $\dot{\varphi}$ is the actually measured and transformed value from the smartphone $\omega_{x,mcy}$.

$$x = [\varphi_{meas}, \dot{\varphi}]^T \tag{19}$$

2.5 Course Angle Calculation

The course angle signal calculated in the smartphone with the GPS positions is already available in the recorded measurement data record through the GPS API; short for **A**pplication **P**rogramming **I**nterface. However, after evaluating several test drives, this signal does not meet the requirements for a more precise evaluation. The inaccuracy is due to sporadic outages and the time resolution of the measurement signal (1 Hz sampling rate). As a consequence, a function is integrated into the postprocessing environment which allows the calculation of the course angle from the recorded GPS positions. For the calculation, it should be noted that the GPS coordinate system is not Cartesian and therefore the points are first transferred to a Cartesian system via UTM (**U**niversal **T**ransverse **M**ercator) transformation (see e.g. [42]). Using this method, the earth's surface is in parts transformed into a Cartesian coordinate system. Equation 20 shows the formula on which the calculation with the transformed coordinates is based. The indices "2" and "1" in this context denote successive measured data points where the calculation variables x and y originate from the UTM transformation.

$$cos(\psi) = \frac{y_2 - y_1}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}} \tag{20}$$

The result of the calculated course angle provides the angle between the direction of travel and the north direction. As a result, maximum values of $\pm 180°$ are thus achieved, which must be taken into account, for example, when calculating the change in course angle of curves.

2.6 Curvature and Curve Cegmentation

For the determination of useful curve segments, the respective curve radius is calculated from the recorded driving data which can then be used for segmentation of the data.

Curvature The curve radius can be calculated with different data, however, the sometimes faulty (GPS) speed is usually included in the calculation term. The following formula is used to ensure that this speed is not included in the calculation as far as possible:

$$R_c = \frac{v \cdot cos(\varphi)}{\dot{\psi}_{mcy}} = \frac{1}{\kappa} \tag{21}$$

The resulting signal is saved for further inquiries as the inverse curve radius (curvature κ).

Curve segmentation To evaluate curve features like the maximum driven roll angle from a statistical point of view, automated data preparation and segmentation has to be carried out to evaluate individual events. For automated segmentation, the curvature is searched for sign changes. A segment between two sign changes is defined as a curve if the course angle of the motorcycle within the segment changes by more than $\psi_{thresh} = 10°$. Gorges et al. [43] set this value to $\psi_{thresh} = 60°$ which is more restrictively sorting out curve segments. Their curve detection algorithm is not based on a course angle directly, but they calculate the course angle difference from the timespan, velocity and mean curve radius of the curve.

3. Measurement Chain Verification

After developing the methods to measure motorcycle dynamics, they are verified by comparing the smartphone measurement chain to a high precision inertial measurement unit.

3.1 Inertial Measurement Unit (IMU)

The ADMA[5] G inertial measuring system from GeneSys [28] is used for comparative measurements in Dresden and Darmstadt. ADMA G is a high-precision measuring system that was specially developed for vehicle dynamics measurements in the automotive sector to determine acceleration, speed, position and rotation rates in all three spatial directions while driving. A fusion algorithm (EKF) calculates speed, position and location in space from the raw data and compensates measurement inaccuracies of the individual sensors. In addition, the drift behavior is compensated by using a GPS receiver, resulting in a highly precise measurement signal. The size of the ADMA is very compact so that it can be easily attached to the motorcycle.

The system has already been used in other studies for measuring the driving dynamics and roll angle of motorcycles, so that it also appears suitable for validating the smartphone. Schlipsing et al. [38] used the ADMA system for reference measurements of a low-cost IMU as well as for roll angle calculation from camera data.

3.2 Test Vehicle

A BMW R1200 GS Adventure (K51) motorcycle is used for the comparison and validation measurements. Figure 11 shows the motorcycle on the test track with the measuring systems to be compared (Smartphone and ADMA).

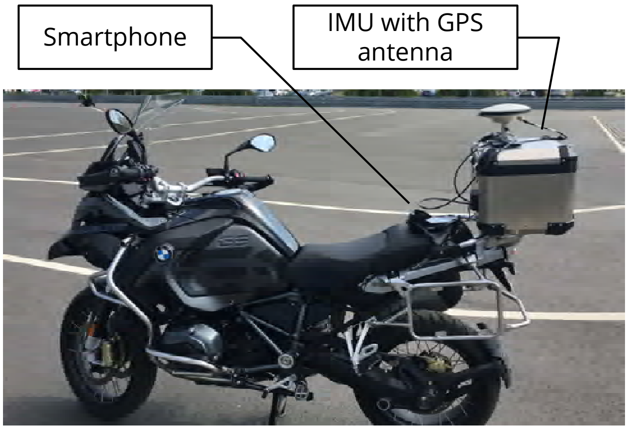


Figure 11. Test vehicle equipped with two data acquisition systems

The IMU is fixed within the topcase for testing purposes and connected to the on-board power supply. In addition, the GPS antenna is mounted on the lid of the topcase. For data logging of the IMU-measurement-data, a laptop is used, which is carried in the backpack of the rider. For the validation ride on the test tracks the smartphone is either fixed on the pillion seat utilizing adhesive tape and a cover, on a professional fixture system (SW-Motech[6]) X-Grip or directly on fairing parts. It should be noted that both measuring systems must be installed on the vehicle so that they are fixed to the body.

3.3 Test Tracks

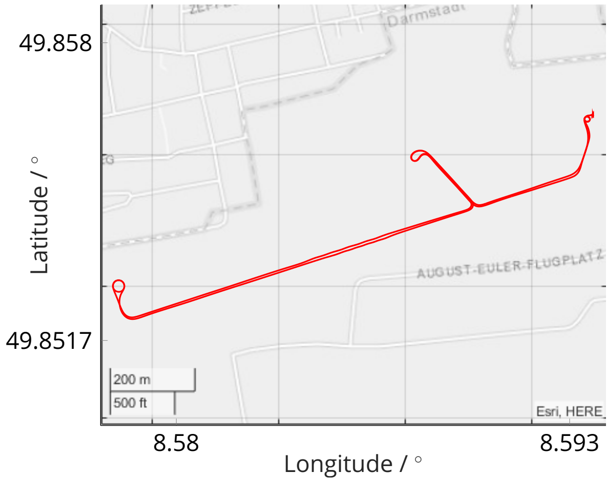
Two test tracks are used for the validation phase. The first one is an airfield near Darmstadt, see Figure 12

For the design of the Dresden test track, it was important that the majority of the test track should run on rural roads with many bends, as there is a particular accumulation of fatal accidents. The route selection is therefore also based on sections of the ”Accident Atlas” of the German statistical offices of the federal and state governments. [44]

As a general condition for the test track, the area of the Technische Universität Dresden will be defined as start and finish point. For the detailed planning of the course, left and right curves should preferably occur in equal parts. At the same time,

[5] Automotive Dynamic Motion Analyzer

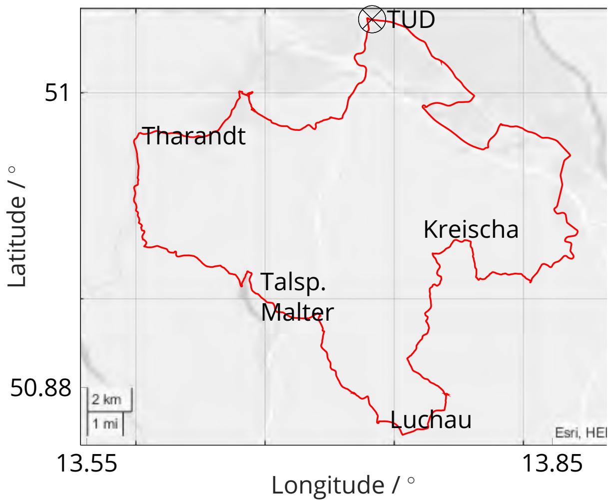
[6] SW-MOTECH GmbH & Co. KG, Rauschenberg, Germany



The **Darmstadt** test track is assembled of different sections at the August-Euler airfield nearby Darmstadt. With a total length of 4km, it is absolved in about 5 minutes. ©OpenStreetMap contributors

Figure 12. Test track in Darmstadt

curves with as different radii as possible should be covered in the course of the route. Finally, this results in the route shown in Figure 13.



The **Dresden** test track has a total length of 84 km and a journey time of about one hour and 45 minutes. A significant part of the track has to be completed in the nearby Erzgebirge. ©OpenStreetMap contributors

Figure 13. Test track in Dresden

3.4 Test Setup

The test tracks in Darmstadt (DA) and Dresden (DD) are used in different combinations with the two Data Acquisition (DAQ) systems, see Table 2. IMU and Smartphone data are compared for the Darmstadt (DA) proving ground and the Dresden test track (DD 1). Then, further studies are carried out without the IMU (DD 2)

Table 2. Data acquisition and test track configurations

DAQ	DA	DD 1	DD 2
Smartphone	●	●	●
IMU	●	●	○

3.5 Method Verification

To verify and validate the proposed method, we first give an overview of the basic motorcycle roll dynamic parameters. Then, the data quality delivered by our additional calculations or estimations is investigated. Since the coordinate transformation algorithm is an important part of the whole measurement chain, we deliver a practical example for the reproducibility of our whole measurement chain comparing three smartphones mounted on one motorcycle in different orientations. Finally, the data quality delivered by the most important sensors is investigated.

Overview In the same manner, as the authors do in [36], we depict the speed, roll and yaw rates, roll angle and roll angle error graphs within Figure 14. Concentrating on the roll angle plot φ, the traces show an excellent correlation between the ground - truth - data from the IMU and the smartphone measurement chain. The difference plot $\Delta\varphi$ on the bottom reveals that typical deviations while stationary cornering or riding straight are at max. $3°$ and while rolling dynamically, the deviations are below $6°$. Despite the data are synchronised by their GPS - timestamps, the biggest deviation source can be seen as the time lag between the systems. Especially due to the roll rate being over twice as fast as in [36], bigger roll angle deviations would be expected, but do not occur. The $RMSE$ value for φ is $1.8°$ for this example dataset and typical values lie around $2°$. Switching between the calculated roll angle channels to be fed into the Kalman Filter at $\varphi = 10°$ has no negative effect on the estimation.

Curvature Small curve radii ($\kappa > 0.1$) are calculated inaccurately from the measurement data due to error propagation, but larger curve radii are almost identical to the IMU result, see Figure 15.

The biggest error here is due to the low sampling rate of the GPS. Therefore, a function is integrated into the post-processing algorithm that detects implausible values of the inverse curve radius and sets the inverse curve radius to 0 for those cases. The threshold value is $\kappa_{thresh} = 0.25\frac{1}{m}$, which corresponds to a curve radius of $R_C \leq 4m$ and less. Curves with even smaller radii are not relevant. Despite the absence of an unreadable error plot, we can state that the curve radius estimation error for the stationary curves around 45s is about 3m and from 150s about 4m. These errors are acceptable and far better than an inverse curve radius calculated from GPS data only.

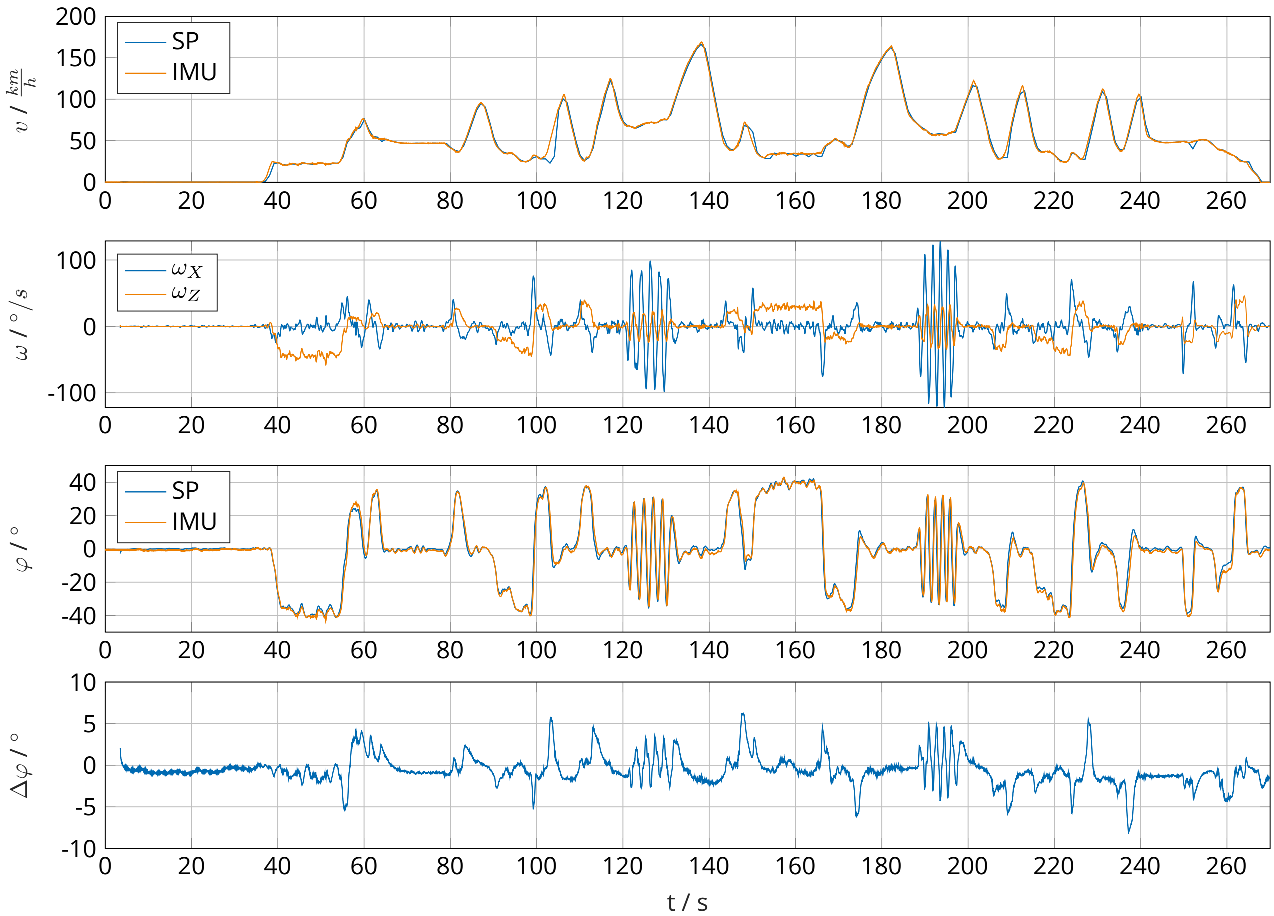


Figure 14. Typical Motorcycle Dynamics Parameters: Speed, Rotational Rates and Roll Angle.

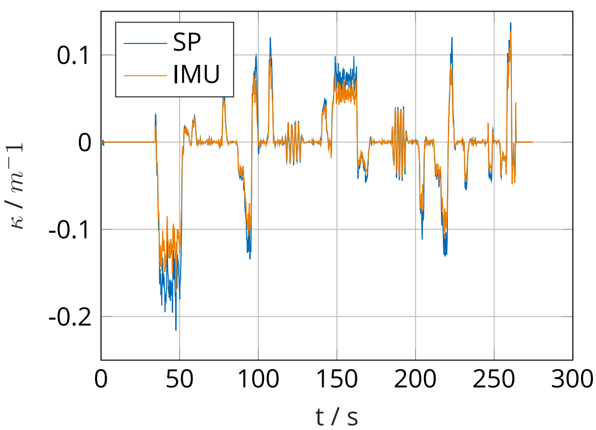


Figure 15. Comparison of the curvature calculation

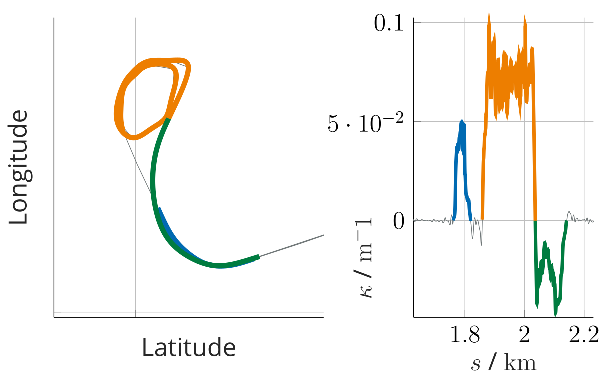


Figure 16. Curve segmentation

Segmentation Figure 16 on the right shows the graph of the curve κ. As there are left and right curves within the driven route (see GPS map on the left), there are positive and negative values for κ.

When the segmentation algorithm from section 2.6 is applied to the data, the curve segments are effectively separated from the straight or slalom sections. Each colour-highlighted section corresponds to one curve segment which can then be used for further feature extraction.

Coordinate Transformation The goal of the coordinate transformation algorithm is to enable reproducible measurement values. The authors, therefore, present a comparison of the calculated roll angle of three differently mounted smartphones with parallel data acquisition of the IMU. The results shown before in Figure 14 are the ones from the second smartphone in Figure 17 which shows the test configuration for the coordinate transformation test.

To be able to compare the datasets in Figure 18, the time offset between the datasets is calculated via the logged GPS - times and their known origins.

Figure 17. Three smartphones mounted on the test motorcycle in different orientations

It can be stated that the result of the transformation algorithm provides an excellent result as the roll angle estimations with the transformed inertial data still show a good correlation with the high - precision IMU for different orientations. The comparison between the smartphones shows that typical deviations while stationary cornering are below 3° . The largest errors occur during dynamic rolling with max. 9°. RMSE values are below 2.2°.

Table 3. Transformation angles for the test configuration

# type	1 Huawei P20 lite	2 LG G6	3 LG G7 fit
φ_{SP}	19.6°	3.6°	2.7°
θ_{SP}	15.8°	18.6°	32.5°
ψ_{SP}	38.7°	105.4°	86.7°

Despite there are no real angle measurements to compare the smartphone orientation angles to, we want to give numbers as ”rule of thumb” for the estimation of the orientation angles. Based on standard deviations, the pitch and roll angles usually are within an interval of $\sigma_{\varphi,\theta} = \pm 5^\circ$ and the yaw angle can be estimated by $\sigma_\psi = \pm 10^\circ$. However, by picking the median of the estimated angles, the method becomes rather robust to outliers in the estimated angles.

Rotational Rates As the rotational rates form the basis of the calculations and therefore could be an error source for the following methods, they should also be assessed regarding their quality. However, they can only be compared with the IMU data after being transformed into the motorcycle coordinate system. The roll and yaw rate are further investigated.

A roll rate time plot (see Figure 19) shows that the graphs overlay so that they cannot be distinguished from each other. An error plot at the bottom shows that the three smartphones deliver a maximum roll

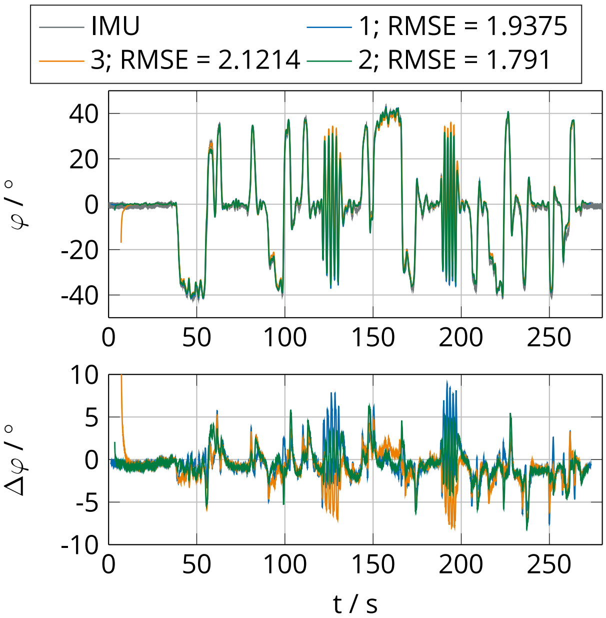


Figure 18. Roll Angle Error Plot / Transformation method test

rate error of $6^\circ/s$ for absolute values of about $130^\circ/s$. That results in a relative roll rate error of under 5%.

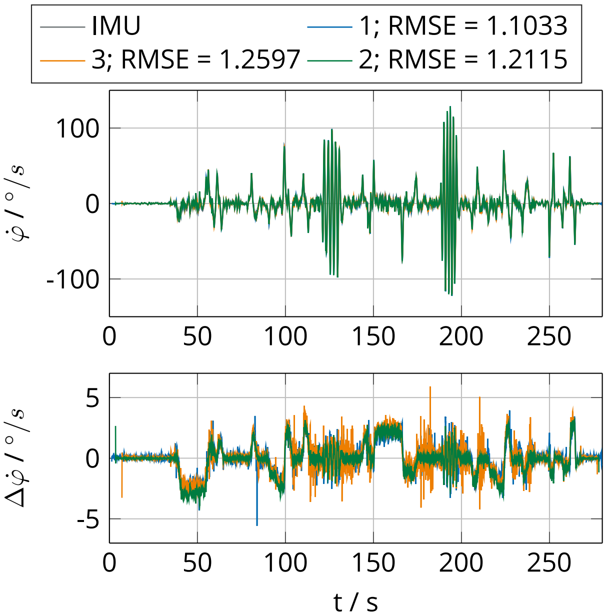


Figure 19. Roll Rate Error Plot

The yaw rate time plot (see Figure 20) reveals nearly the same overlaying quality compared to the roll rate graphs. While the maximum yaw rate value is nearly $60^\circ/s$, the maximum error is $7^\circ/s$ which results in a relative yaw rate error of under 12%.

While the yaw rate does not show a systematic error correlation, the roll rate error is cross-correlated to the estimated roll angle φ with $R = 0.8$. The reason for this correlated deviation could be an angle estimation problem within the coordinate transformation algorithm. Looking also into the pitch rate error data which is not depicted here it

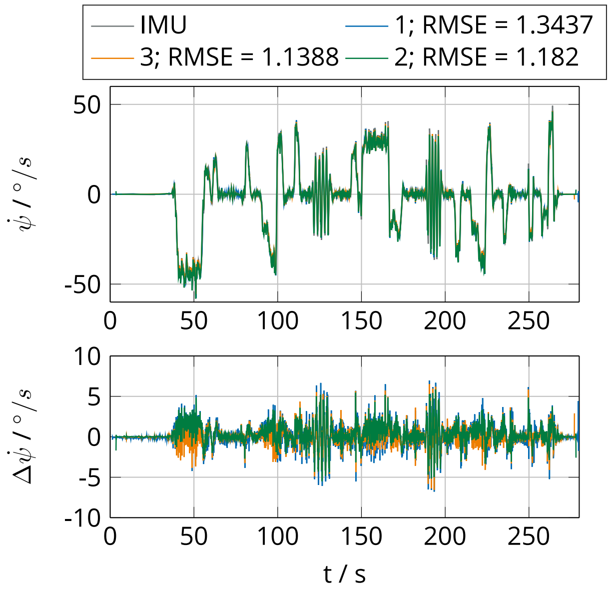


Figure 20. Yaw Rate Error Plot

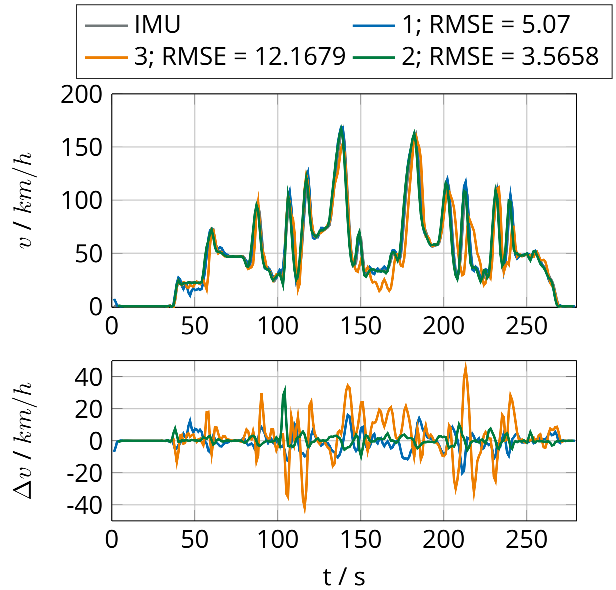


Figure 21. Velocity Error Plot

becomes clear that this is also cross-correlated to the roll angle, but only with $R = 40\%$. From the motorcycle dynamics point of view, this means that the problem can be located to the yaw angle estimation of the smartphone rotation. If the yaw angle estimation $\hat{\psi}_{SP}$ alone is incorrect, the yaw rate will be uncorrelated to the roll angle, but the pitch and roll rate will be affected by the estimation error so that the rotation rates are "crosstalking" into each other because of their misaligned axes. The results for the rotational rate sensors are very encouraging. Further studies should include an enhancement of the smartphone yaw angle estimation.

Longitudinal Acceleration & Velocity Regarding the GPS velocity, in Figure 21 the data channels from the three smartphones are shown. First of all, the rough peaks from smartphone (3) (orange) can be seen. The main reason is that the additional rugged aluminum cover restricts the GPS receiver so that the quality is worse compared to the other phones. The smartphones (1) and (2) without a cover deliver better quality, but still with a maximum error of up to 31 km/h. These results are congruent with Neale et al. [45] whereby it may be stated that the low sample rate of 1 Hz is not suitable to follow "hard" accelerating motorcycles, but riding stationary, errors are small and typically below 5km/h.

The transformed longitudinal acceleration recorded by the internal sensor is acquired with a higher sample rate compared to the GPS receiver. In Figure 22, the IMU and smartphone longitudinal accelerations are shown. The IMU acceleration is given in a horizonted coordinate system whereas the smartphone accelerations are left in the motorcycle coordinate system as the smartphone (and motorcycle) pitch angle is unknown for now.

The maximum error here is $1.5 m/s^2$ and occurs while stationary cornering. Even when accelerating or decelerating substantially ($|a_x| \approx 8 m/s^2$), errors are below $1 m/s^2$. The RMSE values for the whole test maneuver are closely around $0.4 m/s^2$.

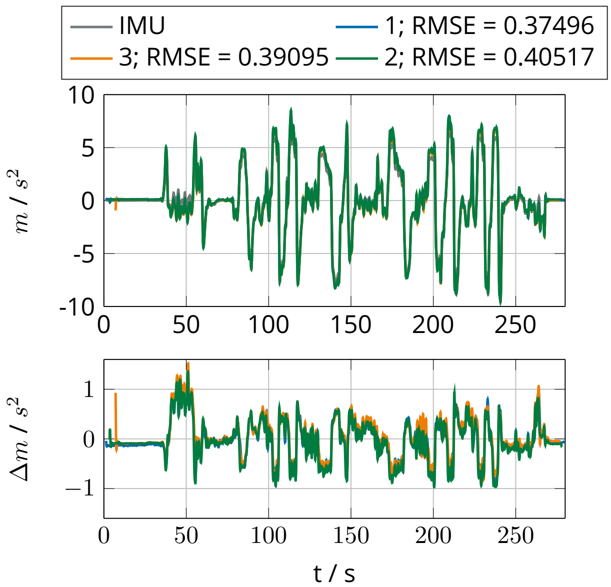


Figure 22. Longitudinal Acceleration Error Plot

As the smartphones themselves show nearly identical values, a systematic error source can be identified as the missing pitch angle correction. Thus, the smartphone acceleration sensors may not be blamed as the main error contributors.

Validation on Dresden test track The same investigations as described in the preceding paragraphs were also carried out for the Dresden test track (configuration DD1). Despite some GPS outages in narrow valleys or deep forest, no additional error sources or drawbacks in the overall method could be identified.

3.6 Proband Study

After the validation of the whole measurement chain, a proband study with 15 participants was carried out. To avoid wrong expectations, we do not want to present the detailed findings of the study, because all the data collected by us was fused with a dataset from another measurement campaign and presented by Pless et al. [46] which can be understood as an accompanying paper to this work. After fusing the datasets, they look further into the aggregated data and provide valuable findings for future motorcycle safety research.

In our part of the study, different private test vehicles were involved and because of that, it was not possible to develop a uniform holder for the smartphone that is suitable for all motorcycles. Therefore, the smartphone is installed in a simple, quickly exchangeable solution with adhesive tape directly on the seat behind the driver (see Figure 23). From the past measurements in the validation phase, it is known that the fixture on the seat causes much fewer vibrations in the smartphone signals.

Figure 23. Fixation of the smartphone: Two examples

In Figure 24 the driven lean angles for all curve segments (see section 2.6) and all probands are graphed for left and right curves. It can be seen that the riders nearly use the same lean angles for left and right curves. The graph shows that in 80% of the observations, for example, the roll angle is up to 25°. Roll angles of more than 30°, which are generally still considered to be harmless, are therefore exceeded in just 10% of observations.

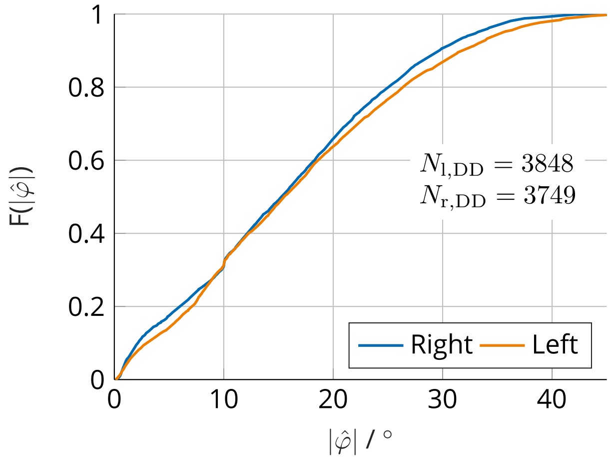


Figure 24. Observed lean angle maxima in left and right turns

4. Results and Discussion

In the presented paper, we proofed the applicability of a low-cost smartphone-measurement-toolchain for the investigation of driven lean angles of large rider collectives. Thereby, all hardware smartphone sensors showed a good performance in the overall validation. The low sampling rate of the GPS receiver led to some limitations. The power of the developed measurement-toolchain could also be shown in a proband study highlighting that the driven lean angles are under $25°$ in 80% of all observations.

The performance of the toolchain is mainly based on splitting it into an on- and offline part. In the online part, the developed Android application "MotoLogger" focuses on high usability and stable data measurement. In the offline part, the implemented MATLAB® processing-toolchain ensures an exact and customizable big data analysis featuring the following highlights: (1) highly robust and motorcycle adapted coordinate transformation algorithm, (2) roll angle estimation using a linear Kalman filter considering the additional roll angle due to tire width and smartphone sensor quality, (3) raw data filtering, (4) course angle calculation and (5) curve segmentation based on curvature being able to analyze a large rider collective.

Future research should especially focus on enhancing GPS sensor performance by fusion algorithms. Apart from that, a pitch angle correction for the longitudinal acceleration signal could also be foreseen in future developments.

In general, researchers could use the developed toolchain for investigating driven lean angles on a large scale. Regarding measurement technology, motorcycles could from now on be equipped with smartphones as they deliver an attractive compromise of price and data quality. From this, specific safety measures for reducing motorcycle accidents could be derived. Furthermore, the toolchain could be the basis for recognizing rider styles (e.g. [47, 48]) and thus adapting the motorcycle's response to each rider individually. Gaining more specific data about the ridden motorcycles, even the estimation of tire width could theoretically be possible. Given the increasing automation of road traffic, the toolchain could be further developed for describing test scenarios to assess automated driving systems [49, 50] or evaluate the effectiveness of safety functions for motorcycles [51].

Finally, practitioners could use the gained knowledge to develop a special lean angle training with direct lean-angle feedback on the riders' smartphones.

5. Conclusion

Driven lean angles of motorcycle rider collectives can be reliably measured by mid-class smartphones, embedded in a holistic measurement toolchain. While the smartphone focuses on collecting raw data, an offline MATLAB® environment realizes the data analysis and lean angle calculation. In general, all smartphone hardware sensors are suitable for dynamic data collection, except the GPS-sensor lacking a sufficient sampling rate. The roll angle estimation algorithm is based on a linear Kalman filter and supported by a robust coordinate transformation algorithm. A big data analysis is ensured by an automatic curve segmentation.

Smartphones as research tools have gained increased attention in the last years. Now, for the first time, a holistic measurement toolchain using smartphones was established and validated to investigate driven lean angles on a large scale. Thus, lean angles of large rider collectives can be investigated in future easily with (1) a low-cost mobile measurement tool and (2) with private motorcycles. We anticipate that our toolchain will help to derive specific safety measures for reducing motorcycle accidents. Moreover, rider styles could be investigated in more detail and a lean angle training with direct feedback could be established.

Acknowledgments

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Coordination patterns in arm versus body steering strategies in free slalom on a motorcycle: A single case pilot study

Marilee Nugent[1], Stéphane Espié[2], Flavien Delgehier[3], Samir Bouaziz[4].

[1] Università degli Studi di Firenze
[2] Université Gustave Eiffel
[3] Centre national de la recherche scientifique (CNRS)
[4] Université Paris-Saclay

Keywords: motorcycle trajectory control, electromyography, motorcycle rider control.

Abstract

The unique dynamics of PTW trajectory control seem to blend unconsciously with human postural and steering actions. For example, the motorcycle seems to follow where the head turns. Expert riders may claim to steer solely by "looking" and "leaning" while engineers know that counter steer inputs to the steering column are required for efficient direction control. How riders coordinate their steering actions and the relative efficiency of different steering strategies or combination of mechanical inputs has yet to be fully explored. In this pilot study we used electromyography to record activation patterns in arm and back muscles of one experienced rider performing slalom maneuvers at ~40 km/h. The test motorcycle was instrumented with sensors recording rider mechanical inputs and vehicle dynamical outcomes. In 10/20 trials the rider attempted to induce direction changes solely using counter steering technique, in the remaining 10, using lateral body movements. Mean cycle length of vehicle roll was significantly longer in the body steer strategy, consistent with this method being less effective in quick steering. Systematic changes in muscle patterns with steer strategy confirmed that different coordination patterns underly and can characterize different steering methods. These pattern changes were seen as differences in muscle onset/offset times, in burst duration, order of activation, and relative timing. Different phasing between muscle bursts and motorcycle roll peaks seen in the two steer methods provides insights into the relationship between rider actions and PTW dynamics which may allow parsing out of the specific and relative influences of different rider control inputs. This study is intended to provide a basis for further investigations into rider control of trajectory and lean angle. The findings have implications for rider control studies development of training methods as well as improving understanding of the complex dynamic control interaction between rider and motorcycle.

Introduction

How riders produce steering and lateral control on a motorcycle is an important topic of study for understanding rider-two-wheeler interaction. Low/ medium speed maneuvering on a motorcycle, as in the performance of emergency collision avoidance maneuvers, requires efficient steering and balance control inputs from powered two-wheeler (PTW) riders, especially in traffic and urban areas. This is an important skillset having implications for both safety and the criteria and assessment procedures in practical license tests. R&D of smart rider assistive systems can benefit greatly from improved models of rider-PTW control interaction as current rider models are insufficient (Loiseau et al. 2020) to explain how the human central nervous system coordinates curve following and trajectory control actions. In this pilot study we investigated the feasibility of using muscle coordination patterns to provide insights into how riders may vary their steering strategies to control heading and lean changes on a motorcycle. It is unknown to what degree steering technique varies between and even within riders. Individuals may express a preference for using 'counter steering' technique, or may claim to control heading and curve following solely by leaning and looking into the curve. Vehicle kinematic measurements alone cannot provide insights about how riders actually achieve this control, or if they are doing what they say they are doing.

Motorcycle steering skill and efficiency is important to safety, as when trying to avoid an unexpected collision hazard or material on the road surface that may cause a capsize. The dynamics of powered two-wheeled vehicles

(PTWs) determine that lateral/trajectory control are produced by varying combinations of lean and steer torque provided by the riders. Although PTW engineering continues to improve vehicle handling, what riders actually do, and what steering skills or strategies may be optimal has been little studied and remains unclear. Specific technique is not obvious from visual observation of riders. Anecdotally, riders differ in their assumptions of what they do to regulate steer control, which is likely explained as their having acquired highly automated control skills through implicit learning. The fact that multiple and fluctuating versions of body and steer torque inputs can produce the same kinematic outcomes means that vehicle signals alone cannot distinguish between categories of steering technique or style. Indeed, this speaks to the concept of the 'motor redundancy' of the central nervous system in voluntary control of movement: multiple solutions are possible for the same motor outcome. For example, theoretically a rider could initiate curve following or direction change using one or more mechanical inputs - counter steer torque applied to the handlebar, lateral mass displacement (e.g. part of all of the trunk), asymmetrical pressure to foot pegs - in various combinations or sequences. In addition the rider can vary which body segments are in line or out of line with the PTW vertical axis (e.g. head, head and shoulders or full hang-off) and size of the angle between body axis and PTW axis. Given that these movement variations result from different joint movement patterns, it should be possible to observe different trajectory control strategies or styles depending on the timing of these control actions and how the rider regulates coupling (i.e. stiffness) across joint segments and between body-PTW interfaces.

In the ongoing project VIROLO++ to study PTW rider curve-taking behaviour, researchers asked riders to use arm versus body inputs to control curve-entering, however data analysis and interpretation has been hampered due to the inability to determine from the vehicle sensor data alone whether the test rider was able to comply with the instructions to voluntarily decouple these inputs (unpublished results) (VIROLO++).

The purpose of this study was to compare PTW angular motion recorded simultaneously with electromyographic (EMG) patterns from the key muscles responsible for PTW lateral (steering and lean angle) control to gain insights into rider-PTW interaction outcomes based on voluntary use of different steer control approaches.

Hypotheses

Hypothesis 1 predicted that the different steering control strategies will require categorically different muscle patterns. These may be seen as differences in phasing between muscles and in the recruitment patterns (roles) for specific muscles, in the body versus counter steer strategy.

Specifically, arm muscles would be expected to show more obvious and regular activation patterns if the rider uses steer torque inputs (ARM) preferentially over body inputs (BODY) to induce direction changes, whereas the reverse would be true for the lateral spine flexors of the trunk and knee extensors.

Hypothesis 2 predicted that given that these 2 different steer strategies would specify changes in the roles of specific muscles, we should also see changes in phasing between muscle burst patterns and vehicle direction changes, for example, low back muscle activity may lead roll changes in BODY steering while arm extension and flexion activity leads back muscle activity in ARM steering.

Methods

Task and protocol

The task chosen to assess muscle and motion patterns in different steer strategies was a free slalom maneuver (alternating right and left steering while traveling forward). In terms of muscle pattern analysis, periodic or rhythmic movements provide a repeatability and regularity of data patterns that is easier to analyze than discrete, random motion patterns. For this pilot study, the second author performed the riding tasks and the first author performed the data collection. Both researchers are experienced motorcyclists in both leisure sport/travel and urban mobility use cases.

For each data recording, the rider performed one of two different steering strategies. In the ARM strategy, he attempted to control direction changes using mainly arm inputs, minimizing body inputs. For the BODY strategy, the rider attempted to control direction changes using mainly body inputs, minimizing inputs from the arms.

All trials performed in first gear. Speed was roughly 40 km/h during the slalom sequences. Two collection sessions were performed in the same day, in the morning and in the afternoon. The EMG sensors were left in place for both sessions, so that individual sensor data would be comparable across all trials. In all, 10 sets of slalom oscillations (5-6 cycles each) were collected for each trial condition. Figure 1 shows performance of the maneuver, instrumentation used and sample kinematic and EMG data. Videos of all trials were recorded on a smart phone. Each data recording included a set of slalom maneuvers for the length of the driveway, moving away from the camera phone (Fig. 1 A), a reversal of direction at the end, and another set of slaloms for the return trip.

Instrumentation and data collection

ELECTROMYOGRAPHY. Muscle activity was recorded using wireless surface EMG (sEMG) sensors (Delsys Trigno™ Mobile system) with 10 mm inter-electrode distance. Sensors contained integrated analog filters providing sEMG signal detection bandwidth from 20-450 Hz and pre-amplification to 909 V_{out}/V_{in}. Each sensor also contains an integrated 9 degree of freedom IMU. Sampling frequencies were 1111.11 Hz for EMG data and 148.15 Hz for IMU accelerometer data.

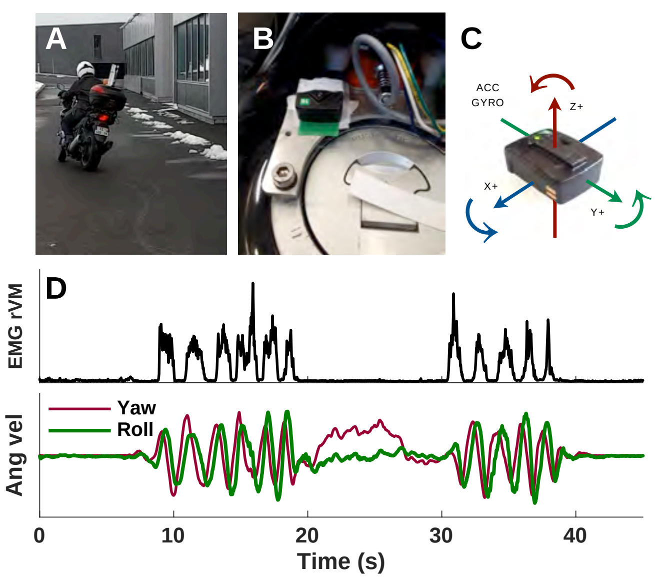


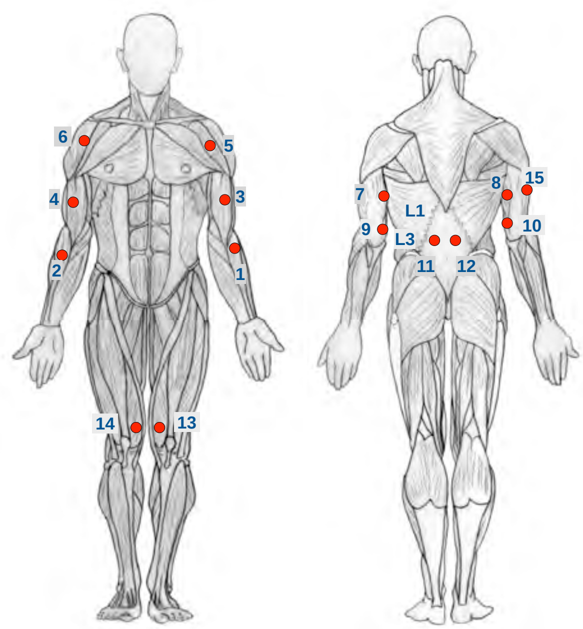
Figure 1 Test vehicle and sample data showing 2 slalom sets. A) Performing the free slalom in a closed parking lot. B) EMG/IMU sensor placed on the motorcycle's tank next to its IMU sensor. C) axes for accelerometer and gyro of the Delsys sensor. D) EMG signal for right vastus medialis (VM - knee extensor) and yaw and roll angular velocities from the sensor placed on the motorcycle's tank.

Since the objective of the study was to differentiate between body versus arm motivated heading changes of the motorcycle, the muscles chosen for recording were those functionally important for pushing and pulling actions of the arms, side bending of the trunk, and pushing or weight support through the leg to the foot pegs An initial data collection session was performed testing a larger number of muscle recording sites in order to determine the ones most representative of steering and leaning actions. The final sites chosen for testing are given in Fig. 2, with the rationale as follows.

Anterior deltoid (AD) provided consistent clear signals associated with arm pushing (shoulder forward flexion)/ direction changes. The erector spinae (ES) muscles of the back straighten or hyperextend the spine when activated bilaterally but perform lateral flexion (side bending) when activated unilaterally. The ES were tested at the 3rd lumbar (L3), 4th lumbar and 12th thoracic levels, since independent activation at different levels has been shown in movements requiring separation of upper and lower spine segments (Nugent and Milner 2017; Nugent et al. 2012). However, L3 alone was deemed sufficient for what (in this rider) appeared to be more global spine motion, being also the recommended site for general back function studies (see SENIAM guidelines (Hermens et al. 2000). The elbow flexors and extensors were expected to be important in alternating handlebar angle in ARM steering. The biceps (BI - elbow and shoulder flexion) and brachioradialis (BR - elbow flexion) were both recorded for pulling actions. Three triceps sites provided somewhat redundant information on elbow extension (pushing), but were all recorded to determine which gave the best signals, due to the difficulty sometimes of obtaining good signals due to skin movement over muscles and the tendency for thicker fat layers in this area. Thicker skin folds are known to reduce sEMG signal amplitude and broaden the burst duration, affecting identified burst onset/offset times (De la Barrera and Milner 1994). These triceps sites were long head (TrLo - bi-articular, acting on both shoulder and elbow), lateral head (TrL), and medial head (TrM - deep to the other two but accessible to sEMG at its distal end). Vastus medialis (VM) was recorded for knee extensor activity (weight bearing on feet, pushing into foot pegs). All muscles were recorded bilaterally except for TrM, as there were only 15 available sensors.

A

Electrode Placements		
1	1-lBR	left brachioradialis
2	2-rBR	right brachioradialis
3	3-lBI	left biceps both heads
4	4-rBI	right biceps both heads
5	5-lAD	left deltoid anterior
6	6-rAD	right deltoid anterior
7	7-lTrLo	left triceps long head
8	8-rTrLo	right triceps long head
9	9-lTrM	left triceps medial head
10	10-rTrM	right triceps medial head
11	11-lES	left ES - L3 level
12	12-rES	right ES - L3 level
13	13-lVM	left vastus medialis
14	14-rVM	right vastus medialis
15	15-rTrLa	right triceps lateral head
16	16-IMU	Moto: on tank beside IMU



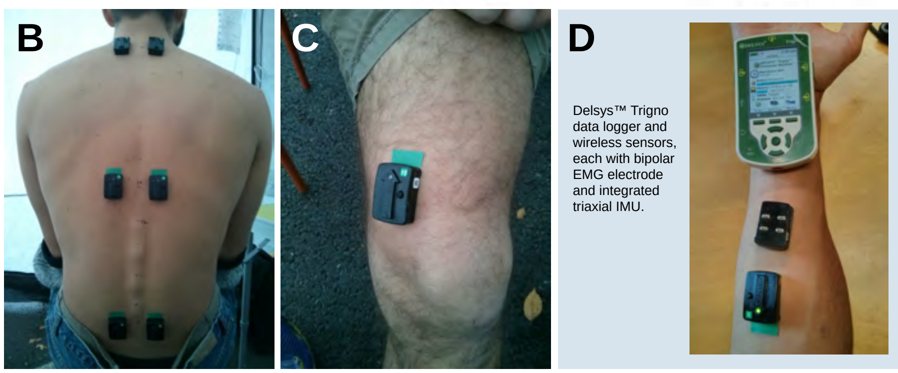


Fig. 2 sEMG sensors and electrode placements. A) Final electrode configuration/muscle sites used in data collection. B) Examples of different electrode locations for different levels of the erector spinae. C) Sensor placed on vastus lateralis, knee extensor of the left knee. D) Delsys Trigno EMG/IMU wearable wireless sensors, showing one sensor active (affixed), the recording and reference electrodes of the other, and the data logger.

Skin was prepared by shaving, lightly abrading and cleaning with alcohol. Sensors were affixed to the skin with double sided tape. Hypafix® stretchable self-adhesive medical tape was placed over top of each sensor to prevent motion artifacts due to clothing or dislodgement from the skin. The rider wore motorcycle protective clothing to perform the trials.

TEST VEHICLE. The test vehicle was a Honda CBF1000F motorcycle, equipped with sensors to measure vehicle kinematics and the rider's mechanical and control inputs, however, the vehicle data were not analyzed for this paper. Instead, recorded muscle patterns were compared to the motion data recorded for the motorcycle from one EMG/IMU sensor placed on the tank (see Fig. 1 B, C).

Data processing and analysis

EMG/IMU data were recorded on the Delsys data logger which was placed in the rider's jacket pocket. After downloading data trials, EMG data were resampled to 1000 Hz and IMU data were resampled to 100 Hz. All EMG data were demeaned, full-wave rectified and low pass filtered at 8 Hz cutoff using a first order Butterworth digital filter implementing the Matlab© (Mathworks Inc., Natick, MA) 'filtfilt' function. The gyro signals for angular velocity around the y and z axes were used to indicate motion for the motorcycle's roll and yaw motion, respectively, for comparison with the muscle signals. Roll and yaw velocity signals were low-pass filtered using a first order Butterworth digital filter, implementing the Matlab 'filtfilt' function, with a 4 Hz cutoff. Documentation for the wireless EMG system states that the signal group delay (from sensor event to analog output) differs by 48 ms between the EMG and IMU data (Delsys 2019). Thus the EMG time series was corrected by this amount for time synchronization with the IMU data.

All trials were plotted and visually inspected. Start and end times for each set of slaloms were identified from gyro signal plots using cursors. The phasing between roll and yaw for each slalom set was determined by cross-correlating the two filtered, full amplitude-range signals. To calculate mean cycle frequency/period (T) for each set, angular velocity peaks were identified using the Matlab function 'findpeaks'.

Muscle activation patterns were analyzed using two methods, cross-correlation with vehicle motion signals, and determination of burst onsets and offsets. To determine relative muscle timing in the movement cycle, cross-correlations were performed between the filtered vehicle angular velocity signals and filtered muscle signals. Custom Matlab script and the 'xcorr' function with 'coeff' option was used. Since the muscle signal data was rectified (all absolute values), negative values (troughs) of angular velocity signals were first converted to zeros. In this way, each muscle activity pattern was cross-correlated in reference to roll right. Lag results from the cross-correlation function reflect the time of the cross-correlation peak between muscle and angular velocity signal, that is, the time shift required for the best fit between signals. For each slalom set, lag values were normalized as percentages of the mean cycle duration, in order to be more directly comparable and to avoid confounding differences in relative activation timing with differences in movement frequency. Mean lags are given as percentages of median cycle duration (Lag%T). With roll angular velocity as the reference signal 0, positive values indicate muscle burst peak amplitude occurring before right roll velocity peak and negative values indicate muscle burst peak amplitude after right roll velocity peak. Thus, a positive or negative Lag%T value close to zero would indicate strong temporal association between a muscle burst pattern and the direction change. For rhythmic movements, a value of +/- ~50%T would indicate strong association between the muscle and the peak roll velocity in the *opposit*e direction. In other words, right and left alternating muscle activity to produce the slalom pattern.

The resulting Lag%T values provided the relative timing between peak muscle activity and vehicle angular motion, as well as the timing sequence among muscles. It should be noted that these delays also include:

- the muscle electromechanical delay (EMD - the time required for force buildup within the muscle before onset of joint movement (Kamen and Gabriel 2010)
- mechanical delay between onset of joint motion and change in vehicle kinematics
- the delay between displacement
- velocity signals, and any internal sensor delays.

To determine relative onset timing and burst durations (Dur) of key muscles, burst onsets and offsets of selected EMG signals were identified using a standard double-threshold algorithm (Kamen and Gabriel 2010; Micera et al. 2001, Bonato et al. 1998) implemented with custom Matlab script. For each slalom set, these were normalized to mean cycle period T and represented as percentages, to allow direct comparisons between steer strategies. The calculated values of Lag%T, Onset%T and Dur%T statistical analyses of muscle timing.

Statistical analyses

Normality tests for Lag%T, Onset%T and Dur%T were significant, therefore considering also the small sample sizes (i.e. number of slalom sets) statistical analyses were performed using non-parametric tests. Wilcoxon rank sum tests for independent samples were performed to test selected key muscles for effect of steer strategy on:

- lag between yaw and roll velocities
- burst onset time as a percentage of cycle period (T)
- burst duration as a percentage of cycle period (T)

Statistical tests were performed using the Matlab Statistical Toolbox, with significance set at .05.

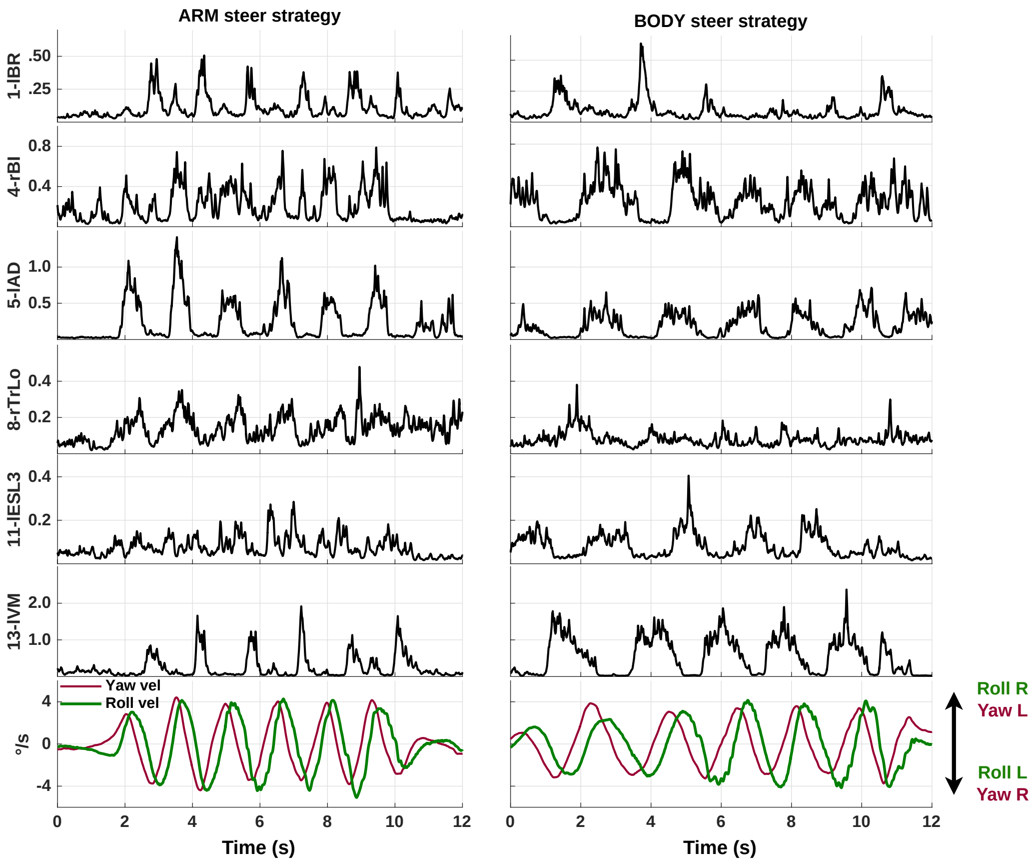


Fig. 3 Examples of slalom set data for the ARM and BODY steering task conditions. Selected muscle EMG in the first 6 rows, vehicle motion in the bottom row. Y-axes scales in each row are the same for direct comparison of signals. Left brachioradialis (lBR), right biceps (rBI), left anterior deltoid (lAD), right triceps long head (rTrLo), left erector spinae, 3rd lumbar vertebral level (lES L3), left vastus medialis (lVM).

Results

All EMG datasets were complete and free from motion artifacts. The final slalom set was excluded from Lag%T analysis since it produced outlier values for most of the muscles, having a roll velocity frequency of 0.90 s compared to the average of 1.23 s. Fig. 3 provides examples of selected muscles plotted with yaw and roll angular velocity, in order to compare the ARM (left column) and BODY (right column) strategies. Axes scales are the same for both columns to allow direct comparison between steer conditions for each muscle. A visual analysis confirms that the AD muscles showed a clear periodic activation to produce the alternating steer actions in the ARM strategy. The BODY also produced clear periodic alternating activity in the AD, but the bursts were lower amplitude and broader. In the ARM trials, elbow flexors (1-lBR, 4-rBI) showed less periodic clarity, and more complex patterns than for the AD, possibly due to having overlaid and/or more variable roles as in the mediation of elbow angle, joint compliance, and transfer of force from shoulder to handlebar grips (point of application of steer torque inputs). As predicted for the BODY trials, the ES muscles had a clear right-left alternating pattern of activity in, whereas in the ARM trials it was difficult to identify activity mirroring the alternating lateral roll of the vehicle. The key muscles associated with the BODY steer strategy were the right & left AD, ES and VM, with periodic activity also evident in the elbow flexors (BR, BI). For the BODY trials, elbow extensor activity was not clearly associated with PTW motion.

Fig. 4 shows roll velocity and EMG plots from an ARM and a BODY trial with examples of onset and offset determinations for 3 representative muscles, lAD, lES, lVM. Median cycle duration was 1.251 s (SD .174 s) in the ARM steer trials and 1.423 s (SD .183) in the BODY steer trials, with median frequency being significantly higher in the ARM steer strategy, p = 0.026, z = -2.23, 0.82 Hz versus 0.72 Hz. This amounts to 14% longer cycle duration in the Body strategy. Median phasing between yaw and roll angular velocities was not different for ARM (20.0% T) and BODY (21.5 % T) strategy, p = 0.065.

Relative timing of muscle activity

Table 1 provides the cross-correlation results, ordered in respective activation sequences for the two steer strategies. Figure 5 is an example of a slalom set from each steer condition to illustrate phasing between muscle bursts and motorcycle roll kinematics.

For simplicity, 3 key muscles - right AD, left ES and left VM - were chosen to test for differences in muscle timing relative to movement cycles depending on the steer strategy. Results are provided in Table 2. A difference in muscle phasing was confirmed only for the lES. Both rAD and lVM showed equivalent phasing relative to roll angular velocity, with all being around one half cycle out of phase (in other words, approximately in phase with left roll velocity peak) regardless of steer strategy. However, steer strategy had an effect on relative onset time for rAD (~24%T earlier in the cycle in ARM trials) and lES (~6%T earlier in the cycle in BODY trials). Burst duration in the ES was not found to be different, although looking at the example in Fig. 4 for the ARM condition, the pattern shows a high frequency modulation that alters the overall shape of the burst, indicating that the similarity of duration does not reflect functional differences. Burst durations were different, however for rAD, being ~20% longer in the BODY condition, as well as for the lVM, being roughly 42% longer in the BODY condition.

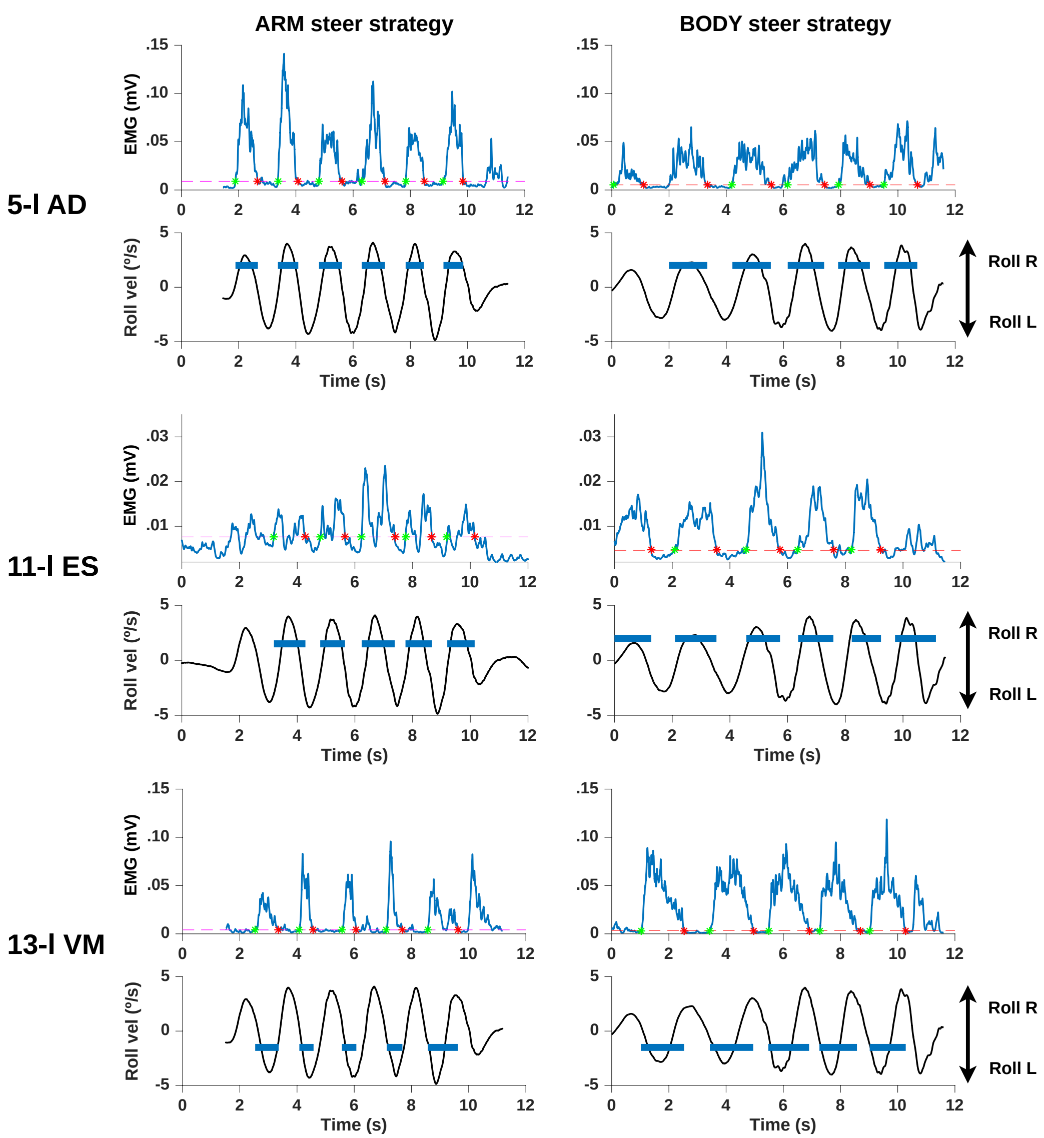


Fig. 4 Determination of onsets and offsets for 3 key muscles. The pink dashed lines on the EMG traces indicate the amplitude thresholds used to determine burst onsets and offsets, indicated by green and red stars, respectively. The burst durations for each cycle were then plotted as bars across the associated half cycle of the roll velocity signal. Note the differences between steering strategies in terms of EMG amplitudes, burst durations, and clarity/regularity of periodic activity.

Table 1 Results of cross correlations between muscle signals and angular velocity.

	ARMS		BODY		
	Muscle	Lag%T	Lag%T	*Muscle*	
Yaw L	12-rESL3	21			
	Yaw vel	***20***	***22***	***Yaw vel***	
	4-rBI	5			
Roll R	5-lAD	3	4	5-lAD	Roll R
	Roll vel	***0***	***0***	***Roll vel***	
			-0	4-rBI	Roll R
			-1	2-rBR	Roll R
	8-rTrLo	-8	-12	11-lESL3	Roll R
	15-rTrLa	-10	-14	14-rVM	Roll R
	10-rTrM	-16	-33	1-lBR	
	11-lESL3	-23	-37	6-rAD	
Roll L	13-lVM	-46	-49	13-lVM	Roll L
Roll L	1-lBR	-49			
Roll L	6-rAD	-49			
Roll L	7-lTrLo	-50			
Roll L	9-lTrM	-54	-55	12-rESL3	Roll L

Mean lags are given as percentages of median cycle duration (Lag%T). Roll velocity was used as the reference signal 0, thus positive values indicate muscle peak amplitude before roll peak and negative values indicate muscle peak amplitude after roll peak.

Table 2 Results of statistical tests on muscle timing relative to movement cycles.

Strategy	ARMS		BODY				
Muscle Variable	*Mean*	*SD*	*Mean*	*SD*	*p*	*z*	*Mean diff*
6-rAD							
Onset%T	24.9	13.7	1.4	9.4	**<.001**	6.57	23.5
Dur%T	48.5	16.0	68.7	10.9	**<.001**	-5.78	-20.2
Lag%T	-49.1	11.5	-36.7	14.8	0.082		
11-lES							
Onset%T	-26.1	9.3	-20.0	9.4	**.002**	-3.04	-6.1
Dur%T	65.9	12.5	64.0	16.4	.254	1.14	
Lag%T	-22.6	2.6	-12.1	3.6	**<.001**		-10.4
13-lVM							
Onset%T	-72.1	5.5	-73.3	6.8	.176	1.35	
Dur%T	34.1	12.1	76.8	9.3	**<.001**	-8.20	-42.7
Lag%T	-46.4	7.5	-49.4	4.2	.173		

Conclusions

This pilot study explored the use of muscle activation patterns to identify and differentiate between motorcycle rider steering control strategies. Specifically, we compared data from trials in which the rider attempted to use either only arm or only body mechanical inputs to perform sequences of free slalom maneuvers. Relative timing among muscles and between muscles and vehicle roll angular velocity were compared to assess differences in rider coordination of the steer task.

Hypothesis 1 (each steer strategy requires a different muscle activation pattern) was confirmed with the identification of differences in muscle phase sequences and observation of differences in the shapes and frequency modulation of the EMG traces. Key muscles associated with the direction changes were evident from the strong periodic patterns, and secondary muscles having more irregular or continuous activity. For this rider, the muscles that appeared to produce the key activity related to the ARM steer strategy were the anterior deltoid, and all of the triceps locations. These observations are consistent with the expectation of the strategy being dominated by arm pushing actions. Interestingly, the left knee extensor also showed consistently periodic activity, but not the right. Such asymmetries may be reflect individual idiosyncrasies in riding style, which can potentially complicate analyses. For the BODY steer strategy, the lumbar spine extensors and knee extensors were very clearly active in producing the slalom pattern, as was expected. The AD was also very clearly active, but what is unknown is whether their activation was related to initiation of the direction changes or rather reflect a postural function in support of body weight distribution changes as a result of motorcycle lean angle. In general, for the BODY trials the elbow extensors showed much less clear periodic activity: what appears irregular periodic bursting modulated by a noisy baseline activity, is likely indicative of an ongoing activation related more to joint stabilization as force is transferred from the trunk to the handlebars.

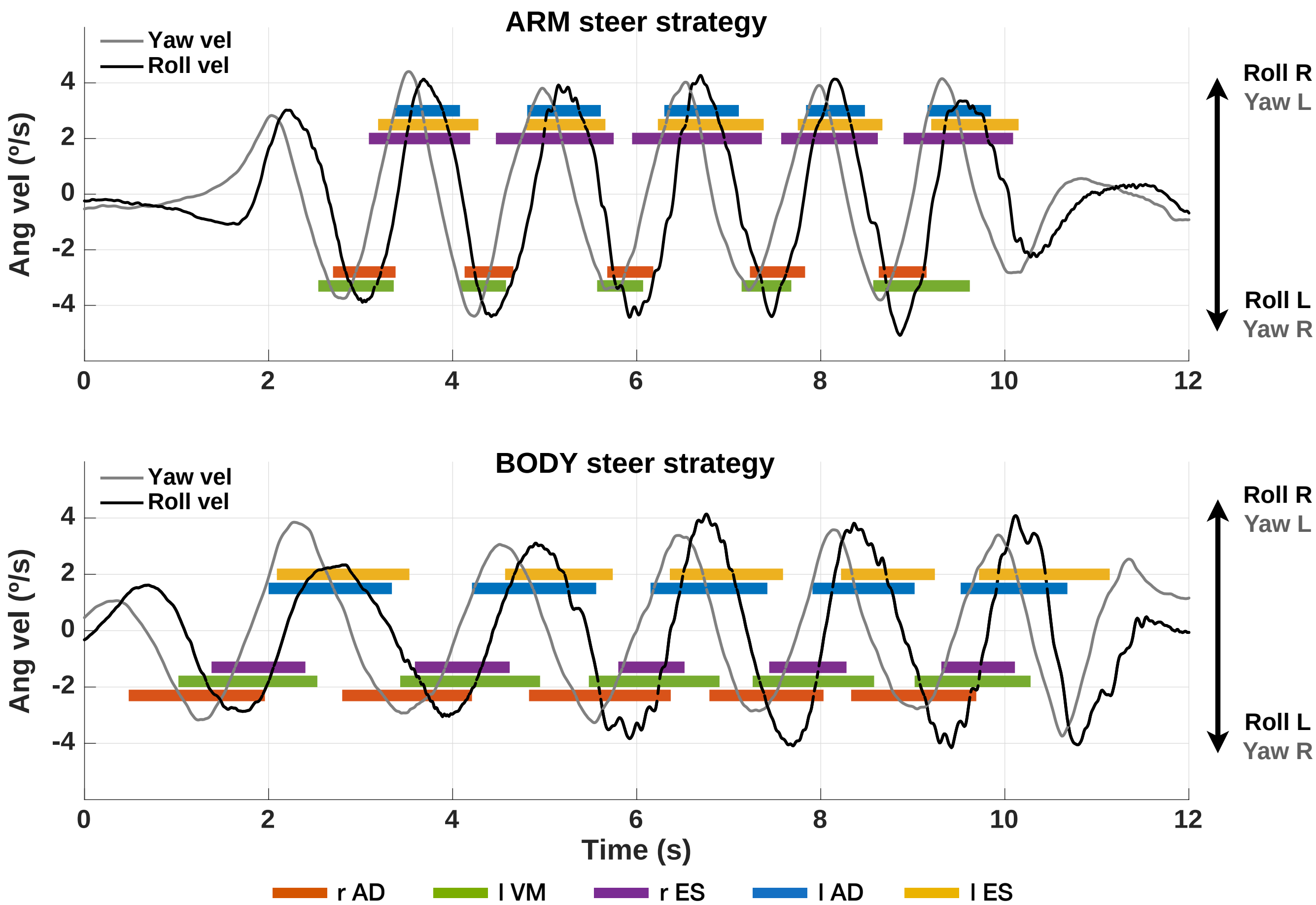


FIG. 5 Examples of muscle phasing from individual trials.

Hypothesis 2 was confirmed by differences in relative onset times between the steer conditions, as well as in burst durations. In particular, the left lumbar ES was in phase with roll velocity to the right in the BODY strategy. This is likely explained as the left spine lateral flexor first becoming active eccentrically towards the end of roll right to reduce roll velocity and then contract eccentrically to reverse direction, initiating leftward roll. The right knee extensor was also in phase with right roll, coherent with the transfer of weight to the right foot peg during right lean, or pushing against the peg to induce roll.

In contrast, in the ARM strategy, the lumbar right ES appeared to be in-phase with left yaw velocity, 20%T earlier than roll angle, and more closely related in time with steer angle. This finding is consistent with a counter steering approach which results first in a transient rotation of the front wheel around the steer axis in the opposite direction to the curve, followed by inward leaning of the motorcycle. Both left and right signals were very noisy, likely being more involved in postural mediation to facilitate arm actions and respond to roll changes, rather being active to motivate direction changes.

In both steer strategies, AD muscles were in phase with roll velocity peaks in the opposite direction. As with the ES in the BODY strategy, this is coherent with the blending of antagonistic and agonistic function of an muscle during movement oscillating to first slow down the motion and then accelerate the segment in the opposite direction. This similarity may relate to a phase-locked role of the AD that is specified by the biomechanics of the system (e.g. weight/postural support) at the time of peak roll, and not by voluntary intention.

AD onset was earlier in the movement cycle in ARM trials whereas ES onsets were earlier in the BODY strategy. ES burst durations were not different between steer strategies but the shape of the patterns suggest very different functions, that is the ES clearly motivate roll in the BODY strategy while in the ARM trials they seem to have a more postural/adaptive function. In the BODY trials, the longer burst durations for AD, ES and VM, together with the very strong periodic bursting seem to be coherent with the need to overcome the high inertia of the PTW in creating direction changes by changing vehicle roll angle without the aid of counter steering. This combined with the finding of significantly shorter cycle duration for the ARM steer strategy provides evidence to support the claim that steering using voluntary application of counter steer inputs to the handlebars is a quicker, more efficient steer strategy. The fact that relative timing of peak activity of the AD muscles with respect to roll velocity was the same regardless of steer strategy, provides further evidence that counter steer inputs may be produced simply thorugh rider-PTW mechanical coupling even if a rider believes they are steering by leaning or pushing against the foot pegs.

Future analyses are can address some of these questions by comparing muscle timing patterns against measured pressure inputs to the vehicle, and vehicle roll and steer angle changes. Future studies will be needed to confirm the generality of muscle timing patterns across other riders.

Importantly, we have demonstrated that it is possible to distinguish between voluntarily selected steering strategies based on the muscle activation patterns, as this cannot be confirmed by vehicle outcome measures alone. Thus EMG can be used to identify different steering strategies to better understand rider-motorcycle control interaction in lateral control. Specifically, we now have confirmation for the assumption that there are different ways to produce direction changes, which is not evident from visual observation or vehicle data analysis alone. Additionally, using EMG we can confirm whether or not a test rider has succeeded in following instructions to implement one or another steering strategy, which can aid interpretation of vehicle outcome data in future steer control and bend-following studies.

Acknowledgements

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VIROLO++ Study of bend-taking behaviour of motorbike riders application to training and intelligent transport systems. http://www.virolo2plus.universite-paris-saclay.fr/.

Recording and evaluating motorcyclists' gaze behaviour in rural roads

Panagiotis Lemonakis[1] (presenter), Eleni Misokefalou[1], Myrofora Koroni[2], Nikolaos Eliou[1] (substitute presenter)
[1] Department of Civil Engineering, University of Thessaly, Volos, Greece
[2] International Hellenic University, Thessaloniki, Greece

Abstract

Over the last years, distracted driving constitutes a considerably increasing road safety problem with disastrous results and it possesses a leading position among the accidents causes. The road safety audit in the rural road environment during the last years includes apart from the car passengers' drivers, the motorcycle riders who also share the road network with other vehicle users like bus and truck drivers.

The present study deals with motorcycle riders' gaze behaviour due to out of the vehicle sources of distraction. The exterior factors, as the most significant sources of distraction, can be grouped in four categories: built roadway, situational entities, the natural environment, and the built environment. All these contribute to the setup of a very dangerous environment by increasing rider's distraction and inattention.

This research is based on a medium scale experimental procedure which took place in an urban and a suburban road sections in Western Greece. The distraction of the motorcyclist's attention is evaluated via a continuous recording of his gaze which acts as the main indicator regarding rider's performance with the use of special equipment under naturalistic riding conditions. The main objective of this paper is to identify and evaluate the main factors of distraction of motorcyclists' attention in rural road segments.

The results of this type of research procedures are very useful as a tool to encourage the adaptation of more precise regulations with regard to the road infrastructure, the placement of roadside elements, etc.

Keywords: Riding distraction, motorcyclists, naturalistic research, road safety

1 Introduction

Driver distraction is a phenomenon that can be easily recognized as a single or repeated visual reaction to certain sources located in the road environment. It is based on a mechanism that is activated and developed in a different way not only among drivers but also at the same person each time. The presence, the frequency of appearance, the duration of distraction are characterized of great variety depended on many factors.

Driver distraction may act in a positive or a negative way during the implementation of the driving task. A positive distraction may offer information to the driver that in the first sight may not be useful to the driving task but eventually may act as a catalyst for the safety. A characteristic example of the positive role of driver distraction is the attraction of the attention by a ball at the side of the road something that rings a bell for a child that may suddenly appear to catch that ball. At certain circumstances such as information signs distraction of attention plays a supportive role at the driving task.

Besides the positive effect on the driving task distraction of driver's attention has a negative form which captures the attention of the driver, binding mental workload, not allowing him/her to operate in a safe way especially in case of an unexpected event. In this case the driver himself as well as other road users become vulnerable and the results are critical for the safety.

Driver distraction has been under research the last decade and it is proved to be one of the main causes of accidents. Furthermore, driver distraction is high on the list of road fatal accidents.

While car drivers are the large majority of the road users, motorcycle drivers considered among the most vulnerable ones with significant participation in accidents. Road safety audit during the last years includes apart from the vehicles' drivers, the motorcycle ones who share the road network with other vehicle users like car, bus and truck drivers (Misokefalou et al., 2010). Scientific research has focused on vehicle drivers leaving a big gap of knowledge regarding the effects of distraction on other road users such as motorcyclists. The improvement of road networks demands to take into consideration all possible causes of accident. To this direction, the question of driver distraction for motorcycle users should be examined in all available aspects.

For this reason, the present study investigates the role of elements that permanently exist in the road environment and may affect the motorcyclists by attracting their attention creating a very dangerous condition due to the vulnerability of this category of road users. The main indicator to evaluate distraction is produced through continuous data recording of the driver's gaze with the use of a gaze tracker.

The present research tries to highlight possible sources of distraction that might have a negative effect on road safety, by analyzing the distraction of motorcyclists' attention both in a suburban and in an urban road network. The study focuses on out-of-the-vehicle factors, especially those that are not necessary for the execution of the driving task, having as its main objective to detect their impact on driver's safety.

A medium scale procedure was developed to serve the objectives of the research. A number of 21 motorcyclists participated in the study. An urban as well as a suburban road were selected for the execution of the measurements. The recording took place with the use of Gaze Intelligence gaze tracker equipment. The results of this procedure focus on the time that the driver's gaze remained on each of the road elements under research. The analysis is based on the total duration of the time that the motorcyclist was gazing at every selected element even if the gaze was interrupted and repeated. At this point it should be noted that the present research is part of a larger research project conducted by the University of Thessaly, Department of Civil Engineering. The first stage of the research included 11 of the 21 drivers and only the urban road environment was analyzed (Lemonakis et al, 2020).

The results of this type of research procedures are very useful as a tool to encourage the adaptation of more precise regulations with regard to the road infrastructure, the placement of roadside elements, etc.

1.1 Theoretical background

The most precise definition on distracted driving has been agreed in the in the first International Conference on Distracted Driving according to which: "*Distraction involves a diversion of attention from driving because the driver is temporarily focusing on an object, person, task, or event not related to driving, which reduces the driver's awareness, decision-making, and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes*" (Hedlund et al., 2005).

Distraction causes are divided into two major categories based on their location. Internal factors of distraction are those that are based into the vehicle while the external factors are based outside of the vehicle. The second category consists of four subcategories built roadway, situational entities, natural environment, and built environment (Horberry & Edquist, 2008). The fourth subcategory, related to road infrastructure and commercial land use, combined with high vehicle speeds that occur in motorways, might contributes to the creation of a very dangerous environment, by increasing driver distraction and inattention.

Scientists have tried to investigate the mechanism behind distraction bringing to the fore psychological tools such as Neisser theories, Gestalt theory etc. (Misokefalou, 2014). Lee and his research team (2009) in an attempt to describe the phenomenon present a multilevel procedure which includes various forms of distraction- visual, cognitive, biomechanical and auditory (Ranney et al., 2001). The various sources of distraction and their impact on different drivers - both the source and the receiver of a message influence and are being influenced in a different way each time - as well as the technology innovations which demands a great amount of mental load make distraction of attention difficult to be managed.

Road advertisement plays an important role in road safety due to the distraction of attention that causes. At this point it is important to note that the main goal of advertisement is to capture driver's gaze in order to gain the attention and transmit the message. The time interval needed to transmit the message may be long enough to be dangerous for the road safety especially in case of changeable messages (Oveedo-Trespalacios et al., 2019) as the ability to respond properly in case of an event diminishes significantly. Many countries have established proper guidelines regarding the placement, the design or even the prohibition of roadside advertisement. On the other hand, the pressure that derives from the industry because of the strong financial impact of advertising is strong and creates problematic conditions (Herrstedt et al., 2013).

1.2 Frequency of driver distraction

Both international and domestic statistics prove the importance of distraction in road safety. Accident data from either fatal or serious accidents place distraction from a secondary task in a high position among accident causes. Virginia Tech Transportation Institute (VTTI) on behalf of NHTSA carried out a characteristic research "100- Car Naturalistic Driving Study" (Klauer et al., 2006). During the 100-Car Naturalistic Driving Study, driver involvement in secondary tasks contributed to over 22% of all crashes and near-crashes recorded during the study period (NHTSA, 2009). These secondary tasks, which can distract the driver from the primary task of driving (steering, accelerating, braking, speed choice, lane choice, maneuvering in traffic, navigation to destination, and scanning for hazards), are manifold and include such things as reading billboards, conversation with passenger(s), viewing the scenery, cell phone use and related conversation, use of other wireless communication devices, and note-taking, to name a few (Hedlund et al.,2006).

Domestic data confirm the above conclusions. Based on the results of the first semester of 2019 that the Greek Traffic Police announced, distraction caused a 6% of the fatal accidents (Greek Traffic Police, 2020). In addition, the accidents from an unknown cause that consist the 18.5% of all accidents or the 52.7% which are under investigation may also contain distraction related cases. External factors are proven to have great impact on road safety. Wallace (2003) confirms that 10% of the accidents have their roots in distraction because of external factors.

Particularly for advertising, many studies have identified them as a significant cause of traffic accidents (Stutts et al., 2001). The few studies that have been conducted regarding billboard effect on the driver task have demonstrated that drivers do look at and process roadside advertisements, and that fixations upon advertisements can be made at short headways or in other unsafe circumstances (Smiley et al., 2004). In Young et al. (2009) simulator study there is a tentative suggestion that more crashes occur when billboards are present. Conservative estimates collated from a review of several accident databases put external distractors responsible for up to 10% of all accidents (Wallace, 2003). University of Thessaly with a naturalistic research confirms the above mentioned (Misokefalou, 2014).

Statistics for motorcyclists' fatal accidents also raise concerns as 37.9% of fatal accidents in Greece are caused by distraction (Greek Traffic Police, 2020).

2 Methodology

2.1 Selection of the appropriate method

The most effective way for the researchers to detect driver's distraction is via the results that distraction produces. These effects are gaze declination from the driving task for a time interval considered as dangerous, loss of control, speed changes, exit from the lane lines and, finally, crashes.

An analysis that conducted from University of Thessaly compared all the available methods to study driver distraction in order to detect the most appropriate in terms of validity and reliability. The available methods can be grouped into the following categories (Misokefalou and Eliou, 2009):

- Studies based on elements of accidents.
- Experimental studies (simulator studies or studies in a test tracks).
- Observational-naturalistic studies (observation of determined point or use of special equipment vehicles).
- Questionnaires studies.
- Specific methods like Peripheral Detection Task and Visual Occlusion.

Not all of the above methods are applicable at all situations. In case that all means are available and the conditions permit it, the most suitable and effective method is an observational one that belongs in the naturalistic methods. These studies take place in the field with the use of gaze recording equipment to detect the cause of distraction as well as to provide data of frequency and duration of the glances on every potential source of visual distraction.

2.2 Design of the experiment

The participants who carried out the measurements were male riders because they constitute the typical rider gender. Their permanent residence was adjacent to the starting point of the experimental routes whereas they were all capable of manipulating the experimental motorcycle. Aiming to ensure the familiarity of the participants with the handling of the instrumented motorcycle and consequently eliminate the possibility of accident occurrence the riders were asked to drive the motorcycle until they felt confident and safe with its operation. They were all experienced riders who travel to the experimental route very frequently on their ordinary life. Therefore, the probability of an accident was very limited because they were familiar with the geometric features of the experimental route.

The recruitment of the participants was based on two crucial principals: The implementation of safety precautions against accidents and the selection of riders who represent a typical rider. Since young riders are over-represented in vehicular accident statistics the age of the subjects of the measurements ranged between 40 and 60 years old, having obtained their riding license for more than 5 years from the date of the experiment. Nevertheless, a valid driving license for more than 5 years' time was a demand from the insurance company of the motorcycle in order to cover any damages occurred during the measurements.

Eventually 10 and 11 male riders were selected for the suburban and the urban route respectively who drove the instrumented motorcycle throughout the experimental routes using special eye tracking glasses which constantly record their gaze (Figure 1). The participants were not aware of the objects of the measurements in order to drive as natural as possible and record unbiased data. The experiments took place between 04/05/2020 - 13/06/2020 and between 27/12/2019 – 30/12/2019 for the suburban and urban measurements respectively under good weather conditions.

Fig. 1. Eye tracking device of Gaze Intelligence

The eye tracking glasses that were used to record riders' visual behaviour were manufactured by Gaze Intelligence. On this equipment, two cameras are installed at the inner side of the glasses recording the behaviour of the eyes whereas one camera is installed in the front capturing the external environment. Since the ambient lighting depends on a number of factors which can change ever during the experiments e.g. clouds, fog, time of the day, sunlight intensity, two pairs of Infra-Red Filtering spare lenses of different shading were also part of the main component aiming to smoothly stabilize the lighting levels around the cameras. That is particularly important because the maintenance of constant lighting levels is a basic prerequisite in order to record reliable data.

In order to ensure adequate space to fit the eye tracking glasses inside the helmet, a flip up one was used from which the side paddings were removed. Every rider, with the help of an assistant and after putting the proper pair lens and a nose rest on the main tracking component, wore the flip up helmet in open face mode allowing thus a convenient adaptation of the recording equipment beneath it (Figure 2). The rider was allowed to use the helmet as a full face or a jet helmet afterwards but he was not allowed to close the visor because that would affect the sunlight level in the camera lens and consequently the recorded data would not be reliable.

Fig. 1. Instrumented motorcycle and eye movement recording equipment

Through a USB portal the eye tracking device was connected to a notebook. The next steps was to run the software that supports the hardware and calibrate the system based on the three points mode at a distance of 3 meters ahead of the rider. The calibration procedure performed for each individual independently because it depends on the current lighting level and the physiology of rider’s eyes. Finally the assistant pressed a button to start the recording of the measurement, closed the lit of the notebook and put it in a rucksack hanging at the back of the rider who then begun his individual measurement. At the ending point the rider took the notebook out of his rucksack and clicked on the stop recording button. By doing so the file of the measurement was saved on the notebook which was then uploaded on a second software program. Through the latter the uploaded raw file was converted to a video file format (i.e. *.avi) which integrated the outcome of the three cameras described above. The successive directions of eye movements are depicted with a coloured circle (Figure 3).

Fig. 3. Snapshot of output video file

The motorcycle that was used to carry out the field measurements was a sport touring motorcycle very much prevalent on the Greek rural roads. The technical specifications of the motorcycle allowed the riders to smoothly cope with the irregularities of a typical rural pavement which consists of scattered potholes, sedimentation parts, puddles etc. For safety reason it was equipped with ABS brakes rendering the specific motorcycle very friendly for rural and urban riding.

Lastly, the environment where the field measurements conducted is on the one hand for the suburban measurements part of a rural road which connects two mid-sized Greek cities and particularly the city of Arta and Preveza in Western Greece and on the other hand for the urban measurements part of the urban network in a mid-sized Greek city, the city of Arta. The coordinates of the starting (A) and ending (B) point of the suburban measurements were A: 39^{o}09′51.63″N, 20^{o}55′45.05″E and B: 38^{o}59′41.20″N, 20^{o}44′20.00″E respectively as depicted in the upper snapshot of Figure 4. The length of the experimental road sections were approximately 39.2 km for the suburban route and 4 km for the urban one, both gathering a great number of fixed and potential situational sources of riding distraction. The weather conditions were ideal for the needs of the experiments although in two occasions the measurements were postponed because of the rain.

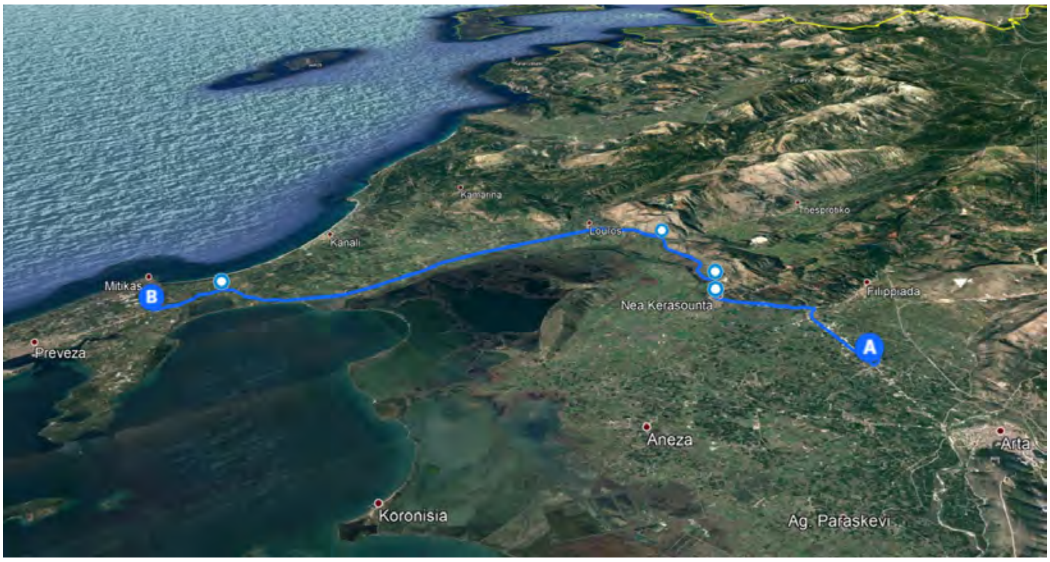

Fig. 4. Routes of the suburban (upper snapshot) and the urban (lower snapshot) experimental road sections

3 Results

3.1 Overview

Observing phenomena are the basis of every research that its goal is the production of representative and reliable conclusions. To this end, descriptive analysis is a very useful tool to identify trends and basic characteristics. For this study a total of 1482 records were collected and analyzed (804 from urban road environment and 678 from suburban road environment) from a total of 21 motorcyclists (11 riders at urban road environment and 10 at suburban road environment). Distraction time intervals were classified into four groups: 0 - 0.7 seconds, 0. 71 - 1.6 seconds, 1.61 - 2.0 seconds and anything more than 2 seconds (Misokefalou, 2014). The study focuses at driving distraction caused by specific visual stimuli for unsafe time intervals, greater than 0.7 seconds as this is considered to be the threshold for safe reaction times.

3.2 Analysis of significant distractions of attention per driver

The frequency of distraction per driver, for time intervals >0.7 sec, >1.6 sec and >2 sec is presented in Figure 5 and 6 for urban and suburban road environment respectively, while Figures 7 and 8 present the average time intervals for each of the previous mentioned cases.

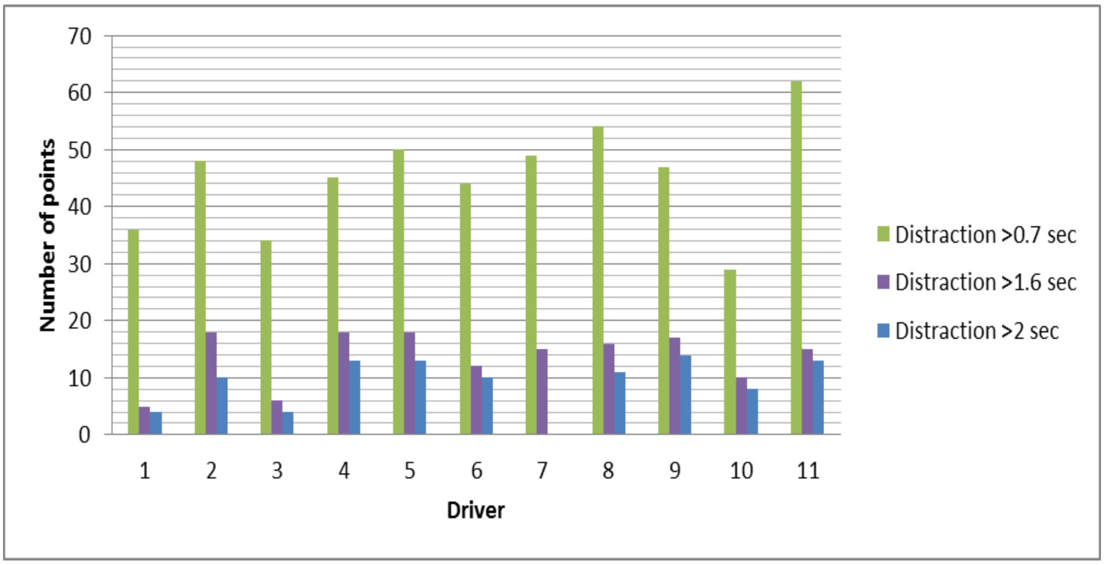

Fig. 5. Frequency of significant distractions per driver – Urban road environment (Lemonakis et al, 2020)

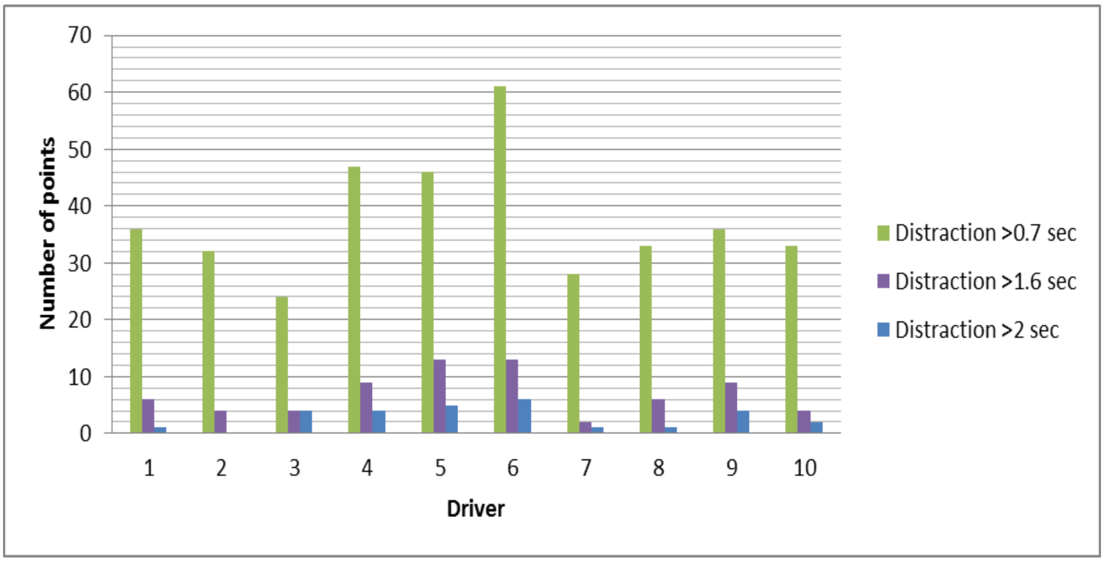

Fig. 6. Frequency of significant distractions per driver – Suburban road environment

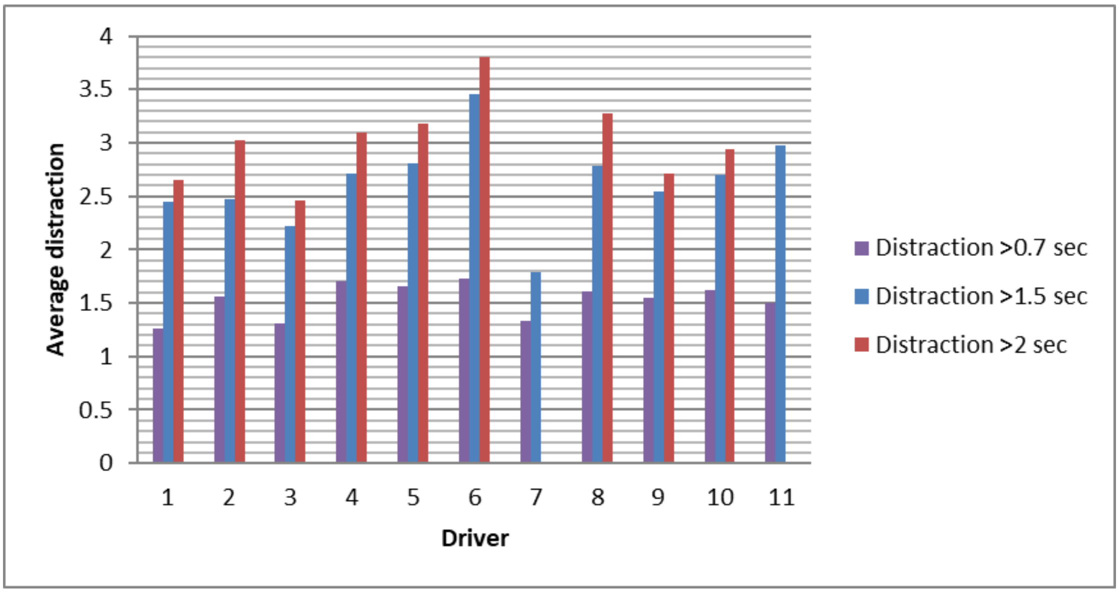

Fig. 7. Average time of significant distractions per driver – Urban road environment (Lemonakis et al, 2020)

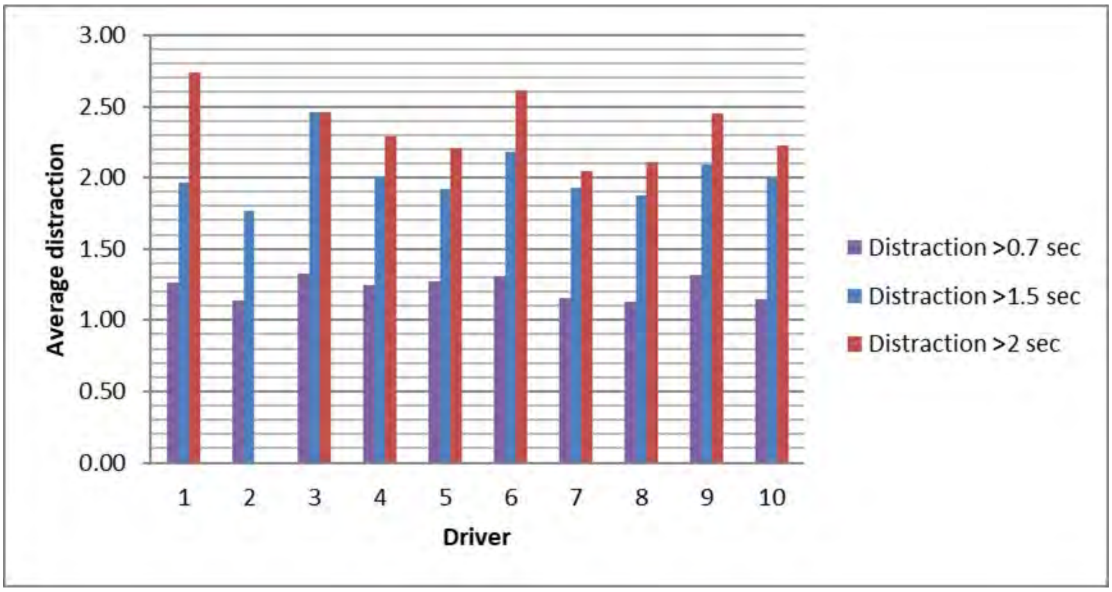

Fig. 8. Average time of significant distractions per driver – Suburban road environment

The study of the frequency of distraction cases shows that numerous road elements at the route attract driver's attention from the driving task for unsafe - in terms of road safety - time intervals. Except from the unrelated to the driving task elements, these results include road signs which are necessary to be seen. Consequently, the question arises regarding the time spent by the driver gazing at them. Another interesting observation is the fact that at the urban road environment there are a lot more drivers with average time of distraction that lasted more than 1.6 and 2 seconds than at suburban which produces lower average distraction times at the suburban road.

The analysis of the average time of distraction for each driver took into consideration only the distractions that lasted more than 0.7 seconds. The results showed that all drivers were distracted for unsafe periods of time. Every one of the participants were distracted on average for more than 1 second at the suburban road and more that 1.2 seconds at the urban road, enough time intervals to permit an accident to take place.

3.3 Analysis of significant distractions of attention per road element category

Figures 9 and 10 present the average time intervals of distraction per road element category, for time intervals >0.7, >1.6 sec and >2 sec. The selected categories are: 1. Road signs, 2: Advertising related signs, 3. Combination of road signs with non-related to driving causes of distraction, 4. Advertising signs with changeable message and 5: Other entities such as a gas station, a bus station etc. (Lemonakis et al, 2020). At this point it should be noted that category 4, signs with changeable message, doesn't exist at suburban environment at all.

Table 1 presents the participation rates of the above categories in the research.

Table 1. Participation rates per road element category

Category of distraction source	Urban	Suburban
1	16.17%	53.10%
2	68.78%	33.92%
3	7.46%	3.24%
4	3.48%	-
5	4.10%	9.73%

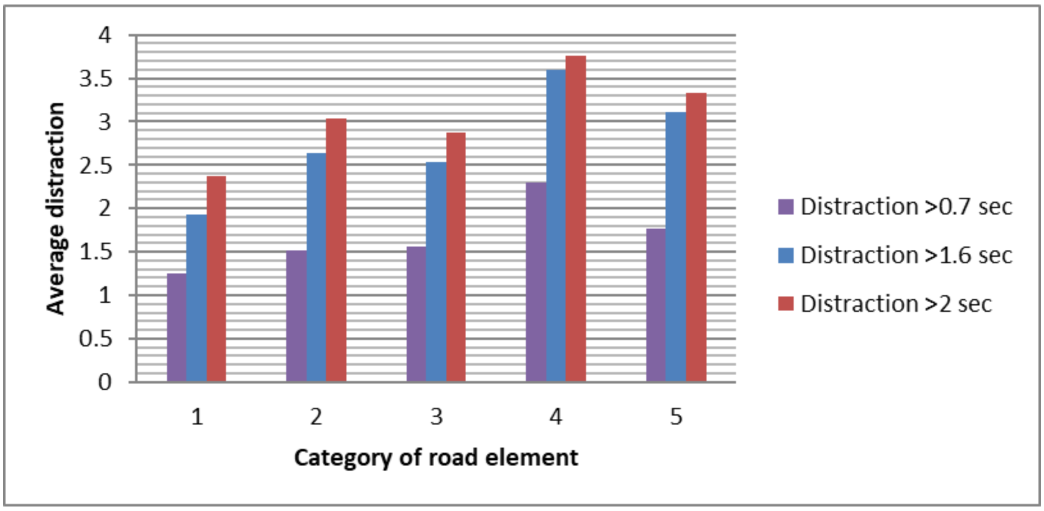

Fig. 9. Average time of significant distractions per road element category – Urban road environment (Lemonakis et al, 2020)

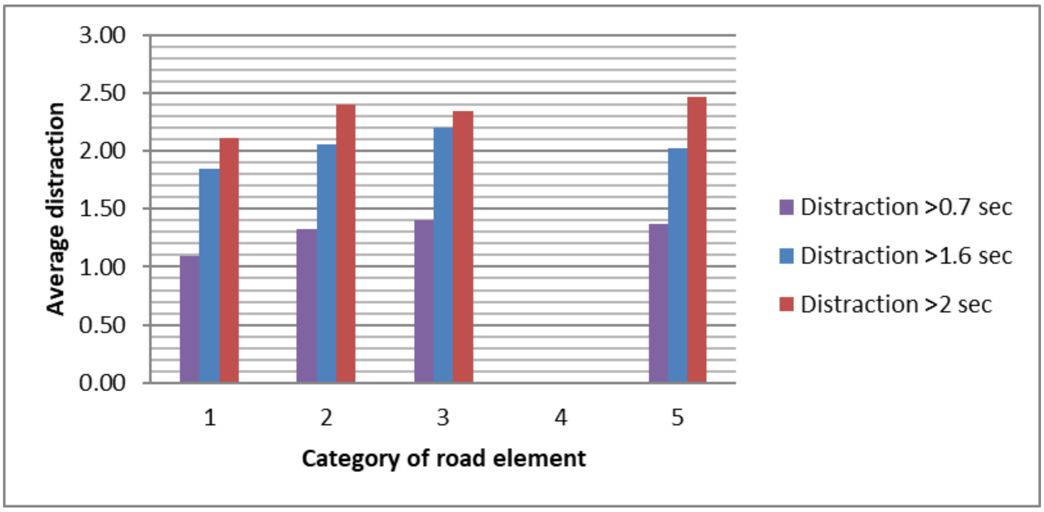

Fig. 10. Average time of significant distractions per road element category – Suburban road environment

From the analysis it is obvious that advertising (categories 2 and 4 cumulatively) possesses the leading position among distraction causes at urban roan environment. The lower distraction times at suburban road environments are obvious at this analysis as well.

Furthermore, signs with changeable messages also concentrate a great number of glances as well as the maximum average times of distraction at urban roads but the research cannot conclude for the suburban roads because of the lack of them at the selected route.

3.4 Analysis of significant distractions of attention per number of the elements

Analyzing the results of distraction based on the number of elements that distract driver's attention at the same time interesting results regarding proximity of road elements make their appearance. At 83% at urban and 78% at suburban environment of the cases there is a single element while at 17% and 22% of them respectively multiple elements that attract driver's attention exist. Figures 11 and 12 show that at both road environments a raise in distraction time appears in case of multi-elements distractors.

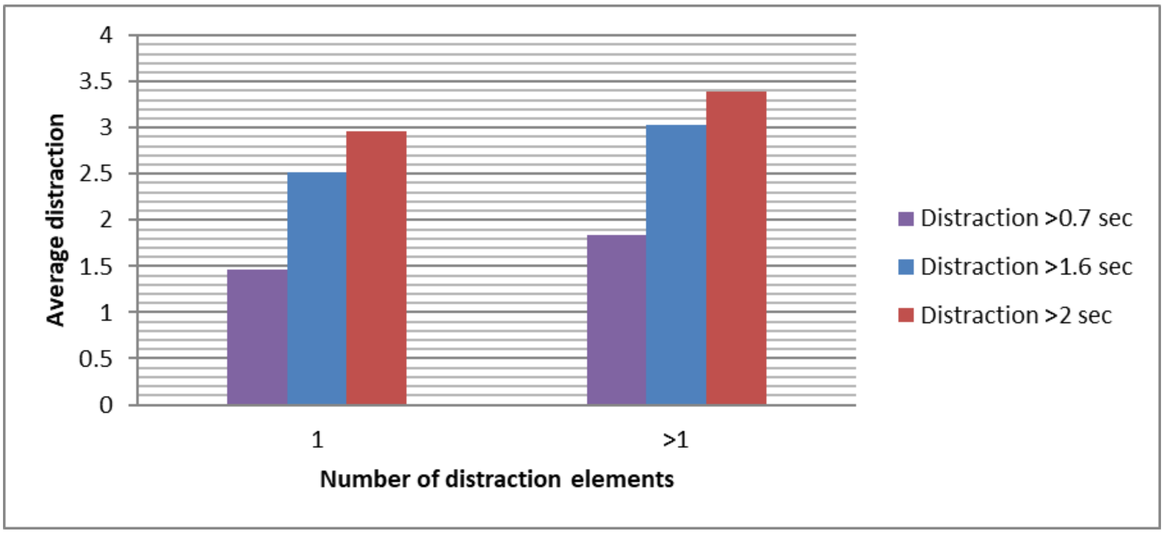

Fig. 11. Average time of significant distractions per number of elements – Urban road environment (Lemonakis et al, 2020)

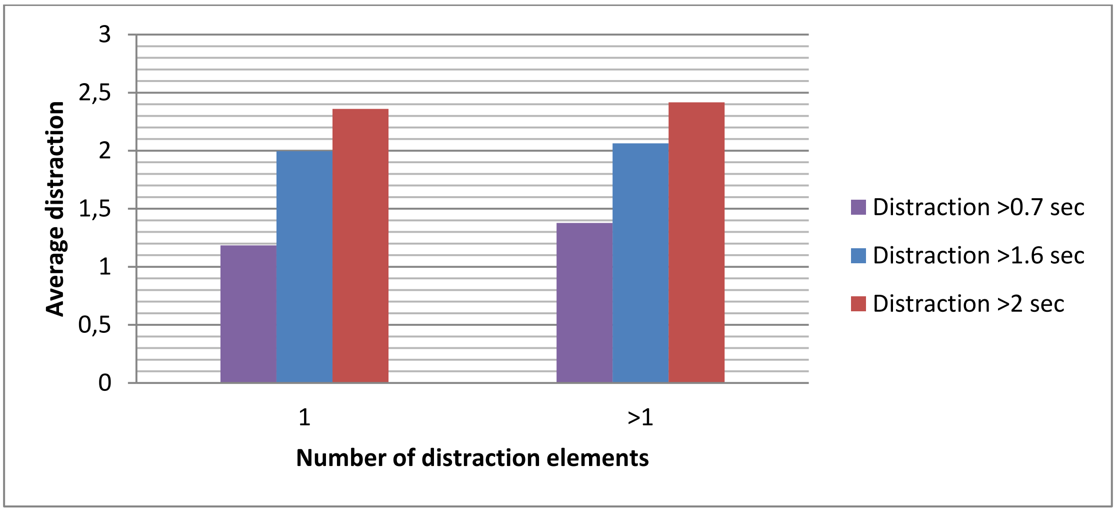

Fig. 12. Average time of significant distractions per number of elements – Suburban road environment

3.5 Analysis of significant non related to driving distractions

Table 2 presents a comparative analysis of frequency of appearance and average time for distractions caused by non related to the driving task causes and lasted for at least 0.7 seconds. This consists the 53% and 32% of all cases at urban and suburban environment respectively.

It is obvious that urban road environments are proved to be significantly more dangerous in terms of distraction duration. On the other hand, speeds at urban roads are lower thus the distance driven while distracted is shorter at this case.

Table 2. Frequency and average time of non-related to driving distractions

	Distraction >0.7 sec	Distraction >1sec	Distraction >2 sec
	Urban/Suburban	Urban/Suburban	Urban/Suburban
Frequency	429/219	130/58	95/27
Average time	1.58/1.34	2.74/2.07	3.12/2.40

Figures 13 and 14 present the average distractions from unrelated to the driving task elements and particularly to advertising signs which prevail in this type of sources of distraction. The analysis highlights the critical role of advertising in road safety as well as the different driving behavior among the riders.

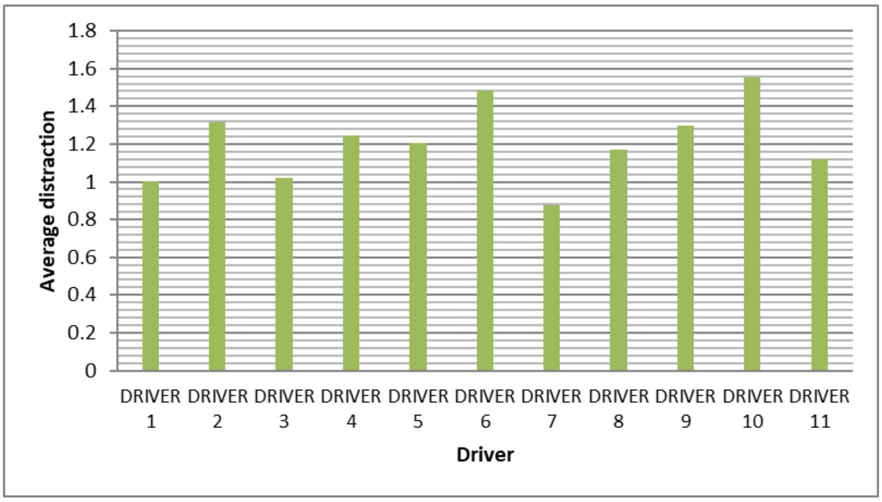

Fig. 13. Average time of non-related to driving distractions – Urban road environment (Lemonakis et al, 2020)

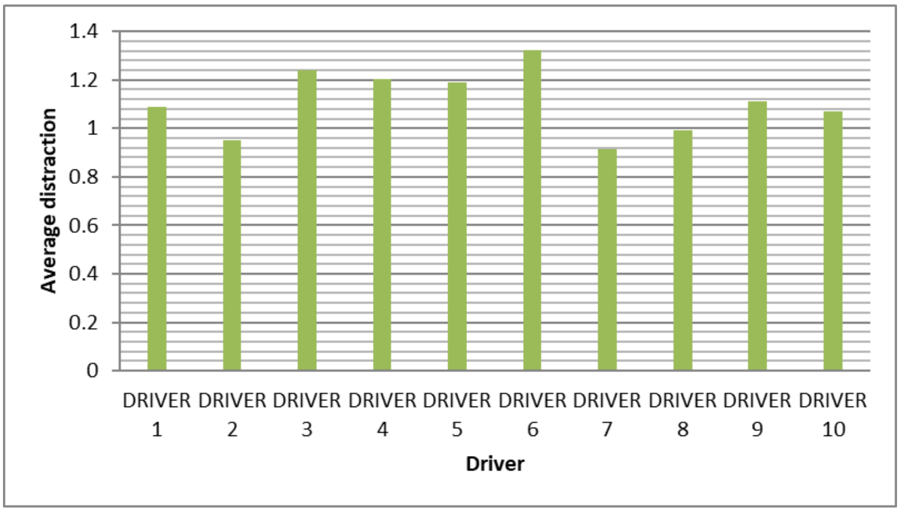

Fig. 14. Average time of non-related to driving distractions –Suburban road environment

4 Conclusions

Distraction of driver's attention during driving is a major road safety problem, which threatens not only the driver's safety but also the safety of other drivers and road users. The representation that motorcyclists have in road safety statistics and their vulnerability as road users arise the need for more targeted research on them.

The main objective of this research is to detect and highlight certain categories of elements in the visual field of the driver that threatens the safe execution of the driving task. The goal of the research is to identify and clarify the causes, the frequency of appearance and the special circumstances under which certain factors influence the distraction of attention of each driver, focusing on the role played by roadside advertising as a parameter of the distraction of the driver's attention.

The selection of a naturalistic method permits the continuous data recording, producing real time data. Thus, the results are reliable and valid to the maximum possible extent.

The research has certain restrictions that a future one might take into consideration. The absence of demographic data is the main reason why an inductive approach is not able to be performed. There is no possibility of controlling the conditions and create desirable driving scenarios. The environmental conditions, also, cannot be controlled and different environmental conditions prevail during the measurements. Finally, there is a difficulty in installing and calibrating the equipment. Attention should be paid in order to minimize the constraints that research inevitably has when planning and performing the experimental procedure.

The most generic conclusion of the analysis is that both at urban and suburban environment exist too many elements that attract the attention of the driver. Average distraction times differ among drivers but every one of them is being distracted for unsafe periods – more than 1 sec at suburban environments and more than 1.2 seconds for urban environments. These distractions last enough to create the circumstances for an accident to take place.

The fact that more than one elements existing at the place distract driver's attention for significantly longer periods raises concerns regarding the proximity of the elements.

Comparing the two road environments it is obvious that more distractions more than 1.6 and 2 seconds take place at urban environment. This is also confirmed from the analysis of the advertising related elements. On the other hand, at suburban roads the speed is higher which leads to shorter distances to be driven while distracted.

Focusing on the elements that are not necessary for the execution of the driving task urban road environment might be more dangerous in terms of road safety than the suburban. A more precise analysis has to take into consideration the speeds in order to conclude properly.

Advertising related elements and other unrelated to the driving task elements on the road attract driver's attention for time intervals greater than the ones derive from driving related elements. The fact that the average distraction times caused by non-related to the driving task elements varies among the drivers reveals the need for a more precise analysis which might take into consideration the personal characteristics of each driver.

Adverting related legislation exists but in many cases remains inapplicable. More work has to be made in that direction in order to prevent future accidents. To this end collaboration with experts and determination of the accident risk are necessary.

The present research may be used as a tool to improve road infrastructure and to eliminate road visual pollution aiming o the creation of a safer road environment, which will lead to less fatal and serious accidents.

5 Funding

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ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΙΑΣ

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ABS and more: Settings and Knowledge on Advanced Rider Assistance Systems of Motorcyclists in Germany

ABS und mehr: Einstellungen und Kenntnisse zu Fahrer-Assistenzsystemen der Motorradfahrer in Deutschland

Dipl.-Päd. Matthias Haasper, Soz. M.A. Markus Krüsemann,
Dr.-Ing. Achim Kuschefski, André Lang B.A.

Institut für Zweiradsicherheit (ifz), Essen, Deutschland
Institute for Motorcycle Safety (ifz), Essen, Germany

Abstract

With its present study ifz surveyed German motorcycle riders (n = 3,805) about the topic of Advanced Rider Assistance Systems for Powered Two-Wheelers (ARAS-PTW) and reveals the level of awareness of this modern technology as well as the riders' knowledge and attitudes towards different current systems.

In recent years, assistance systems for motorcycles have become increasingly important. But how well known are the various ARAS and how much knowledge about individual systems exists? The study provides a corresponding insight into the usage habits, handling skills and user acceptance. Additionally, tendencies regarding a possible over- or underestimation of the potentials of common, safety-relevant ARAS are analyzed. Among other things the results of the study will help to assess the image and user know-how of safety-related ARAS.

Zusammenfassung

Ein Schwerpunkt der vorliegenden ifz-Studie liegt in der Analyse der Einstellungen der befragten Motorradfahrer (n= 3.805) zu Fahrer-Assistenzsystemen an Krafträdern (FAS-M). Die Studie zeigt den Bekanntheitsgrad moderner Technik auf, ebenso Wissen und Einstellungen der Teilnehmer zu verschiedenen Systemen aus dem Motorradbereich.

Insbesondere in den letzten Jahren haben Assistenzsysteme für Motorradfahrer an Bedeutung gewonnen. Doch wie bekannt sind die verschiedenen FAS-M und wie ist das Wissen über einzelne Systeme ausgeprägt? Die Studie liefert einen entsprechenden Einblick in die Nutzungsgewohnheiten, Kompetenzen im Umgang und die Akzeptanz beim Nutzer. Analysiert werden zudem Tendenzen hinsichtlich einer möglichen Über- oder Unterschätzung der Potenziale gängiger sicherheitsrelevanter FAS-M. Die Ergebnisse der Studie sollen unter anderem dabei behilflich sein, das Image sowie das Nutzer-Know-how sicherheitsrelevanter Systeme einschätzen zu können.

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1 Information about the Study and the Collective

1.1 Task and Goal Setting

The results of this study should provide an insight into the attitudes and behavior of motorcyclists – especially with regard to “Advanced Rider Assistance Systems (ARAS)”.

The technical and also other developments of “Advanced Rider Assistance Systems (ARAS)” are of great interest. Although these are currently attracting the media’s attention, there have so far been hardly any rider-centered investigations in the field of Powered Two-Wheelers, in contrast to the passenger car sector. For this reason, we have investigated how motorcyclists in Germany think about these technical aids, what they know about them and where they see future challenges. Especially in recent years, assistance systems for motorcyclists have greatly gained in importance. But how prominent are the individual systems and what do motorcyclists know about the proper handling of them? The study provides an insight into the usage habits, handling competences and user acceptance. It also analyses tendencies with regard to a possible over- or underestimation of the potential of common, safety-relevant ARAS. The results of the study are intended to help, among other things, to present the image and user know-how of safety-relevant systems and to better evaluate riders' knowledge of these systems in order to close gaps in the long term here.

The online-survey carried out for this purpose gathered statements from a total of almost 4,000 participants.

1.2 Method

1.2.1 Questionnaire

Based on the motives described above, a comprehensive questionnaire was created to obtain detailed statements from motorcyclists that are active in Germany. The catalogue of questions has an extent of up to 70 core questions. Depending on the individual answer of a participant, constellations of questions based on each other could also lead to a reduction of the total number of questions if the filter questions were negated.

The answers to the individual questions were prescribed in various ways. These were the possibilities to make a selection within the framework of multiple-choice or to also formulate additional free answers.

For some questions, multiple answers were possible with regard to the multiple-choice solutions. This means that not only one but also several answers could be ticked off. The combination of given and free answers was also possible. Another possible answer to various questions was to be able to make a personal evaluation/weighting on a five-level Likert scale (see Fig. 1).

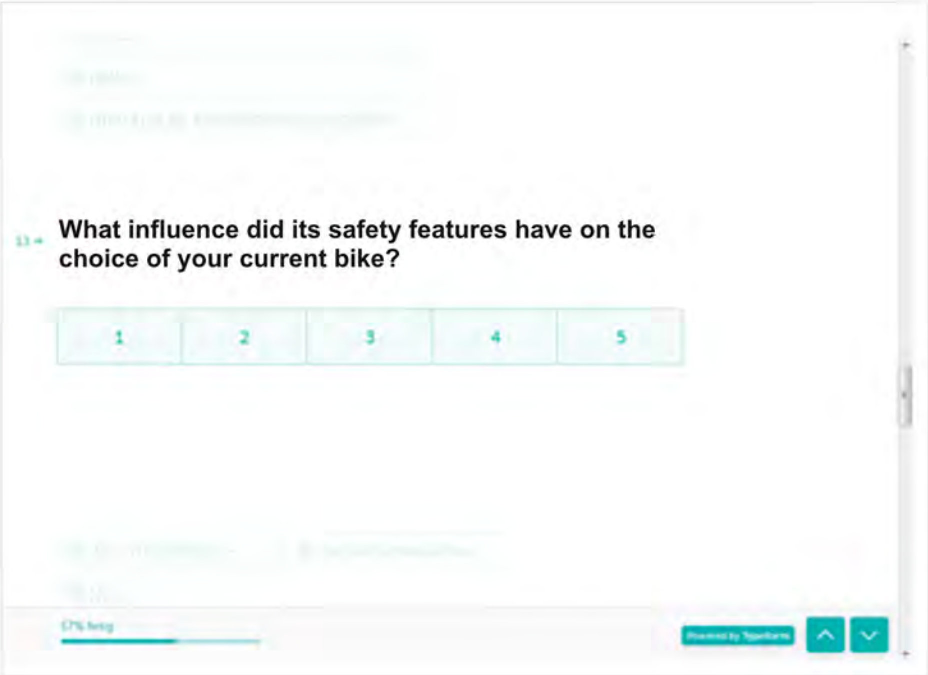


Fig. 1: Sample, Questionnaire

1.2.2 Online-Survey

On March 1, 2018 the opportunity to participate in the survey was made available online. The survey was carried out anonymously. The motorcyclists had the opportunity to take part in the online survey via the ifz's website (www.ifz.de). Calls for participation were delivered via the trade and daily press as well as via the common social media platforms. The questionnaire could be filled in directly online and transmitted to the ifz.

At events such as the motorcycle fair "MOTORRÄDER Dortmund 2018" visitors as well were given the opportunity to fill in the questionnaire at the ifz stand via online terminals. This was also offered to the visitors of INTERMOT COLOGNE 2018.

Fig. 2: Online-survey at events and at www.ifz.de

1.2.3 Timeline

Start of survey: March 1, 2018

Publication of interim results: October 1, 2018 (12th International Motorcycle Conference, Cologne)

End of survey: October 31, 2018

Final results: August 5, 2020

1.3 Participants

Extent

In the course of this study 3,805 motorcyclists took part in the ifz online-survey. All answers from motorcyclists with a minimum age of 18 years were evaluated. The share of survey participants who were also actively riding motorcycles at the time of participation was 97.2 percent. This was important to us, as statements made by currently active riders are to be incorporated into the results, particularly with regard to safety-relevant usage habits.

Riding Activity

At the time of the survey 97.2 percent of the participants were active motorcyclists.

Gender

The collective of respondents consists of 88.2 percent male and 8.9 percent female. 2.9 percent did not provide any information in this regard. The distribution of the sexes thus corresponds approximately to that of the total stock of motorcycles in Germany (source: Kraftfahrtbundesamt (KBA)[1])

Age

59.1 percent of the respondents can be assigned to the "50+" age group. The second largest share is made up of the 40- to 49-year-olds with 18.0 percent, followed by the age group of the 20- to 29-year-olds (10.1 %). The 30- to 39-year-olds follow at an almost identical level with a share of 9.7 percent. Young riders up to the age of 20 years are only represented with 2.2 percent. This age distribution approximately lines up with the distribution of the ownership age according to the German motorcycle stock.

The average age of the respondents is 49.1 years (median: 52.0 years), which according to the KBA complies fairly accurate to the average age of motorcyclists in Germany (50.4 years according to the Kraftfahrbundesamt (KBA)[2]).

[1] Source: Kraftfahrt-Bundesamt (KBA), Flensburg, 1. Januar 2019.

[2] Source: Kraftfahrt-Bundesamt (KBA), Flensburg, FZ 23, 1. Januar 2018.

School-Leaving Qualification

To further examine various statements delivered by the participants, also against the background of their level of education, the disclosure of relevant school-leaving qualifications was requested. 1.1 percent of the participants did not respond to this. With 53.3 percent the largest share is made up of the participants who have completed the Abitur (general higher education entrance qualification). After that, with a percentage of 31.9 percent, the Realschulabschluss (secondary school certificate) follows. 13.7 percent of the collective reached a Hauptschulabschluss (lower secondary school certificate).

Starting Age ’’Powered Two-Wheelers’’

When posing the question of when the participants started riding a Powered Two-Wheeler (PTW) it can be shown that 43.2 percent had ridden a moped (average starting age here according to the participants' statements between the age of 15 and 16). 53.6 percent of the collective started their ’’two-wheeled career" with a moped or light motorcycle (average starting age here according to participants’ statements between 16 and 17 years). Therefore, more than half of the participating motorcyclists have been on the road on Powered Two-Wheelers since the age of 15 or 16. These motorcyclists have been riding on two-wheeled motorized vehicles since their youth and got to the motorcycle via vehicles subject to compulsory insurance (mopeds) and light motorcycles.

45 percent of the 3,805 study participants started motorcycling at the age of 18 regardless of any experiences with mopeds or light motorcycles.

At the ages immediately following, about five percent per each started riding motorcycles at the ages of 19 (5.2 %) and 20 (4.6 %). 3.5 percent started at the age of 21 years (direct entry until January 2013) and further 3.2 percent at the age of 25 (direct entry from January 2013). Almost 10 percent entered between the ages of 30 and 39 (9.9 %), 10.1 percent between the ages of 40 and 49. The remaining ’’starting ages’’ are distributed up to the entry age of 71. Up to and including the age of 50, 95.6 percent of the participants had found their way into motorcycling. From the age of 51 upwards, the figure equals only 4.4 percent.

Owning a Motorcycle / Different Types

97.2 percent of the collective own at least one motorcycle. With regard to different types of motorcycles, the intramural participant stock are as follows: The majority of participants by their own account move a vehicle that can be assigned to the category ’’Touring Bike’’. The group of riders of ’’Naked/Classic’’ motorcycles adds up to 23.3 percent, closely followed by the ’’Enduros’’ with 20.9 percent. With a share of 5.1 and 4.4 percent the types ’’Chopper’’ and ’’Sportsbike’’ are almost equal.

Scooters and others make up 3.3 percent. Riders of sporty machines (’’Supersports Bikes’’) are represented with nine percent of the total share.

This distribution for the most part corresponds to the market shares of the segments according to information delivery by the KBA/IVM[3]. While the ’’Enduro’’, ’’Classic’’, ’’Supersport’’ and ’’Chopper’’ segments are more

[3] Industrie-Verband Motorrad Deutschland, IVM-Jahresbericht (Annual Report) 2018.

or less congruent with the stock statistics, it is striking that the share of ''Tourers'' happens to be greater in the study, while that of ''Sportsbikes'' is smaller. The market shares according to the stock statistics of the German Motorcycle Industry Association (IVM) are the opposite. However, the totals for the two segments (Tourers + Sportsbikes) are comparable. Deviations for the unequal distribution at this point may be caused by the fact that the participating motorcyclists did not manage to classify their vehicles correctly in all cases. Whether ''Sportsbike'' or ''Tourer'' is the correct group to choose can be quite difficult to distinguish for some models. Many motorcycle models are considered to be so-called ''Sports-Tourers'', so that the participants had to choose one of the two groups with regard to the classification.

Year of Construction

With a share of 38.2 percent, most participants ride a motorcycle built between 2014 and 2018. The second largest sector: the years of construction 2009 to 2013 with 18.7 percent, relatively closely followed by motorcycles built between 2004 and 2008 (16.5 %). At 23.7 percent, more than a fifth of the participants ride vehicles that were built until 2003.

Annual Mileage

Only 6.9 percent of those surveyed ride their motorcycle for less than 2,000 km per year. 28.2 percent of the respondents state that they travel up to 5,000 km a year. The collective's majority (40.7 %) rides up to 10,000 km per year. 3.6 percent ride their motorcycle for more than 20,000 km a year.

The arithmetic mean of these figures lies at 8,703 km per year, the hereby more meaningful median at exactly 7,000 km. In the latter case, extreme outliers (very low and very high mileages) have little impact. The Federal Highway Research Institute (BASt) most recently determined an average annual mileage for motorcycles of 2,982 km per vehicle on the basis of a mileage survey for the year of 2014 [4].

[4] Marcus Bäumer, Heinz Hautzinger, Manfred Pfeiffer, Wilfried Stock, IVT Research GmbH, Mannheim Barbara Lenz, Tobias Kuhnimhof, Katja Köhler, Institut für Verkehrsforschung DLR, Berlin; BASt-Bericht V290, 2017.

2 Advanced Rider Assistance Systems on Motorcycles (ARAS-PTW)

A pronounced safety awareness and appropriate behavior in road traffic form an important basis for the reduction of the number of accidents. The users of motor vehicles, regardless of their type, thereby have a great responsibility. However, the possibilities for greater safety are also taking hold more than ever on the vehicle side, especially where technical systems support riders in traffic situations. A majority of all accidents are due to human error, as, for example, hazards are not recognized at all, too late or are even misinterpreted. The riding skills of road users also vary, which can lead to different results in extreme situations, particularly in the case of single-track vehicles. A central measure to improve road safety is therefore the support of the rider by technical systems. In recent decades, these systems have already made a considerable contribution to reducing the number of road traffic accidents. Modern rider assistance systems contribute to this by using the latest and most precise technology, can inform the rider at an early stage and thereby help to optimize the execution of his riding tasks. Growing rates of equipping rider assistance systems in vehicle fleets are expected to further increase road safety in the future.

As we know from another part of the ifz-studies, the safety awareness of German motorcyclists is at a high level. In addition to the aspects of technical safety of the machine, rider safety or the importance of rider equipment, which have already been examined, we aim to examine in the further course of the study what the knowledge, the attitudes and the handling of the questioned motorcyclists are with regard to Advanced Rider Assistance Systems for Powered Two-Wheelers (ARAS-PTW) on motorcycles.

Studies from the car sector show that user knowledge of individual systems needs to be improved. But how well known are the various motorcycle-specific ARAS among motorcyclists and how pronounced is their knowledge of individual systems? In recent years in particular, assistance systems for motorcyclists have become increasingly important and it is foreseeable that they will continue to penetrate the market. The following results should, among other things, help to estimate the image and user know-how of safety-relevant systems in the motorcycle sector more accurately.

2.1 The Necessity of ARAS-PTW

Anyone using a motor vehicle on public roads inevitably finds themselves in situations that can be dangerous, both for themselves and for other road users. This is also confirmed by the results on the question of whether the participants have been in one of the dangerous situations (listed in Figure 3) on their motorcycles at least once in the last twelve months.

At 14.8 percent, only slightly more than one in seven of the survey participants has not been involved in at least one of the critical situations indicated in the last twelve months. In contrast, the majority (85.2 %) had experienced a dangerous situation at least once.

Figure 3 reveals which situations these are, according to which 53.1 percent of the study participants were overlooked by another road user within the last twelve months. It is interesting to note that the need to brake in bends is already mentioned in second place: In 38.4 percent of cases, braking was necessary in an inclined position, which must not necessarily have been a dangerous trigger. Nevertheless, for riders who are inexperienced in this area, there are risks which can be significantly minimized with appropriate technical assistance (Cornering ABS).

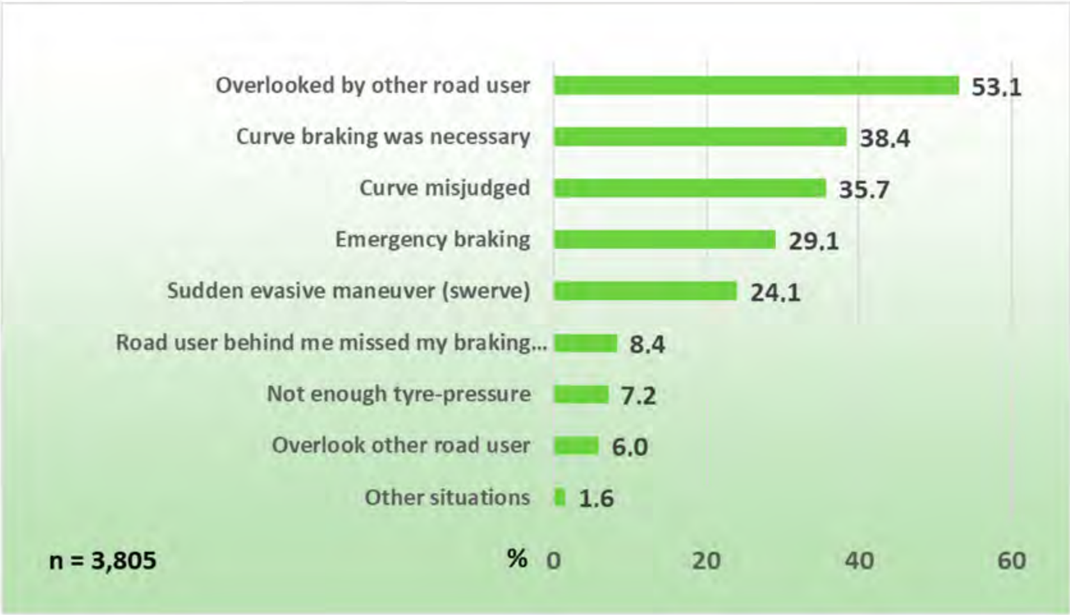


Figure 3: Critical situations on the road in the last twelve months

In most cases, these situations have turned out all right. In many cases, luck is one of the reasons for that, but it also shows that most road users are able to deal with these situations in everyday riding on the basis of their training and experience. Unfortunately, this is not always the case. Modern technology therefore represents a welcome opportunity to alleviate such conflicts and to relieve the riders in the accomplishment of complex riding tasks.

How useful and literally ’’necessary’’ ARAS-PTW is, is shown by the statements made by the motorcyclists questioned about the riding situations that cause them the greatest difficulties in another ifz-study. The greatest challenge stated there is riding in the wet. Approximately 40 percent of the respondents answered that they had difficulties with this. For 30.3 percent of the riders, braking in an inclined position is a stress factor, and also in the third and fourth place on the scale, there are challenges resulting from cornering (assessing the corner correctly, driving in an inclined position). In all these cases, ARAS-PTW such as Cornering ABS or Traction Control, an adapted Mapping, but also a Semi-active Suspension System can make a considerable, possibly even decisive contribution to alleviating dangerous situations and providing greater security for riders in the problem areas mentioned above.

2.2 Defining ARAS-PTW

Already in 2010, the ifz dealt with Advanced Rider Assistance Systems within the scope of its study „Advanced Rider Assistance Systems For Powered Two-Wheelers (ARAS-PTW)[5].

In the course of the research work carried out at that time, it was established that there are various existing definitions of rider assistance systems in literature. For this reason, the study attempted to give a definition for "Advanced Rider Assistance Systems for Powered Two-Wheelers" that would do justice to the vehicle or the riding of a Powered Two-Wheeler and its specific characteristics. ARAS-PTW also occupies a large space in the study at hand. In this respect, it seems helpful and reasonable to briefly outline the definition of "Advanced Rider Assistance Systems for Powered Two-Wheelers" formulated at that time. The definition refers exclusively to the vehicle level, i.e. to systems that can be assigned to the vehicle. A distinction has been made here quite deliberately, although numerous solutions exist starting at the level of personal rider equipment for riders of Powered Two-Wheelers. The background to this decision is the fact that it is based on the automotive sector, where no driver equipment is required.

Definition:

The term ''Advanced Rider Assistance System for Powered Two-Wheelers'' (abbr. ARAS-PTW) denotes equipment which supports and assists the operator of a Powered Two-Wheeler and/or reduces the stress and strain for the rider. It is a means of active safety (accident avoidance) but also influences accident results during a precrash-phase in a positive way. An ARAS-PTW should be assigned to at least one of the three levels of rider tasks (navigation level, maneuver level, operating level).

According to this definition, Advanced Rider Assistance Systems for Powered Two-Wheelers are mainly used for active safety. Thus, systems such as eCall or those that reduce fuel consumption and thus emissions, for example, do not fall into the group of ARAS-PTW.

A characteristic of ARAS-PTW, according to the definition above, is that the load and thus the strain on the rider is reduced by systems that, among other things, promote comfort. The field of ARAS-PTW also includes systems which draw attention to a Powered Two-Wheeler and its ''unprotected rider'' (self-protection) by giving acoustic and/or visual warnings to other road users. These can, for example, be vehicle-to-vehicle systems which are currently still under development but will have an enormous influence on traffic in the future.

In the following explanations and presentation of results, the abbreviation "ARAS-PTW" is mainly used to represent the term "Advanced Rider Assistance Systems for Powered Two-Wheelers".

[5] Kuschefski, A.; Haasper, M.; Vallese, A.: Fahrer-Assistenzsysteme an motorisierten Zweirädern (FAS-M), Studie des Instituts für Zweiradsicherheit, 2010.

2.3 Name Recognition of ARAS-PTW

Certainly, most motorcyclists will know the pure terms or names of most ARAS-PTW or have heard of them before. We did not want to pursue a general inquiry of the terms at this point. We are rather interested in which ARAS-PTW can be spontaneously (actively) named by participants.

Within the scope of a previous ifz-study from 2010, a total of 2,317 motorcyclists were asked at that time, among other things, which „Advanced Rider Assistance Systems for Powered Two-Wheelers (ARAS-PTW)" they know or are able to name. The former answers indicated significant deficits in the knowledge of rider assistance systems. Today, ten years later, it is reasonable to assume that the participants in the current study are more familiar, at least in name, with those systems that have been in use for some time, i.e. are more established, due to the increasing market penetration of ARAS-PTW. In order to provide clarity here, in the current study, the participants were also asked whether they are familiar with ARAS-PTW and if so, which ones.

What should be noted here is that the participants were not provided with any specifications at this point. In other words, up to five ARAS-PTW should be mentioned. In the context of the replies, some participants sometimes listed systems that do not belong to the ARAS-PTW, such as the airbag. The needed deletion of this information led to the following result.

First nomination	
ABS	3,158
Cornering ABS	82
Stoppie Control	2
Wheelie Control	5
Mapping	3
Combined Braking System	11
Traction Control System	49
Semi-Active Suspension	8
Tire Pressure Monitoring System	4
Adaptive Brake Light	2
Cornering Light	1
Daytime Running Light	2
Cruise Control	10
Quickshifter	4
Hill Start Assist	3
Side View Assist	2
Automatic/Dual-Clutch Transmission	1

Second Nomination	
ABS	145
Cornering ABS	604
Stoppie Control	17
Wheelie Control	62
Mapping	24
Combined Braking System	70
Traction Control System	1,335
Semi-Active Suspension	72
Tire Pressure Monitoring System	62
Adaptive Brake Light	3
Cornering Light	25
Daytime Running Light	10
Cruise Control	43
Quickshifter	20
Hill Start Assist	19
Side View Assist	1
Automatic/Dual-Clutch Transmission	7
Hazard Warning Light	7

Third Nomination	
ABS	54
Cornering ABS	340
Stoppie Control	40
Wheelie Control	182
Mapping	93
Combined Braking System	91
Traction Control System	529
Semi-Active Suspension	113
Tire Pressure Monitoring System	154
Adaptive Brake Light	7
Cornering Light	69
Daytime Running Light	8
Cruise Control	128
Quickshifter	64
Hill Start Assist	38
Side View Assist	8
Automatic/Dual-Clutch Transmission	22
Radio with Traffic Information	1
Hazard Warning Light	4

Fig. 4: Frequencies of the mentions of ARAS-PTW

It is not surprising that the ABS assistance system is ranked number one in the first nominations. 3,158 participants actively named the antilock braking system at first (89.7 % of first answers). This is undoubtedly the best-known ARAS-PTW up to now. In the 2010 ifz-study, 75.6 percent of three answers given or ARAS-PTW mentioned were ABS first. While only one ARAS-PTW could be named at that time, the answer was ABS in 93 percent of cases. Back to the current study: In second place comes the equally popular ARAS-PTW ''Traction Control'' (39.1 percent of the second answers). In third place, the majority of participants named the ''Traction Control'' as well (15.8 %). Those who already mentioned this system in the second place, self-evidently stated a different ARAS-PTW in the third place. Here, the Cornering ABS dominates with 340 entries.

In comparison to the above mentioned previous survey from 2010, it can be noted that the proportion of those who were not able to name an ARAS-PTW has decreased significantly. More than one fifth of the respondents (20.9 %) were not able to name an ARAS-PTW at the first go, even though it was assumed in 2010 that almost everyone must have heard of “ABS” and its level of awareness at that time. The current figures look different here: This time only 4.8 percent of motorcyclists were not able to name an ARAS-PTW or gave an incorrect answer. On the part of those questioned, the difficulty at the time may have been to make sense of the term ’’Rider Assistance System’’. The initial situation was therefore different in 2018, as the term has become established. The proportion of respondents who were able to name the required three rider assistance systems in 2010 was one third.

2.4 Participants’ General Knowledge about ARAS-PTW

2.4.1 General Knowledge on the Subject of ARAS-PTW available

With a share of 40 percent, the majority of the participants with their knowledge about ARAS-PTW is located in the middle of the field (Fig. 5). In contrast, only 6.1 percent of those surveyed consider their ARAS-PTW-knowledge to be excellent, while a good fifth (22.9 %) believe that they are well informed.

In terms of this very general question, the participants were able to classify their knowledge on a five-level Likert scale between the poles 1= “excellent” and 5= “not at all”. For the evaluation, the first and last two classifications above and below the ’’neutral’’ value ’3’ were combined. According to this, 29 percent of the entire group rated their own knowledge as positive and 31 percent (rather) as negative or non-existent. Evaluations also showed that 91 percent of those who assess their knowledge about ARAS-PTW as good to very good have practical experience with systems. In the middle field (3), the proportion of participants with practical experience is 79.8 percent. Among those who assess their knowledge rather negatively, only half of them have their own experience with assistance systems (53.7 %).

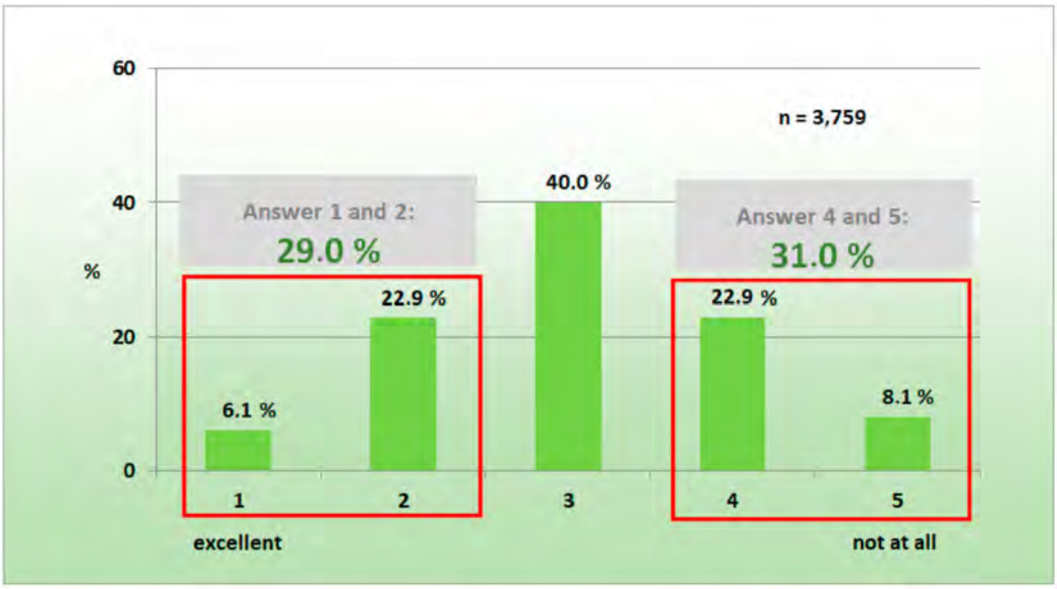
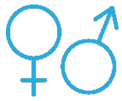
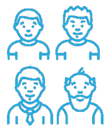


Fig. 5: Participants' general knowledge about ARAS-PTW

If the positive response values 1 and 2 are added together with response 3, i.e. those that are in the middle of the field in terms of knowledge, the resulting value is 69 percent. This means that significantly more than two thirds of the participants assess their general knowledge about the topic ''ARAS-PTW'' as ranging from excellent to average.



There is a big gap between the sexes in this self-assessment. While only 12.2 percent of female riders consider their knowledge about ARAS-PTW to be good or better, this figure is significantly higher for male riders at 30.8 percent. The group of those who assess their own knowledge rather negatively is already quite large among the male participants with 28.3 percent. Among the female participants, the figure is even more than half (57.6 %).



Differences also arise with regard to the age of motorcyclists. In the group of under 30-year-olds, only a quarter (25.1 %) stated that they were good to excellent. 34.4 percent saw themselves as having little to no knowledge. With increasing age, the proportion of participants who assess their own knowledge in this area positively then increases significantly.

The annual mileage also has an influence on the general ARAS-PTW-knowledge. With increasing annual mileage, the proportion of those who have a better knowledge increases. For riders with an annual mileage of more than 10,000 km, the proportion is above average. Exactly the opposite is the case for low annual mileage. Riders with an annual mileage of up to 2,000 km attest to a low general knowledge level of over 50 percent.

In view of the fact that a large number of new, often complex systems have only been installed in recent years, the current state of knowledge can be assessed positively. Furthermore it can be expected that with the increasing spread of rider assistant systems, more and more motorcyclists will gain additional knowledge. At the latest when their own new machine comes with a variety of safety-relevant features, riders will deepen into the subject matter. A causal relationship which is substantiated by the following chapter.

2.4.2 Source of ARAS-PTW Knowledge

The general knowledge about the subject of ARAS-PTW primarily arises (38.7 %) from own experience with the systems installed on one's own motorcycle (Fig. 6). This leading position in the range of information sources suggests that the best way to increase knowledge about ARAS-PTW is to use it oneself (''learning by doing''), which is also confirmed by the corresponding contexts of other questions. Again, it should be noted that more than 60 percent of the study participants ride a motorcycle that is older than four years, which limits the possibility of gaining their own experience with more recent systems. This also explains the relatively low level of awareness of newer, more advanced systems documented in 2.3.

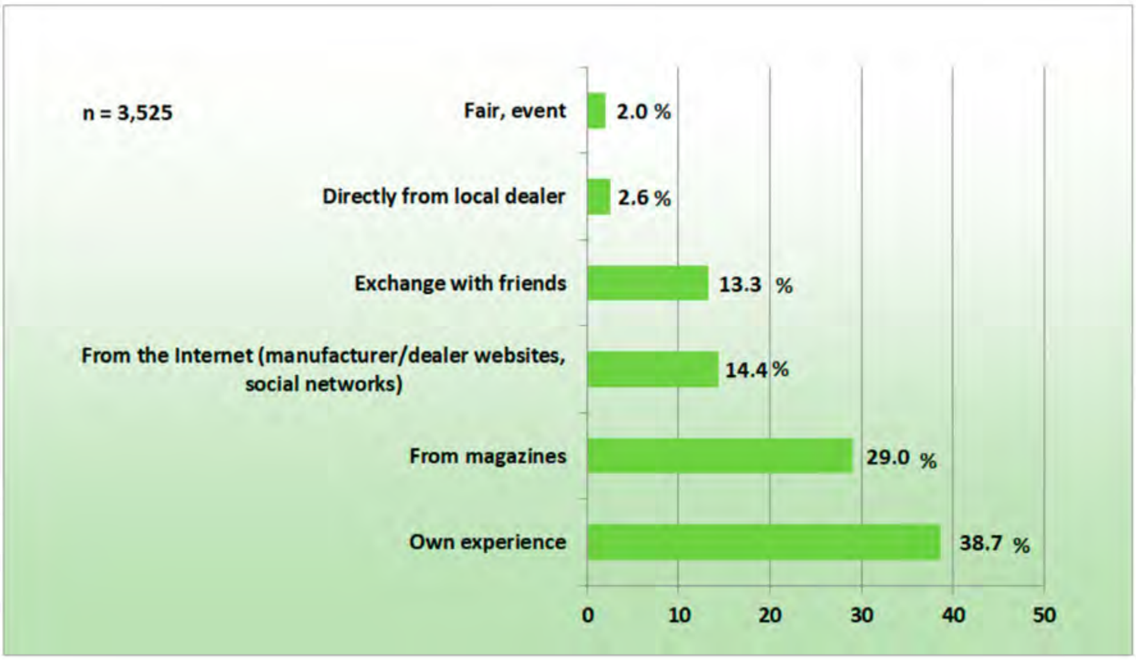


Fig. 6: Origin of general knowledge regarding ARAS-PTW

Almost one third (29 %) of knowledge about rider assistance systems stems from reading specialist journals. The internet and social networks follow at a noticeable distance as a source of knowledge about rider assistance systems (14.4 %). 13.3 percent of the participants obtain their knowledge from the exchange with friends and acquaintances. Information provided by motorcycle traders does not yet play a major role with regard to the general knowledge about ARAS-PTW surveyed here (2.6 %) but becomes more important in the field of specific information (see 2.5.2). Trade fairs and events represent the smallest area, at two percent, for obtaining or recording specialist information about ARAS-PTW.

With regard to the origin of knowledge about ARAS-PTW, cross-comparisons allow to identify gender-specific differences. While the internet and knowledge gained from experience with the own motorbike are mentioned by both genders with approximately the same frequency, men draw more knowledge from specialist journals (28.3 % compared to 11.6 %). Women make more frequent use of exchanges with friends and acquaintances (28.5 % compared to 10.6 %). Women also rely more often on information gained directly from the trader (4.5 % compared with 2.1 %).

In terms of age, it is the younger riders (up to 39 years) who make more use of the internet. Social media are also increasingly used by younger riders, but only up to the age of 29. Knowledge gained from experience with their own motorcycles increases with age, as does the use of specialist magazines. Younger riders dominate the acquisition of knowledge via friends and acquaintances, although this source of information is used less and less with increasing age. Information from the trader and through visits to trade fairs/events is balanced according to age.

With regard to school-leaving qualifications, there are at best slight differences in the field of knowledge acquisition, and there are no differences at all between everyday and leisure-time riders.

One final observation seems interesting here: Those who stated that they intended to buy a brand-new motorcycle in the near future have gained most of their ARAS-PTW-specific knowledge from their own experience with the current motorcycle.

2.4.3 Specific Knowledge about selected ARAS-PTW

In 2014 the German Academy of Driving Instructors had examined the subject-specific knowledge of car drivers with regard to various driver assistance systems and concluded that some of the respondents had some knowledge about the functionality of ARAS, but that the exact modes of action are still insufficiently known [6]. The following figure illustrates the individual levels of expertise among the group of motorcyclists who took part in the ifz-survey.

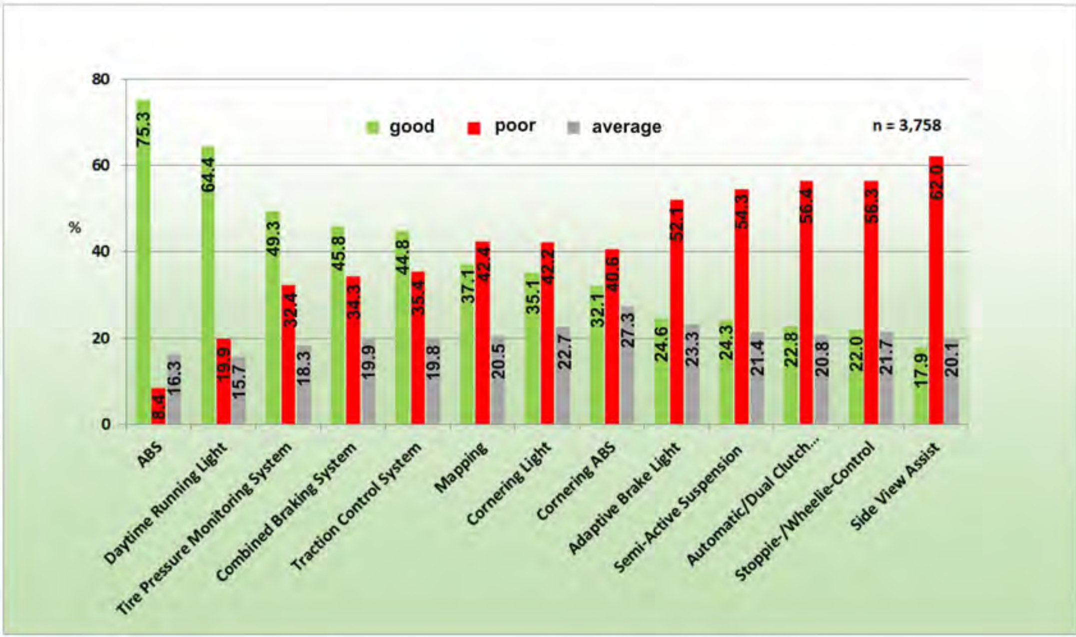


Fig. 7: Participants' level of knowledge about ARAS-PTW

Also for this question, the participants were able to assess their knowledge or expertise in various rider assistance systems on a five-level Likert scale (1= "excellent"; 5= "poor").

The green bars in Figure 7 show how many of the participants rated their knowledge as good to excellent (=1-2 on the scale). The figure illustrates that greater knowledge is available, above all, in the case of systems that have been on the market for some time and are therefore more established. Conversely, the shares of those with a low level of knowledge increase for systems that have not yet become widely used by comparison.

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[6] Maier, F.: Wirkpotentiale moderner Fahrerassistenzsysteme und Aspekte ihrer Relevanz für die Fahrausbildung, Korntal-Münchingen: Deutsche Fahrlehrer-Akademie e.V., 2014.

The latter observation can be demonstrated particularly vividly by using the example of ABS, which represents the classic rider assistance system. This best-known system was first fitted as standard on motorcycles in 1988 and was present on 68.5 percent of the participants at the time of the survey. More than three quarters of those surveyed stated that they were well informed about antilock braking systems (75.3 %). However, the figures are already significantly lower for another development stage of ABS, namely Cornering ABS, which enables technically controlled braking even in leaning positions. At 32.1 percent, less than half of the motorcyclists surveyed stated that they had knowledge. Here, the fact that so far only 12.1 percent of the participants own a motorcycle equipped with this technology certainly plays a role. The grey bars, however, prove that Cornering ABS has arrived in the minds of motorcyclists. After all, it is the assistance system that is most frequently used in the area of mediocre knowledge (27.3 %).

Although Daytime Running Light is only ’’on board’’ for 30.6 percent of the participants, more than twice as many (64.4 %) have good to very good knowledge of it. The influence of a technology already familiar from the automotive sector is unmistakable here.

The situation is similar with the Tire Pressure Monitoring System, which about half of the participants know well to very well, although it is only part of the equipment on the motorcycle in 17 percent of cases. At the other end of the scale, the low level of familiarity with the Side View Assist, which is already frequently used in cars (also known as Blind Spot Assist), is striking. Here, 62 percent of the participants have little or no knowledge of this ARAS-PTW. However, this system has not yet found its way into the motorcycle sector (see 2.7.2).

90.1 percent of the participants stated that they already had experience with driver assistance systems in passenger cars. Many of the available results indicate that the dissemination of participants' experience with ADAS in passenger cars has an impact on the participants' knowledge about motorcycles. However, this is not mandatory in every case, if one recalls the example of the Side View Assist. ARAS-PTW is an independent category of assistance systems with specific functional logic. Understanding and correctly using them requires a targeted approach to their respective characteristics and possibilities, a point which is also confirmed in the following chapter when it comes to functional knowledge.

The following table provides detailed correlations regarding the level of knowledge about individual systems for selected characteristics. The values within the table refer to the information on the respective Likert scale 1 to 5 (1= “excellent”; 3= “medium”; 5= “poor”).

ARAS-PTW	Sex	Age	Purchase Intention Motorcycle	Annual Mileage	Type of Motorcycle owned
ABS	Males tend to 1 & 2; Females: strong center (3)	Almost no differences Youngsters (under 20) stand out slightly with good knowledge (1 & 2)	If 1 & 2 combined: New bike: 80.9 % Used bike: 72.0 % No intention: 75.5 %	Higher level of knowledge with increasing mileage	Almost no differences Chopper riders with significantly less knowledge
Daytime Running Light	Men generally rate their knowledge bettter	Almost no differences People under 50 stand out slightly with good knowledge (1 & 2)	Almost no differences Purchasers of new bikes stand out slightly positively (1 & 2) *(no significance)*	No noticeable features	No noticeable features
Tire Pressure Monitoring System	Males strongly tend to 1 & 2 Female answers concentrate slightly on the midfield (3)	No noticeable features	Almost no differences Purchasers of new bikes stand out slightly positively (1 & 2)	Higher level of knowledge with increasing mileage	Almost no differences Chopper riders with significantly less knowledge
Combined Braking System	Men strongly tend to 1 & 2 Female answers concentrate slightly on the midfield (3) Two thirds of women show a negative level of knowledge	Higher level of knowledge with increasing age, whereas youngsters (under 20) stand out with good knowledge	Almost no differences Purchasers of new bikes stand out slightly positively (1 & 2)	Higher level of knowledge with increasing mileage Compared to less frequent riders (up to 2,000 km/year), the knowledge of frequent riders (5,000 to 10,000 km/year) is twice as high	Chopper riders with significantly less knowledge Riders of naked and classic bikes show lesser knowledge
Traction Control System	Men strongly tend to 1 & 2; 3: balanced; Two thirds of women show a negative level of knowledge (4 & 5)	Almost no differences Youngsters (under 20) stand out slightly with good knowledge (1 & 2)	If 1 & 2 combined: New bike: 59.0 % Used bike: 39.6 % No intention: 44.0 %	Higher level of knowledge with increasing mileage Compared to less frequent riders (up to 2,000 km/year), the knowledge of frequent riders (5,000 to 10,000 km/year) is twice as high	Almost no differences Chopper riders with significantly less knowledge
Mapping	Men tend to answers 1 & 2 3: balanced More than two thirds of women show a negative level of knowledge (4 & 5)	Almost no differences Youngsters (under 20) stand out slightly with good knowledge (1 & 2)	If 1 & 2 combined: New bike: 50.5 % Used bike: 33.4 % No intention: 35.9 %	Higher level of knowledge with increasing mileage	Chopper riders with significantly less knowledge Riders of naked, classic and touring bikes show lesser knowledge

ARAS-PTW	Sex	Age	Purchase Intention Motorcycle	Annual Mileage	Type of Motorcycle owned
Cornering Light	Fairly balanced Males show a slightly higher level of knowledge	Younger riders tend to have more knowledge. Riders under 30 years of age with good knowledge	If 1 & 2 combined: New bike: 44.3 % Used bike: 37.2 % No intention: 33.4 %	Higher level of knowledge with increasing mileage	Almost no differences Chopper riders with significantly less knowledge
Cornering ABS	Men prefer answers 1 to 3 More than 50 % of women show a negative level of knowledge (4 & 5)	Almost no differences	New bike (1 & 2): 46.3 % Used bike: 31.8 % No intention: 30.3 %	Higher level of knowledge with increasing mileage	Almost no differences Chopper riders with significantly less knowledge
Adaptive Brake Light	Men prefer answers 1 to 3 More than 50 % of women show a negative level of knowledge	Almost no differences	If 1 & 2 combined: New bike: 31.8 % Used bike: 23.5 % No intention: 23.8 %	Higher level of knowledge with increasing mileage	Almost no differences Chopper riders with significantly less knowledge
Semi-active Suspension System	Men generally rate their knowledge bettter More than 60 % of women show a negative level of knowledge	Higher level of knowledge with increasing age	If 1 & 2 combined: New bike: 36.5 % Used bike: 20.6 % No intention: 23.3 %	Higher level of knowledge with increasing mileage	Chopper riders with significantly less knowledge Riders of naked and classic bikes show lesser knowledge
Automatic; Dual-Clutch Transmission	Men prefer answers 1 to 3 More than 50 % of women show a negative level of knowledge	Almost no differences	If 1 & 2 combined: New bike: 27.5 % Used bike: 25.5 % No intention: 21.8 %	Higher level of knowledge with increasing mileage	Almost no differences Chopper riders with significantly less knowledge
Stoppie & Wheelie Control	Men generally rate their knowledge bettter More than 65 % of women show a negative level of knowledge (5)	Almost no differences Riders under 20 show outstanding good knowledge (1 & 2)	If 1 & 2 combined: New bike: 33.4 % Used bike: 23.4 % No intention: 21.2 %	Higher level of knowledge with increasing mileage	Variances between different types of bikes owned Remarkable: Higher level of knowledge among riders of supersport machines

ARAS-PTW	Sex	Age	Purchase Intention Motorcycle	Annual Mileage	Type of Motorcycle owned
Side View Assist	Men generally rate their knowledge bettter	Riders up to the age of 30 reveal a slightly higher level of knowledge than older ones	If 1 & 2 combined: New bike: 23.8 % Used bike: 18.9 % No intention: 16.9 %	Almost no differences Frequent riders (over 20.000 km/year) stand out positively	Almost no differences Chopper riders with significantly less knowledge

Tab. 1: Correlations to the level of knowledge

At this point, we would like to note that especially the riders of scooters indicated a consistently good level of knowledge about all systems. It was also noticeable in the evaluation that the riders of super sports motorcycles showed a rather moderate level of knowledge.

2.5 Knowledge in Dealing with ARAS-PTW

74.5 percent of the study participants have their own practical experience with motorcycles equipped with rider assistance systems.

While more than three quarters of the men surveyed have practical experience with ARAS-PTW, the proportion is somewhat lower among women, at just under two thirds.

With increasing age, these experience values increase slightly but noticeably for both sexes.

2.5.1 Use of Rider Assistance Systems

Although the topic of assistance systems is not only booming in the motorcycle sector, it is not a new one. Rider assistance systems have been available for many years, some of them have been in use for decades. The following Figure 8 provides information on which of them have become correspondingly more widespread.

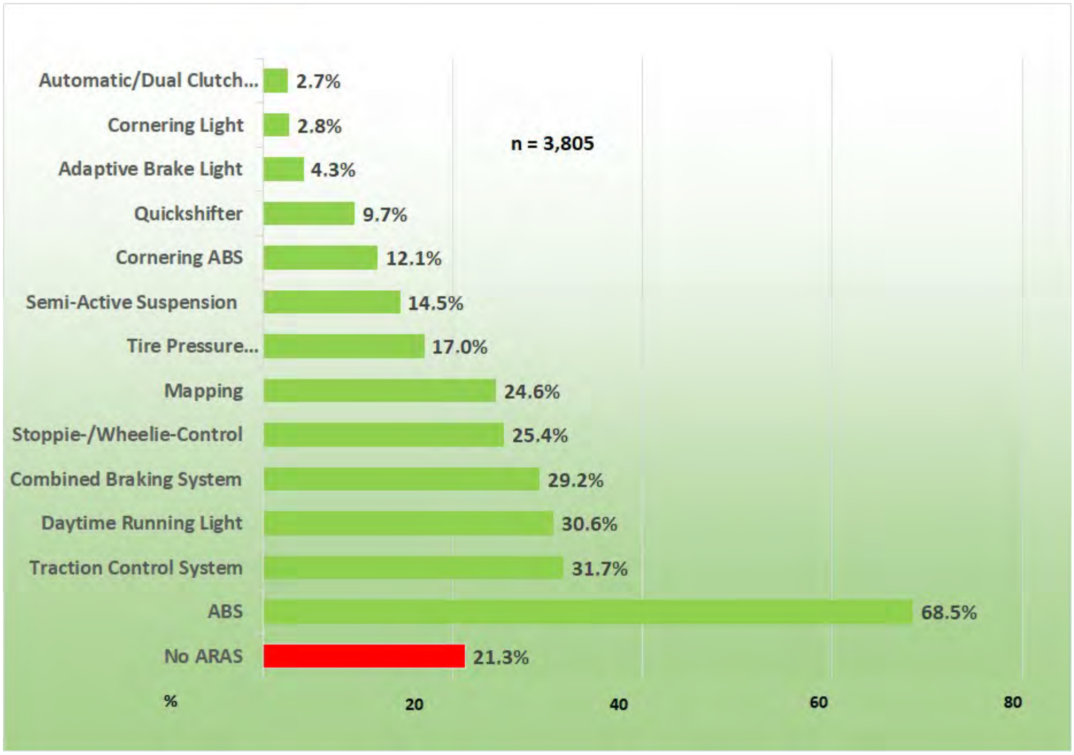


Fig. 8: Available/ used ARAS-PTW

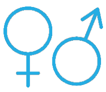
First of all, it should be noted that one fifth (21.3 %) of the vehicles used by the respondents still do not have an ARAS-PTW at all, which can mainly be explained by the year of construction of the motorcycles used. The example of ABS shows that only 19.9 percent of the vehicles in use that were manufactured in 1998 or earlier are equipped with ABS.

As the age of the vehicles increases, the proportion of riders who have no practical experience with ARAS-PTW also increases significantly. It was to be assumed that ABS will also be far ahead when it comes to which rider assistance systems are used in practice by the study participants. 68.5 percent own or ride a motorcycle with this technical braking aid. Traction Control, which is technically closely related to ABS, is by far the second most frequently used system.

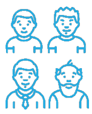
2.5.2 Functional Knowledge of existing ARAS-PTW

More than three quarters of all respondents (78.1 %) say they know how the ARAS-PTW they use on their own vehicle works or how to use it. 14.2 percent are uncertain about this, while 7.7 percent take a clear stand and admit to having no idea about it (Fig. 9).

Fig. 9: Knowledge: Usability of utilized ARAS-PTW



The gender evaluation shows a clear difference here. While 74.9 percent of the male participants indicate that they have knowledge, the female respondents, at 54.3 percent, are significantly below this figure.



A significant dependence can also be seen when looking at the age of the participants. Younger riders know less about this than older ones. The self-assessment of knowing how to use their own ARAS-PTW therefore increases with age.

In order to further deepen the topic of functional knowledge regarding ARAS-PTW used by or installed on the motorcycle, we also wanted to know from the respective participants from which source they obtained their knowledge about the handling of the systems. The 2,835 participants in question responded as follows:

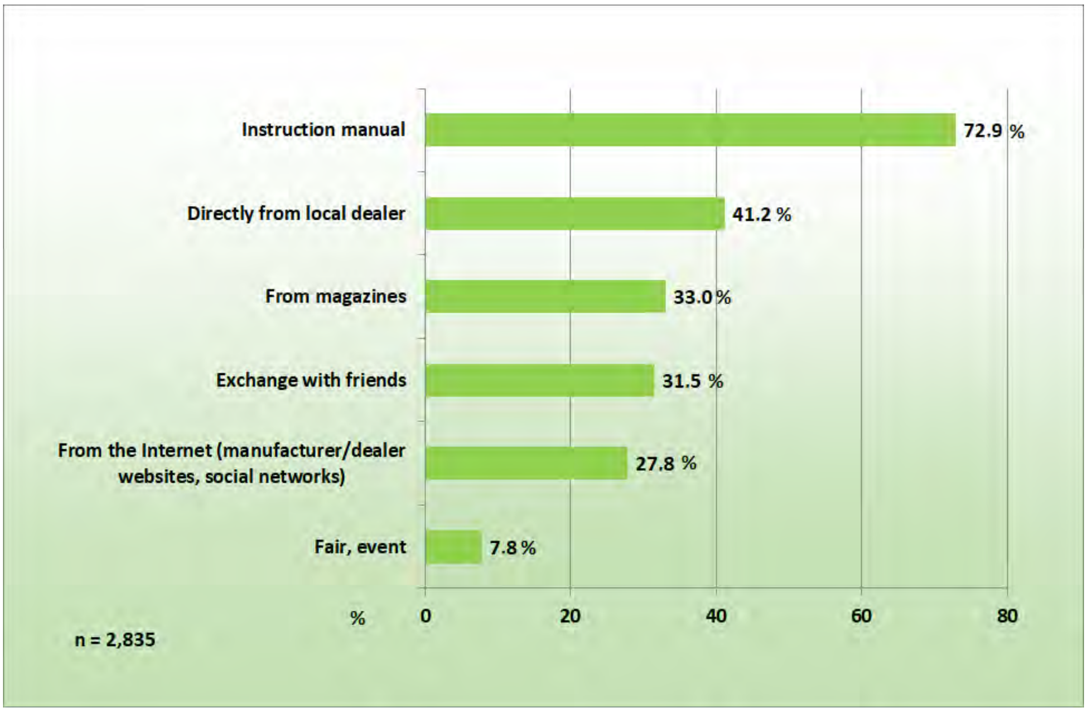


Fig. 10: Source: Knowledge operability of utilized ARAS-PTW

At 72.9 percent, the owner's manual of the owned vehicle is the primary source of information on the operation and handling of ARAS-PTW. While the motorcycle traders have hardly played any role as a source of general knowledge about ARAS-PTW (2.6 %; see 2.4.2), here they are the second most frequent source of information (41.2 %). When it comes to detailed technical questions about one's own motorcycle or the ARAS-PTW installed, the specialist therefore plays a greater role than with knowledge on general topics, which one prefers to obtain from specialist magazines and discussions with friends and acquaintances. ARAS-PTW explanations often take place when the vehicle is handed over, which further emphasizes the important role of the traders in this context.

Trade fairs and events also seem to be more popular in direct comparison for specific technical questions (7.8 %) than for general information about ARAS-PTW (1.9 %; see 2.4.2). “Fuel talks” with like-minded people (friends and acquaintances) are equally well represented in both areas and represent a frequently used opportunity to exchange knowledge. Some participants also pointed out that driving schools have already provided them with system knowledge. Others mentioned safety training courses. In this respect, both areas represent an area that can be expanded.

Also on this occasion, the analysis was able to identify gender-specific characteristics. While men use technical journals and operating instructions much more often, women prefer to exchange information with friends and acquaintances more often than average. They also mentioned riding schools and advanced rider training courses proportionately more often than men. The local dealer, on the other hand, was an almost equally important source of information for both sexes.

In addition to motorcycles, most participants (90.1 %) also use the car to be mobile. Certainly, experience in this area also plays a certain role as “Advanced Driver Assistence Systems (ADAS)” in the passenger car sector already have a longer history. Although the systems installed there cannot be transferred one-to-one to the Powered Two-Wheelers, it can nevertheless be assumed that they provide a foundation of experience.

2.5.3 Rider Information for ARAS-PTW

Certainly, it is important and necessary to deal with most of the ARAS-PTW already before the journey in order to understand their mode of operation. To be able to use them optimally, additional operating knowledge is usually required. For this reason, the study participants were also asked how motorcyclists should best be informed in future about the ARAS-PTW installed, i.e. about the “individual ability of their vehicle”.

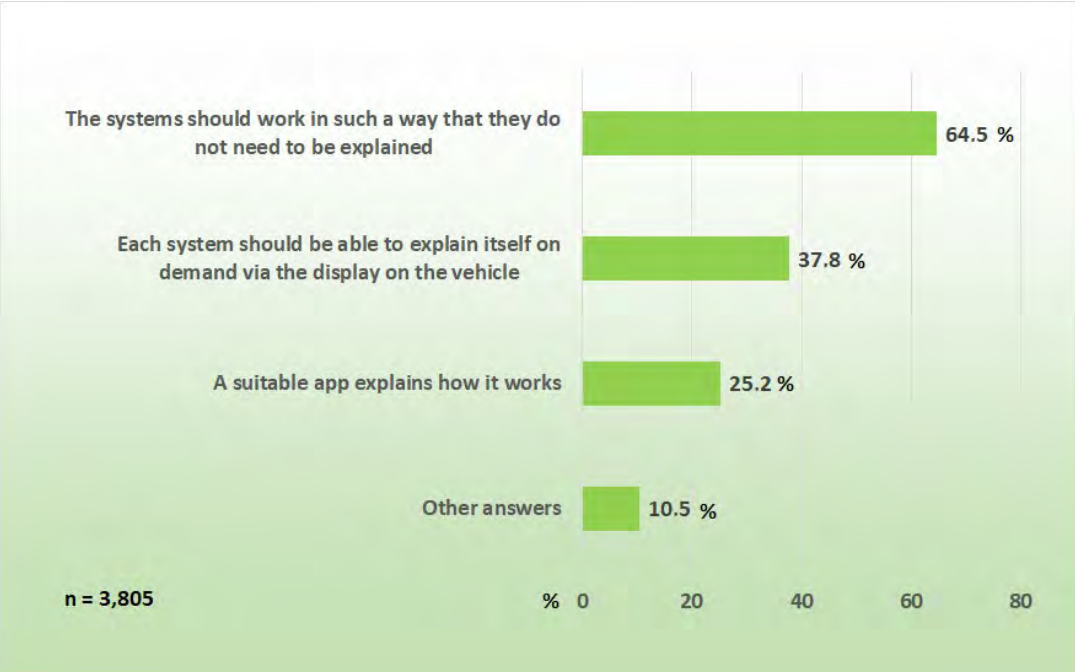


Fig. 11 Wish/ideas: Information on the operability of utilized ARAS-PTW

Figure 11 shows the most frequent answers (multiple answers were possible) to this question. Almost two thirds of the respondents (64.5 %) are of the opinion that a safety-related system must function in such a way that no explanation is required. However, as soon as a system has different modes, for example, for different purposes, this becomes difficult. 37.8 percent would like the ARAS-PTW in question to be able to explain itself on demand via the display on the motorcycle (if available).

Anyone who wants to find out about the capabilities of their ARAS-PTW at home on the sofa or on the motorbike could do so via a corresponding app. A quarter of the participants would prefer this (25.2 %).

A good one in ten respondents (other answers: 10.5 %) had also made use of the possibility of formulating their own suggestion in addition to the choice of answer specifications. The participants particularly often requested a (supplementary) explanation/instruction by the specialist trader. Another suggestion that was often made was that the operation of the various systems could be explained and practiced in advanced rider trainings.

2.6 Personal Benefit through ARAS-PTW

Some questions of the study deal with the personal benefit of ARAS-PTW. The question is whether the participants have both positive and negative experiences with the technical helpers. Under certain circumstances, these can have a significant influence on general attitudes towards the topic of ARAS-PTW.

2.6.1 Own Experience with ARAS-PTW

With 65.2 percent, almost two thirds of the participants have positive experiences with ARAS-PTW. When it comes to specifying the system on which the experience is based, ABS clearly dominates, followed by the Traction Control System.

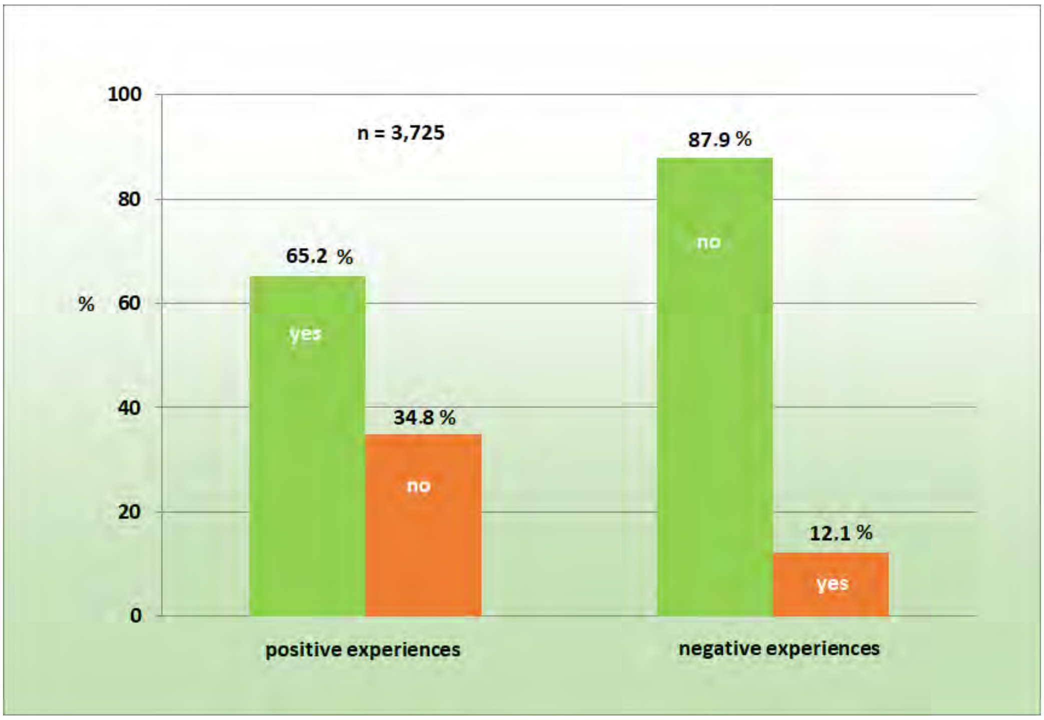


Fig. 12: Experience with ARAS-PTW

On the other hand, more than a third (34.8 %) do not have this positive experience. This does not mean, however, that this proportion of respondents has a negative opinion of ARAS-PTW. The only difference is that there are no positive experiences. The direct counter question about negative experiences provides more clarity here. The majority of the participants (87.9 %) had no negative experiences with ARAS-PTW. Only 12.1 percent of the participants had negative experiences. The survey did not determine what these experiences were.

While no gender-specific conspicuities are apparent, the age of the participants plays a role in that motorcyclists report positive experiences more frequently with increasing age.

The age of the own motorcycle is also relevant. Positive experiences with ARAS-PTW decrease with increasing age of the vehicle. Probably simply because no systems are installed. The age of the vehicle is not important for negative experience values.

As far as the motorcycle type is concerned, it is mainly the “Adventure” type, 75 percent of whose riders have had positive experience with ARAS-PTW. The group of “Enduro”-riders comes to 68.2 percent, on a par with the “Tourers” (68.2 %), and the owners of “Naked Bikes” to 62.8 percent. In contrast, 41.3 percent are “Chopper” users.

2.6.2 Accident Prevention by ARAS-PTW

64.2 percent of all participants have already experienced a fall/accident with their motorcycle. Specifically, we would like to know from this group whether a corresponding ARAS-PTW could have prevented this fall or accident.

About one in five of those affected (20.3 %) believes that an ARAS-PTW could have prevented at least one of their accidents. With 16 percent of undecided (“I don’t know”), a large proportion of this group (63.7 %) believe that a suitable ARAS-PTW (concerning the cause of the fall/accident) would not have prevented the incident.

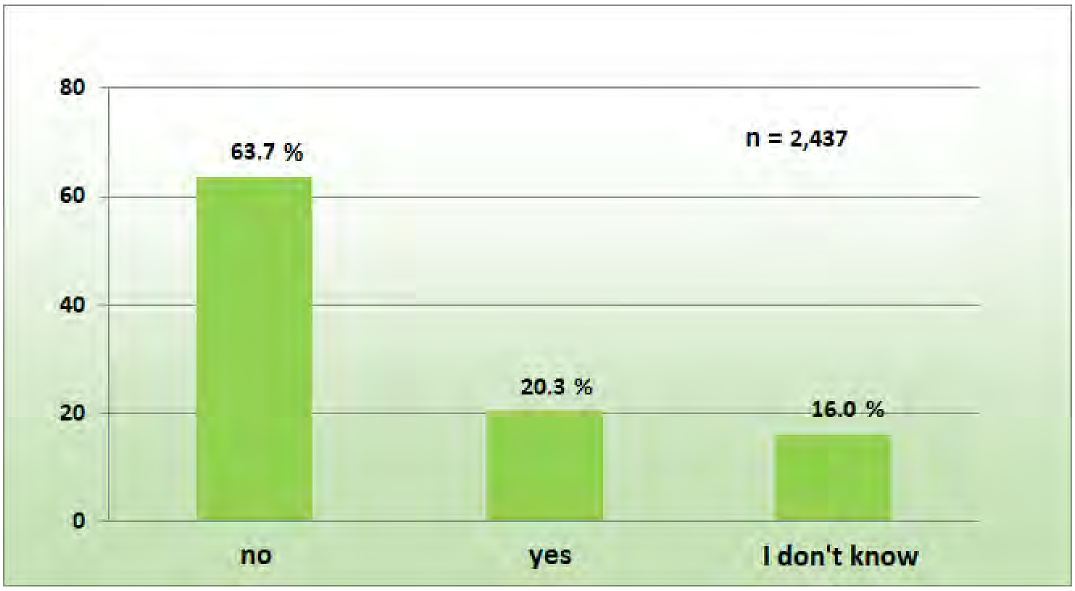
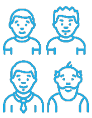
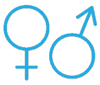


Fig. 13: Review: Fall prevention with the help of ARAS-PTW



This opinion varies greatly between the different age groups.



However, there are gender-specific differences. After deducting those who did not provide any information, the proportion of male participants who are certain that an ARAS-PTW could have prevented a fall or accident was 20.9 percent. For women, this is only 13.1 percent. Overall, around three quarters of the female participants (74.3 %; men 63.1 %) were certain that an ARAS-PTW would not have helped.

If the systems are not sufficiently known, it will be more difficult to assess whether and when a system could have been helpful. In order to substantiate this obvious thesis empirically, we have examined the subgroup of accident victims to what extent their respective knowledge about ARAS-PTW influences the judgement above. This revealed a clear correlation: The less knowledge about ARAS-functions, the greater the uncertainty, but also the skepticism about whether a suitable ARAS-PTW could have prevented the accident. If very good to good knowledge of the system is available, only 11.3 percent will not want to commit themselves. Among those who say they have little or no knowledge about ARAS, 19.9 percent do not want to or cannot make a clear judgement.

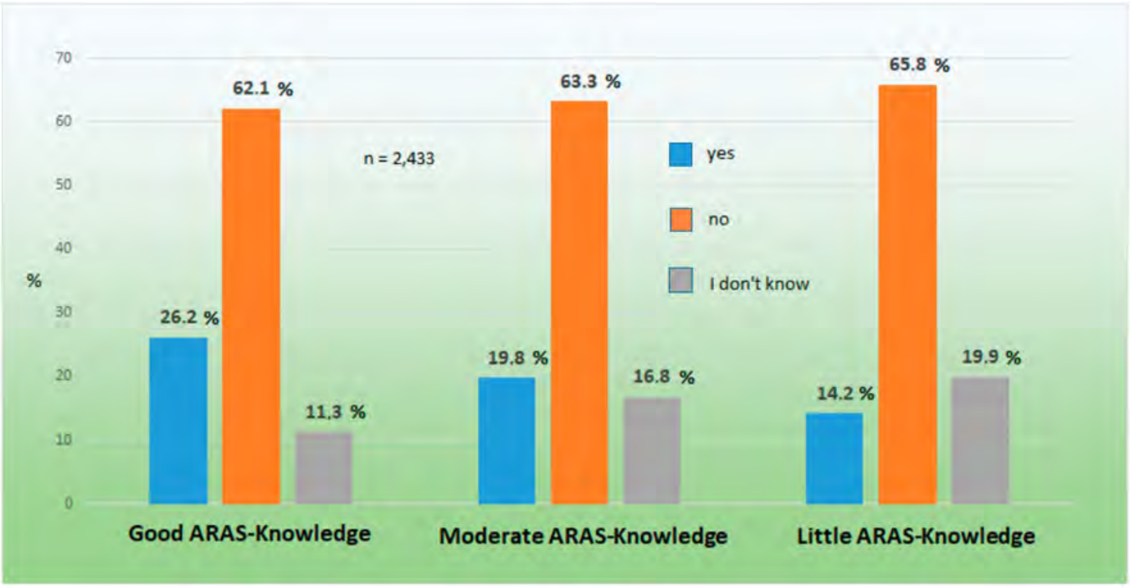


Fig. 14: ARAS-PTW

This is also true in the case of the ARAS-PTW retroactively being attributed an accident-preventing effect. Here as well, those participants with good knowledge are more likely to come to a positive assessment of the potential protective function of systems that were not yet present on the motorcycle at the time of the accident. The relatively high number of negations across all three groups can be explained primarily by the fact that a significant proportion of accidents are due to causes that even ARAS-PTW cannot counteract. For example, no assistance system has yet been deployed in the motorcycle sector to prevent accidents resulting from being overlooked at intersections.

The retrospective individual assessment of the abatement potential of an ARAS-PTW is certainly influenced by subjective factors. This thesis is supported by another observation: In the group of those accident victims for whom an ARAS-PTW would not have prevented the accident/fall, an above-average proportion also believe that rider assistance systems on motorcycles are generally not useful for safety reasons. This can be interpreted as an indication that even fundamental reservations about the usefulness of ARAS-PTW may have a negative impact on the assessment of its potential protective function in individual cases.

The subjective experience, the subjective perception of the participants also has a great influence on the formation of opinion or the assessment of the future effectiveness of ARAS-PTW on the accident situation in general (see 2.7.6). It can be seen, for example, that 74.5 percent of those who believe that a corresponding ARAS-PTW could have prevented their own fall assume that ARAS-PTW will further reduce the number of accidents in the future. Among those who do not have this experience, the figure is only 55.9 percent. Also, in this second group, the proportion of those who are uncertain about this is larger.

2.7 Opinions on ARAS-PTW

2.7.1 ARAS-PTW make Sense for Road Safety Reasons

When asked whether the participants consider rider assistance systems on motorcycles to be useful for safety reasons, the vote was unequivocal: 94.6 percent of the participants see a safety gain in ARAS-PTW (see Fig. 15). Riders' age and gender have hardly any influence on the assessment, and the level of education (measured by the highest level of education) is also irrelevant here. Even the hypothesis that participants who consider themselves to be particularly safe riders tend to regard ARAS-PTW as less useful could not be consistently confirmed. Only those who rated themselves as "very safe" on the five-level Likert scale denied ARAS-PTW as road safety support twice as often as the "supporters" (20.0 % vs. 10.6 %).

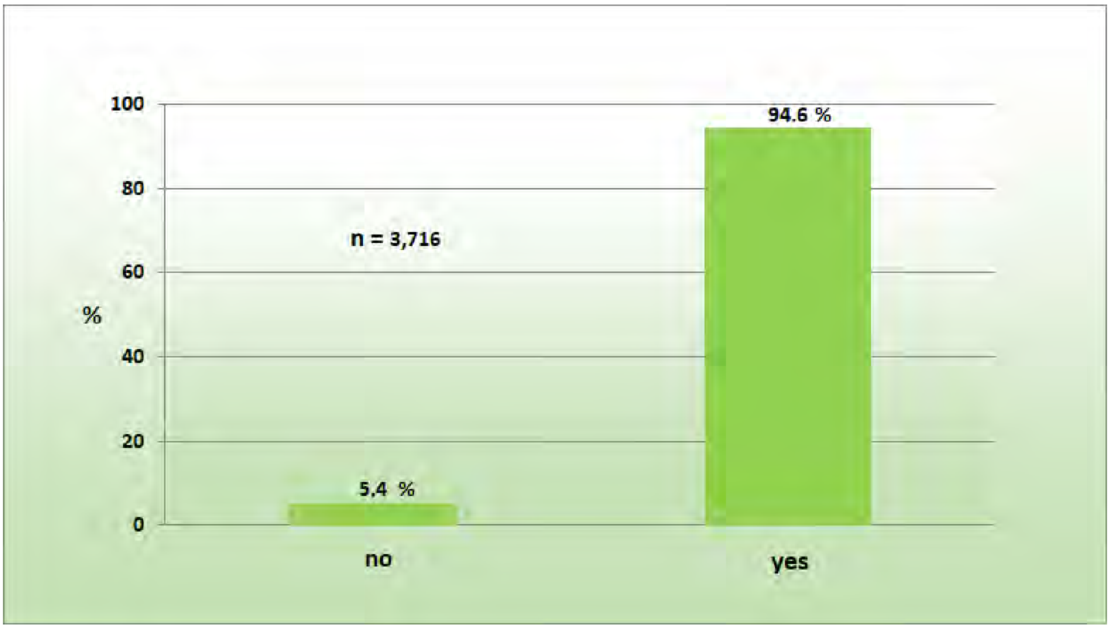


Fig. 15: Assessment of safety gain by ARAS-PTW

Let us consider separately only the 2,835 participants for whom “own experience with ARAS-PTW is available”. In this group, 96 percent agreed, while just four percent of them (instead of 5.4 % above) denied that the security aspect made sense. On the other hand, it is noticeable here that motorcyclists without their own experience tend to doubt the safety benefit more frequently (11.7 % instead of 3.2 %). In addition, experience from passenger cars is also particularly relevant. More positive assessments of ARAS-PTW for road safety are made by those who already have experience with ADAS from passenger cars.

Conclusion: Anyone already familiar with rider assistance systems in practice is almost always convinced of their relevance to riding safety. Thus, in the end, it is not surprising when 93.9 percent of all riders who already have experience with ARAS-PTW say that their next motorcycle should be equipped (again) with such assistance systems. A similar correlation was also confirmed by other parties: “Riders who experience the support of driver assistance systems (DAS) on a daily basis are also open to other DAS”[7].

In contrast to that, those with little or no experience with ARAS-PTW, tend to be “skeptical”, according to a press release issued by the German Road Safety Council (DVR)[7] as part of the “Best Co-Rider” campaign.

2.7.2 Individual Consideration of ARAS-PTW: Benefits for the Security of ARAS-PTW

The green columns in Figure 16 show the participants' assessment of various ARAS-PTW with regard to their safety relevance. The systems that have already been on the market for a longer time and are therefore more established, stand out particularly here. On the other hand, two more recent systems in particular stand out: On the one hand the Cornering ABS. Based on the classic ABS, this system attracted a lot of attention when it was introduced just a few years ago. The possibility of being able to brake to a certain degree in a curve was until then rarely used by many motorcyclists for fear of falling. Cornering ABS is and will continue to help motorcyclists to overcome these fears and thus increase safety in extreme situations – and 89.5 percent of the motorcyclists surveyed are already convinced of this.

More conspicuous at this point, however, is the Side View Assist. This is considered by the participants to have an above-average effect on safety, even though it has not yet made any inroads into the motorcycle sector and the specific knowledge in this area is not yet very well developed (see 2.4.3). Only one scooter of a renowned manufacturer is equipped with this system. The generally quite popular problem of blind spots as well as the experiences of the respondents from the passenger car sector probably play a major role here. The fact that the Cruise Control, the Quickshifter and the Hill Start Assist, three systems that are more conducive to riding comfort, end up in the rear places, shows that motorcyclists are able to make a differentiated and informed assessment of the safety benefits offered by the various ARAS-PTW.

[7] Pressemitteilung des DVR vom 07.06.2016: „Auf den Geschmack gekommen: Fahrerassistenzsysteme überzeugen in der Praxis“.

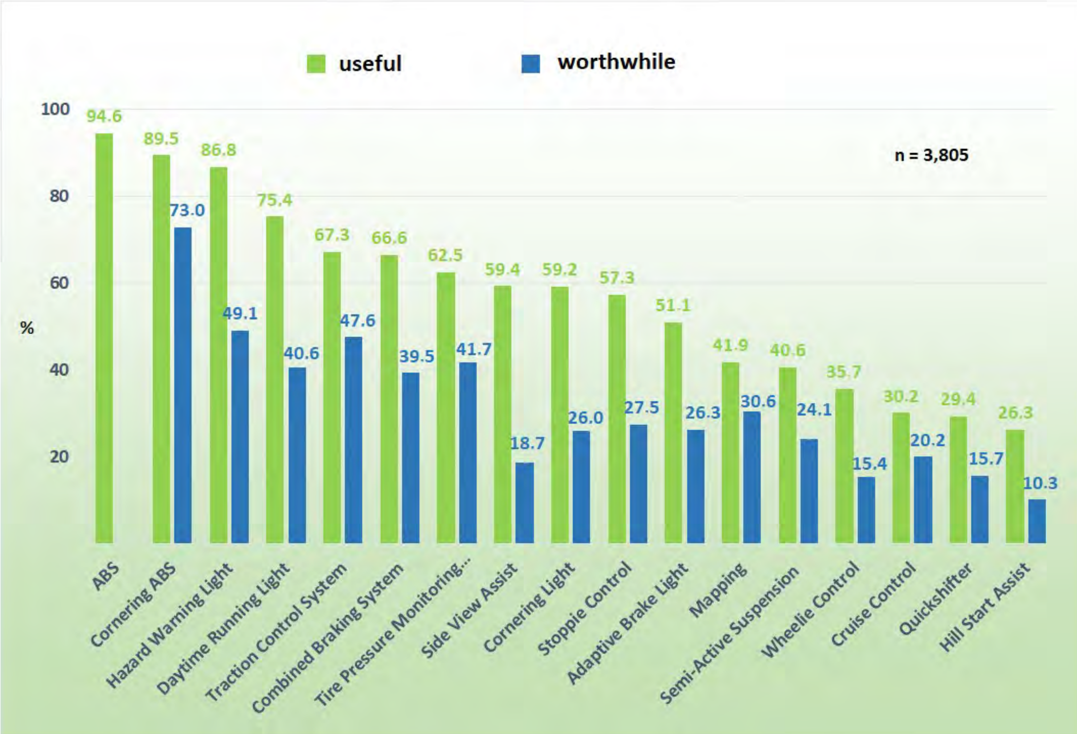


Fig. 16: Assessment of security gain through ARAS-PTW- Desire

If we take a look at the blue columns in Figure 16, we can see the characteristics of the different ARAS-PTW, which tell us whether the next motorcycle should be equipped with such a system. In general, it is noticeable that the respondents consider the different ARAS-PTW more often than they consider these systems necessary or desirable as equipment for their future motorcycle. The discrepancies are in most cases quite marked. The Cornering ABS, where the deviation between the two postures is the smallest, comes off best here. 89.5 percent of those surveyed consider the system to be useful and 73 percent of those surveyed expect their next own motorcycle to be equipped with it. This is a proportion of 82.6 percent of those who generally consider Cornering ABS to be useful. Mapping and Traction Control System also scored quite positively, with over 70 percent agreeing between sensible and desirable.

The discrepancy is particularly large for the Side View Assist and the Hill Start Assist. 59.4 percent of those surveyed consider a Side View Assist system to be useful, but only 18.7 percent of all respondents want to see their next motorcycle equipped with it. Here, knowledge or presumption about the still very low availability of this equipment feature mentioned above may play a role. Only 10.3 percent can imagine a Hill Start Assist on their own motorcycle, although 26.3 percent still consider this equipment feature to be useful from a safety perspective. However, there are differences according to motorcycle type. While riders of touring motorcycles in particular consider the Hill Start Assist to be sensible (34.4 %) and also personally desirable (15.4 %), the majority of "sports motorcycles" and "super sports motorcycles" users reject the system. Only 6.1 percent of riders of both motorcycle types would like to see their future two-wheeler equipped with it.

ABS was only placed here in the context of the assessment concerning safety relevance. The wish with regard to the next purchase is not taken into account, as ABS has been mandatory for all new vehicle registrations since January 2017 and is no longer an option.

2.7.3 Feeling of Safety through ARAS-PTW

Whether the study participants feel more comfortable on a motorcycle equipped with rider assistance systems (e.g. ABS, Cornering ABS, Traction Control, etc.) could also be assessed on a Likert scale from 1 ("exactly") to 5 ("completely wrong").

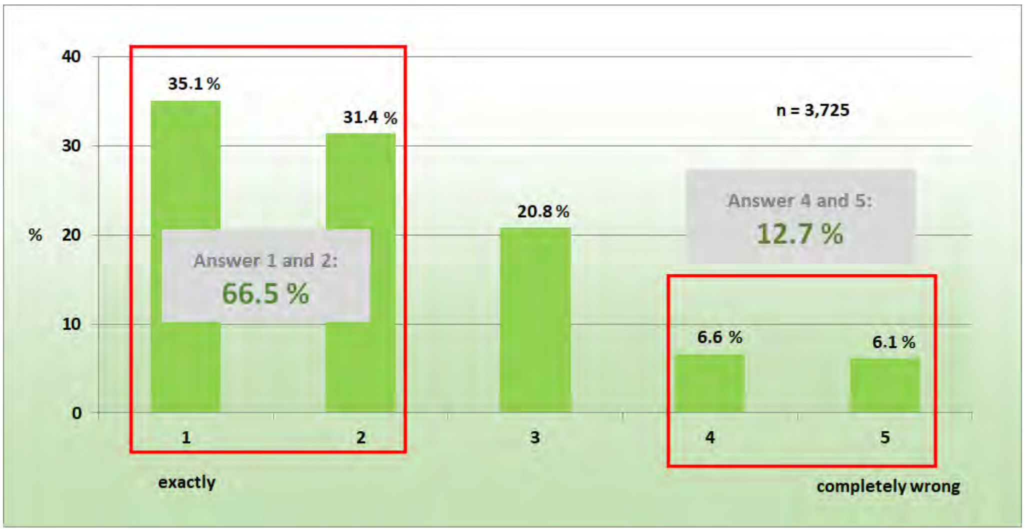
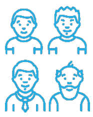
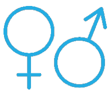


Fig. 17: Feelgood factor ARAS-PTW

Figure 17 shows a clear left-weighting trend towards "exactly". If we combine the two values above and below the middle value 3, i.e. 1 and 2 as well as 4 and 5, we receive the "rather agree" and "disagree" answers summed up. According to this, two thirds of the participants (66.5 %) agree with the statement; they feel more comfortable with the support of ARAS-PTW. Only 12.7 percent do not feel more comfortable on a motorcycle equipped with ARAS-PTW. We can conclude from this that ARAS-PTW makes an important contribution to a more positive driving experience.



The mood is slightly different for the different age groups. While riders under the age of 30 and, even more so, riders between the ages of 30 and 39 are disliked more than average, the group of riders aged 40 and over is characterized by higher approval ratings.



The feelgood factor, on a motorcycle equipped with ARAS-PTW, is also assessed differently according to gender. Simply put, among men, approval is higher. Women, in contrast, reject the statement more frequently, but tend to remain in the middle of the field: 29.1 percent of women voted for the 3 on the Likert scale (among all participants, the figure was only 20.8 percent). Incidentally, the greater skepticism expressed here is independent.

The latter finding is surprising in that those participants with their own ARAS-PTW-experience generally have much more positive opinions about ARAS-PTW than respondents who have not yet ridden a motorcycle with ARAS. As a reminder, 96 percent of participants with ARAS-PTW-experience, but 'only' 92.5 percent of all respondents consider such systems to be useful. The following answers are similar, limited to the almost 75 percent large subgroup who know at least one ARAS-PTW from their own experience.

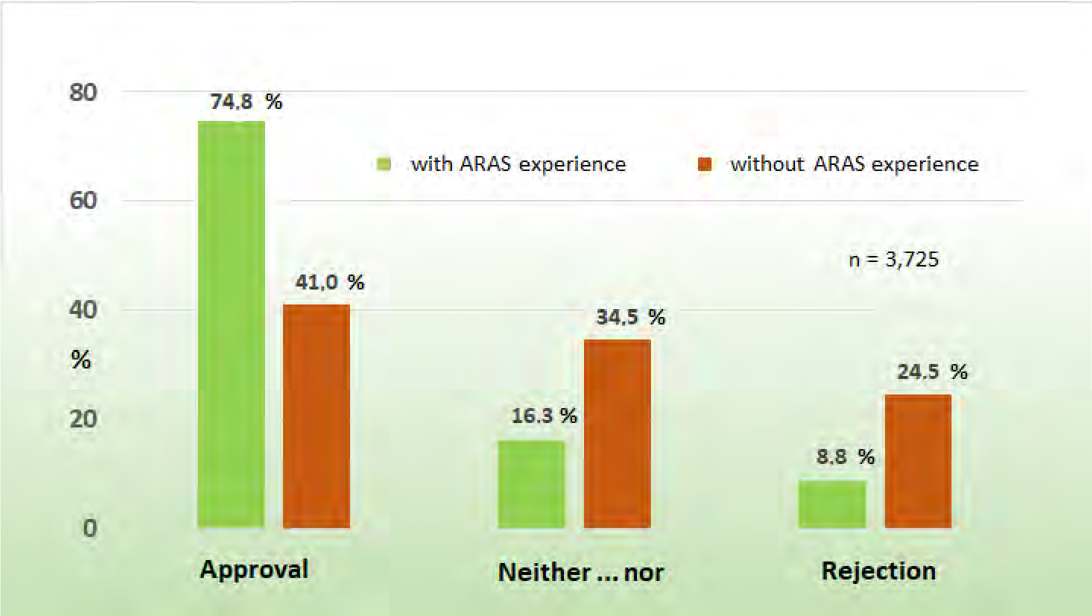


Fig. 18: ARAS-PTW feel- good factor based on experience with systems

First of all, it is noticeable that there is a clear increase in agreement with the question posed at the beginning of the question. Instead of a total of 66.5 percent (see Fig. 17), 74.8 percent of respondents with their own practical experience stated that they felt more comfortable on a motorcycle equipped with ARAS-PTW. Accordingly, the proportion of refusals also fell from 12.7 to only 8.8 percent. The situation is similar, but at a significantly lower level, in the group of those without own experience. The findings can be seen as a clear indication that own experience plays a central role in the positive formation of opinion about ARAS-PTW.

2.7.4 Less “Rider Skills” through ARAS-PTW?

The extent to which the participants in the study believe that ARAS-PTW reduces their own ability on the motorcycle is being analyzed again, using a five-point Likert scale (1= “exactly” to 5= “completely wrong”). The answers provide a fairly evenly distributed picture. And here again we have combined the two choices listed above and below the middle value 3 (Fig. 19).

When considering bundling, a balanced picture emerges between agreement with the statement (36.9 %), indecision (30.8 %) and rejection (32.2 %).

Obviously, it is not yet clear among motorcyclists whether or how the use of ARAS-PTW will affect their own riding skills. A clearer mood could emerge in the future as such systems become more widespread.

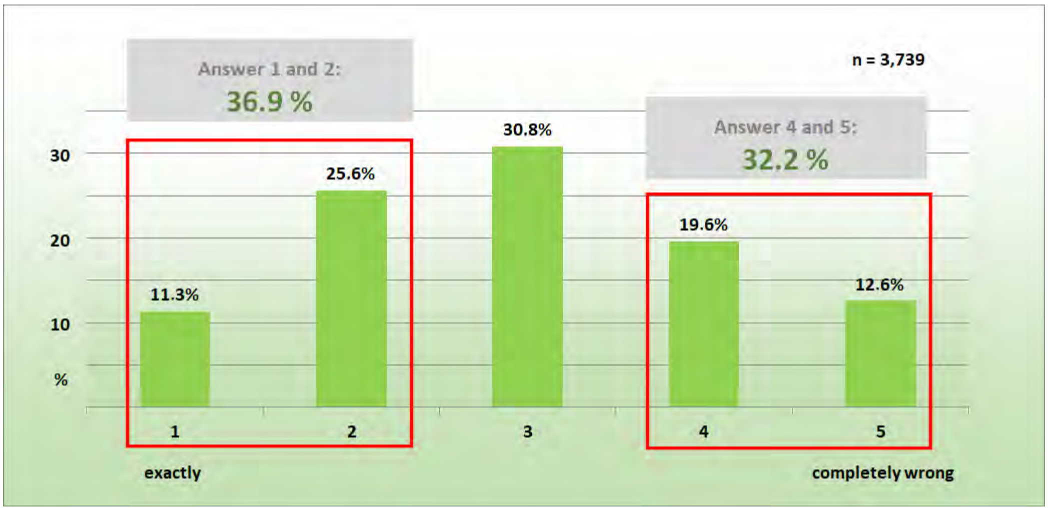


Fig. 19: Unlearning of riding skills through ARAS-PTW

Even if, as in the previous chapter, the focus is on the group of respondents who have their own practical experience with ARAS-PTW, the mood will only be slightly clearer, as Figure 20 shows. Of these, 32.9 percent (one third) still believe that their own riding skills decrease with the use of ARAS-PTW (combined answers 1 and 2). 36.9 percent of the “experienced” do not see it this way (combined answers 4 and 5).

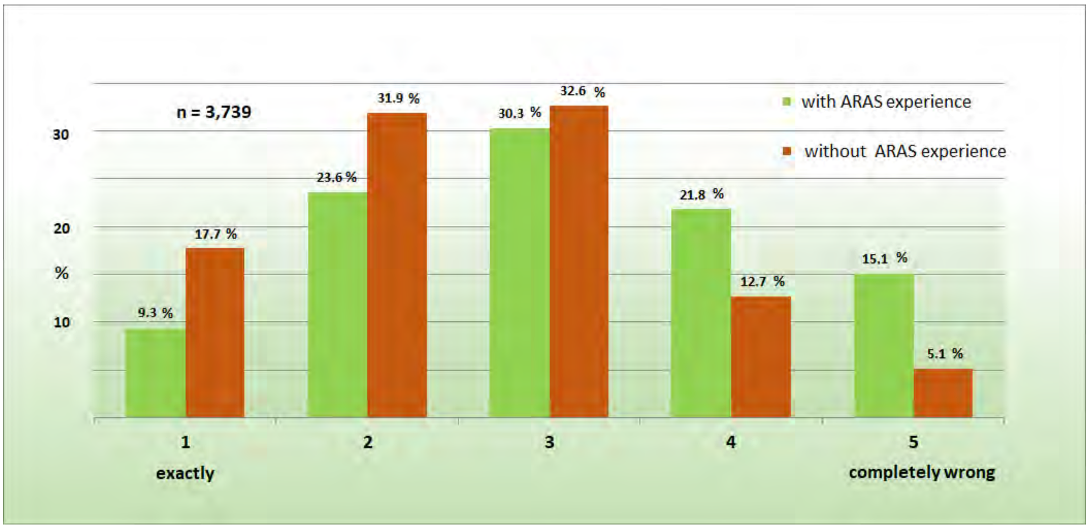
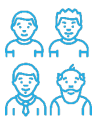


Fig. 20: Unlearning of driving skills trough ARAS-PTW

It is striking that there are clear differences of opinion with regard to the existing experience with ARAS-PTW. Motorcyclists who have not yet had any experience with ARAS-PTW are far more skeptical about it.



When looking at the age groups, the first thing that stands out is that the assessments do not vary greatly. However, it is interesting to note that the group of younger riders (up to 29 years of age) tends to agree most strongly with a rather skeptical assessment (41.1 %). After all, it is precisely the riders of the younger generations who have been able to gain experience on modern motorcycles equipped with ARAS-PTW from the very beginning during their driving school training and in many cases have no experience at all with motorcycles without these systems.

The possibility of ARAS-PTW being able to help to unlearn important driving skills is seen above all by frequent riders (47.3 % with over 20,000 km of annual mileage).

While a differentiation according to gender does not show any conspicuous features, the self-assessment of whether someone considers him- or herself a safe or less safe rider is certainly relevant for the assessment of the question asked. The approval rate (skills get lost) of 39.4 percent among participants who consider themselves to be safe riders is slightly above the rate for all respondents (36.9 %). In the camp of the "rejecters" the situation is mirrored. 32.2 percent of all respondents, but 35.1 percent of riders who consider themselves to be less safe do not believe that they unlearn important skills when assistance systems are on board. Overall, therefore, we can speak of a striking correlation. The assumption that riders who rate themselves as less safe also tend to answer the question with a neutral "neither, nor" plays a role here.

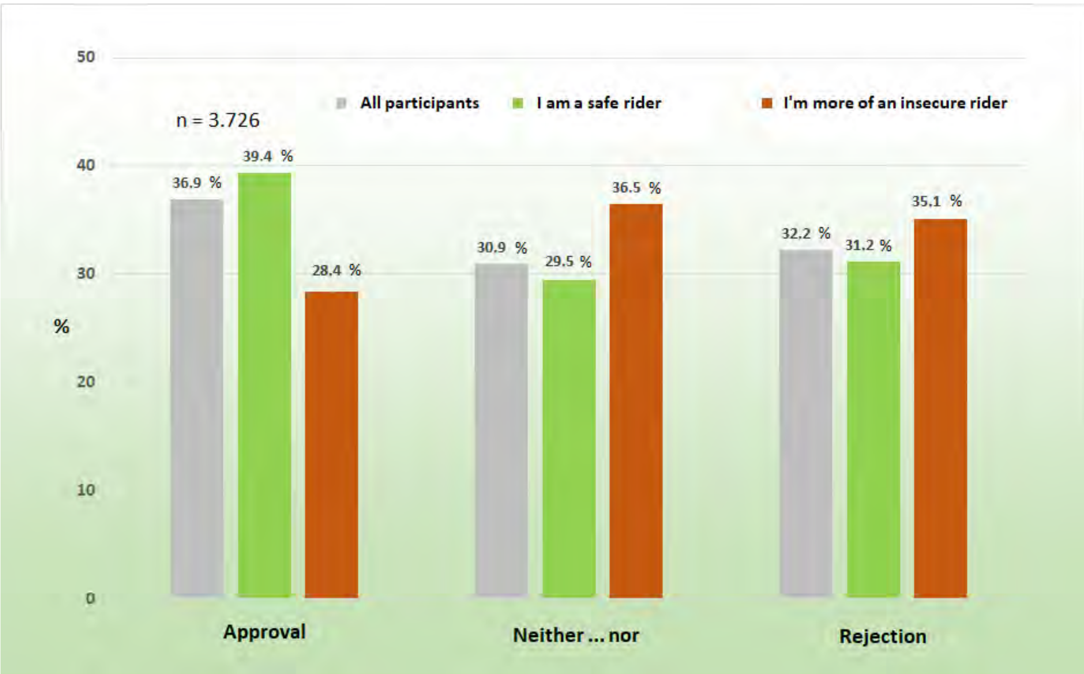


Fig. 21 Unlearning of driving skills trough ARAS-PTW- Assessment of driving ability

As in other contexts before, the factor "own practical experience" plays a significant role here as well. The judgements of those who consider themselves 'safe' and those who consider themselves to be rather insecure riders differ considerably with regard to whether or not they have their own practical experience with ARAS on motorcycles. For example, among those who consider themselves being a save rider, the approval rate (skills lost through ARAS-PTW) rises rapidly if there is no practical experience with ARAS-PTW. In this subgroup, the approval rate of 54.9 percent is significantly higher than the 39.4 percent measured for all "safe" riders. Also in this case, the reverse is true: In the group of riders who consider themselves to be "unsafe riders", the approval rate for the above statement drops even further as soon as the rider has his own practical experience with ARAS-PTW. It is in this subgroup that the greatest rejection is logically evident: 37.2 percent of them do not believe that important skills are forgotten when assistance systems are on board.

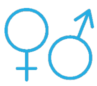
Conclusion: Overall, the skepticism that rider assistance systems could have a negative impact on one's own riding skills is comparatively high. Although this skepticism decreases significantly as soon as the respondents are familiar with the systems from their own experience, even within subgroups which, for various reasons, are generally very positive towards the ARAS-PTW, there is still a relatively high proportion of people, regularly more than a quarter, who expect a decrease in riding skills through the use of rider assistance systems.

2.7.5 Risk Compensation through ARAS-PTW

As with many of the questions in this study, a five-level Likert scale was used as standard to answer the question. The question aims to determine whether ARAS-PTW (albeit unconsciously) induce people to risk more or whether they favor a riskier riding style because they feel safer or more advantaged due to the technical support. The titles of the extreme values are: 1= “exactly” and 5= “completely wrong”. Figure 22 shows a strong tendency towards the negative answers of the extreme values.

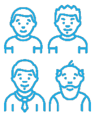
Fig. 22: Risky driving through ARAS-PTW

For further analysis, we summarized the pairs given above and below the middle answer option. According to this, only 13.4 percent of the participants believe that ARAS-PTW tempts them to ride riskier. Almost two thirds of the participants, however, do not want to attribute such a risk potential to the assistance systems.



A separate consideration of the sexes does not reveal any striking deviation from this result.

The assessment is also independent of the annual mileage.



However, what clearly influences this assessment with regard to a possibly riskier riding style due to the equipment with ARAS-PTW is the age of the rider. With increasing age, motorcycle riders are less and less likely to believe that the safety potential of the ARAS-PTW can be the cause of a riskier riding style. While younger riders (up to 29 years of age) still admit to "ride riskier" at 23.2 percent against this background, this proportion falls continuously as the rider age increases.

30- 39 years: 16,9 %

40- 49 years: 15,1 %

50 years and older: 10,4 %

A connection between the answer to this question and own practical experience in dealing with ARAS-PTW, as has frequently occurred above, is only given to a lower level. Thus, 15.6 percent of those who only know ARAS-PTW from theory or not at all are of the opinion that a negative influence on safe riding is possible.

By contrast, only 12.8 percent of respondents with ARAS-PTW- experience believe that it can have a negative impact (all: 13.4 %). So, this time the differences are comparatively small.

2.7.6 Impact of ARAS-PTW on future Accident Figures

With regard to this question, participants should assess the impact of ARAS-PTW on future accident figures. Will they decrease, remain unchanged or even increase due to increased use of ARAS-PTW?

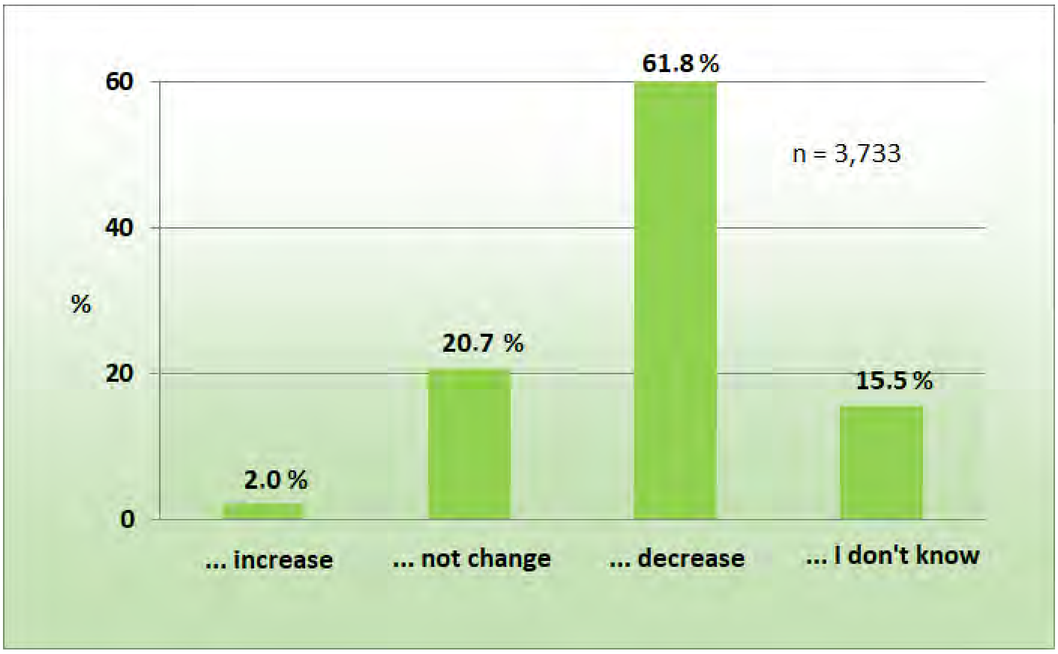


Fig. 23: Influence of ARAS-PTW on the development of accident figures

The majority of participants (61.8 %) believe in the positive influence of the ARAS-PTW on future accident figures. Only two percent expect the ARAS-PTW to increase accident figures. An opinion that runs through all age and annual mileage groups.

The group of participants with experience with ARAS-PTW is again above the average of all respondents. With 66.5 percent, they are of the opinion that ARAS-PTW will change the accident situation positively in the long term. In the group without ARAS-PTW-experience values, in contrast, 47.3 percent maintain this. Even those who are just about to buy a new motorcycle are more positive about the assumption of an accident-reducing effect of the development.

Only when the sexes are considered separately, a conspicuous feature can be identified: While 62.9 percent of men expect the number of accidents to fall as a result of the use of ARAS-PTW, women are more skeptical about the influence of ARAS-PTW and only expect this development to occur to a degree of 46.9 percent.

As already described under 2.6.2, the personal experience of the participants plays a major role in this opinion-forming process. The experience with falls/accidents also has an impact here.

Anyone who has already had a fall or accident in the past and is of the opinion that an ARAS-PTW could have prevented it, attaches much greater importance to the future positive influence of the ARAS-PTW on the occurrence of accidents. Here, the figure is almost 75 percent compared to those who say that an ARAS-PTW would not have helped them in the past, at just under 56 percent.

2.7.7 Future Outlook: Human or Technology

The riders themselves or technical systems? The answers to the question of who will make a greater contribution to reducing the number of accidents involving Powered Two-Wheelers on the roads in the future are relatively evenly distributed. The rider himself is just ahead in the participants' assessment. Of the 3,720 participants who responded at this point, exactly 56.6 percent believe that it is mainly the rider himself who will control future developments. In contrast, 43.4 percent of the respondents predict that technology will have the greater influence here.

Again, the result is interesting when personal ARAS-PTW knowledge (here: theoretical knowledge) is taken into account. It shows that those who assess their knowledge as excellent to good are, with 53 percent, more likely to rely on technology. Those who are familiar with the technology (mode of operation) of ARAS-PTW are therefore confident that it will provide significantly more accident protection in the future. Conversely, those who are less familiar with the subject continue to rely primarily on the skills of the rider. This attitude is supported by the group of participants who can draw on practical experience with ARAS-PTW. Here, 45.4 percent of the participants ascribe safety successes to the technology. By contrast, for the riders without practical ARAS-PTW-experience this is only 34.9 percent.

Years ago, the results here might have been different. One just has to think, for example, of the great skepticism surrounding the advent of the first ABS systems on motorcycles, which today are almost a matter of course. The enormous technical progress has already made its contribution and has thus proven many skeptics of that time wrong. Nevertheless, it should not be forgotten that, at the moment, confidence in the potential of the riders dominates, albeit narrowly. This is an exciting development that we will certainly continue to pursue.

3 Intelligent Transportation Systems

When looking at the number of traffic accidents in Germany, the long-term declining trend is striking. Both, the number of accidents and fatalities in the Powered Two-Wheeler sector are falling – both in absolute terms and in relation to the number of vehicles on the road, which does not exclude occasional deviations from this trend.

Car drivers are still the main opponents in terms of accidents involving Powered Two-Wheelers in Germany. On average, car drivers are the main cause of two thirds of all collisions between cars and motorcycles every year. The causes here usually lie in overlooking or ’’misinterpreting’’ an approaching motorcyclist. In addition, the risk of injury to the two-wheeler occupant as the so-called ’’external road user’’ is higher in case of a collision, even though modern motorcycle helmets and motorcycle clothing can noticeably reduce the consequences of a collision.

Where there are limits to human perception, technology can enable communication between vehicles and the traffic infrastructure that supports drivers/riders on “both sides”. The keyword here is: Networking. By this, for example, other road users who may not yet be visible to the driver/rider can be pointed out and the risk of a collision reduced. At this point, future technology could – as it is already the case for other ARAS-PTW – provide useful support for the rider. The development potential in this area gives rise to hopes for the future of two-wheel-safety. However, it will take a long time before any effectiveness sets in and becomes noticeable. Supplier companies are putting forward figures which assume that all newly sold motorcycles will be networked by around 70 percent by 2025. Numerous manufacturers have been active in this field for some time now and are developing suitable systems under high pressure.

Manufacturers and numerous research institutes are active in promoting and developing cooperative intelligent transport systems (C-ITS) at a global level. For example, the Connected Motorcycle Consortium (CMC) has been in existence since 2015. This is a collaboration between manufacturers, suppliers, researchers and associations with the aim of making the motorcycle and scooter vehicle group a part of future networked mobility and improving the safety and comfort of motorcyclists. The CMC’s aim is to create a common basic specification for Motorcycle ITS with as many manufacturer-independent standards as possible.

In anticipation of this promising development, the participants of the study were asked about their knowledge of modern and future possibilities.

3.1 Connectivity

3.1.1 Popularity of the Term “Connectivity”

Frequently, in the media, amongst others, terms are used that establish themselves relatively quickly. However, if one questions the meaning of some of these terms, it often turns out that many people are not really aware of what it is about. At this point, we asked the participants to tell us whether they are familiar with the term “connectivity” or “Konnektivität”, the German word for it, or what it stands for. In addition, to the correct information, two incorrect answer options were placed among the answer choices. It was also possible to indicate beinge unsure or never having heard of it before. 47.4 percent of the participants were able to select the correct answer (“Yes, it stands for the networking of rider, vehicle and traffic environment”). 18.7 percent of the participants chose the term “never heard of it”, another 23.7 percent chose “already heard of it, but do not know exactly what it means”. 10.2 percent of those surveyed associate incorrect contents with this term and chose definitions that are simply wrong. As a consequence, not even half of the motorcyclists who took part in the survey knew exactly what the topic ’’connectivity’’ is about.

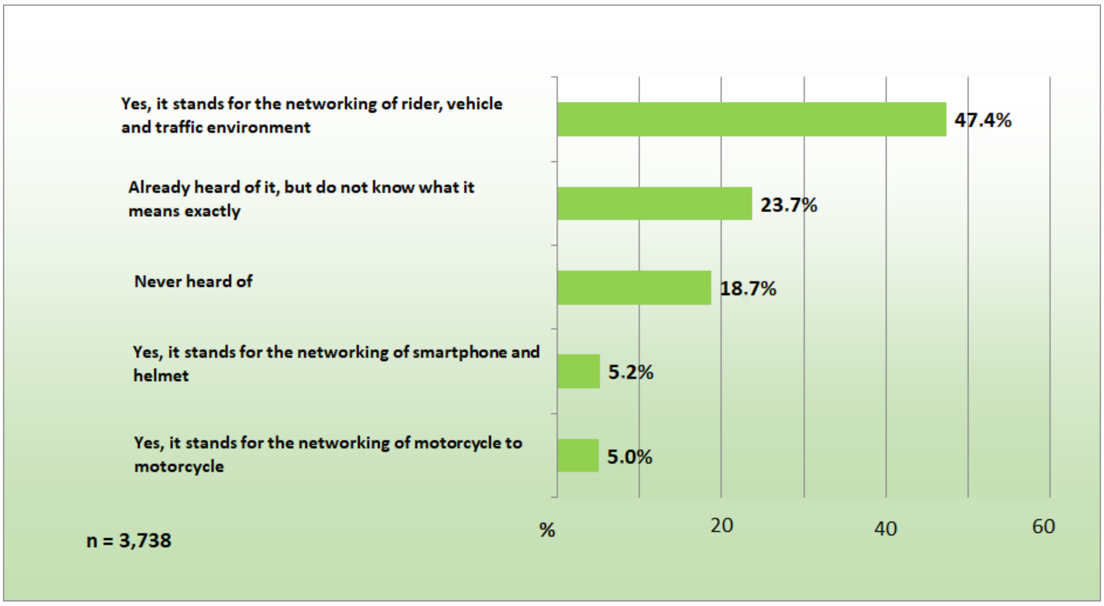
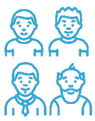
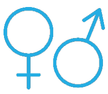


Fig. 24: Popularity ’’connectivity’’



Bringing together the statements with the age group variables, it becomes clear that ambiguity about this term is most likely to be found among the youngest and oldest riders, while the groups in between achieve better results.



The results vary greatly when considering the sexes separately. While only 16.8 percent of men state that they have never heard this term, this statement applies to 41.2 percent of women. While 49.5 percent of men give the correct answer, this is true for 24.9 percent of women.

3.1.2 Connectivity: Does it Make Sense?

At the beginning of this question, the participants were given a definition of what the term ’’connectivity’’ in connection with the motorcycle is all about. After that, they were asked to express their opinion on the influence on future accident development. The opinions are as follows:

The majority of respondents consider connectivity on the motorcycle to be a tool that “serves the safety on the road” (47 %). Another large proportion is undecided (“don't know”: 40.2 %), while the smallest proportion of 12.8 percent believe that connectivity on the motorcycle has a rather disadvantageous effect on road safety.

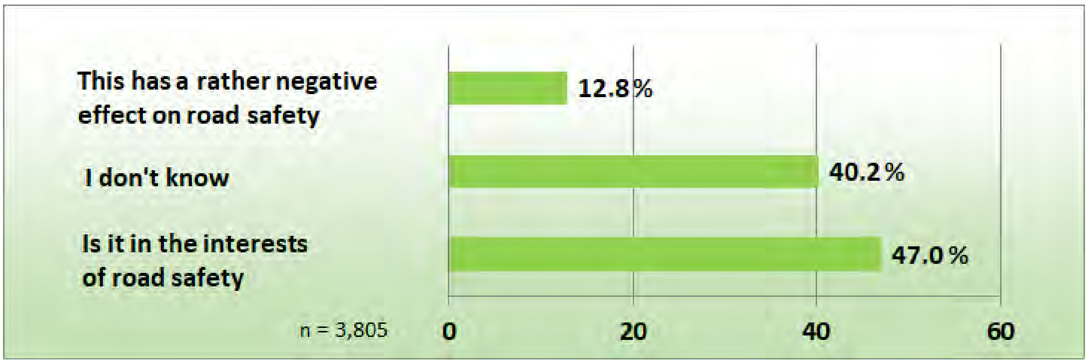


Fig. 25: Evaluation of connectivity in terms of motorcycle safety

Taking into account the different age groups, an increase in the field of agreement "serves the safety on the road" is noticeable with increasing age.

The female participants take over a more skeptical position in terms of the advantages of connectivity. 32.6 percent of them regard connectivity as being beneficial to safety on the road. Among men, this figure is 47.2 percent. Among those who generally view connectivity negatively,the gender-specific responses are balanced.

The annual mileages do not play a significant role in the assessment of connectivity options.

It is also noticeable that there is less distrust than a large portion of uncertainty in connection with the topic of ''connectivity''. The uncertainty about this still relatively new topic is obviously due to the current low level of knowledge of the majority of participants (see 2.1.1).

3.2 Vehicle-To-Vehicle Communication (V2V)

Intelligent networking inside and outside the vehicle will play an increasingly important role in the future. Experts agree on the fact that, in the long term, this is a great opportunity to significantly reduce the number of accidents and casualties. As already shown under 2.1, over 53 percent of participants have experienced situations in which they were overlooked by other road users. This is also in line with the urgent need to think about risky situations while riding a motorcycle. Here, 51.3 percent of those surveyed put being overlooked in the first place. It is precisely in these situations that future technology can help to prevent accidents.

After the study's participants had been given a brief outline of what V2V is all about, they were asked to assess the potential of vehicle-to-vehicle communication (V2V) for an increase of motorcycle safety. While 50.5 percent of the participants are not sure, 13.7 percent assume that V2V will not bring any improvements. In contrast to that, the remaining 35.8 percent believe that this will reduce the number of accidents.

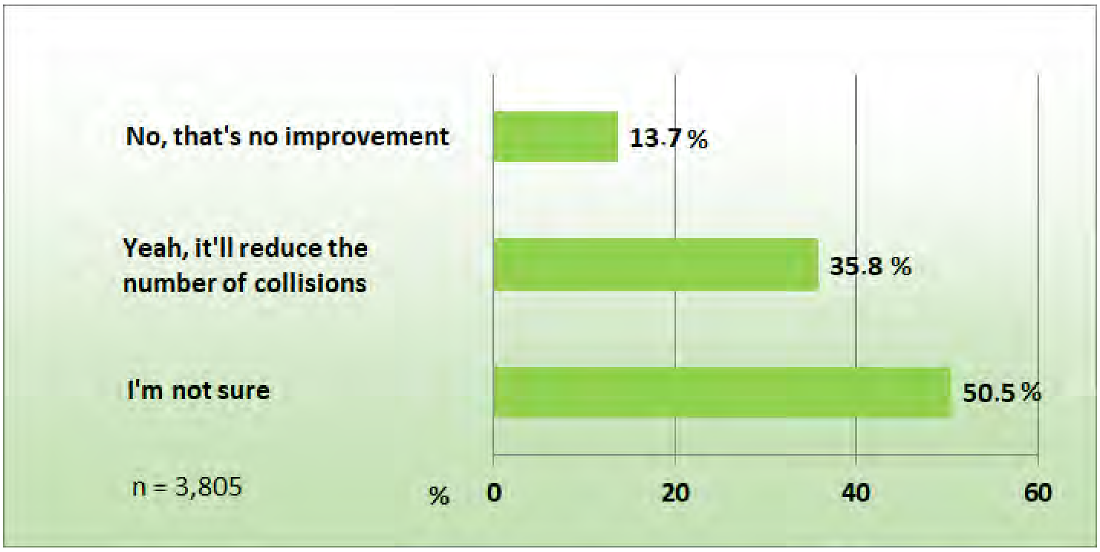


Fig. 26: Evaluation of connectivity in terms of motorcycle safety

Essentially, this result pulls through all age groups. The results vary only marginally, with only a slight increase in the expectation of fewer collisions with increasing age.

Men (36.3 %) proportionally believe much more strongly in an improvement in road safety through V2V than women (22.8 %), who are similarly skeptical about this as they are about the benefits of connectivity.

4 Summary of the Results

In recent years, assistance systems for motorcycles have become increasingly important. Advanced Rider Assistance Systems for Powered Two-Wheelers (ARAS-PTW) hold enormous potential for improving the road safety of motorcycles, which will become even more noticeable in the future. But how well known are the various technical aids and how much knowledge about individual systems exists? What are motorcyclists' opinions on these and other modern technology scenarios? Are they open towards new developments or do they react with reservation?

With the help of this study, the ifz is breaking new ground, as studies of this kind have not been available for the motorcycle sector to date. Besides technical aspects related to the topic ARAS-PTW, there is hardly any information available so far for the Powered Two-Wheeler sector, in contrast to the passenger car sector. Thus, the study, for the first time, does not only provide a deeper insight into the opinions of the riders. It also asks about existing skills in dealing with assistance systems and provides information about their current acceptance among users and those who are not users yet. In short, the results of the study, which are the result of a nationwide survey among almost 4,000 motorcyclists, are thus intended to provide information and to assess the image and user know-how with regard to safety-relevant rider assistance systems.

To summarize, one fact above all can be captured: The majority of the survey participants is already convinced that Advanced Rider Assistance Systems for Powered Two-Wheelers can help when facing dangerous situations, and this is not only recognized, but also evaluated positively. The openness that is thus emerging in this area offers an excellent basis for further anchoring safety-relevant topics among motorcyclists and for making even better use of the potential of the individual systems. How many of the motorcyclists surveyed can be taken along shows the following figure: 94.6 percent of the participants consider ARAS-PTW on motorcycles to be useful for safety reasons. Characteristics such as the rider's age and gender have hardly any influence on this assessment, and the level of education is also irrelevant in this respect. In contrast to this, own experiences with ARAS-PTW positively reinforce the attitudes towards these helpers, as do corresponding experiences from driving a car.

Many of the rider assistance systems discussed are familiar to motorcyclists. It has been shown that systems that have been on the market for a longer period of time generally achieve a higher level of awareness and popularity than newer assistance systems. Whereas ten years ago, over a fifth of motorcyclists were unable to name an ARAS-PTW at the first go, the available study results show that this figure is now only just under five percent. The conclusion to be drawn from this is that the term "rider assistance system" has now become established, just as the multitude of systems behind it is no longer unknown terrain.

The use of rider assistance systems on Powered Two-Wheelers is already widespread and will increase in the future. The main motives for this are: To provide the rider with more riding comfort and, above all, more safety and to reduce the number of accidents in the long term. As the term "assistance" already suggests, the new technologies are intended to relieve the rider in complex situations and thus make riding more comfortable and above all safer. In the case of Powered Two-Wheelers, systems are used primarily with a view to active safety. They aim at ensuring that a fall or an accident does not happen. Many improvements have only been made possible by modern measurement technology and corresponding reliable control and regulation systems. Starting with the established assistance system, ABS, through Traction Control Systems to Semi-active Suspension System, the useful aids that make riding more comfortable and offer enormous safety potential are an integral part of everyday riding.

Nevertheless, not all motorcyclists are sufficiently aware of the modern systems. At this point it is all about the general knowledge about the topic ARAS-PTW. While just under 30 percent rate their own knowledge as good, the majority (40 %) consider their general knowledge of ARAS-PTW to be in the broad middle range of a “goes like this” between good and moderate. Overall, more than two thirds of the participants rated their general knowledge of the topic ARAS-PTW to be positive. This leaves 30 percent of motorcyclists who do not have any knowledge at all. As the market penetration of the systems continues to increase, knowledge about them has not yet been able to keep up with the same degree.

The general knowledge of ARAS-PTW primarily (39 %) comes from own experience with the systems installed on one’s own motorcycle. Among the participants who tend to judge themselves or their knowledge in a negative light, only half have own experiences with assistance systems. Almost a third (29 %) of the motorcyclists cite reading specialist journals as a source of general knowledge about rider assistance systems. This is followed by the internet or social networks as a source of information (14 %).

In view of the fact that a large number of new, often complex systems have only been installed in series in recent years, the current state of knowledge can be assessed as positive overall. This becomes even more obvious when one considers that over a fifth of the motorcyclists surveyed are not yet using an ARAS-PTW or have not installed a system on their own motorcycle, which can be primarily justified by the year of manufacture of the machine used. It is therefore to be expected that with the increasing spread of rider assistance systems, which are already conquering the middle class on a broad front, more and more motorcyclists will gain further knowledge. At the latest, when their own new machine comes with a variety of safety-relevant features, most riders will become more familiar with the subject. According to the survey, almost 80 percent of those participants who already ride a motorcycle with ARAS-PTW on board state that they are aware of its function and operation.

This causal link is, incidentally, underpinned by the questioning about specific knowledge of individual systems. Here, it is particularly the more established ARAS-PTW, with which the participants are more familiar with. This is reinforced by the fact that 90 percent of the participants state that they already have experience with assistance systems in passenger cars. Many of the available results indicate that the dissemination of and experience with ADAS in the passenger car sector has an impact on the participants' knowledge regarding the motorcycle.

In terms of gender, around three quarters of men have specific skills in dealing with existing ARAS-PTW. At 54 percent, the womens’ results are significantly lower. There are also significant differences in the age of the participants. Younger riders are more conspicuous by their lower knowledge than older riders. According to this, the self-assessment of knowing how one's own ARAS-PTW works and how to use it increases with increasing age. The first source of this knowledge of the functions of their own systems is the vehicle's operating manual (73 %). Then, in second place, come the motorcycle traders, where over 40 percent of the participants have the special handling of the technology explained to them. In most cases, the systems are explained when the vehicle is handed over. With over 30 percent, the circle of friends and acquaintances serves as a source of information. The analysis was also able to reveal gender-specific characteristics at this point. While men use technical journals and operating instructions much more often, women prefer to exchange information with friends and acquaintances more often than average. They also mentioned initial and advanced rider training proportionately more often than men. In contrast, the local trader was an almost equally important source of information for both sexes.

As far as the specific experience with the ARAS-PTW is concerned, this can be summarized as positive in two ways: While on the one hand almost two thirds of the respondents are speaking of positive experiences with the systems, almost 90 percent of them have no negative experience with ARAS-PTW. There are no gender-specific conspicuous features here. It is not surprising that 94 percent of ARAS-PTW-experienced riders do not want to give up on the assistance systems for their next motorcycle. Two thirds of motorcyclists also agree with the statement that they feel more comfortable on the bike with the support of ARAS-PTW. Only 13 percent do not feel more comfortable on a motorcycle equipped with ARAS-PTW. We can conclude that ARAS-PTW makes an important contribution to a more positive riding experience.

Almost two thirds of the participants disagree with the repeatedly heard assumption that motorcyclists tend to more or less ’’think themselves safe’’ due to the technical support and are tempted to perform riskier riding maneuvers. When asked directly about the topic of risk compensation, only 13 percent of the participants feel tempted to ride more risky maneuvers at times because of ARAS-PTW at work.

Another prejudice about ARAS-PTW that is sometimes expressed in fuel talks can only be partially refuted on the basis of the survey results: The skepticism that rider assistance systems could have a negative effect on one's own riding skills is comparatively high. Thus, almost 40 percent of the participants are of the opinion that the use of ARAS-PTW could lead to the fact that one unlearns riding skills. All in all, this results in a comparatively balanced picture among the participants (agreement = 37 %, undecided = 31 %, rejection = 32 %). That this is a prejudice is indicated by further evaluations. As a consequence, this skepticism decreases significantly as soon as the respondents know and appreciate the systems on the basis of their own experience. Modern rider assistance systems and future traffic scenarios see the rider as having the primary control function, especially for Powered Two-Wheelers. This knowledge has not yet been sufficiently disseminated among motorcyclists without practical experience of rider assistance systems.

Equally interesting remains the slightly ambivalent attitude of the respondents with regard to the safety relevance of ARAS-PTW, which becomes apparent when their general assessment of different ARAS-PTW with regard to promoting motorcycle safety is compared with their own wishes and future purchase intentions. The various ARAS-PTW are all considered to be more useful or helpful than being desired or planned as equipment for the future motorcycle. Financial aspects may play a role here. Often, the new systems are only available for an additional charge, which the participants self-evidently include in their purchase decision. Technology-related follow-up costs can also play a role in this respect.

The image of the ARAS-PTW, which is quite positive based on the results of this study, is also reflected in the expressed expectations of future developments. For example, over 60 percent of motorcyclists believe that ARAS-PTW will continue to contribute to reducing the number of accidents in the Powered Two-Wheeler sector. Just under 36 percent expect no changes and only two percent expect an increase in accident figures as a result of the increase in technology.

As far as the future "networking" of road users and infrastructure is concerned, half of motorcyclists are not sure in which direction the number of accidents will develop due to increased use of technology. Around 14 percent are of the opinion that networking will not bring about any improvements. The remaining 36 percent, in contrast to that, are confident about a technology that is not yet very well known. A certain skepticism on the part of motorcyclists cannot yet be dismissed, which, it must be assumed, is primarily based on a still rather low level of knowledge about the topic.

The advancing technology will continue to provide further services for motorcycle safety in the future, especially with regard to the networking of vehicles and road users. On the one hand, cooperative systems will then react within the framework of the infrastructure, for example to traffic lights or traffic guidance systems. On the other hand, the vehicles communicate with each other, react automatically or pass on safety-relevant information to the rider. But there is still a long way to go to achieve these changes. Until this point in time, the rider still has central responsibility and acts as such with regard to the safety awareness at a pleasantly high level, as we were able to ascertain in the course of this study.

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13th International Motorcycle Conference

Characteristic Rider Reactions to Autonomous Emergency Braking Maneuvers on Motorcycles

Nora Leona Merkel, Hermann Winner
Technische Universität Darmstadt, Institute of Automotive Engineering (FZD)
Otto-Berndt-Str. 2, 64287 Darmstadt

Abstract

To be able to use autonomous emergency braking systems for motorcycles in a safe way, it is necessary to anticipate the reaction of riders to automatic braking maneuvers. Elsewise, an unintended reaction could inhibit the rider from being able to stabilize the vehicle or even cause destabilization (even through to a fall). It is therefore important to design automatic braking interventions in such a way that the rider's reaction stays within appropriate limits.

In previous studies, measures allowing the evaluation of the rider's adaptation to the changing vehicle state during a braking maneuver have been identified. In particular, head and upper body movement as well as the supporting force on the handlebars proved to be promising indicators. The reproducibility of the measured reactions for repetitions of a certain maneuver with the same rider could be proved [1].

In the studies described here, different maneuvers were repeated in a participant study with 14 riders in order to evaluate the reproducibility across riders. Both, automatic braking maneuvers and braking maneuvers operated by the rider him/herself were performed. Obviously, riders show significant differences in their behavior when braking themselves, whereas the upper body movements - as an involuntary reaction to the unexpected braking maneuver - are very homogeneous during automatic braking maneuvers.

The results of the study show that the pitch movement of the rider's upper body alone can be used to determine whether the rider has reached a state in which he/she can control a maximum automatic deceleration. Furthermore, the results indicate that the physical reactions of unprepared riders to braking interventions show a high degree of homogeneity. This knowledge creates confidence that the evaluation of the controllability of automatic braking interventions in studies with relatively small numbers of participants can be transferred to a large number of riders.

13. Internationale Motorradkonferenz

Charakteristische Fahrerreaktionen auf automatische Notbremsmanöver auf dem Motorrad

Nora Leona Merkel, Hermann Winner
Technische Universität Darmstadt, Fachgebiet Fahrzeugtechnik (FZD)
Otto-Berndt-Str. 2, 64287 Darmstadt

Zusammenfassung

Um automatische Notbremssysteme für Motorräder risikoarm einsetzen zu können, ist es notwendig, die Reaktion der Fahrer auf automatische Bremsmanöver einschätzen zu können. Das liegt darin begründet, dass der Fahrer durch eine ungewollte Reaktion sein Fahrzeug nicht mehr stabilisieren, oder es sogar (bis hin zum Sturz) destabilisieren könnte. Es gilt also, automatische Bremseingriffe so zu gestalten, dass die Fahrerreaktion sich in geeigneten Grenzen bewegt.

In vorangegangenen Studien wurden Maße identifiziert, mit denen sich die Anpassung des Fahrers an den sich ändernden Fahrzeugzustand während eines Bremsmanövers bewerten lassen. Hierbei erwiesen sich insbesondere Kopf- und Oberkörperbewegung sowie die Abstützkraft am Lenker als vielversprechend. Die Reproduzierbarkeit der gemessenen Reaktionen für Wiederholungen des Manövers mit dem gleichen Fahrer konnte nachgewiesen werden [1].

In den hier beschriebenen Untersuchungen wurden verschiedene Manöver im Rahmen einer Probandenstudie mit 14 Fahrerinnen und Fahrern wiederholt, um auch die fahrerübergreifende Reproduzierbarkeit zu evaluieren. Es wurden sowohl automatische als auch vom Fahrer selbst betätigte Bremsmanöver durchgeführt. Dabei wird deutlich, dass Fahrer bei selbst durchgeführten Bremsungen deutliche Unterschiede im Verhalten zeigen, während die Oberkörperbewegungen – als unwillkürliche Reaktion auf das für den Fahrer unvorhergesehene Bremsmanöver – bei automatischen Bremsmanövern sehr homogen ausfallen.

Die Ergebnisse der Studie zeigen, dass die Nickbewegung des Fahreroberkörpers alleine herangezogen werden kann, um zu ermitteln, ob der Fahrer einen Zustand erreicht hat, in dem er eine maximale automatische Verzögerung kontrollieren kann. Darüber hinaus deuten die Ergebnisse darauf hin, dass die körperlichen Reaktionen unvorbereiteter Fahrer auf einen Bremseingriff eine hohe Homogenität aufweisen. Dieses Wissen schafft Vertrauen, dass die Evaluation der Kontrollierbarkeit von automatischen Bremseingriffen in Studien mit verhältnismäßig kleinen Probandenstichproben auf eine große Anzahl an Fahrern übertragbar ist.

1 Introduction

The basis to design autonomous emergency braking systems (AEB) for motorcycles that can be used at al low risk is the knowledge on how riders react to unforeseen braking interventions of their vehicle. This knowledge is necessary to avoid rider reactions that can destabilize the rider-vehicle system. The autonomous braking intervention needs to be controllable for an unprepared rider. Maximum decelerations can only be applied, when the rider is in a ready-for-braking state. To reduce kinetic energy already in the phase before the ready-for-braking state is achieved, automatic braking interventions have to be designed in such a way that the rider's reaction stays within appropriate limits.

During a braking maneuver, the rider has to support inertial forces to control the forward movement of the body relative to the motorcycle. To stop this forward movement, the rider builds up body tension and supports the upper body against the handlebar. The faster the rider reacts to the changing state of the motorcycle, the faster the deceleration of the AEB can be maximized. When riders brake their motorcycle themselves, parts of the body tension and supporting force on the handlebar can be built up even in preparation to the deceleration, whereas in an automatic braking maneuver it is always a reaction to a surprising intervention.

In previous studies the limits for feasible decelerations in the phase before being 'ready-for-braking' have been identified [2], [3]. These limits represent a conservative estimation that is controllable for a large number of riders, including novice or untrained riders. To achieve a better understanding on how riders adapt to the changing vehicle state during a braking maneuver, a further study addressed the identification and evaluation of appropriate measures [1]. The identified measures focus on the relative movement between the rider's upper body and the motorcycle.

In the studies described in this paper, the previously identified measures were used to analyze the reproducibility of the rider behavior during braking maneuvers, including a comparison of automatic braking interventions vs. maneuvers in which the riders applied the brakes themselves. The aim of the experiments is to identify the most suitable measure to evaluate if the ready-for-braking state is already achieved.

2 Methods

In order to measure natural rider reactions, the participants shall not expect the autonomous braking maneuver as otherwise they could possibly prepare for it and this would distort the results. Therefore, they are not informed about the AEB testing before they experience the first automatic braking intervention.

Although, the emergency braking during the experiments is supposed to be unexpected, it should not express the character of a false positive braking intervention. Therefore, it is necessary to create a situation that presents a realistic true positive emergency braking scenario to the rider, like a suddenly decelerating target vehicle[1].

In the test scenario, the riders had to follow the preceding vehicle at a given velocity (70 km/h) at a certain distance (time headway 1.5 s). The emergency braking situation was caused by a sudden deceleration of the target vehicle. In order to avoid the risk of collisions between the motorcycle and

[1] Paragraph adopted from [3].

the target vehicle, the dummy target EVITA (Experimental Vehicle for Unexpected Target Approach) was used. The dummy target, other test equipment and the experiments are described in the following sections.

2.1. Test equipment

Test Motorcycle[2]

The motorcycle used for the experiments is equipped with an inertial measurement unit (IMU) to record translational accelerations and rotational velocities, a GPS receiver to track the vehicle, and pressure sensors to monitor the actuation of the brakes. These measurements are used to determine the vehicle state.

For decelerating the motorcycle without an intervention of the rider, an actuator is mounted to the vehicle operating the foot brake. The test vehicle is equipped with a combined brake system. This means that by operating the foot brake, brake pressure is not only built up at the rear wheel, but also at the front. With this setup, it is possible to apply much higher automatic decelerations (up to 7 m/s^2) than by only applying the rear brake. The brake actuator can be activated via remote control.

To evaluate the rider state, additional measurement technique is installed. During the experiment, the rider is equipped with three motion tracking sensors that analyze the upper body and head movements. These sensors measure the translational accelerations in three axes and they contain 3-axes-gyroscopes. Two of the motion trackers are mounted on the rider's back, one at the level of the shoulder blades and one at the level of the lumbar spine. The third motion tracker is mounted at the top of the rider's helmet. The positions of the sensors are shown in Figure 1. Furthermore, to monitor the rider inputs, forces on the handlebar as well as brake actuation, clutch actuation and throttle are also recorded.

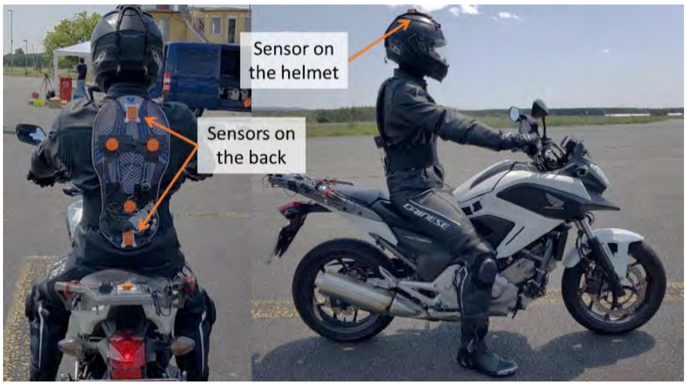

Figure 1: Sensor Positions

EVITA[3]

The EVITA test tool was developed to allow collision free investigation of anti-collision systems [4]. The dummy target consists of a towing vehicle and a trailer with a vehicle rear. The trailer can be decelerated independently from the front vehicle to simulate a rear-end collision situation. If the time-

[2] Adopted from [1].
[3] Adopted from [3].

to-collision (TTC) between the following vehicle and the dummy target gets too short, the trailer is pulled forward to avoid a collision. The system is shown in Figure 2.

Figure 2: EVITA Dummy Target

2.2. Experiments

In order to analyze the characteristic rider reactions during autonomous emergency braking interventions, the participants experienced automatic braking interventions, as well as situations in which they had to apply the brakes themselves. The experiments were carried out successfully with 12 test persons.

For the automatic braking maneuvers, the desired brake pressure is built up with the maximum gradient defined by the system. Automatic decelerations of about 5 m/s^2 were implemented for the experiments. This level has been determined to be still controllable for unprepared riders in [5]. The related brake pressures were built up within 200 ms. An exemplary diagram is shown in Figure 3.

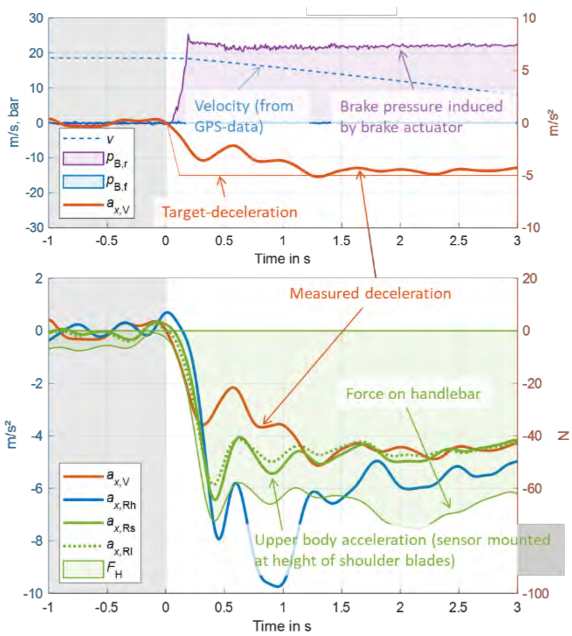

Figure 3: Exemplary diagram of an autonomous braking maneuver

The upper half of the diagram describes the vehicle state. It shows the GPS velocity v of the vehicle, the target deceleration as well as the longitudinal deceleration measured with the vehicle IMU $a_{x,V}$. The diagram also contains the brake pressures at the rear brake cylinder $p_{B,r}$ (where the automatic braking is initiated) and the front brake cylinder $p_{B,f}$ (in case the rider additionally applies the hand brake lever)[4].The lower diagram shows the rider behavior. It contains the longitudinal decelerations at different points of the rider's upper body (head $a_{x,\mathrm{Rh}}$, shoulder level $a_{x,\mathrm{Rs}}$, lumbar spine level $a_{x,\mathrm{Rl}}$) as well as the force on the handlebar F_{H}. The vehicle deceleration $a_{x,\mathrm{V}}$ is added as a reference.

During a braking maneuver, the deceleration of the vehicle causes a forward displacement of the rider's upper body relatively to the vehicle. Only when the rider adapts to the changing vehicle state, the deceleration can also be found at the upper body. This causes a certain time lag between the vehicle deceleration and the deceleration of the rider body. This reaction time varies from rider to rider and is subject to the evaluations described in this paper. The aim is to find the most suitable measure to identify the reaction time and thus find the point at which the rider is ready to control maximum automatic deceleration.

3 Results

As described before, when the rider experiences an automatic braking intervention, due to inertial forces, the upper body moves forward. As the rider is connected to the motorcycle at the seat and the forward movement is limited by the tank, this results in a pitch movement that can be measured at different points of the upper body and also at the head of the rider. We assume that the point at which the rider starts to work against the forward movement is represented by the maximum of the pitch rate. From this point the pitch is slowed down until the rider pushes him/herself back to the initial position (→ negative pitch rate).

In experiments in [1] the head movement appeared to be the most promising measurement to evaluate the rider adaption to the decelerating motorcycle. This assumption was based on the fact that the head movement allowed the best differentiation between different maneuvers (autonomous braking vs. manual braking, see Figure 4). This analysis was limited by the fact that it was based on data from only one rider.

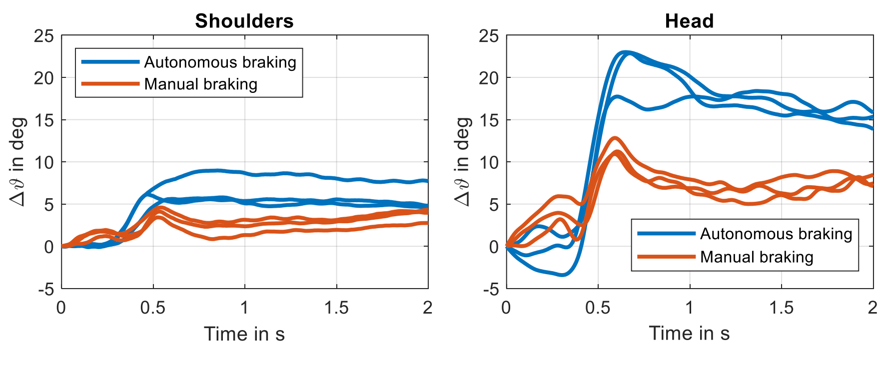

Figure 4: Pitch movement during braking maneuvers: Shoulder vs. Head [1]

Assessing the data from the experiments described here, it turns out that comparing different riders, the reaction to an automatic braking intervention is very homogenous for the upper body (measured at the shoulder and lumbar spine level), whereas the head movement can differ significantly (see Figure 5).

[4] During the automatic braking maneuver, the pressure at the rear brake cylinder still causes pressure at one brake caliper at the front brake (combined brake system), to achieve sufficient deceleration. The caliper brake pressures are not shown in the diagram, in order to keep the clarity.

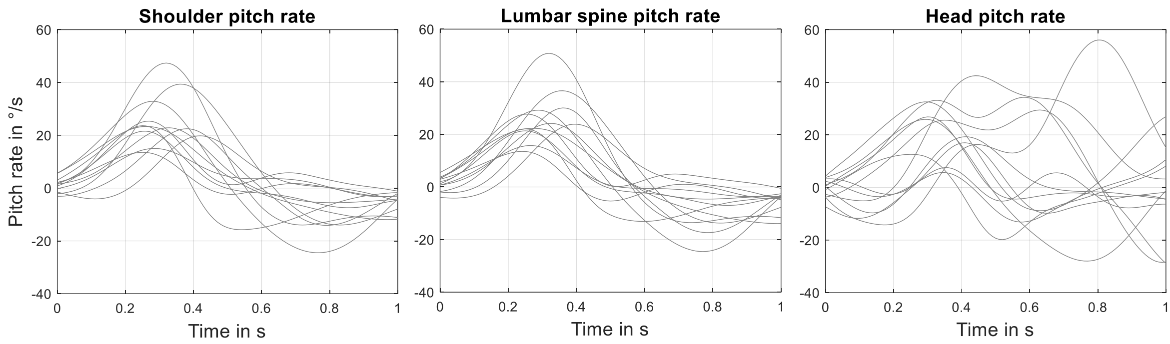

Figure 5: Body pitch rates for all participants after the beginning of the brake pressure increase in the AEB maneuvers[5]

The maximum of the pitch rate (rider starts counteracting the forward movement) was analyzed for shoulder, lumbar spine level and head for all 12 riders. For the analysis, the time at which the maximum is reached is particularly interesting. The absolute values are subject to a lot of influencing factors (e.g. body measurements of the rider), so they are barely comparable. Time t = 0 represents the beginning of the brake pressure increase.

As Figure 5 shows, the pitch rates at the shoulder and lumbar spine level follow a characteristic behavior, while the head movement can differ. This can be explained by the fact that the cervical spine is the most flexible part of the spine and the rider might for example raise or lower the head during the maneuver to get a better overview of the situation. Figure 6 shows examples for a rider whose head movement goes closely with the back (left diagram) during an automatic braking intervention and a rider whose head moves quite independently from the rest of the upper body (right diagram).

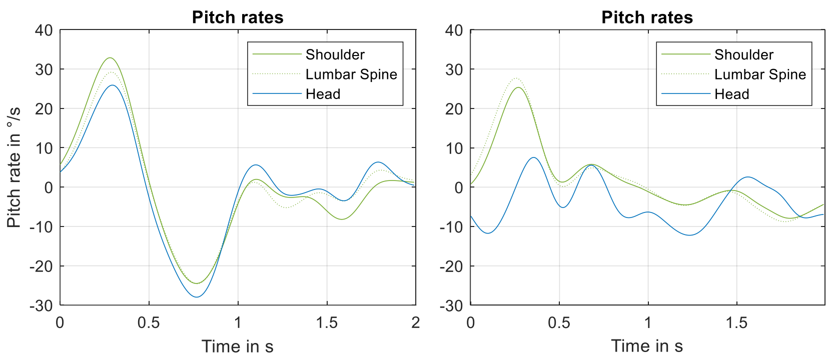

Figure 6: Body pitch rates of two different riders in AEB maneuvers

This partially occurring difference between the back and the head movement can also be found by comparing the time of the maximum pitch rate over all 12 riders. While the mean time of the maximum pitch rate is still very close for shoulder, lumbar spine and head, the standard deviation is significantly higher for the head. It is about twice as high as for shoulder and lumbar spine (see Table 1).

Table 1: Mean time for maximum pitch rate over all riders in the AEB maneuvers

	Mean time of max. pitch rate & std. dev. in s		**Min. time** of max. pitch rate in s	**Max. time** of max. pitch rate in s
Shoulder	0.32	0.06	0.26	0.43
Lumbar spine	0.31	0.05	0.25	0.41
Head	0.33	0.12	0.02	0.46

[5] All data shown here are filtered with a Butterworth lowpass IIR filter, 2nd order, cutoff frequency 2 Hz.

The rider does not only counteract the relative forward movement and the pitch movement of the upper body by building up muscle tension in the torso. A not negligible part of the inertial forces is supported through the arms to the handlebar. This force was also measured during the experiments. Again, the informative value of the absolute values of the force rate is quite limited, e.g., due to the fact, that body proportions and body masses of the participants differ. Furthermore, because of different body postures, the force is applied to the handlebar in different angles, but only the force component perpendicular to the steering axis is measured. Due to these limitations, again, the time of the force rate maximum is evaluated.

As Figure 7 (left) shows, the qualitative course of the force rate curve is quite similar to the one of the upper body pitch rates. Comparing them directly (Figure 7, right), it turns out that the maximum of the force rate is reached slightly earlier than the maximum of the pitch rate. This does not only apply for the mean values (see Table 2) but also for each single rider. The maximum of the force rate is always reached before the maximum shoulder pitch rate. The time gap shows a mean value of 98 ms (min. 20 ms, max. 230 ms). This observation indicates that the support against the handlebar is required to counteract the pitch movement of the upper body. Due to the upper body acting as a long lever, it is not sufficient to support the movement against the vehicle via seat/tank by building up body tension.

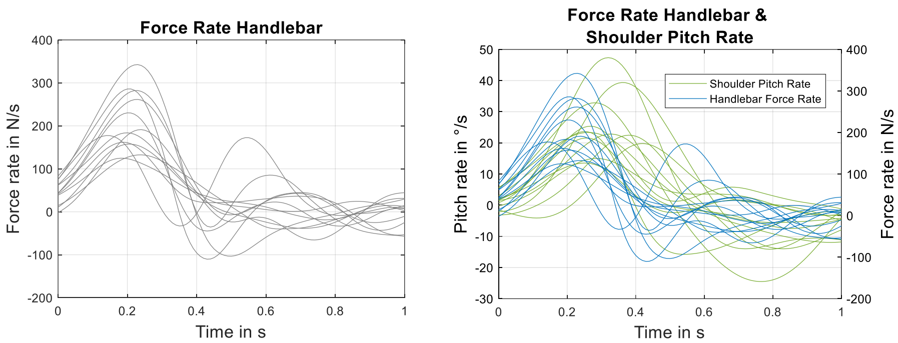

Figure 7: Handlebar force rates for all participants after the beginning of the brake pressure increase in the AEB maneuvers

Table 2: Mean time for maximum shoulder pitch rate/handlebar force rate over all riders in the AEB maneuvers

	Mean time of maximum & std. dev. in s		**Min. time** of maximum in s	**Max. time** of maximum in s
Shoulder pitch rate	0.32	0.06	0.26	0.43
Force rate handlebar	0.22	0.03	0.15	0.25

The homogeneity of the upper body movements in autonomous braking maneuvers cannot be retrieved in the maneuvers in which the riders had to apply the brakes themselves. In these cases, the pitch rate curves differ a lot between the riders. This can be explained by the fact that in the manual maneuvers, the deceleration profiles vary significantly. For example, some riders build up brake pressure very fast as soon as they notice the deceleration of the target vehicle and then slowly release the brakes again, while others apply the brakes smoothly and observe the situation and increase the deceleration when they get quite close to the target vehicle. Furthermore, the body movement is not a pure reaction to the changing vehicle state anymore. The rider initiates the deceleration consciously and thus can prepare for it, e.g. by building up body tension prior to applying the brakes. Some riders even show a negative pitch rate while applying the brakes, i.e. they straighten up during the maneuver. The diagrams in Figure 8 show the body movements for all participants in the manual braking maneuvers.

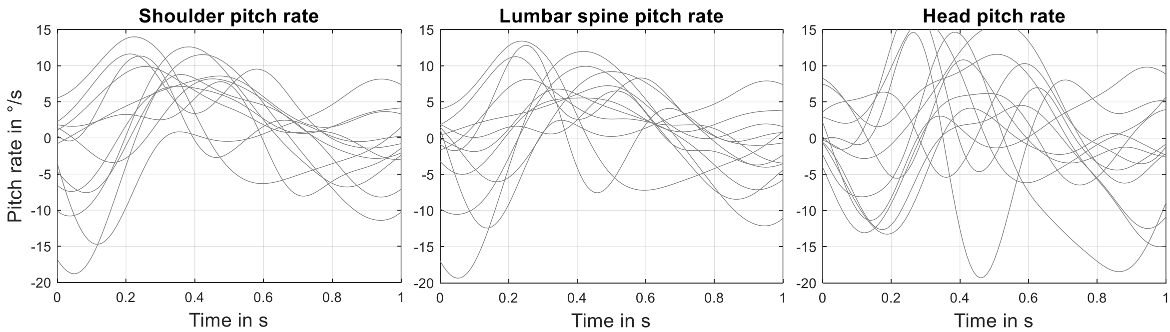

Figure 8: Body pitch rates for all participants in the manual braking maneuvers

The observations regarding the manual braking maneuvers allow the conclusion that the automatic braking interventions help to make the rider reaction 'controllable' or at least predictable. By provoking an unintentional rider reaction, influences of rider individual (conscious) behavior are interrupted and a characteristic process is initiated.

4 Conclusions

The experiments show that while the rider behavior in rider-induced braking maneuvers is quite inhomogeneous, the unintentional reactions to automatic braking interventions follow a certain pattern. This creates confidence that it is possible to estimate rider reactions when designing automatic braking interventions and to use this knowledge to develop autonomous emergency braking systems that can be used at low risk.

While the head movement appeared promising in former investigations as it showed the most significant differentiation between different maneuvers for one individual rider [1], the experiments described in this paper show that this measure shows a clear weakness in terms of reliability and reproducibility when comparing various riders. Thus, the head movement cannot be seen as a liable measure to evaluate if a rider has achieved the 'ready-for-braking' state.

It has been shown that the pitch movement of the rider's upper body is a more reproducible measure to describe the rider reaction during automatic braking interventions. This measure stays within a slim corridor for all evaluated maneuvers. Due to the low flexibility of the spine between the lumbar spine level and the shoulder level, the pitch rates at both measuring points stay very close. For future studies this creates confidence that one single pitch rate sensor at the back might be sufficient.

An alternative measure to the pitch of the upper body is the force rate when the rider supports the movement against the handlebar. The force rate turned out to be similarly reproducible as the pitch rate. As the support against the handlebar seems to be required for counteracting the pitch of the upper body, the maximum occurs slightly earlier. Applying a force sensor to the handlebar could thus be an alternative to the pitch rate sensor at the rider's back. While the pitch rate sensor gives the more conservative estimation on if the rider is ready for maximum deceleration (maximum pitch rate occurring later than maximum force rate), the advantage of the force rate evaluation is that the sensor is directly mounted to the vehicle and thus can be integrated to an AEB system more easily.

An additional conclusion of the study is that the homogeneity of the rider reactions in autonomous braking scenarios is quite promising regarding the possibility to evaluate the controllability of motorcycle AEB systems in studies with relatively small numbers of participants and to transfer the results to a large number of riders.

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Ethical approval

Ethical approval for the test track studies was obtained from the Ethics Commission of Technische Universität Darmstadt under reference *EK 39/2019*.

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