Forensic Evidence Relating to Motorcycle Pre-Crash Maneuvers

Gesicherte Nachweise von Fahrmanövern vor dem Motorradunfall

Stein E. Husher, Michael S. Varat,
Christopher D. Armstrong, John C. Steiner

KEVA Engineering

Abstract

When analyzing collisions involving powered two wheelers, often, the determination of pre-crash maneuvers is sought. These pre-crash maneuvers generally involve braking and cornering which can leave evidence on the roadway or on the tire. This roadway evidence, when present, generally consists of tire marks which can result from both braking and steering. Observed vehicle evidence from pre-crash maneuvers often consists of surface modifications on the tires which can provide information relating to the severity of the braking and cornering motions.

The present research is undertaken to evaluate observable scene and vehicle evidence based on documented motorcycle dynamics during pre-crash braking and steering. Case studies from real world collisions are presented. Braking test data is presented and roadway and vehicle evidence is described.

A series of riding tests were performed and the vehicle dynamics and associated tire evidence was documented. It was found that if roadway evidence from some pre-crash maneuvers is overlooked by the on-scene investigator, careful analysis of the motorcycle tires can yield valuable information relating to the severity of the maneuvers performed. Additionally, motorcyclist utilization of available vehicle performance may be evident from the condition of the motorcycle tires at the post event analysis. This careful tire documentation, as a crash research technique, provides valuable information not available from other sources.

Kurzfassung

Bei der Auswertung von Kollisionen, in die Motorradfahrer involviert sind, wird oft nach Erkenntnissen aus den Pre-Crash-Manövern (Manöver vor dem Unfall) gesucht. Denn diese Pre-Crash-Manöver enthalten Brems- und Ausweichaktionen, die sich auf der Fahrbahn oder der Bereifung nachweisen lassen. Der Nachweis auf der Fahrbahn besteht meistens aus Reifenspuren, welche aus Brems- und Ausweichvorgängen resultieren. Fahrzeugspuren zeigen sich häufig in Veränderungen der Reifenoberfläche, die Informationen hinsichtlich der Intensität der Bremsung und der Ausweichbewegung liefern können.

Die vorliegende Untersuchung wurde durchgeführt, um erkennbare Orts- und Fahrzeugnachweise mit der dokumentierten Motorraddynamik während des Bremsens und Ausweichens zu vergleichen. Fallbeispiele von realen Kollisionen werden dargestellt. Bremstestdaten werden vorgestellt, zudem Fahrbahn- und Kraftfahrzeugnachweise beschrieben. Eine Serie von Fahrtests wurde durchgeführt, die Fahrzeugdynamik und die daraus resultierende Beschaffenheit der Reifen wurden dokumentiert.

Bei der Auswertung einiger Reifenspuren auf der Fahrbahn zeigte sich, dass durch sorgfältige Untersuchungen der Motorradreifen wertvolle Informationen über das Ausmaß des Manövers vor dem Unfall sichtbar werden. Ergänzend dazu kann die nachträgliche Untersuchung der Motorradreifen eine Aussage darüber liefern, wie die Fahrfertigkeiten des jeweiligen Fahrers in Bezug auf maximales Bremsen und Kurvenstil zu bewerten sind.

Forensic Evidence Relating to Motorcycle Pre-Crash Maneuvers

Introduction

A normally operated vehicle is capable of three basic maneuvers: acceleration, braking and turning (cornering). Typically, when reconstructing pre-crash dynamics, the focus of interest will be on either braking or turning. Since the tire contact patch is where the tractive forces are generated, the tire contact patch, when examined in detail, can provide significant insight into the vehicle dynamics. Different motions will manifest tire evidence which can identify the orientation and force application during the maneuver.

Braking Maneuvers

Braking maneuvers that will generate observable forensic evidence on a tire involve some relative motion between the surfaces in the contact patch. Due to weight transfer it is more likely that a rear wheel will lock up than a front wheel. Motorcycle brake systems are changing; anti-lock brake systems (ABS) and combined brake systems (CBS) are becoming more prevalent. Therefore, the configuration in which the motorcycle is braked must be considered when evaluating forensic evidence on roads and tires.

Real world examples are presented where both roadway and vehicle data are available. Additionally, data generated specifically to evaluate braking performance will be presented. These aggressive maneuvers generate distinctive markings on the roadway as well as on the tire.

Braking Example – Locked Front Wheel

On a curving mountain roadway, approaching a right hand corner, the rider over-brakes and locks up the front wheel. Figure 1 shows a locked front wheel tire mark left by a sport motorcycle on Dunlop Sportmax tires. This short tire mark is characteristic of a locked front tire. Locked front tire marks tend not to be of long length due to the inherent instability of a motorcycle with a locked front tire. Figure 2 shows the corresponding abrasion on the front tire. Note that the abraded area of the tire is not parallel to the rim. This is a result of the motorcycle lean angle continuing to increase which causes the abrasion to progress to the lateral aspect of the tire.

Figure 1. Locked front tire mark between the white dots.

Figure 2a. Front tire abrasion.

Figure 2b. Front tire abrasion.

Braking Example – Loss of Rear Tire Traction

In Figure 3 a sport motorcycle, equipped with Michelin Pilot tires, was proceeding on a slight downgrade. The rider then departed the roadway at a shallow angle and entered the dirt and gravel shoulder. When he attempted to re-enter the roadway at significant yaw, tire marks were left before the motorcycle began to tumble. Figure 4 shows the corresponding, roughened rear tire surface generated as the motorcycle lost traction prior to falling.

Figure 3. Straight roadway with downgrade.
Note the tire marks in the lower left corner.

Figure 4a. Roughened tire surface.

Figure 4b. Roughened tire surface.

Braking Example – Locked Rear Wheel

Figure 5 shows a locked rear wheel skid, left by a cruiser motorcycle braking in response to a vehicle crossing the roadway. Note that the tire mark has a gap, indicating that the brakes were released then re-applied. This generated two distinct contact areas on the tire. Figure 6 shows the heavier, more significant tire abrasion corresponding to the second, longer portion of the mark. Figure 7 shows the lighter tire abrasion corresponding to the first, shorter portion of the tire mark.

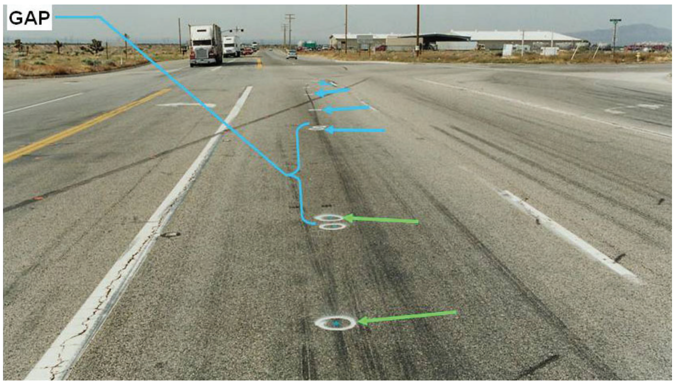


Figure 5. Two distinct locked rear tire marks with a gap between.

Figure 6. The second longer locked tire mark.

Figure 7. Initial locked mark.

Braking Example – Locked Rear Wheel

A sport motorcycle, on Pirelli tires, locked up the rear wheel in a right hand curve, crossed the center-line, and impacted an oncoming motorcycle riding near the centerline. The tire mark is indicated with orange paint marks, Figure 8. The corresponding tire abrasion of the rear tire is shown in Figure 9.

Figure 8. Locked rear tire mark leading over the road centerline.

Figure 9a. Abraded rear tire.

Figure 9b. Abraded rear tire.

Braking Evaluation – Locked Rear Wheel

Significant velocity is not required in order to leave visible tire abrasions. A low speed, 20 kph locked rear brake test was conducted using a sport motorcycle equipped with Michelin Pilot Power tires. This relatively short and low speed event generated clear evidence on the roadway and associated marking to the tire, Figure 10. Figure 11 shows the corresponding area which demonstrates the light onset of the abrasion which then becomes heavy with rubber balling and embedded particles at the maximum wear area.

Figure 10. Locked Rear Wheel Test Tire Mark 20 kph.

Figure 11a. Feathered onset of abrasion.

Figure 11b. Heavy end of abrasion.

Braking Evaluation – Locked Rear Wheel

Figure 12 shows a locked rear tire mark left by a cruiser motorcycle on HD OE Dunlop tires. This tire mark is not straight; lateral motion is often evident in locked rear braking. The skid start is highlighted with white chalk and leads to the parked motorcycle. Figure 13 shows the corresponding wear mark on the rear tire. Note the feathering of the rubber at the trailing edges of the tread blocks.

Figure 12. Locked rear tire mark.

Figure 13. Abraded "flat spot" on rear tire.

Braking Evaluation – Locked Rear Wheel

A braking test with a cruiser motorcycle on HD OE Dunlop tires is shown in Figure 14. When compared with the higher speed test shown in Figure 12, this moderate speed test yielded a lighter tire mark. The corresponding tire abrasion, Figure 15 shows a lighter onset (higher in photo), leading to the heavier abrasion (bottom of the photo). Figure 16 shows the heavier abrasion in more detail.

Figure 14. Locked rear mark.

Figure 15. Onset tire abrasion.

Figure 16a. Tire abrasion flat spot.

Figure 16b. Flat spot detail.

Cornering Maneuvers

During cornering, the lean of the motorcycle causes the contact patch to move laterally away from the tire centerline. The tire-ground interface is where forces develop that result in physical changes to the tire rubber that can be observed. Therefore the observable changes to the surface of the tire moves laterally away from the tire centerline. Since the amount of cornering is proportional to lean angle, careful observation of the tire provides valuable insight into the extent of cornering performed by the motorcycle.

Cornering Evaluation – Rural Mountain Road

A study was performed in order to evaluate the tire contact area utilized on a sport type motorcycle on a rural mountain road at significant lateral acceleration. For this study, a Ducati 1098 sport motorcycle with Michelin Pilot Power tires was instrumented and ridden over the same series of corners on a rural, mountain road, Figure 17. The lateral and longitudinal acceleration was monitored and is reported in Figure 18. Lateral accelerations approached 0.9 g's. At this level of cornering, rubber abrasions at the lateral aspect of the tire included balling of the rubber readily observable in a post test examination, Figure 19. Examination of this abraded test tire allows an investigator to determine that this motorcycle was ridden in a manner consistent with the lateral movement of the contact patch and the utilization of most of the available tire cross section.

Figure 17. Cornering study location.

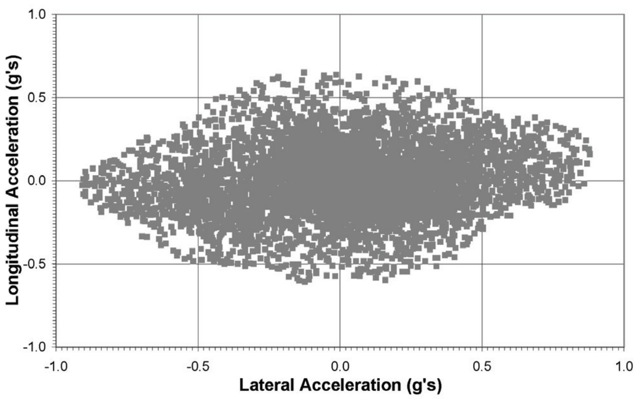


Figure 18. Lateral and longitudinal acceleration.

Figure 19. Front tire wear pattern after maneuvers.

Cornering Evaluation – Urban Area

An urban area, naturalistic riding study was performed in order to analyze the tire contact area utilized in an urban roadway setting. This study provides insight into the lateral progression of the contact patch and wear pattern with known performance usage of the motorcycle. The urban route was ridden in a slow manner and then in a more rapid manner.

A BMW R1150RT with Michelin Pilot tires was driven 37 km in an urban setting at speeds between 40 and 105 kph. Significant stops and a primarily urban setting provided a distinct riding environment and associated tire wear. The course is shown on the map in Figure 20. The course was ridden in both a slow and more rapid manner in order to study the tire usage when compared to the acceleration experienced.

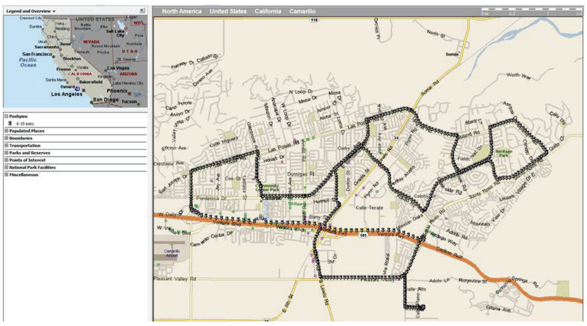


Figure 20. Urban riding environment.

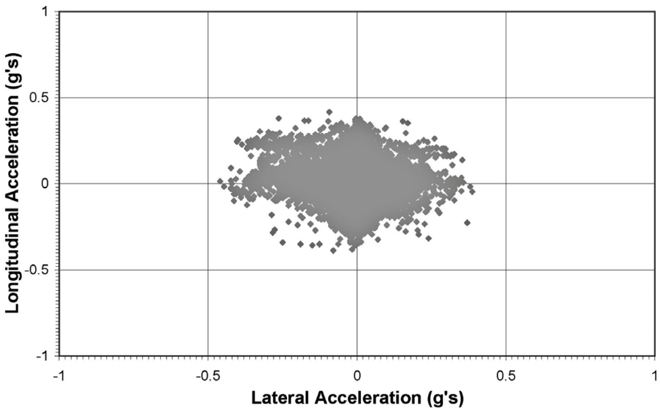


Figure 21. Acceleration data – slow urban riding.

Figure 22a. Front tire. *Figure 22b. Rear tire.*

After slow urban riding study. White markers placed to clearly define tire area utilized during driving study.

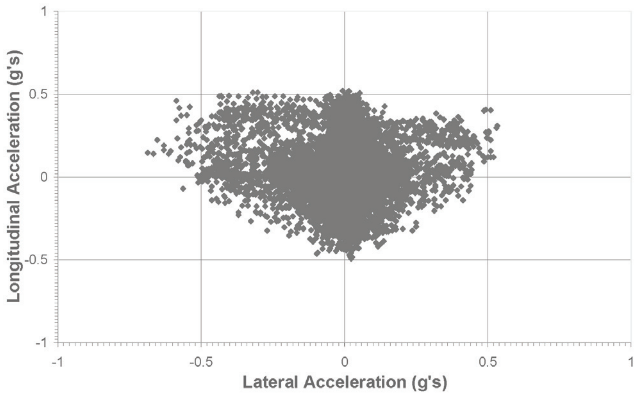


Figure 23. Acceleration data – rapid urban riding.

Figure 24a. Front tire. *Figure 24b. Rear tire.*

After rapid urban riding study. White markers placed to clearly define tire area utilized during driving study.

From the acceleration data, Figures 21 and 23, it is clear that the slow ride uses a smaller portion of the motorcycle's performance envelope than the rapid ride. It is also evident from the tire photos that the more rapid riding uses more of the tire cross-section. Indicators were applied to the tires to clearly identify the extent of contact during the motorcycle lean. Measurements at multiple locations were made from the tire shoulder to the edge of contact. For the easy ride 17mm / 26mm (front/rear) of the available tire contact patch was not utilized. However, in the rapid ride, all of the tire contact patch except for the most lateral 8mm / 15mm (front/rear) was utilized. Examination of the abraded portion of the tire rubber, for a motorcycle used primarily in an urban setting, may yield valuable data regarding the rider's utilization of the motorcycle.

A naturalistic riding study was also performed in a rural setting in order to analyze the tire contact area utilized on a rural roadway. This study gives the analyst some insight into the progression of the contact patch and wear pattern with known performance usage of the motorcycle. Two motorcycles were ridden along a prescribed rural route over a length of 30 km. As with the urban study, the rural route was ridden in both a slow manner as well as in a more rapid manner. The same BMW R1150RT used in the urban setting was used again for these rural runs. It was joined by a BMW R1150GS, equipped with street tread Continental Road Attack tires. The route is shown in Figure 25. The tire photos in Figures 27 and 29 are from the same R1150RT used in the urban study.

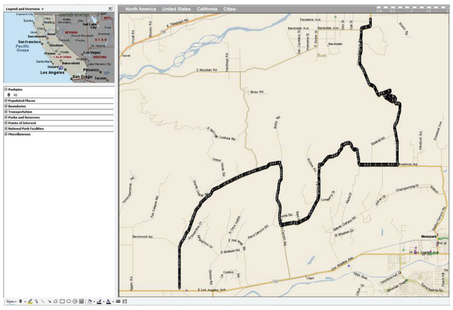


Figure 25. Rural riding environment.

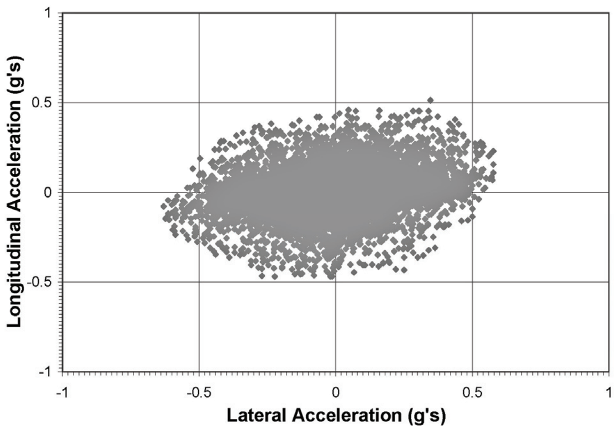


Figure 26. Acceleration data – slow rural riding.

Figure 27a. Front tire. Figure 27b. Rear tire.

After slow rural riding study. White markers placed to clearly define tire area utilized during driving study.

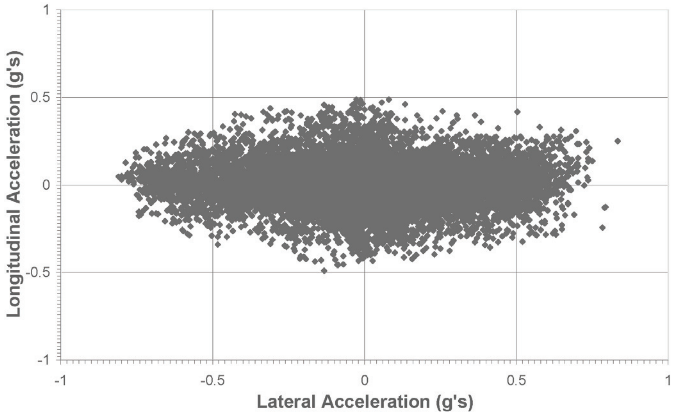


Figure 28. Acceleration data – rapid rural riding

Figure 29a. Front tire. *Figure 29b. Rear tire.*

After rapid rural riding study. White markers placed to clearly define tire area utilized during driving study.

From the acceleration data, Figures 26 and 28, it is clear that the slow ride uses a smaller portion of the motorcycles performance envelope than the rapid ride. It is also evident from the tire photos, Figures 27 and 29, that the more rapid riding uses more of the tire cross-section. Indicators were applied to the tires to clearly identify the extent of contact during the motorcycle lean. Measurements at multiple locations were made from the tire shoulder to the edge of contact. Observed on the BMW R1150RT tire after the slow ride, 16mm / 24mm (front/rear) was not used. For the rapid ride that decreased to 6mm / 8mm (front/rear). By comparison the 1150GS for the easy ride 24mm / 25mm (front/rear) was not used while for the rapid ride that decreased to 8mm / 3mm (front/rear).

Conclusions

Tire examination yields valuable data regarding the nature and source of observed at-scene tire marks.

Vehicle and tire parameters need to be considered when evaluating marks on the road or tire.

Locked wheel tire marks can generate clear data on both the road and the tire. Onset abrasions occur before the wheel fully stops rotating, but maximum abrasions occur at the stopped tire contact patch.

Tire examination yields valuable data to the investigator regarding the rider's use of the motorcycle's available performance.

Further testing of motorcycles equipped with ABS and CBS systems needs to be conducted to more fully understand tire and road markings generated by these systems.

The purpose of these cornering evaluations was not to ride the motorcycles at its maximum capability. Rather, the purpose was to undertake a naturalistic study of rider and motorcycle performance and examine the forensic evidence available from the tires at known performance levels.

It is recommended that further naturalistic driving studies using motorcycles be performed. This would allow a wider statistical collection of evidence in order to understand how motorcycles are being ridden on the public roadways.

It is recommended that any driving studies be accompanied by examination of tire wear to evaluate whether riding history observed in this testing can be observed through tire examination in a wider study.

RIDER – a complete study on accidents involving a powered two-wheelers: accident causations, safety equipment and injury mechanisms

FAHRER – eine Studie über Unfälle motorisierter Zweiräder: Unfallursachen, Sicherheitsausstattung und Verletzungsformen

Vuthy Phan, Maxime Moutreuil, Alain Martin,
Jean-Charles Feurxer, Thierry Hermitte

CEESAR – Centre Européen d'Etudes de Sécurité et d'Analyse des Risques
European centre of studies on safety and risk analysis

LAB – Laboratoire d'Accidentologie et de Biomécanique
Laboratory of Accidentology and Biomechanics.

Abstract

CEESAR has initiated the project RIDER[1] using the accident investigation methodology of MAIDS[2] project. In addition to accident data gathering, RIDER went deeper in the knowledge of powered two-wheelers accidents and injury mechanisms, in the understanding and explanation of the failures of the drivers, the riders, the infrastructures or the vehicles. Finally, this study gave guidances to policy, decision makers, scientific community, protective clothing manufacturers, vehicles and powered two-wheelers industry for future actions contributing to the improvement of road safety.

In order to take up the challenge, CEESAR PTW experts have investigated 210 French accidents, using in-depth accident analysis methodology. It means that all the accidents have been reconstructed in details in order to identify their causes and consequences. Moreover, all the information about the infrastructure, the riders, their safety equipments, their injuries and the vehicles have been collected in a complete database. Around 1800 parameters per accident were informed.

The project has begun in 2003 and has been achieved in 2005. Thanks to the database, the role of the infrastructure in the accident sequence and in the injury mechanism has been determined. Rider protective clothes and helmets have been analyzed (usage and deficiencies). The use and the efficiency of a better braking system for PTW during an emergency situation have been evaluated. Relevant scenarios of accidents were underlined according to their frequencies and risks.

Kurzfassung

Das Projekt RIDER[1] wurde durch CEESAR mit der Unfalluntersuchungsmethodik des MAIDS[2]-Projektes initiiert. Neben der Unfalldaten-Erhebung beschäftigte sich RIDER tiefer mit den Erkenntnissen der Unfälle motorisierter Zweiräder und den daraus resultierenden Verletzungen. Ebenso förderte es Erkenntnisse und Erklärungen über das Fehlverhalten der Verkehrsteilnehmer, der Infrastruktur oder der Fahrzeuge zu Tage. Abschließend zeigt diese Studie Anregungen für künftige Maßnahmen für Politik, Entscheidungsträger, Wissenschaft, Bekleidungshersteller und Fahrzeugindustrie, um die Verkehrssicherheit verbessern zu können.

Um die Herausforderung anzunehmen, haben die Zweiradexperten von CEESAR 210 Unfälle in Frankreich innerhalb einer Tiefenstudie untersucht. Dies bedeutete, dass alle Unfälle im Detail rekonstruiert wurden, um ihre Ursachen und Folgen zu identifizieren. Darüber hinaus wurden alle Informationen über die Infrastruktur, die Fahrer, ihre Sicherheitsausstattung, ihre Verletzungen und die Fahrzeuge in einer umfassenden Datenbank mit rund 1.800 Parametern pro Unfall gesammelt.

Das Projekt begann 2003 und wurde 2005 fertig gestellt. Dank der Datenbank konnte die Rolle der Infrastruktur bei den Unfällen und Verletzungen bestimmt werden. Auch Motorradbekleidung und -helme wurden genau durch das Trageverhalten und durch Schäden analysiert. Zudem wurden der Einsatz und die Effizienz eines besseren Bremssystems für Fahrer motorisierter Zweiräder während einer Gefahrensituation bewertet. Bedeutsame Unfall-Szenarien wurden entsprechend ihrer Häufigkeiten und Risiken herausgearbeitet.

RIDER – a complete study on accidents

involving a powered two-wheelers:

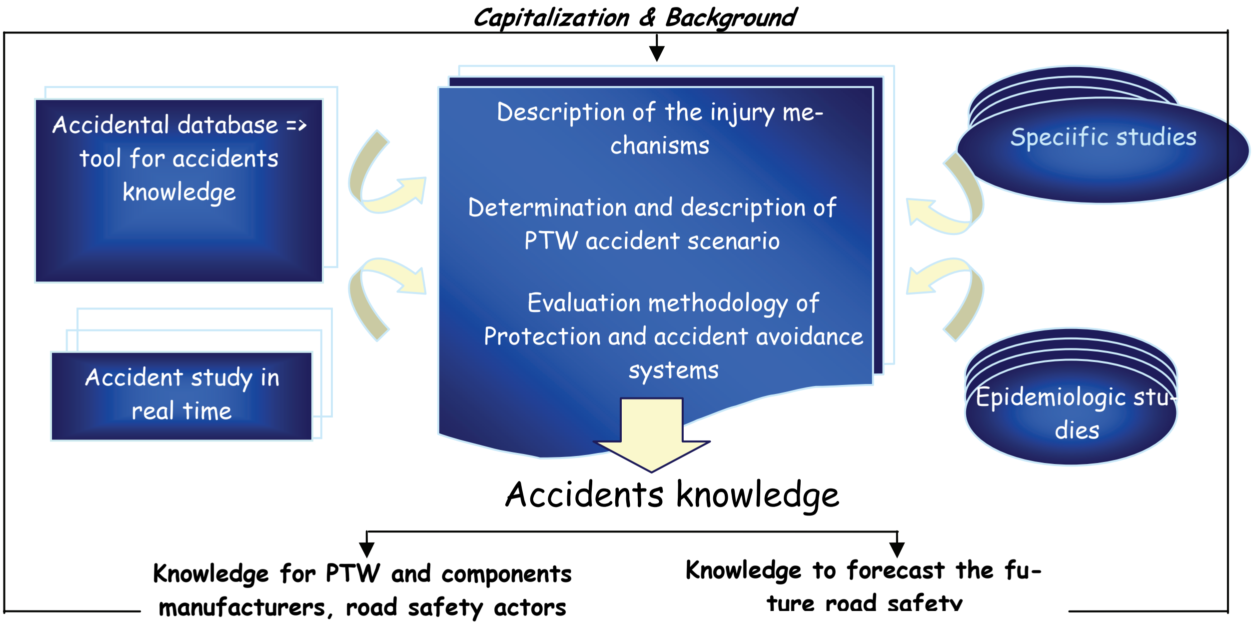
accident causations, safety equipment and injury mechanisms

Introduction

The powered two-wheelers (PTW) riders are, with the pedestrians and the cyclists, the more vulnerable road users. Indeed, more than 15% of the road fatalities[3], in 2006, in Europe, were PTW users. It means that the fatality rate per passenger kilometer is 20 times higher for PTW users than for passenger car ones. In France, PTW road users are the only category which knows an increase of injury accidents and fatalities. So a better understanding of these accidents is necessary to reverse the trend. To reach this goal, the project RIDER has been created. RIDER is the logical continuity of the European program MAIDS (Motorcycle Accidents In-Depth Study) in which the CEESAR worked during two years, allowing him to enrich its knowledge on the accidental mechanisms of motorized two wheels vehicles.

These two years enabled us to validate an accident collection and coding information methodology defined by OECD[4] on 150 cases of accidents. In addition to its mode of financing (the first study was European whereas RIDER rests on a 100% French[5] financing), RIDER is distinguished from MAIDS by proposing thematic studies on subjects such as the equipment of the motorcyclist, the infrastructure, the braking in emergency situation, the helmet and the scenarios of accident...It is important today to go deeply into our knowledge of the accidental and injury mechanisms involving the motorized two wheels vehicles, since this mode of displacement is one of the most risky.

Finally, this study gave guidances to policy, decision makers, scientific community, protective clothing manufacturers, vehicles and powered two-wheelers industry for future actions contributing to the improvement of road safety. CEESAR PTW experts have investigated 210 French accidents, using in-depth accident analysis methodology. Around 1800 parameters per accident were informed. The project has begun in 2003 and has been achieved in 2005. Thanks to the database, the role of the infrastructure in the accident sequence and in the injury mechanism has been determined. Rider protective clothes and helmets have been analyzed (usage and deficiencies). The use and the efficiency of a better braking system for PTW during an emergency situation have been evaluated. Relevant scenarios of accidents were underlined according to their frequencies and risks.



Methodology

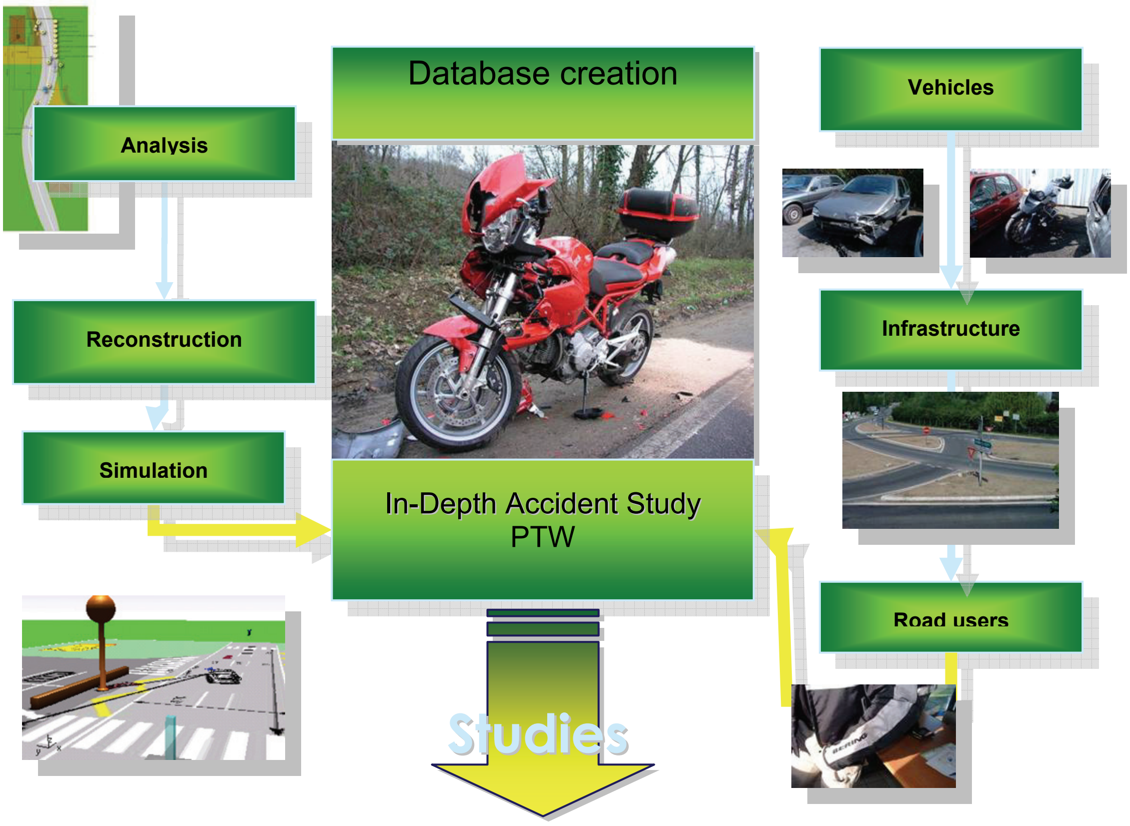
Main results focusing on PTW accidents come from descriptive analysis or macro accidentology level that rely on intensive accident databases such as census of accident data registered by the police forces and put into national files or European data such as CARE database. This macro accidentology study is rather poor in identifying accident causation factors because the complex process of a crash is not analyzed and recorded in such databases and because many of the recorded variables are mostly descriptive and not analytic. Nevertheless, they provide us reliable information which was used to identify the magnitude of the problems (e.g. 25% of fatalities were young road users between 18 and 24 years old, 70% of the fatalities occurred on rural roads, 20% of injury accidents occurred on wet pavements, etc.).

This lack of accident causation knowledge can be filled by the microscopic or in-depth analysis through a detailed analysis of microscopic databases. As the descriptive analysis is able to provide the representative accident configurations, this step is aimed at obtaining more details on information that cannot be gathered in national police accident databases tackling those configurations. This type of information is essential to the addressing of accident causation and can only be obtained through the analysis of in-depth databases.

As an accident is clearly the result of inadequate interactions between the driver behavior, the road infrastructure configurations before and at the scene of the accident, the vehicle dynamics and state, and of course the conditions of trip (weather, traffic, passengers, etc.), accidents need to be investigated in-depth by a multi-disciplinary team, composed by a road expert and a vehicle one. They collect directly the information if it is available on the spot or later on, at the hospital. They seldom use the police report. If they are called by the rescue service and come on the accident scene after the driver left the scene or the vehicles were moved from their rest position and there is no clue to find the crash point and the place of vehicles at rest after the crash, the accident is not investigated. The objective is really to get as much information as possible to be able to make a cognitive and kinematic reconstruction of the accident.

Complementary collection is made afterwards at the hospital (second interview of the involved users and collection of the injury form) or at the local transport authority to get further details about the traffic or the road configurations. Most of the data is then coded and filled in a special database. Information that can not be coded is conserved in original dockets along with photos, sketches and sometimes videomovies.

The outcomes of such accident investigations are a complete database and accident researches that help car manufacturers to understand the accident genesis, and noticeably the vehicle collision course and the driver's actions or failures in emergency sub-phases, and to evaluate *a priori* situations for which driver assistance or safety devices could have avoided the crash or slighted its injury consequences.



The sample

From January 2003 to April 2005, 210 PTW in-depth accidents have been collected and analyzed. The place of the investigation was at the Essonne departement, in France. This area has been chosen because it was where MAIDS accidents have been investigated. So CEESAR was introduced and then well known by the emergency services, the police forces, the hospitals and had an authorization to analyze the accidents on the scene. Indeed, in-depth accidents investigation requires a good acquaintance network to be on the spot on the accident as soon as possible and to be enlisted the services of them.

Moreover, the investigation area has to be representative of the PTW accidents in France in order to have relevant results. And finally, the area need to have different road types (highway, national road...) and area types (urban and rural area). The Essonne department answered to all these criteria and that is why it has been chosen. RIDER database gathered 210 PTW accidents from January 2003 to April 2005. All theses accidents are injury ones and 10% of them were fatal.

In our sample, touring PTWs (including sport touring) represent 29% of the PTW damaged. This is the most important group. Then, 16% are street and roadster motorcycles. And finally sport motorcycles and moped are, each of them, 15% of the PTW involved in the accidents (Figure 1). It seems necessary to identify which kind of PTW is involved in injury accidents as there is a large diversity in PTW type. Each of them can differ in an important way: driving, driving licence, PTW power and size, owner, uses, gears.

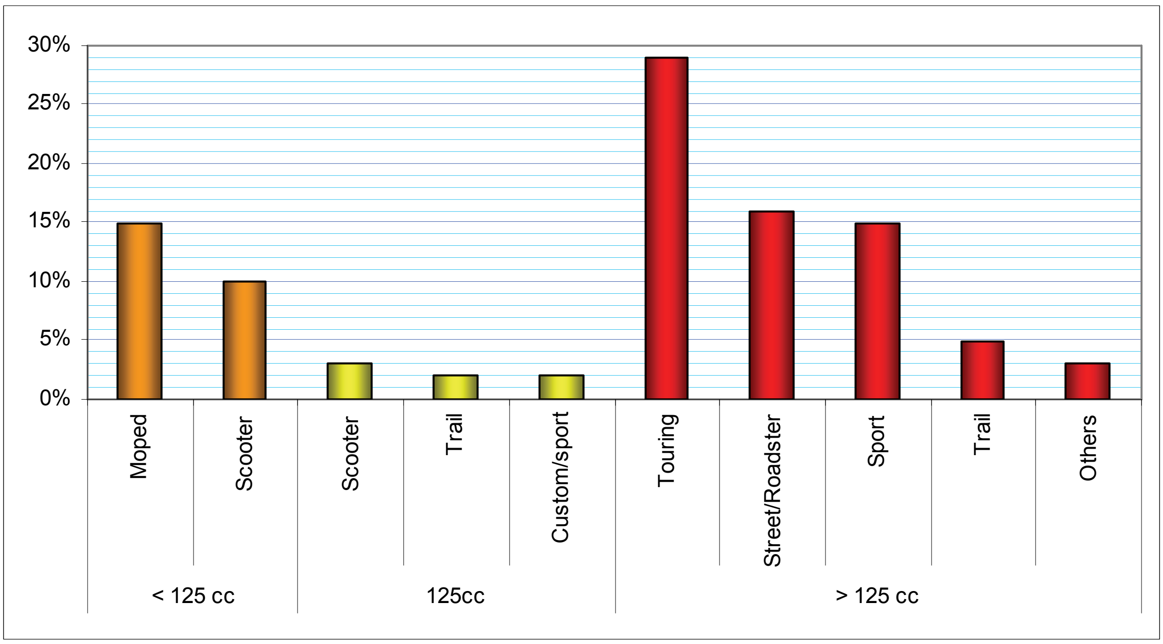


Figure 1: PTW types involved in RIDER accidents

As specified earlier, the Essonne departement has varied infrastructure and area. This diversity gave us the possibility to study PTW accidents in different configurations. Moreover, RIDER sample is quite representative of PTW accidents in France as the trends are the same. So the main results from our sample are (Figure 2):

- 51% of the injury accidents are at intersection (or a roundabout),
- 39% of them are on a straight road,
- 59% are inside urban (in France, in 2005, it is 76%),
- 5% are on highways and has always involved at least 2 road users.

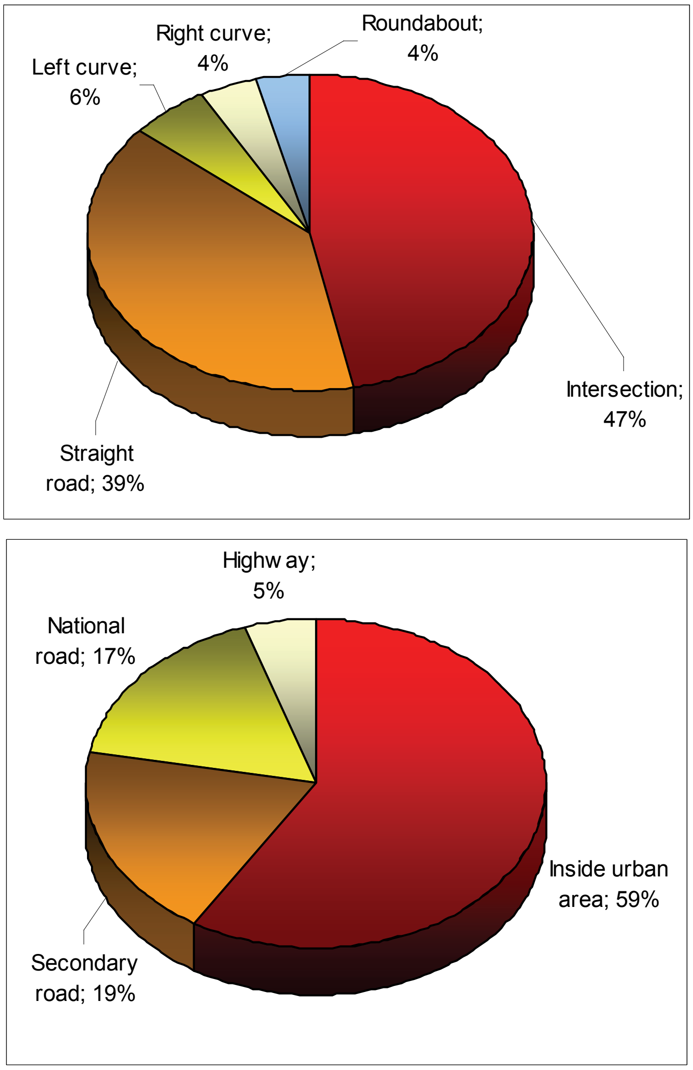


Figure 2: Accidents by geometry and road type

Most of the riders in our sample were younger than 35 years old (66%). And young riders between 15 and 24 represent the most important category (Figure 3). Moreover, this one is the category where the risk to be involved in an accident is the most important.

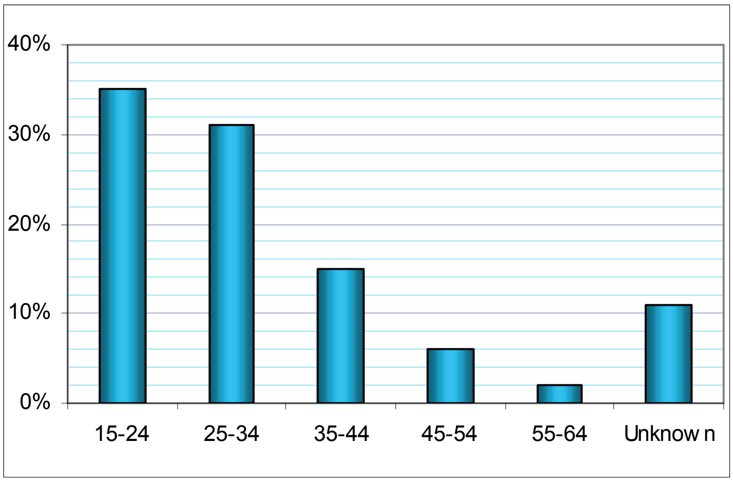


Figure 3: Age of riders in the database

In RIDER study, 2 kinds of impact has been determined, one for the PTW road users and another one for the opponent vehicle road users. For each rider and passenger, an in-depth analysis of the injury has been done. Each injury has been coded with the AIS[6] scale. Moreover, for each injury, we correlate it with an impact area.

The ground was at the origin of 52% of the injuries (Figure 4). And in 38% of the cases, the opponent vehicle hurted the PTW users (Figure 4).

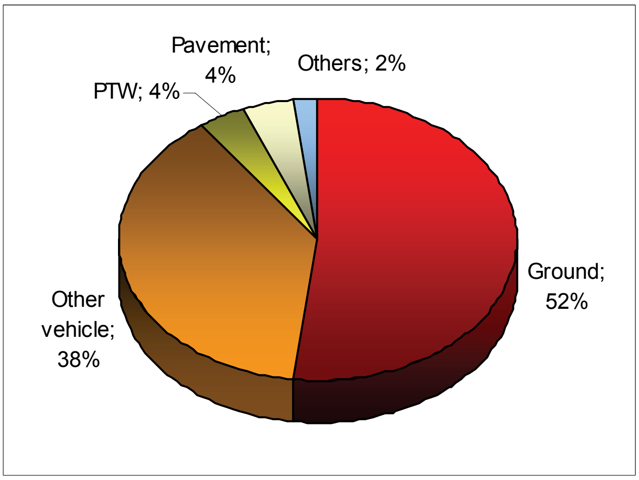


Figure 4: First impact for the PTW users

Considering all the injuries of all the PTW road users, lower and upper extremities are the body regions the most often injured, respectively 35% and 32% (Figure 5). Nevertheless, these injuries are minor (AIS 1).

Now if we consider the ratio of AIS 2+ injury (at least injury AIS 2 which is a moderate injury), the head, the thorax and the spine are the body regions where most of the injuries are at least moderate injuries, respectively 86%, 58% and 63% (Figure 7).

More than 50% of the injuries at the head and at the thorax segments are severe ones (at least AIS 3, Figure 6).

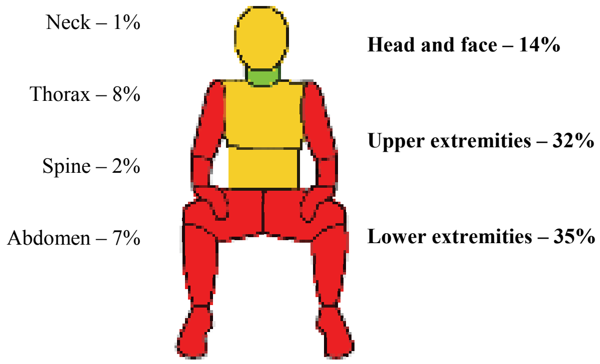


Figure 5: Injury distribution for PTW road users

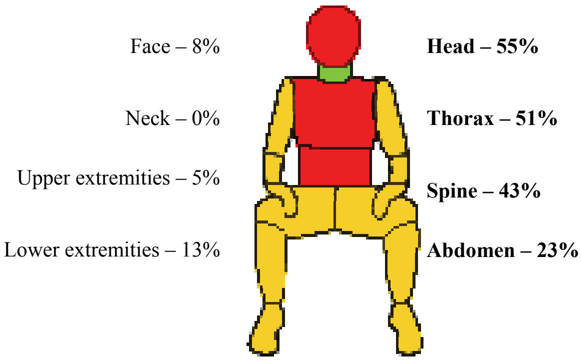


Figure 6: AIS 3+ injury ratio per body region

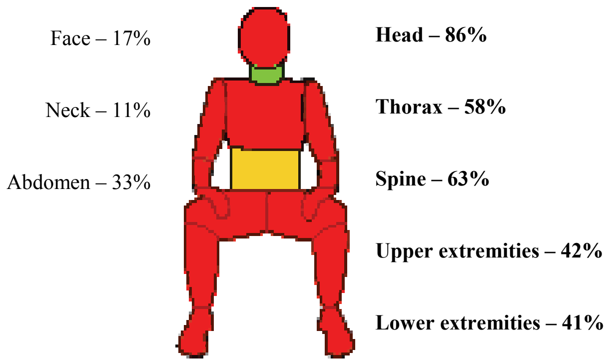


Figure 7: AIS 2+ injury ratio per body region

The role of the infrastructure in PTW accidents

The infrastructure seems to be a big issue for PTW in accidents. Indeed, such vehicles are less stable compared to passenger car for instance. It means that PTW have probably more risk to have a loss of control or an off-road accident driving on a “degraded” infrastructure. Moreover, passive safety systems for PTW road users do not really exist (except the helmet). So, in case of falling off, the seriousness of injury against obstacle on the infrastructure (pavement, trees on the shoulders...) can be increased. So the aim of this chapter is to well understand the role of the infrastructure in PTW accidents. To reach this goal, we have shared our work according to 3 points:

1. What kind of road elements can have an influence on the PTW driving?
2. What are the measures set up by the road department to reduce the role of the infrastructure in accidents and especially in PTW accidents?
3. What are the injuries of PTW road users when they crash a road obstacle?

The analysis of RIDER database has confirmed the fact that the infrastructure plays an important role in the PTW accidents:

For the PTW behaviour, pedestrian crossing, manhole cover or road surface quality can be the source of a loss of roadholding. A degraded road, rough surfaces or humps (Figure 8) can destabilize the PTW. Nevertheless, even if infrastructure is often quoted (by riders and PTW organization) as a danger for riders and even if it is assumed that it can have an influence on the PTW behaviour, our database analysis shows that infrastructure is not at the origin of the accident (except in very few cases). It is rather a factor contributing to the accident.

Figure 8: Rough surface and hump onbraking area

For the rider behaviour, the visibility and the perception of the infrastructure are very linked to the markings and the signs on the road. It is necessary to offer to the road users a good visibility (and particularly at intersection) and a good information (traffic signs) focusing on the main information.

Considering the side effects of the infrastructure, in case of fall of a PTW, trees, posts, street furniture crash barriers and road signs are the most relevant obstacles for PTW accidents (Figure 9). Indeed, these elements can be at the origin of serious injuries and they are aggressive.

Figure 9: Obstacles (trees and rocks) on the shoulder of the road which can cause more serious injuries

Crash barriers (Figure 10) are also pointed out by PTW organization because of their aggressiveness. Indeed, they are elements of the infrastructure which contribute to more serious injuries when the PTW users fall and slide on the road shoulder. In France, several measures have been taken in order to solve this problem. For instance, a new decree specifies what to do when installing a new crash barrier or when updating old ones to protect PTW users. Moreover, SETRA[7] has published a guideline named "how can we take into consideration PTW users in infrastructure development and management?".

Figure 10: Wider barrier advocated by SETRA

The first parts of the infrastructure chapter have summarized its role and potential issues in the PTW accidents. It is necessary to link them to the micro and macro accidentology to have a better view of what has to be done and on what road safety has to concentrate their efforts. In France, 10% of PTW accidents are against obstacles. When considering fatal PTW accidents, the rate is 28%. So the issues are not insignificant and the infrastructure is one of the contributing factors leading to the more serious accidents.

From a macro accidenlotogy level, RIDER database shows that most of the injuries at the lower or upper extremities are very minor (AIS 1) or moderate (AIS 2) whereas injuries on the head, the thorax, the abdomen and the spine are more severe and critical (Figure 11 & Figure 12). That is why it seems important to well protect especially these body regions.

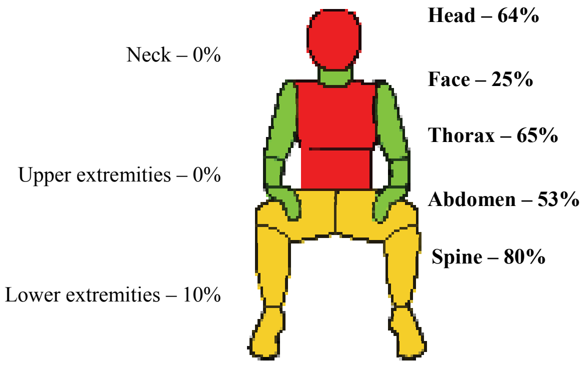


Figure 11: Injury AIS 3+ ratio per body region for accidents

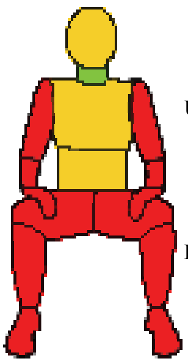


Figure 12: Distribution of injuries for accidents

Protection of PTW users with equipments

The PTW users can not be protected by the body of the PTW itself (such as for passenger car) in case of an accident. Excepted the C1 BMW which has been designed with a survival unit (which protect the users during a crash) or the Honda Goldwing which propose an airbag, only few of the other PTW has such passive safety systems. Then, it means that PTW users can only rely on their protection equipments in case of accident.

In order to better understand the issues linked to the PTW user equipments, two points have been examined.

- What are the equipments available on the market? What are the standards for them? And what do they protect?
- Thanks to the RIDER database, the rate of PTW user equipment has been determined and the injuries of the users have been linked to the protection clothes used. This study has helped us to identify the efficiency of PTW user equipments and their potential issues.

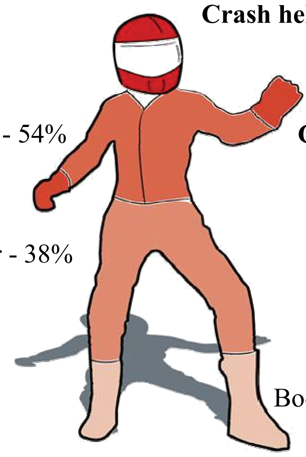


Figure 13: Rate of PTW equipment worn

To answer to the first question, many types of equipment exist for the PTW users: crash helmet, gloves, jacket, trousers, and boots. Unfortunately, except for the crash helmet, no other equipment has to follow a standard focussing on road safety and is compulsory. Recently 3 French standards[8] focusing on the gloves, the clothes and the boots have been created but they only concern (for the moment) professional PTW riders equipments (but they are not obligatory).

The RIDER study has shown well known results: the rate of helmet wearing is very high and varies from 94% to 99% whatever is the type of PTW used or the type of road on which PTW users are riding.

The study has also underlined another issue which is rarely studied: the rate of PTW user equipments. The proper and adapted (good size, no crash impact...) wearing of crash helmet and gloves is satisfactory for big engine PTW users (92% and 84% respectively). Nevertheless when examining the other safety equipments such as jackets, boots and trousers, the rate is lower: 55%, 40% and 19% respectively.

For small engine PTW users, the correct use of safety equipment is rare whatever the equipment is. For instance, 52% of these drivers do not wear any crash helmet or wear an inadapted one. 57% of PTW passengers do not wear any gloves and 83% of theses users do not have any specific trousers.

The first step of the analysis of the PTW equipment was to estimate its "real" protection, associating the body region supposed to be protected by the equipment and the injuries of the PTW users after the road accident. For instance, even if the knees are protected, there are often injuries at this body region. It means that the knee protection can be improved. For the feet, most of the injuries of PTW users wearing boots concerned the toes (fracture, bare toes...). It seems necessary to improve boots for this body region.

Considering the stomach and the lower extremities, only 18% of the PTW users wore a specific pair of trousers. The body regions the most exposed to injuries (and especially fracture) are the femur, the pelvis and the hip. Such results are not surprising as trousers can easily protect users from skin burn but not from bone fractures. For the upper area of the body and the upper extremities, spine injuries (bruise, medulla spinalis injury, bone injury...) concern all PTW users whatever is the equipment they wore. Indeed, none of the PTW users studied was wearing an efficient dorsal protection (different from rubber protection). Like the spine, for scapula, collarbone, organs and humerus injuries, there is no difference between PTW users wearing a specific equipment or not. For the hand, PTW users wearing gloves often have injuries at the wrist and at the carpus. An improvement of such equipment seems necessary. The protection of the head will be studied in the next paragraph as it is the equipment the most worn.

In spite of the difficulty to estimate the efficiency of PTW equipment, we tried to assess the potential issue of PTW equipments if these ones were worn by all the road users. To reach that goal, we have compared the rates of injuries, by body region, between a road user wearing specific PTW equipment protecting the studied body region and another one which does not wear any specific equipment. For instance, in RIDER database, 20,4% of PTW users did not wear any foot protection and have had at least one injury at the foot. And 13.3% of PTW users wore foot protection and have had at least one injury at the foot. So the decrease between the two samples is 35% less injuries (Figure 14).

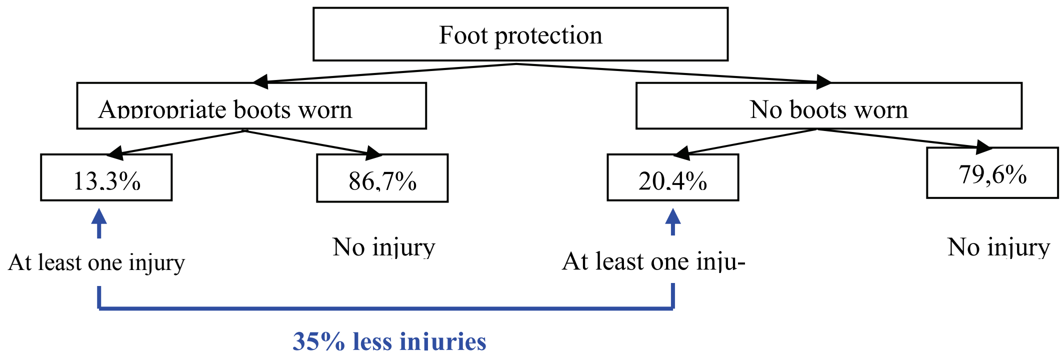


Figure 14: Efficiency estimation methodology

The result of the estimation is that with crash helmet, many injuries can be avoided. Such a result is not surprising as the head is weak and any impact can cause injury. Potentially, 59% of the injuries of the PTW users who did not wear any helmet or did not wear it properly could be avoided (Table 1).

For the feet and the arms, the injury saving is high (respectively 35% and 25%). But it mainly concerns moderate injuries (with AIS 1 and 2).

For the legs, the hands, the thorax, the abdomen and the spine the results confirm what we found above, PTW protection equipments need improvement to be efficient (Table 1).

Table 1: Equipment efficiency

Body region	Appropriate equipment – At least 1 injury	Not appropriate equipment – At least 1 injury	Injury saving
Head / Face	12,3%	30,3%	59%
Feet	13,3%	20,4%	35%
Arms	47,6%	63,3%	25%
Legs	72,4%	73,1%	1,0%
Hands	24,3%	21,4%	0
Thorax/abdomen/spine	19,8%	15,2%	0

The crash helmet

Since December, 1st 1975, in France, helmet is compulsory to drive a PTW. This law is now well accepted by the riders in France as the rate of helmet wearing is around 95%.
Nevertheless, head injuries still exist and are often serious ones. That is why we have decided to devote a full chapter to this subject. The PTW crash helmet study was focussed on several points:

- What are the equipments available on the market? What are the standards for them?
- How the helmet is used by riders?
- How efficient is a PTW crash helmet and what kind of head injuries has a PTW user?

On the whole, PTW protection equipment is not subject to strict rules (such as the wearing) or standards. There is only one exception: the crash helmet whose wearing is controlled has to follow many standards[9] to be approved. Different crash tests at different area of the helmet are realized: its capacity to protect the head according to the severity of the crash and its stiffness are quantified...

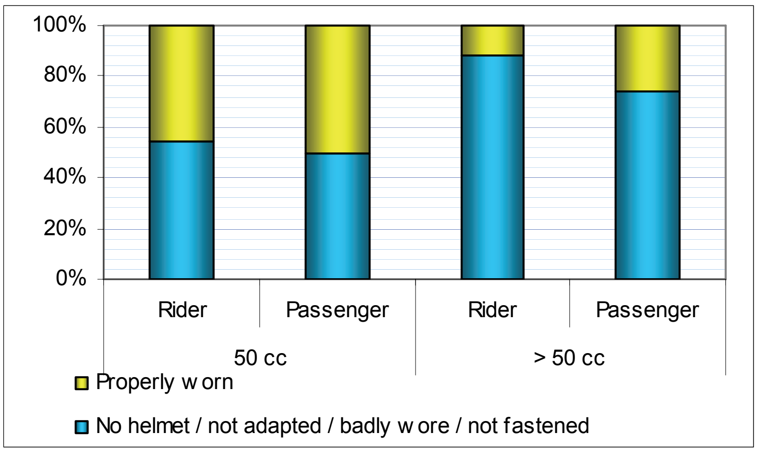


Figure 15: Crash helmet wearing

In spite of appearances, PTW users do not seem conscious of the importance of the helmet. Indeed, statistics show a high rate of helmet wearing but in reality, what is important is how users wear it. Indeed, RIDER database has shown that every second small PTW (50cc) users does not wear any helmet or this one is not adapted (too big, too small) or it is just not fastened (Figure 15). This road user category has to be informed of the importance of the helmet: wear one does not mean to be protected as well. Indeed, an helmet badly worn could be thrown out (in the database 70% of the helmets badly worn has been thrown out) or not adapted could not be efficient in case of collision. In addition to this information, we worked on the state of the helmet. It results that for small engine PTW, 89% of the riders and 100% of the passengers wore helmet in bad state: the helmet jugular and / or the helmet itself (inside and / or outside) were damaged. For big engine PTW, the results are different as the riders and the passengers wore, respectively 85% and 67%, an helmet in good conditions.

During the accident data collecting, our experts have focussed their analysis on the helmet and especially on the impact on it. They described the different impacts (splinter, abrasion, paint on it, crack) affected by the collision and their places on the helmet. The graph on the side summarizes the distribution of these impacts (Figure 16).

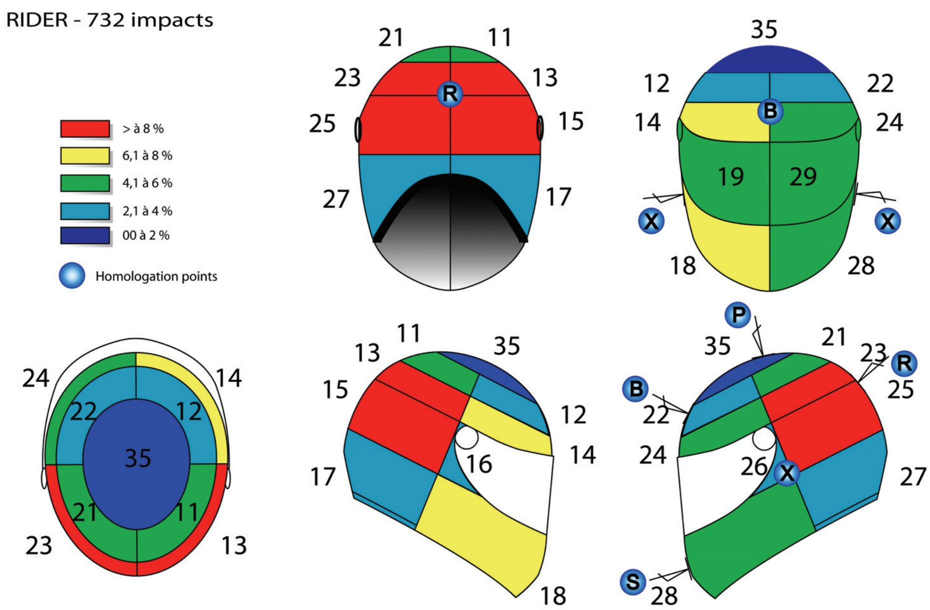


Figure 16: Impacts on the helmet

It results that two main areas are often impacted: the chin piece (18 & 28 on the Figure 16) and the top back of the helmet (13, 15, 23, 28).

It is interesting to notice that crash helmet standards impose resistance tests on different areas of the equipment. And one of them is at the top of it (35), the area the less often impacted during a collision.

Now focussing on the head injuries of the PTW road users, obviously, users not wearing any helmet are more exposed to head injuries. Nevertheless, to wear one does not mean to be protected from any injuries. The study shows that most of them are abrasions, fractures and fainting (Figure 17).

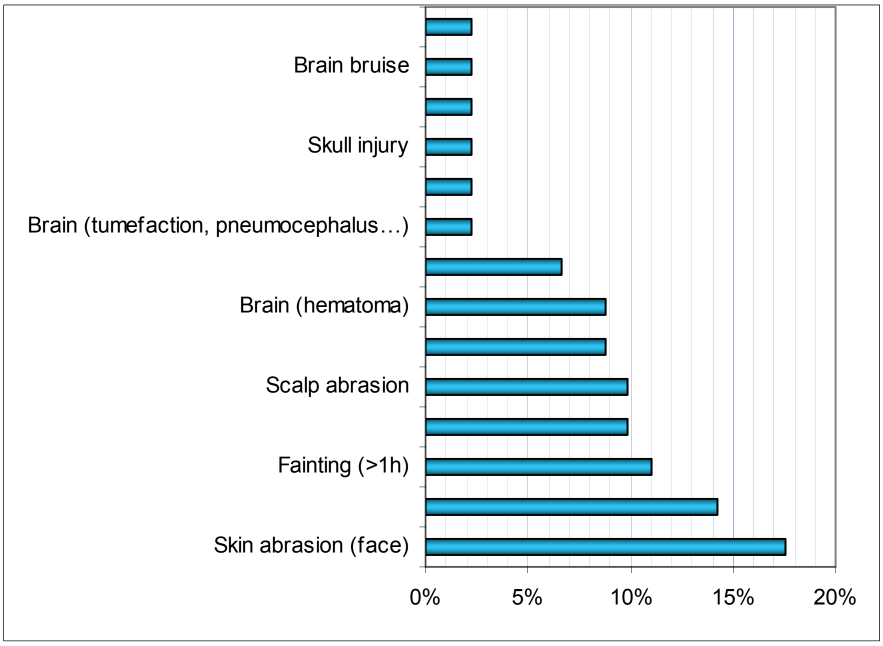


Figure 17: Head injuries distribution

Emergency reaction

Road safety is a big issue in France and in Europe. Stakeholders, manufacturers, authorities worked together in order to reduce road fatalities. For instance, car manufacturers have focussed their work on active safety system such as ABS[10], ESC[11], EBA[12] in order to avoid the accident or to reduce its violence. And the European Commission, in July 2004, imposed ABS fitted in new cars. Nevertheless, all these technological advances mainly concern passenger cars. For PTW, safety systems are less numerous and are not often a standard. They are principally focussed on the braking help. The first system is the ABS which prevents from wheel locking and help to remain in control of the PTW. The second one is the integral braking (CBS[13]) system which balances the braking between the front wheel and the rear one. And the last one is the braking increase system.

In spite of these systems which help the rider to brake, this driving manoeuvre is not an easy manoeuvre and especially when it is an emergency manoeuvre. The consequence of such manoeuvre badly performed is the falling. That is why we estimated that the emergency reactions were an important field which could help the manufacturers, the components manufacturers to understand the rider behaviour.

Braking is the manœuvre the most performed during the emergency phase. Indeed, more than half of the riders braked in order to avoid the accident: 45% of them braked and 9% of them performed an evasive action and braked. Nevertheless, one rider in four did not perform any manoeuvre. It means that the rider was not able to anticipate the accident (for instance lack of time, no visibility...) or judged that it was not necessary. Then the evasive manoeuvre has been tried by 7% of the riders.

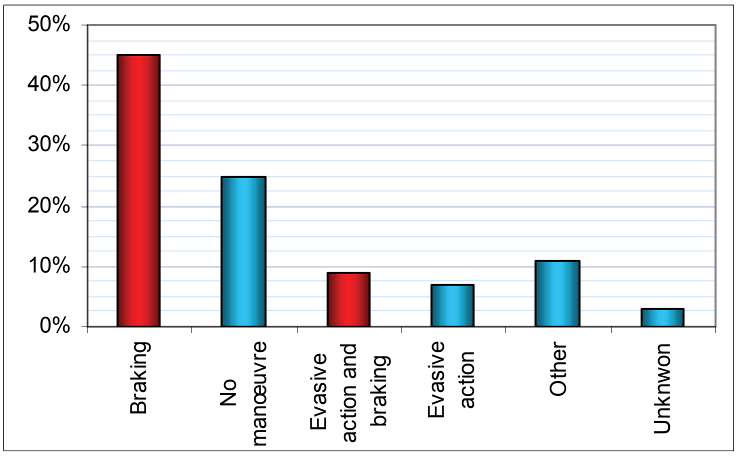


Figure 18: Distribution of the emergency reactions of riders

It seems that braking and to a lesser extent evasive actions are the first reactions of riders during an emergency phase. The study of the driving experience of the riders does not show any relevant conclusions. Whatever is the experience of the riders, the distribution of the emergency manoeuvres is homogeneous.

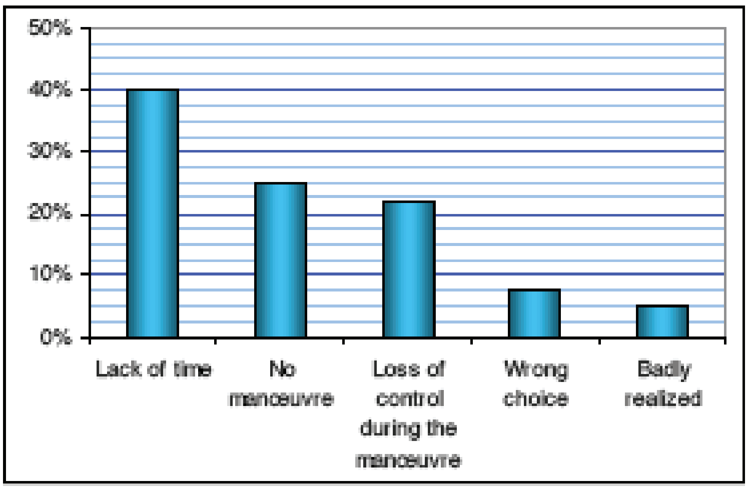


Figure 19: Why the emergency manoeuvre has been badly performed

The rider database has shown that in around 80% of the cases, the manoeuvre performed to avoid the accident is badly realized. The reasons are that for around 40% of the manoeuvres, the rider did not have enough time to do something to avoid the accident: it reveals a problem of anticipation of a potentially dangerous situation. In 25% of the cases, any manoeuvre has been performed by the rider. This one was not able to react because of inattention, alcohol or to well see because of a problem of visibility (mask, rear crash). Finally, for more than one rider in five, the manoeuvre failed because of a loss of control of the vehicle. For instance, the rider braked and locked the wheels or fall down before the collision.

The aim of the Figure 20 is to better understand the level of control of the PTW by the rider when he is braking during his emergency reaction. Around one rider in two kept the control of his PTW (49%). More than one third (36%) of the riders locked their PTW wheels and fell off. And finally 15% of them kept the control of their PTW in spite of the wheels lock. We deduce that potentially for more than one third of the riders, ABS would have been useful to keep the control of their PTW.

Moreover, CBS and brake increase system would have decreased the collision speed of the PTW and would have probably reduced the risk to be injured.

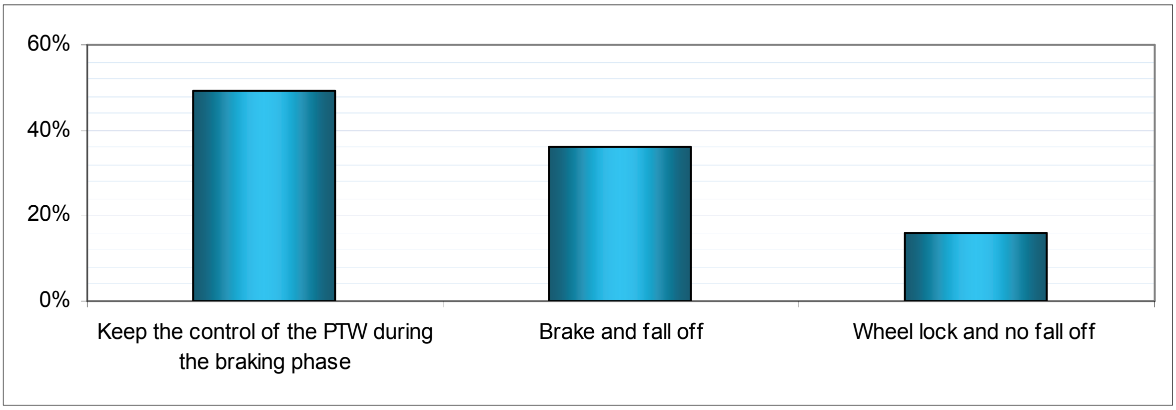


Figure 20: Consequences of the braking manoeuvre

As we said before, braking manoeuvre is the one the most tried by the rider to avoid the collision. And most of them badly performed them (36% fell down and 16% locked the wheels). This fact shows that it is necessary to help the driver in such manoeuvre. And that is why we have stressed our study on systems which can help the rider to brake.

In our sample, the number of PTW fitted with help braking systems is very low: only 7% of the PTW studied in the accidents had at least one (Figure 21). And this is the CBS which is the more fitted on the vehicle. Moreover, all these motorcycles are big engine ones.

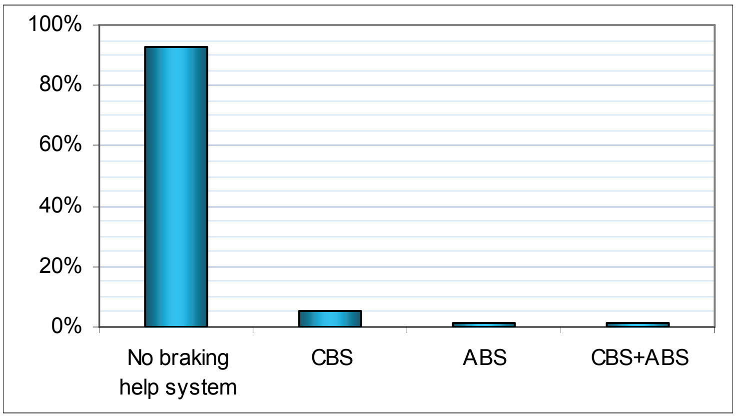


Figure 21: Rate of help braking systems fitted on PTW

Accident configurations

An accident scenario can be defined as a prototype of an accident process corresponding to a series of accidents or situations, which present overall similarities regarding the chain of facts and causal relationships throughout the various accident stages. The accident scenario is determined upon a description and an analysis of the sequential process of the accident.

Note that injury accident classification techniques depend on the objectives of the classification and on the type and volume of information available in the databases. The objectives range from the determination of general characteristics of accidents to the analysis of accident mechanisms or evaluation of the safety policies. Accidents are often classified according to a single criterion. For example, accidents can be distributed according to collision type (head-on, rear-end, front-side, side-swipe, roll-over), road geometry (crossing collisions at junctions, accidents on straight roads, loss of control in bends), vehicle configurations (single vehicle accidents, car-to-car collisions, collisions with obstacles, etc.) or even driving situations (overtaking, change of direction, loss of control, Uuturn, left-turn, right-turn, parking accidents, etc.).

The statistical results of the accident configurations give us an overview of the issues linked to each of them. And finally we can estimate the potential benefit of possible countermeasures. Moreover, such accident configurations are communication and information tools easy to understand.

The Laboratory of Accidentology and Biomechanics PSA-RENAULT (LAB) and CEESAR proposed their own accident classification based on road profile (intersection / no intersection), pre-accidental manoeuvre and type of collision. The main accident configurations are illustrated by so-called accident pictograms. The aims of such pictograms are to show specific accident situations linked to the PTW use (for instance: riding between two lanes, visibility problems, risk taking, loss of control...). And that is why this classification has been used for RIDER database. The graph below summarizes the issues by pictogram classification.

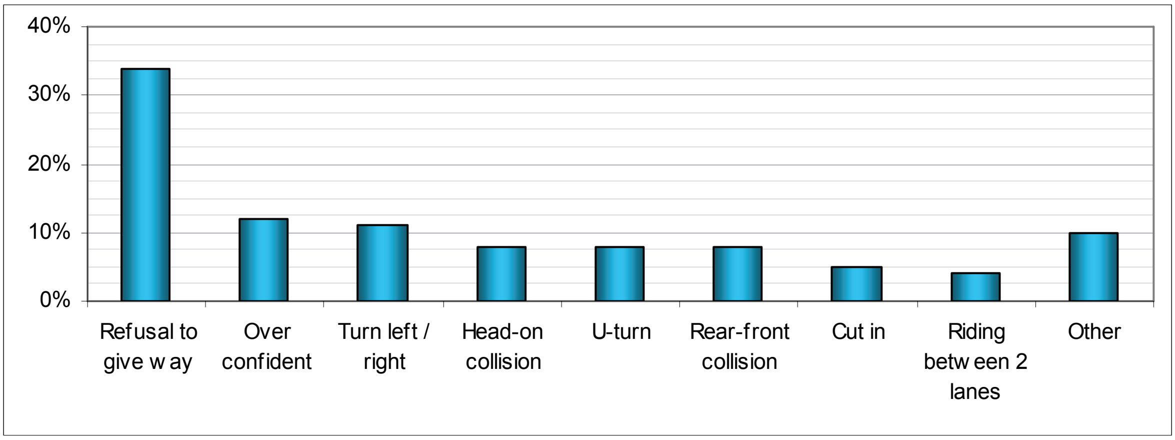
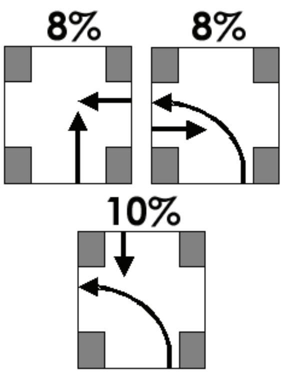


Figure 22: Accident configurations

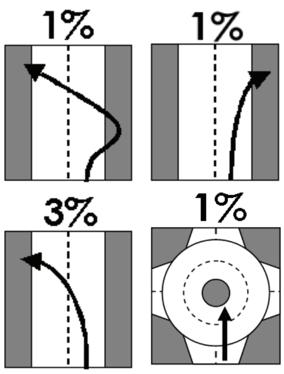
Accidents at intersection represent 50% of the accidents in RIDER database. It means that it is a big issue. And it is not surprising to see that our first pictogram category which is "refusal to give way" gathers 34% of the accidents: one driver has right of way and another one did not give it to him. Such scenario underlines a problem of inattention, speed estimation or visibility: the other vehicle does not see the PTW and the rider thinks that he is visible for the other road user. The database shows that in 75% of the accidents this is the other road user (and not the rider) who did not give the way to the PTW user.



The three pictograms on the side are the three main scenario in which there is a refusal to give way:

- A road user coming from the right at the intersection, no manoeuvre
- A road user (not the PTW) coming from the right and turning left at the intersection,
- A road user (not the PTW) coming in front of you and turning left at the intersection.

The second main accident category is the loss of control of the rider due to over confidence. In this category, the infrastructure is not the criteria which gathers the accidents but the rider behaviour such as risk taking and especially the excessive speed considering the situation. The rider is not over the legal speed limit but he is riding too fast according to the situation (traffic jam, rain, bad visibility due to weather...) and the driving experience.

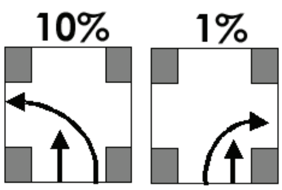


12.2% of RIDER accidents belong to this category and the four main pictograms are on the side:

- Rider ran off onto the right shoulder and crossed the opposite lane,
- Rider lost the control of his PTW on the left
- Rider lost the control of his PTW on the right
- Loss of control in a roundabout.

Of course, in these cases, all the riders are at the origin of the accidents.

11% of the accidents took place at intersection. The two road users are coming from the same way and the other road user (not the PTW) turns left or right. This category differs from the first one presented above (refusal to give way) because the two road users are driving in the same way and the problems are not the same.



Indeed, these accidents show that the other road user (not the PTW) who changes direction does not have enough information to turn left or right safely. The problem of visibility differs from the first category. The driver did not check if someone was coming from his side or he was not able to see him because of blind spot.

It has to be noted that in this category, 10% of the driver turned left whereas only 1% turned right. And 85% of the drivers (not the PTW riders) are responsible of the accidents. RIDER database study has identified the problems linked to the accident configurations: visibility and conspicuity of the PTW by the other road users combined with a specific dynamics of the vehicle (PTW) are the more relevant risk factors. Moreover, when focusing on the events at the origin of the accident, in only 1 case in 3, it is linked to the rider.

The table below summarizes the problems found for each accident configuration and proposes countermeasures to solve the problems. These ones are of course not exhaustive and can be added by other counter-measures proposed by other actors of road safety.

Table 2: Counter-measures associated to accident configurations

Accident configuration	Problems linked to the configuration	Counter-measures
- Refusal to give way - Tun left / right - Head-on - U-turn - Cut in - Roundabout	- Bad perception of the PTW - Bad visibility	- Improvement of visibility masks - Improvement of the lisibility of intersection and simplification of them
- Refusal to give way - Tun left / right - Head-on - Rear front collision - Cut in	- Lack of attention of the driver - Right of way feeling	- Communication between vehicles - Information about the PTW dynamics
- Refusal to give way - Tun left / right - Head-on - Cut in	- PTW not expected - PTW dynamics badly known	- Enforcement of PTW positionning on the road - Incentive riders to ride more slowlier - Information about the PTW dynamics
- Loss of control - Rear front collision - Riding between 2 lanes	- Risk taking from the rider	- Sanctions - Training and information on the consequences of risk taking

Conclusion

This paper has presented RIDER project and results. CEESAR PTW experts have investigated 210 French accidents, using in-depth accident analysis methodology. It means that all the accidents have been reconstructed in details in order to identify their causes and consequences. Moreover, all the information about the infrastructure, the riders, their safety equipments, their injuries and the vehicles have been collected in a complete database.

Around 1800 parameters per accident were informed.The accident investigation has begun in January 2003 and was completed in april 2005. This complete database which gives a detailed knowledge on PTW accidents has been realized thanks to the work of a multi-disciplinary team and has produced several thematic studies:

- The role of the infrastructure in PTW accidents
- PTW users protection equipments
- The crash helmet
- The emergency reaction
- The accident configurations.

The recommendations, as a result of the thematic studies, were the main purposes of the project. Therefore, we have summarized them in the following graph and we have determined to whom they are addressed.

Relevant conclusions	**Action field**
In around 80% of the cases, the manoeuvre performed to avoid the accident is badly realized	Technical improvement
To improve passive safety	
PTW not visible because of the infrastructure	
Serious injury when collision with infrastructure obstacles	
PTW protection equipments are not efficient in case of violent impact	
Inattention of the other road user (not the rider)	Information
Unexpected PTW	
PTW dynamic not familiar, risk taking	
Rate of PTW equipment protection correctly wore very low	
Wrong manœuvre choice	
Bad use of brakes	
In around 80% of the cases, the manoeuvre performed to avoid the accident is badly realized	Training
PTW rider risky behaviour	Sanction
Rate of PTW equipment protection correctly wore very low	Financial incentive
Only 7% of the PTW was fitted with braking help systems	
Poor standards for PTW protection equipments (except helmet)	Standards
Current standard for helmet can be improved	

The next step of the study will be to integrate the French accidents from MAIDS project in order to have a larger sample. And of course, it should be interesting to update the study to current accidents. Indeed, PTW fleet has increased and several passive safety equipments are now a standard for several PTW manufacturer.

Key words

Power two-wheelers, injury mechanism, PTW protection equipment, accident configuration, active safety system

1 Recherche sur les accidents Impliquant un Deux-roues motorisé – Research study on accidents involving a powered two-wheels

2 Motorcycle Accidents In-Depth Study – founded by the European Commision and the ACEM RIDER[1] – a complete study on accidents involving a powered two-wheelers: accident causations, safety equipment and injury mechanisms

3 European Commission – CARE database

4 Organisation for Economic Co-operation and Development

5 Fund by the French programme of research, experimentation and innovation in land transport and foundation – MAIF

6 Abbreviated Injury Scale – update 1998

7 SETRA is a Technical Department for Transport, Roads and Bridges Engineering and Road Safety of the French ministry for Ecology, Sustainable Development and Spatial Planning

8 NF EN 13594, NF EN 13595, NF EN 13634

9 Standards are different according to the country. In Europe, the standard is ECE E22.05

10 **A**nti-lock **B**raking **S**ystem

11 **E**lectronic **S**tability **C**ontrol

12 **E**mergency **B**rake **A**ssist

13 **C**ombined **B**rake **S**ystem

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Analysis of Motorcycle Accidents

Interdisciplinary analysis of the status quo

of motorcycle riders in Germany

Analyse des Motorradunfallgeschehens

Interdisziplinäre Analyse der Sicherheitslage

von Motorradfahrern in Deutschland

Dr.-Ing. Matthias Kühn
Unfallforschung der Versicherer

Dipl.-Ing. Matthias Körner
TU Dresden

Dipl.-Ing. Martin Unger
TU Berlin

Abstract

By order of the GDV, an interdisciplinary research project was realised from July 2006 till February 2008. The topic of the analysis was the safety situation of the driver of powered two wheelers (PTW) in Germany. In collaboration with the TU Dresden, which described the event of the accident of a motorcyclist concerning the traffic engineering, constellations and factors have been determined which led to a higher injury severity.

Based on the accident data of the insurance companies, an in-depth analysis was carried out. In addition to technical factors on the side of the motorcycle, street side factors, like alignment and curviness, were assessed regarding injury severity. Furthermore, a survey was arranged, gathering more than 6800 responses, to correlate the individual way of driving, technical attributes and the suffered injuries in an accident.

The accident relevant scenarios were determined and characterised. For example the influence of mass power ratio on injury severity was identified and added by an interrelated analysis of the sequence of accident events and habit of the motorcyclist. Basically, driver of high power, low weight motorcycles have much more severe accidents than drivers of heavy and low power motorcycles. Additionally they are overrepresented in traffic offenses like speeding or low following distance.

Consequential counteractive measures were developed. They reach from road safety education over active and passive safety devices to infrastructural measures.

Kurzfassung

Im Auftrag des GDV wurde von Juli 2006 bis Februar 2008 die Sicherheitslage der Motorradfahrer in Deutschland in einem interdisziplinären Forschungsprojekt ermittelt. Zusammen mit der TU Dresden, welche das Unfallgeschehen und die Straßenverkehrstechnik bewertete, wurden Konstellationen und Faktoren ermittelt, welche die Verletzungsschwere von Motorradfahrern beeinflussen. Basierend auf den Unfalldaten der Versicherer wurde eine in-depth Analyse durchgeführt, die fahrzeugtechnische Eigenschaften aufdeckt, welche zu einem Unfall führen und dessen Schwere beeinflussen.

Außerdem wurden die Motorradunfälle in Sachsen analysiert und ein paarweiser Vergleich von unfallauffälligen und unfallunauffälligen Streckenabschnitten durchgeführt. Darüber hinaus wurde unter 6800 Motorradfahrern eine Umfrage durchgeführt, deren Ergebnisse es ermöglichen, das Motorradfahrerverhalten im Straßenverkehr mit deren Fahrstil, motorradtechnischen Eigenschaften und den erlittenen Unfällen zu korrelieren. Neben Statistiken wurden Analysen erhoben, welche die Signifikanz einzelner Einflussfaktoren und deren Stärke auf die Unfallschwere aufzeigen.

Die im Unfallgeschehen relevanten Unfallszenarien wurden ermittelt und in ihren Eigenschaften beschrieben. So wurde z.B. der Einfluss des Leistungsgewichts auf die Verletzungsschwere betrachtet und durch die Analyse sowie Bewertung des Unfallablaufes und Ermittlung des Verhaltens des Motorradfahrers ergänzt.

Grundlegend erleiden Fahrer von Maschinen mit niedrigem Leistungsgewicht schwerwiegendere Motorradunfälle. Diese fallen häufiger in Straßenverkehrsdelikten, wie z. B. durch falsches Überholen, zu geringen Abstand oder zu hohe Geschwindigkeiten, auf. Die aus der Analyse entwickelten Gegenmaßnehmen reichen von verkehrserzieherischen Programmen auf Seiten des Motorradfahrers und Unfallgegners über infrastrukturelle Maßnahmen bis hin zu aktiven und passiven Sicherheitssystemen in der Motorradtechnik.

Analyse des Motorradunfallgeschehens

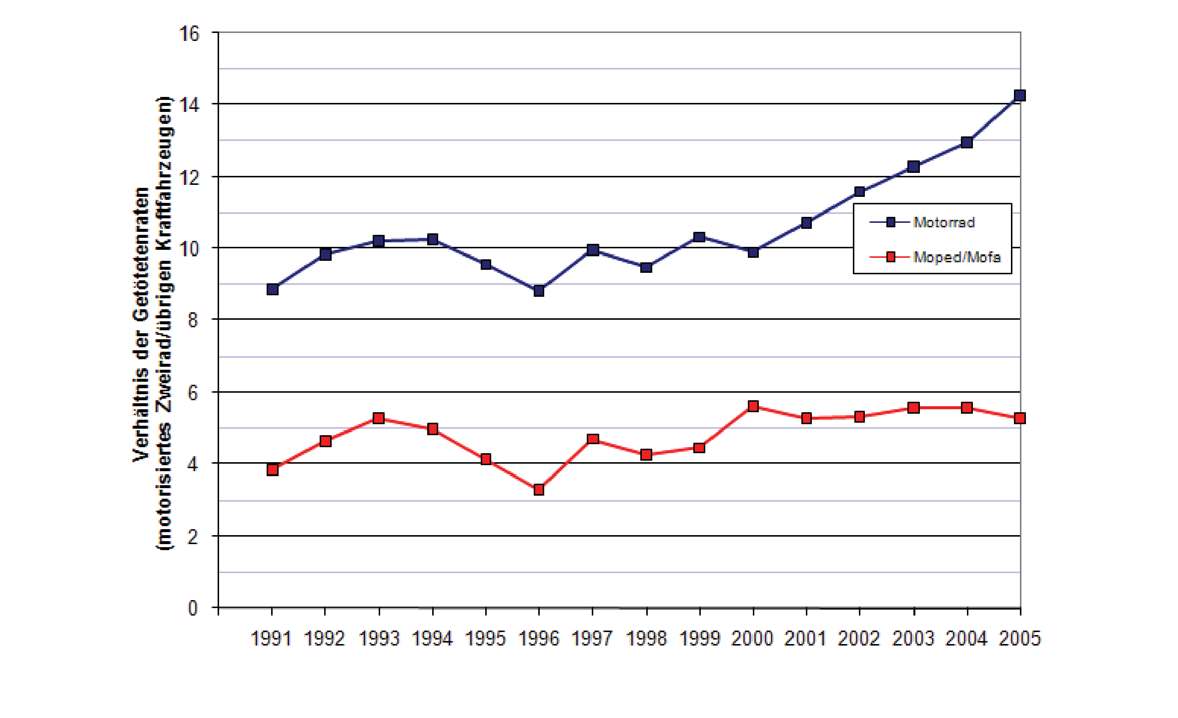
Interdisziplinäre Analyse der Sicherheitslage

von Motorradfahrern in Deutschland

Inhaltsverzeichnis

1 Einleitung

Das fahrleistungsbezogene Risiko, in einem Unfall getötet zu werden, liegt für Motorradfahrer um ein 14-faches höher als das Risiko für die übrigen Kfz-Nutzer.[1] Dieser Wert hatte sich in den letzten Jahren zum Nachteil der Kraftradfahrer noch verschlechtert.



Jahr	Moped vs. ü. Kfz	Motorrad vs. ü. Kfz	Jahr	Moped vs. ü. Kfz	Motorrad vs. ü. Kfz
1991	3,8	8,8	2005	5,3	14,3

Abbildung 1-1: Entwicklung des Verhältnisses der Getötetenrate von Motorrädern bzw. Moped/Mofas zu den übrigen Kraftfahrzeugen von 1991 bis 2005 nach [Statistisches Bundesamt 2007] und [Verkehr in Zahlen 2005/06]

Die Zahl der in Verkehrsunfällen getöteten Verkehrsteilnehmer in Deutschland ging von 1991 bis 2006 um 55% zurück. Davon profitieren Motorradfahrer allerdings erheblich weniger als andere Verkehrsteilnehmer: Während bei den Pkw-Nutzern bspw. ein Rückgang von 61% zu verzeichnen ist, ergibt sich für die Motorradnutzer nur eine Reduzierung um 20%. Deshalb untersuchte die Unfallforschung der Versicherer (UDV) gemeinsam mit dem Fachgebiet Kraftfahrzeuge der TU Berlin und der Professur für Straßenverkehrstechnik der TU Dresden die Unfallgefährdung von Motorradfahrern erstmals aus einer verknüpfenden Perspektive von Fahrzeug- und Straßenverkehrstechnik.

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[1] Deutschland, 2005

Das Ziel lag in der Ermittlung von fahrzeugtechnischen und straßenseitigen Einflussfaktoren auf Unfallgeschehen sowie Verletzungsschwere von Motorradfahrern, um durch gezielte Maßnahmen eine Angleichung der Entwicklung der Verkehrssicherheit für die Motorradbenutzer an die generelle positive Entwicklung in Deutschland erreichen zu können. Diese interdisziplinäre Verbindung ermöglicht abgestimmte Empfehlungen für Fahrzeugnutzer, Fahrzeug und Straßenraum gleichermaßen.

2 Datenbasis

Neben einer bundesweiten Analyse von über 100.000 Unfällen mit Motorradbeteiligung, die zu einer Definition von Zielgruppen genutzt wurde, sind vertiefte Untersuchungen in Sachsen durchgeführt worden, da sich das Motorradunfallgeschehen in diesem Bundesland als repräsentativ erwiesen hat (Abbildung 2-1 und Abbildung 2-2).

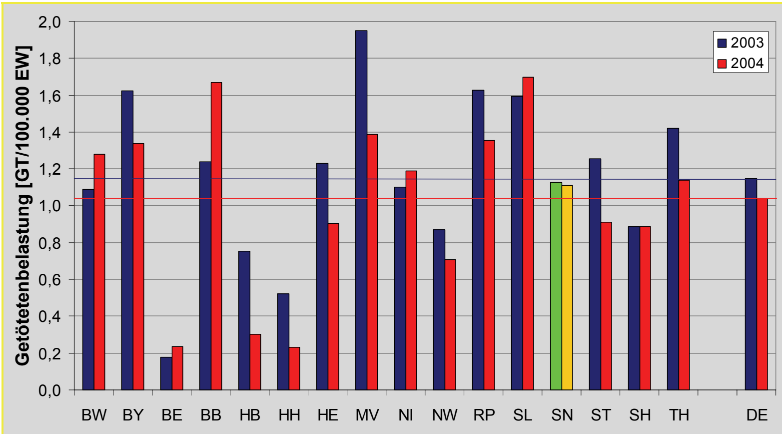


Abbildung 2-1: Getötetenbelastung nach Bundesländern für die Unfälle mit Motorradbeteiligung 2003 und 2004

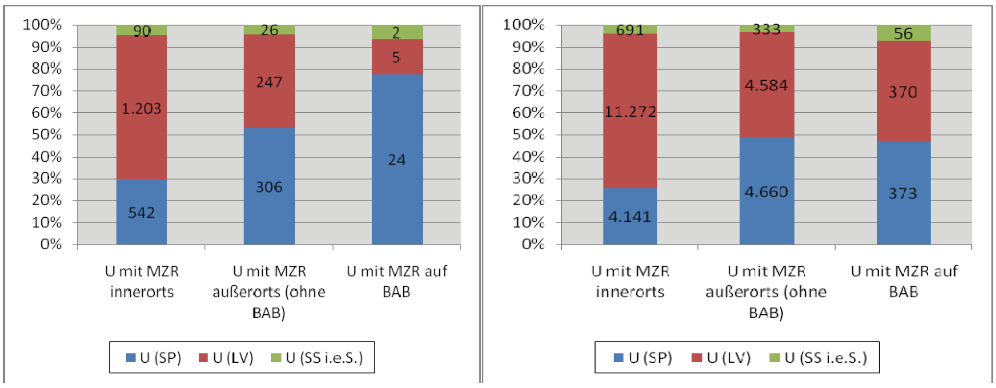


Abbildung 2-2: Vergleich der Unfallschwereverteilung in Sachsen (links) und Deutschland (rechts) für das Jahr 2005

Grundlage der örtlich detaillierten Untersuchungen sind über 12.000 Unfälle mit Beteiligung motorisierter Zweiräder in Sachsen 2004 bis 2006. Dort wurden 219 Streckenabschnitte mit 1622 Unfällen für einen paarweisen Vergleich ausgewählt: Die Hälfte der Strecken sind durch ein besonders konzentriertes Motorradunfallgeschehen aufgefallen und wurden vergleichbaren Strecken gegenübergestellt, die nicht unfallauffällig sind (Tabelle 2-1). Von diesen wurden 126 Strecken mit insgesamt 530 Motorradunfällen besichtigt und auf örtliche Umstände hin analysiert.

Tabelle 2-1: Abschnitte in Sachsen differenziert nach Ortslage (igo/ago) und Unfalldichte (UD). (mittleren Unfalldichte der ausgewählten Innerorts- bzw. Außerortsabschnitte: UD = 1,4 (igo) und 0,5 (ago) in Unfällen pro Kilometer und Jahr)

Anzahl Abschnitte			
	geringe UD	**hohe UD**	**Summe**
Innerorts	70	46	116
Außerorts	52	51	103
Summe	122	97	219
mittlere Abschnittslänge in [km]			
	geringe UD	**hohe UD**	**alle**
Innerorts	2,6	2,2	2,4
Außerorts	3,5	2,2	2,9
alle	3,0	2,2	2,6

Es zeigte sich, dass die in der (Tabelle 2-2) aufgeführten Punkte zu den das Motorradunfallgeschehen begünstigenden Straßeneigenschaften zählen.

Tabelle 2-2: Unfallbegünstigende Straßeneigenschaften

Außerorts (ago)	**Innerorts (igo)**
hohe Knotenpunktdichte	Mängel im Straßenzustand
Lage von Kuppen im Bereich von Kurven oder Knotenpunkten	auf der Fahrbahn geführter Straßenbahnverkehr
hohe Kurvigkeit	
Strecken mit großer Längsneigung	

Auf der Fahrzeugseite wurden über 1300 Datensätze aus der Unfalldatenbank der Unfallforschung der Versicherer ausgewertet, um die spezifischen Einflüsse von Fahrzeugeigenschaften und Fahrerverhalten zu beschreiben. In diesem Schritt wurden die aus der örtlichen Untersuchung erkannten typischen Unfallkonstellationen ergänzend von der Fahrzeugsicht her überprüft und generelle Erkenntnisse abgeleitet.

3 Typische Unfallkonstellationen aus Sicht der Verkehrsinfrastruktur

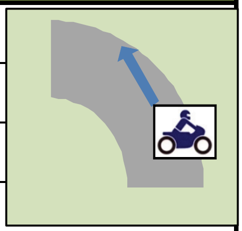
Typische Unfallkonstellationen lassen sich auf Basis von Ortslage, örtlicher Charakteristik der Unfallstelle, Unfalltyp und Unfallart bilden. Für diese Unfallkonstellationen werden Zusammenhänge zu Fahrzeug- und Fahrereigenschaften hergestellt und geeignete Empfehlungen abgeleitet. Dabei bilden die abgeleiteten Konstellationen 41% aller untersuchten Unfälle mit schwerem Personenschaden (U(SP)) ab. Das sind 36% der untersuchten U(SP) außerorts und 46% der untersuchten U(SP) innerorts.

3.1 Fahrunfälle in Außerortskurven ohne Beteiligung weiterer Verkehrsteilnehmer

Diese Unfälle sind mit einem Abkommen von der Fahrbahn nach rechts verbunden, i.d.R. handelt es sich dabei um die Durchfahrt von Linkskurven (Tabelle 3-1). Kennzeichnend sind eine hohe Schwere der Unfälle und ein hoher Anteil der Unfälle, die am Wochenende passieren. Dies zeigt, dass es sich besonders um Ausflugs- oder Freizeitverkehr handelt. Die hohe Unfallschwere hängt neben den außerorts hohen Geschwindigkeiten mit einem Aufprall auf ein Hindernis neben der Fahrbahn zusammen. In mehr als 2/3 der Fälle erfolgte ein solcher Aufprall, bei rund der Hälfte davon prallt der Motorradfahrer an eine Schutzplanke.

Tabelle 3-1: Fahrunfälle in Außerortskurven

Alleinunfall in Außerortskurve mit Abkommen von der Fahrbahn nach rechts (i.d.R. Linkskurve)	
Unfallkollektiv	28
Unfallschwere: Anteil U (SP)	68%
Anteil Hauptverursacher PTW	100%
Anteil Unfälle am Wochenende	50%

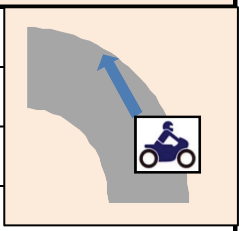


Unfall begünstigend für diese Konstellation wirken vor allem eine hohe Kurvigkeit (> 225 gon /km) sowie Fahrbahnen mit geringer Breite (< 6 m) und ohne Mittelmarkierung. Zudem wirken Kuppen sowie Steigung bzw. Gefälle im Bereich von Kurven negativ auf das Unfallgeschehen.

3.2 Fahrunfälle in Innerortskurven ohne Beteiligung weiterer Verkehrsteilnehmer

Diese Unfälle sind meist mit einem Abkommen von der Fahrbahn nach rechts verbunden und haben die höchste Unfallschwere innerorts (Tabelle 3-2). Im Gegensatz zu der entsprechenden Konstellation auf Landstraßen weist keiner der untersuchten Unfälle einen Aufprall auf ein Hindernis neben der Fahrbahn auf. Ein Anteil von mehr als 1/3 der Unfälle bei Dämmerung/Dunkelheit deutet auf einen Einfluss der Lichtverhältnisse hin.

Tabelle 3-2: Fahrunfälle in Innerortskurven

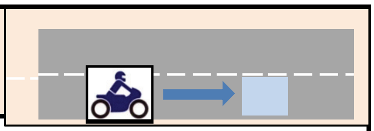
Alleinunfall in Innerortskurve mit Abkommen von der Fahrbahn nach rechts (i.d.R. Linkskurve)		
Unfallkollektiv	8	
Unfallschwere: Anteil U (SP)	63%	
Anteil Hauptverursacher PTW	100%	
Anteil Unfälle am Wochenende	13 %	

Anders als außerorts – wo Mängel im Fahrbahnbelag nicht unfallrelevant aufgefallen sind – wirken vor allem erhebliche Mängel im Straßenzustand ungünstig auf das Unfallgeschehen.

3.3 Fahrunfälle innerorts ohne besondere örtliche Charakteristik

Es handelt sich um Alleinunfälle, die vornehmlich werktags passieren. Eine deutlich ungünstige Wirkung auf das Unfallgeschehen zeigt dabei ein witterungsbedingt schlechter Straßenzustand, vor allem Nässe auf der Fahrbahn (Tabelle 3-3). Im Straßenraum besitzen insbesondere Abschnitte mit straßenbündigem Bahnkörper oder kreuzende Gleisanlagen einen ungünstigen Einfluss. Das Befahren der Schienen in Kombination von Nässe erweist sich für den motorisierten Zweiradfahrer als problematisch. Über 90% dieser Unfälle sind mit Personenschaden, fast die Hälfte davon mit schwerem Personenschaden ausgegangen.

Tabelle 3-3: Fahrunfälle innerorts

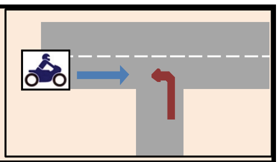
Fahrunfall innerorts anderer Art ohne Charakteristik	
Unfallkollektiv	12
Unfallschwere: Anteil U (SP)	42%
Anteil Hauptverursacher PTW	100%
Anteil Unfälle am Wochenende	16%

Innerorts handelt es sich zu einem großen Teil um Berufsverkehr, der auch bei schlechter Witterung auf seine Maschine angewiesen ist. Außerorts hat sich keine analoge Unfallkonstellation herausgebildet.

3.4 Vorfahrtunfälle an Kreuzungen oder Einmündungen innerorts

Schwerpunktmäßig sind dies Unfälle an vorfahrtgeregelten Knotenpunkten an Werktagen, wobei dem motorisierten Zweiradfahrer auf der übergeordneten Straße die Vorfahrt genommen wird. Sichteinschränkungen z.B. durch parkende Fahrzeuge am Fahrbahnrand wirken häufig mit (Tabelle 3-4). Verglichen mit der analogen Außerortskonstellation ist die Unfallschwere deutlich geringer.

Tabelle 3-4: Vorfahrtunfälle an Kreuzungen und Einmündungen innerorts

Einbiegen/Kreuzen-Unfall innerorts an Kreuzungen oder Einmündungen	
Unfallkollektiv	61 (TU Dresden) / 135 (TU Berlin)
Unfallschwere: Anteil U (SP)	25% (TU Dresden) / 76% (TU Berlin)
Anteil Hauptverursacher PTW	25% (TU Dresden) / 20% (TU Berlin)
Anteil Unfälle am Wochenende	11% (TU Dresden) / 50% (TU Berlin)

Dabei lässt sich für Einmündungen eine typische Unfallsituation ableiten: Der Fahrer des motorisierten Zweirades nähert sich auf der übergeordneten Straße von links und wird von dem links einbiegenden Pkw zu spät wahrgenommen. Eine besondere Ausprägung ist zu beobachten, wenn die übergeordnete Straße in mindestens einer Richtung Stau oder stockenden Verkehr aufweist. Dem links einbiegenden Pkw oder Lkw der untergeordneten Straße wurde durch ein in der Kolonne stehendes Fahrzeug eine Einbiegemöglichkeit signalisiert. Bei diesem Manöver näherte sich ein in zweiter Reihe an der Kolonne vorbeifahrendes motorisiertes Zweirad, wodurch es zum Unfall kam.

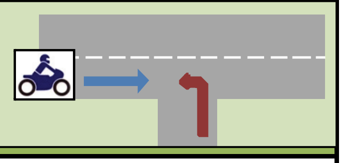
Die Dunkelheit wirkt sich auf solche Unfälle an vorfahrtgeregelten Kreuzungen ungünstig aus. Dabei deutet sich bei dunklen Lichtverhältnissen eine Beeinträchtigung der Sicht der Motorradfahrer an, die möglicherweise auch durch den Helm verstärkt wird.

Die Untersuchung der Zielgruppen bei den Motorradbenutzern lässt eine hohe Beteiligung von jugendlichen Fahrern und Fahranfängern erkennen. Die Beteiligung dieser Gruppen steigt bei den Unfällen mit Hauptverursachung durch den motorisierten Zweiradfahrer noch einmal deutlich an. Des Weiteren sind Rollerfahrer mit einem etwa doppelt so hohen Anteil gegenüber ihrem Auftreten in den anderen Unfallkonstellationen überrepräsentiert.

3.5 Vorfahrtunfälle an Einmündungen außerorts

Bei den Unfällen an Vorfahrtknoten nähert sich der Motorradfahrer vornehmlich von links dem Knotenpunkt auf der übergeordneten Straße, ist vorfahrtberechtigt und wird von dem links einbiegenden Pkw aufgrund von Fehleinschätzung der Geschwindigkeit oder zu schlechter Sichtverhältnisse zu spät wahrgenommen (Tabelle 3-5). Eine überhöhte Geschwindigkeit des Motorradfahrers trägt zu dem Zustandekommen des Unfalles bei und führt zu einer höheren Unfallschwere.

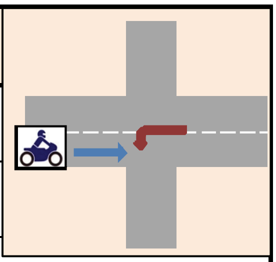
Tabelle 3-5: Vorfahrtunfälle an Einmündungen außerorts

Einbiegen/Kreuzen-Unfall außerorts an einer Einmündung	
Unfallkollektiv	9 (TU Dresden) / 80 (TU Berlin)
Unfallschwere: Anteil U (SP)	55% (TU Dresden) / 84% (TU Berlin)
Anteil Hauptverursacher PTW	22% (TU Dresden) / 9% (TU Berlin)
Anteil Unfälle am Wochenende	33% (TU Dresden) / 29% (TU Berlin)

3.6 Abbiegeunfälle an Kreuzungen innerorts und Zusammenstoß mit einem entgegenkommenden Fahrzeug

Der typische Unfallhergang ereignet sich werktags an Kreuzungen mit LSA-Regelung. Der links abbiegende Pkw als Hauptverursacher übersieht das entgegenkommende vorfahrtberechtigte motorisierte Zweirad (Tabelle 3-6). Nach Auswertung der Unfalltexte kann davon ausgegangen werden, dass in diesen Fällen das Linksabbiegen nicht mit einer eigenen Phase abgesichert war. Die beschriebene Unfallsituation ist zusätzlich auch an vorfahrtgeregelten Kreuzungen anzutreffen. Die Unfallschwere dieser Unfälle ist mit einem Anteil von rund 1/4 der Unfälle mit schwerem Personenschaden hoch.

Tabelle 3-6: Abbiegeunfälle an Kreuzungen innerorts

Abbiegeunfall innerorts an Kreuzungen mit entgegenkommenden Kfz		
Unfallkollektiv	21 (TU Dresden) / 39 (TU Berlin)	
Unfallschwere: Anteil U (SP)	24% (TU Dresden) / 88% (TU Berlin)	
Anteil Hauptverursacher PTW	14% (TU Dresden) / 33% (TU Berlin)	
Anteil Unfälle am Wochenende	15% (TU Dresden) / 20% (TU Berlin)	

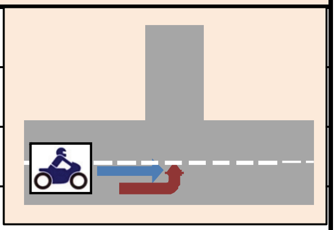
Der Blick auf die untersuchten Zielgruppen zeigt eine hohe Beteiligung von jugendlichen Fahrern. Da auch schlechtes Wetter häufig auftritt, ist anzunehmen, dass ein nasser oder winterglatter Straßenzustand für jugendliche Fahrer ein besonderes Problem darstellt. Fahrer von Naked Bikes und von Sportmaschinen besitzen bei diesen Unfällen höhere Verletzungsschweren als die Fahrer anderer Motorradtypen.

Ungünstige Einflussfaktoren des Straßenraumes sind für diese Konstellation insbesondere die Mängel im Straßenzustand oder Schienen auf der Fahrbahn. Das Auftreten dieser Unfälle auf Abschnitten mit einer zulässigen Höchstgeschwindigkeit über 50 km/h deutet daraufhin, dass ein Teil der Unfälle bzw. deren Schwere auch durch eine hohe Geschwindigkeit der vorfahrtberechtigten motorisierten Zweiradfahrer mit verursacht wird.

3.7 Abbiegeunfälle an Einmündungen innerorts und Zusammenstoß mit einem Fahrzeug, das seitlich in gleicher Richtung fährt

Diese typische Unfallsituation tritt werktags an vorfahrtgeregelten Einmündungen auf und ist durch links abbiegende Pkw beschrieben, die mit einem im Überholvorgang befindlichen motorisiertem Zweirad kollidieren, welches sich in gleicher Richtung von hinten nähert (Tabelle 3-7). Die Ursachen liegen zum einen beim Pkw-Fahrer, der spät sein Abbiegevorhaben signalisiert oder verbotenerweise abbiegt, zum anderen aber auch beim motorisierten Zweiradfahrer, der im Bereich von Knotenpunkten Überholmanöver durchführt.

Tabelle 3-7: Abbiegeunfälle an Einmündungen innerorts

Abbiegeunfall innerorts an Einmündungen mit seitlich in gleicher Richtung verkehrenden Kfz		
Unfallkollektiv	9 (TU Dresden) / 57 (TU Berlin)	
Unfallschwere: Anteil U (SP)	11% (TU Dresden) / 75% (TU Berlin)	
Anteil Hauptverursacher PTW	11% (TU Dresden) / 21% (TU Berlin)	
Anteil Unfälle am Wochenende	22% (TU Dresden) / 68% (TU Berlin)	

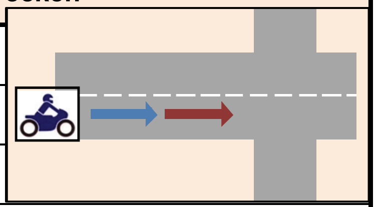
Als straßenseitig zusätzlich ungünstig wirkende Einflussfaktoren zeigen sich deutlich Abschnitte mit Straßenbahnverkehr in straßenbündiger Mittellage sowie Abschnitte mit erheblichen Mängeln im Straßenzustand.

3.8 Auffahrunfälle an Kreuzungen, Einmündungen oder Gefällestrecken innerorts

Kennzeichnend für Auffahrunfälle sind eine geringe Unfallschwere sowie ein Werktag als Unfalltag. Der motorisierte Zweiradfahrer ist i.d.R. der Hauptverursacher und kollidiert mit dem verkehrsbedingt haltenden oder abbremsenden Pkw (Tabelle 3-8). Stürze resultieren hierbei bspw. aus Sand, Öl oder Nässe auf der Fahrbahn, den Markierungen auf den Fahrstreifen oder einem zu starken Abbremsen des motorisierten Zweirades.

Tabelle 3-8: Auffahrunfälle innerorts

Auffahrunfall innerorts an Kreuzungen, Einmündungen und Gefällestrecken	
Unfallkollektiv	36
Unfallschwere: Anteil U (SP)	8%
Anteil Hauptverursacher PTW	78%
Anteil Unfälle am Wochenende	17%



Unfälle, bei denen ein Pkw einem motorisierten Zweirad auffährt, treten selten auf, führen aber häufiger zu einem Personenschaden. Insgesamt sind vor allem die Fahranfänger sowie jugendliche Fahrer besonders stark in dieser Konstellation vertreten.

Weitere Auffahrunfälle innerorts ohne besondere örtliche Charakteristik, bei denen sich die Hauptverursachung nicht so deutlich auf die Zweiradfahrer konzentriert, ereignen sich häufig an LSA in Betrieb. Jugendliche Fahrer weisen eine hohe Beteiligung an den Unfällen dieser Konstellation auf.

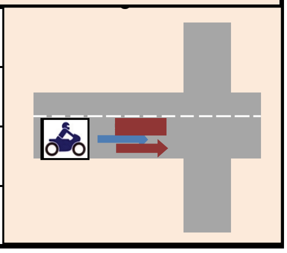
Bei den untersuchten Straßeneigenschaften zeigen sich generell hohe Anteile an solchen Auffahrunfällen auf Abschnitten mit erheblichen Mängeln im Straßenzustand oder mit Straßenbahnverkehr auf der Fahrbahn.

3.9 Längsverkehrsunfälle innerorts mit einem Zusammenstoß von seitlich in gleicher Richtung verkehrenden Kfz

Diese Unfallkonstellation weist die geringste Unfallschwere aller untersuchten Konstellationen auf. Der Großteil der Unfälle passiert werktags. In 60% der Fälle ist der motorisierte Zweiradfahrer Hauptverursacher (Tabelle 3-9). Der häufigste Unfallhergang resultiert aus einem Konflikt bei Fahrstreifenwechselvorgängen. Die restlichen Unfälle sind in verschiedenen Konfliktsituationen begründet.

Die Betrachtung der Zielgruppen ergibt eine überdurchschnittliche Beteiligung der Kraftrollerfahrer. Die Unfälle ereignen sich häufiger als im Durchschnitt auf Straßen mit zweistreifigen Richtungsfahrbahnen sowie auf Abschnitten mit kreuzenden Gleisanlagen.

Tabelle 3-9: Längsverkehrsunfälle innerorts

Unfälle mit seitlich in gleicher Rtg. verkehrenden Kfz an Kreuzungen oder Einmündungen sowie ohne Charakteristik innerorts		
Unfallkollektiv	35	
Unfallschwere: Anteil U (SP)	6 %	
Anteil Hauptverursacher PTW	60 %	
Anteil Unfälle am Wochenende	23 %	

3.10 Maßnahmenvorschläge zu den Unfallkonstellationen

Für diese charakteristischen Unfallkonstellationen lassen sich die in der folgenden Tabelle zusammengefassten Maßnahmen ableiten.

Tabelle 3-10: Maßnahmevorschläge bezogen auf die abgeleiteten Unfallkonstellationen

Unfallkonstellation	Maßnahmen
1. Fahrunfälle in Kurven ago ohne Beteiligung weiter Verkehrsteilnehmer (siehe Abschnitt 3.1)	hindernisfreier Seitenraum in der Kurvenaußenseite Beseitigung nicht erforderlicher passiver Schutzeinrichtungen Einsatz motorradfreundlicher passiver Schutzeinrichtungen
2. Fahrunfälle igo ohne besondere örtliche Charakteristik (siehe Abschnitt 3.2)	Beseitigung von Fahrbahnschäden Verdeutlichung der Linienführung (besonders bei Dunkelheit) Geschwindigkeitsbeschränkung und -überwachung (betrifft vor allem die PTW-Fahrer)
3. Fahrunfälle igo ohne besondere örtliche Charakteristik (siehe Abschnitt 3.3)	Beseitigung von Straßenschäden Schulung der Fahrer von PTW (insb. Bremsvorgänge) Promotion Motorräder mit ABS
4. Vorfahrtunfälle an Kreuzungen oder Einmündungen igo (siehe Abschnitt 3.4)	keine Anordnung von Parkbuchten/Parkflächen auf der übergeordneten Fahrbahn im Bereich von Knotenpunkten Verbesserte Ausbildung von Fahranfängern (insb. Fahren bei Dunkelheit)
5. Vorfahrtunfälle an Einmündungen ago (siehe Abschnitt 3.5)	Überprüfung unfallauffälliger Knotenpunkte auf Erkennbarkeit, Begreifbarkeit und Sicht Beseitigung von Sichteinschränkungen Geschwindigkeitsbeschränkung und -überwachung (betrifft vor allem die PTW-Fahrer auf der übergeordneten Straße)
6. Abbiegeunfälle an Kreuzungen igo und Zusammenstoß mit einem entgegenkommenden Fahrzeug (siehe Abschnitt 3.6)	Einrichtung einer eigenen Phase für Linksabbieger Schulung des Bewusstseins für Motorradfahrer beim Unfallgegner
7. Abbiegeunfälle an Einmündungen igo und Zusammenstoß mit einem Fahrzeug, das seitlich in gleicher Richtung fährt (siehe Abschnitt 3.7)	Anordnung von Linksabbiegestreifen auf den übergeordneten Zufahrten Schulung der PTW-Fahrer, dass im Bereich von Knotenpunkten nicht überholt werden darf Schulung des Bewusstseins für Motorradfahrer beim Unfallgegner
8. Auffahrunfälle an Kreuzungen, Einmündungen oder Gefällestrecken igo (siehe Abschnitt 3.8)	Verbesserte Ausbildung von Fahranfängern (insb. Bremsvorgänge) Promotion Motorräder mit ABS
9. Längsverkehrsunfälle igo mit einem Zusammenstoß von seitlich in gleicher Richtung verkehrenden Kfz (siehe Abschnitt 3.9)	Schulung des gegenseitigen Bewusstseins sowohl beim Fahrer des PTW als auch beim Unfallgegner

4 Motorradfahrerbefragung

Zur Ermittlung des Fahrverhaltens von Motorradfahrern wurde ein Fragebogen entwickelt, der in ca. 40 Punkten Fragen zur Einstellung zum Motorradfahren, zu begangenen Ordnungswidrigkeiten im Straßenverkehr und erlittenen Unfällen sowie den daraus resultierenden Verletzungen stellt. Im Zusammenhang mit den technischen Eigenschaften der jeweiligen Fahrzeuge und den individuellen personenbezogenen Unterschieden der dazugehörigen Fahrzeugführer soll die empirische Datenbasis Aufschluss darüber geben, inwieweit es Auffälligkeiten bei bestimmten Personengruppen, Fahrzeugkategorien oder kategorieübergreifenden Fahrzeugeigenschaften auch mit auftretenden Interaktionseffekten gibt.

Die Datenerhebung fand im Zeitraum vom 19.01.2007 bis zum 18.02.2007 ausschließlich im Internet unter www.motorradumfrage.de per Online-Befragung statt. Der Aufruf dazu wurde in dem 14-tägig erscheinenden Motorradmagazin „MOTORRAD", Ausgabe 03/07, mit einem doppelseitigen Hinweis zum Projekt gedruckt. Bei einer Auflage von 146.000 Exemplaren und einer Teilnehmerzahl von 6.879 mit teils unvollständig beantworteten Fragebögen ergibt sich eine beachtliche Rückmeldequote von 4,7%. Mit den 5.297 vollständig ausgefüllten Fragebögen ergibt sich immer noch eine Rückmeldequote von 3,6%.

Von den Motorradfahrern der 5.297 vollständigen Datensätzen haben 2.983 Personen bereits einen Unfall erlitten. Dies entspricht einem Anteil von 56,3%. Bei einem Frauenanteil von 5,5% ($n = 293$) haben nur $n = 105$ weibliche Motorradfahrer einen Unfall erlitten. Dies entspricht einem Anteil von 35,8%.

Die Befragung ermöglicht eine Aussage zur Dunkelzifferproblematik im Zusammenhang mit nicht polizeilich erfassten Unfällen: Von den 2555 angegebenen Unfällen, zu denen nähere Angaben gemacht wurden, erfolgte in 49% der Fälle keine polizeiliche Aufnahme. 69% davon sind Alleinunfälle. Werden allein die Unfälle betrachtet, bei denen der Motorradfahrer eine Verletzung davon trug, verbleibt eine Dunkelziffer von 33%. Diese sinkt bei alleiniger Betrachtung der Unfälle mit schwer verletzten Motorradfahrern auf 14%.

4.1 Altersverteilung

Betrachtet man die Altersverteilung (Abbildung 4-1) der Personen, die an der Befragung teilgenommenen haben, so ist zu erkennen, dass auch hier der allgemeine Trend zum immer älter werdenden Motorradfahrer bestätigt wird.

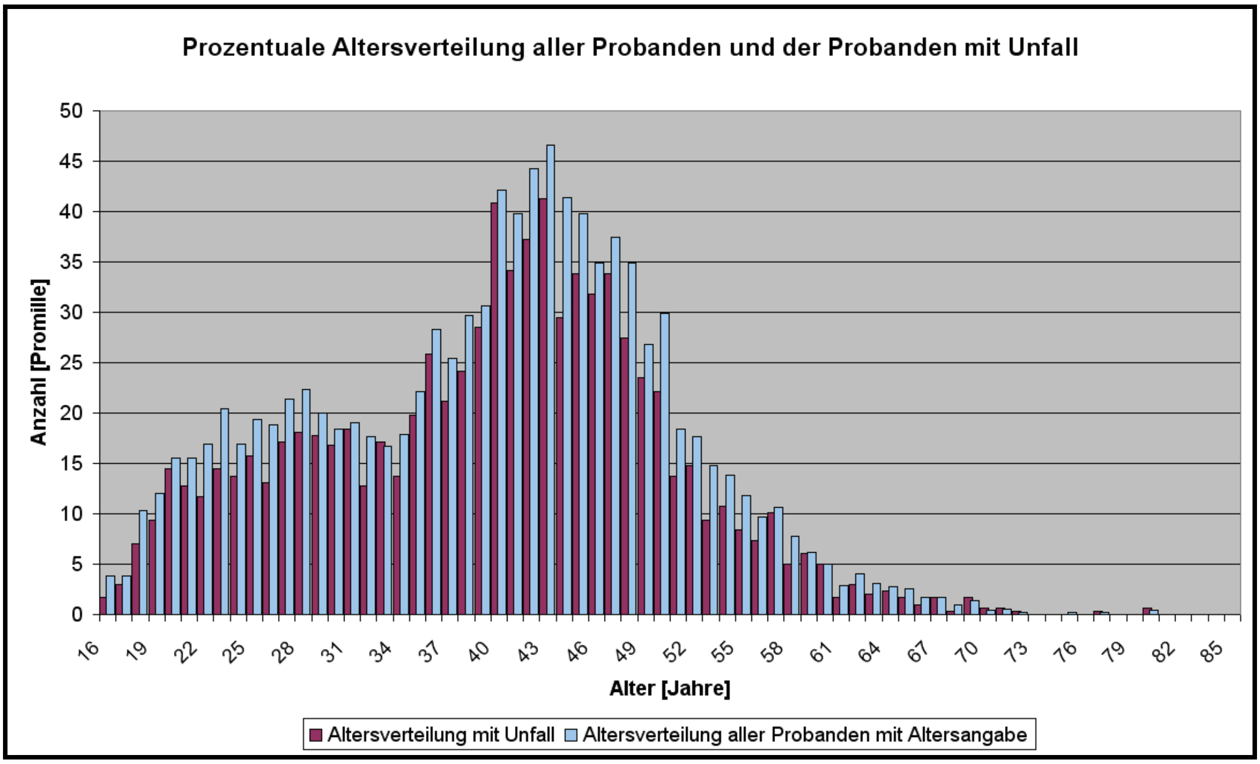


Abbildung 4-1: Altersverteilung der Teilnehmer an der Befragung

Ein Großteil der Motorradfahrer ist zwischen 35 und 50 Jahren alt. Betrachtet man die Altersverteilung der Motorradfahrer mit Unfall in der Stichprobe, so ist zu erkennen, dass keine Altersgruppe besonders über- oder unterrepräsentiert ist.

4.2 Motivation zum Motorradfahren

Knapp die Hälfte der Antworten auf die Frage, aus welchem Grund Motorrad gefahren wird, waren auf die Fahrdynamik des Motorrades ausgerichtet. So wurden Kurvenfahrt und Beschleunigung als Hauptmotivationen zum Motorradfahren genannt. Die erzielbare Geschwindigkeit selbst ist mit 8% von untergeordneter Bedeutung. Eine zweite Hauptmotivation des Motorradfahrens ist die empfundene Freiheit als Aufsasse eines Zweirades (Abbildung 4-2).

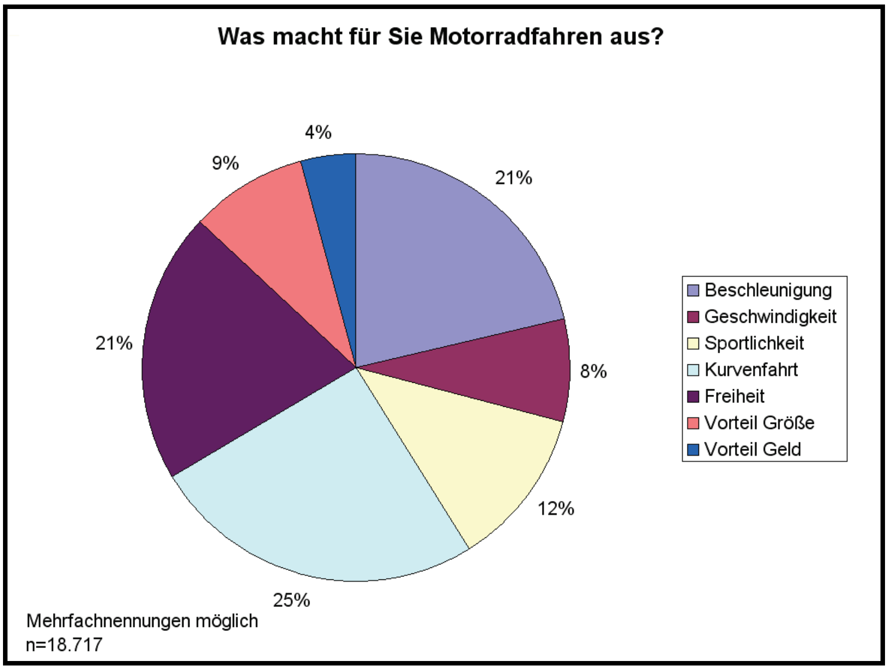


Abbildung 4-2: Motivation zum Motorradfahren

Betrachtet man die Aussagen jedoch differenziert über die Motorradtypen (Abbildung 4-3), so wird ersichtlich, dass Fahrer der unterschiedlichen Klassen andere Anforderungen an das Fortbewegungsmittel stellen und gerade daher auch einen bestimmten Motorradtyp benutzen. Chopperfahrer schätzen besonders die Freiheit auf einem Motorrad, wogegen Sportmaschinenfahrer im Vergleich zu den anderen Segmenten verstärkt die Sportlichkeit und Geschwindigkeit ihrer Motorräder in den Mittelpunkt stellen. Die auffälligste Abweichung ist im Rollersegment zu finden. Diese Personengruppe hat besonders den Kosten- und Größenvorteil in den Vordergrund gestellt.

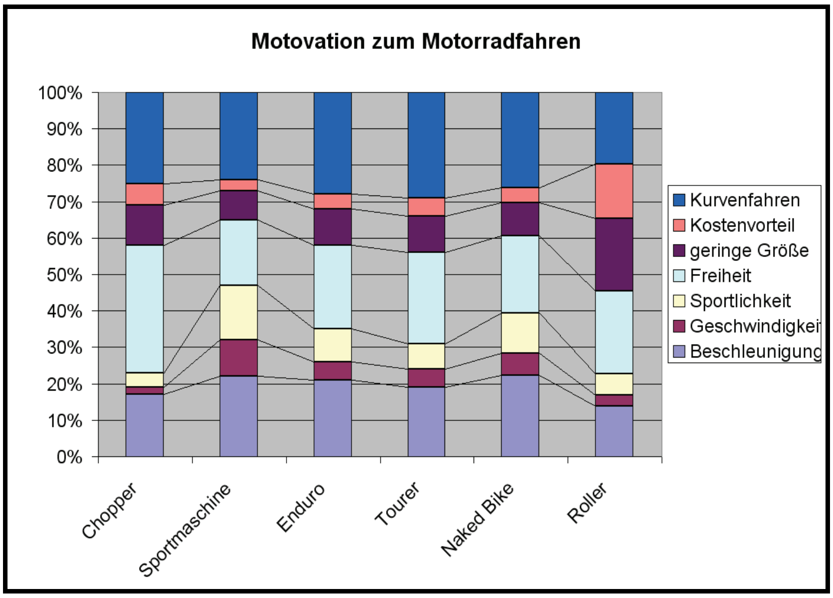


Abbildung 4-3: Differenzierung der Motivation zum Motorradfahren nach Motorradtyp

4.3 Verkehrsverstöße

Um eine Korrelation zwischen Verkehrsauffälligkeit und Unfallhäufung/-schwere aufstellen zu können, wurden die Motorradfahrer auch nach den begangenen Verkehrsverstößen befragt. Um unter den verschiedenen Motorradsegmenten einen Vergleich zu ermöglichen, wurden die jeweiligen Einzelfälle auf die Antworthäufigkeit in dem Segment in der Umfrage bezogen. So ist zu erkennen, dass Fahrer von Sportmaschinen ein wesentlich höheres Risiko in Kauf nehmen, wegen eines Verkehrsverstoßes belangt zu werden als Fahrer anderer Motorradtypen (Abbildung 4-4). Als Verstoß sind dabei Vergehen wie z.B. überhöhte Geschwindigkeit oder zu geringer Abstand zu verstehen.

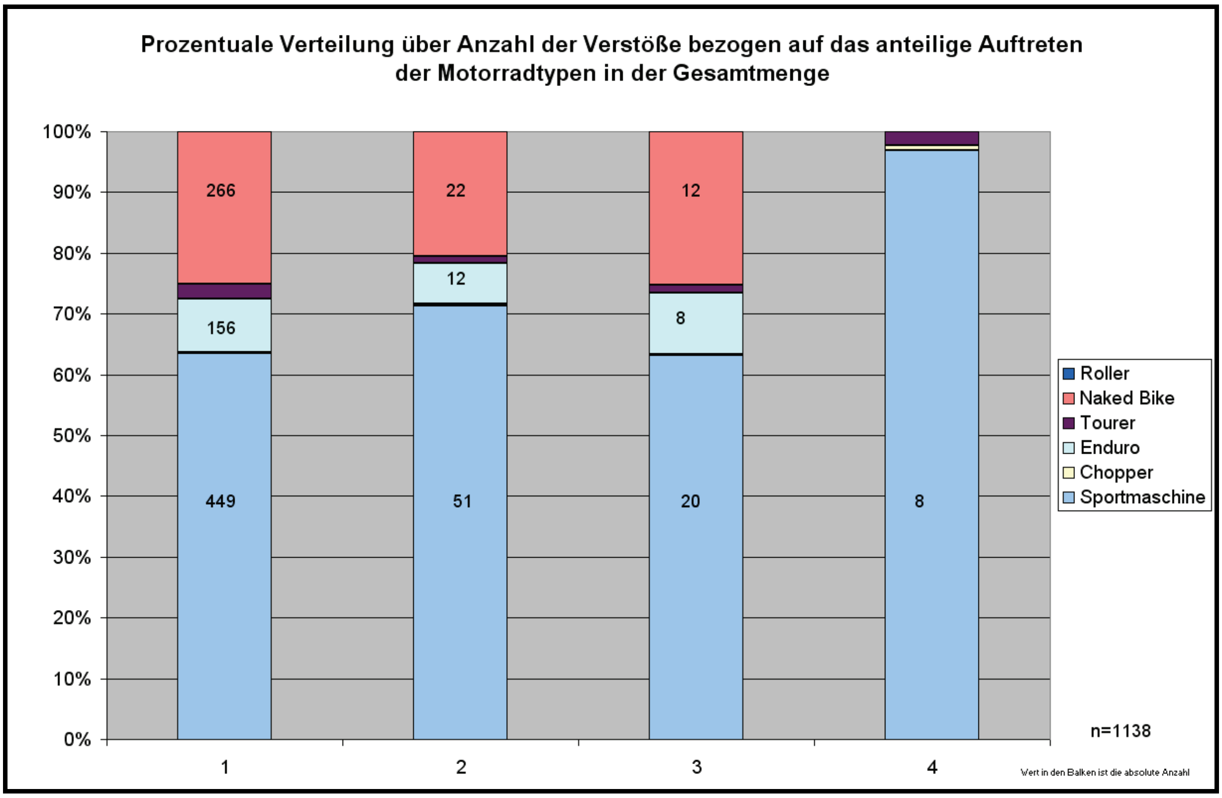


Abbildung 4-4: Anzahl der Verkehrsverstöße der Befragten über Motorradtyp

Dabei werden größtenteils Regelverstöße wegen zu schnellen Fahrens verübt (Abbildung 4-5). Danach folgen Verstöße auf Grund von falschem Überholen und Mängel an den Fahrzeugen, die nach Sportmaschinen und Naked Bikes mit abgefahrenen Reifen und zu lauten Auspuffanlagen bei Choppern gegliedert werden können.

Die Verstöße wegen zu schnellen Fahrens und riskanter Überholvorgänge können ein Zeichen dafür sein, dass besonders leistungsstarke Motorräder den Fahrer dazu verleiten, nicht jederzeit den Verkehrsregeln entsprechend zu fahren. Dieses Phänomen kann losgelöst von den Fahrzeugtypen auf das Leistungsgewicht bezogen beobachtet werden (Abbildung 4-6). Je geringer das Masse-Leistungs-Verhältnis, desto eher wird der Fahrer durch Geschwindigkeits- oder Überholverstöße auffällig. Das starke Schwanken bei den höheren Leistungsgewichten ist durch die geringen Anzahlen innerhalb der Gruppen zu erklären.

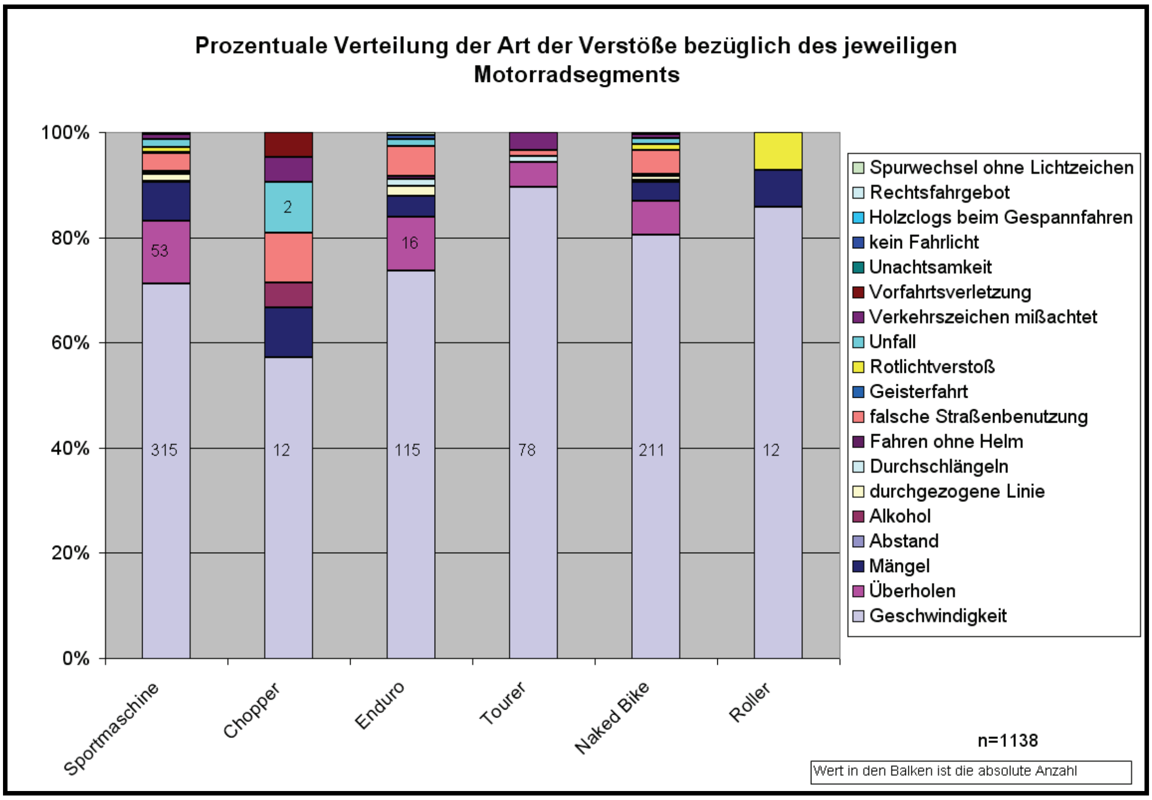


Abbildung 4-5: Art der Verkehrsverstöße

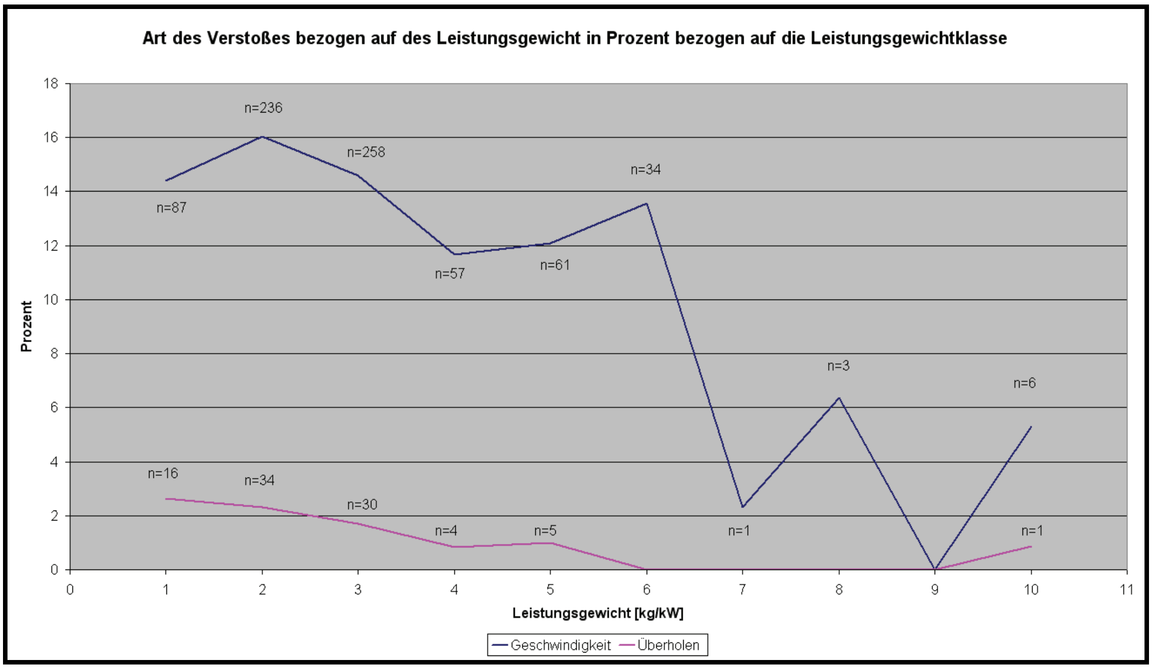


Abbildung 4-6: Art des Verstoßes über das Leistungsgewicht

Für die Verteilung der Alleinunfälle bezogen auf Leistungsgewicht und Ortslage (Abbildung 4-7) ist zu erwähnen, dass sich mit steigendem Leistungsgewicht prozentual mehr Alleinunfälle in geschlossenen Ortschaften ereignen. Fahrer leichter und leistungsstarker Motorräder erleiden außerhalb geschlossener Ortschaften häufiger einen Alleinunfall als Fahrer schwerer und leistungsschwächerer Maschinen.

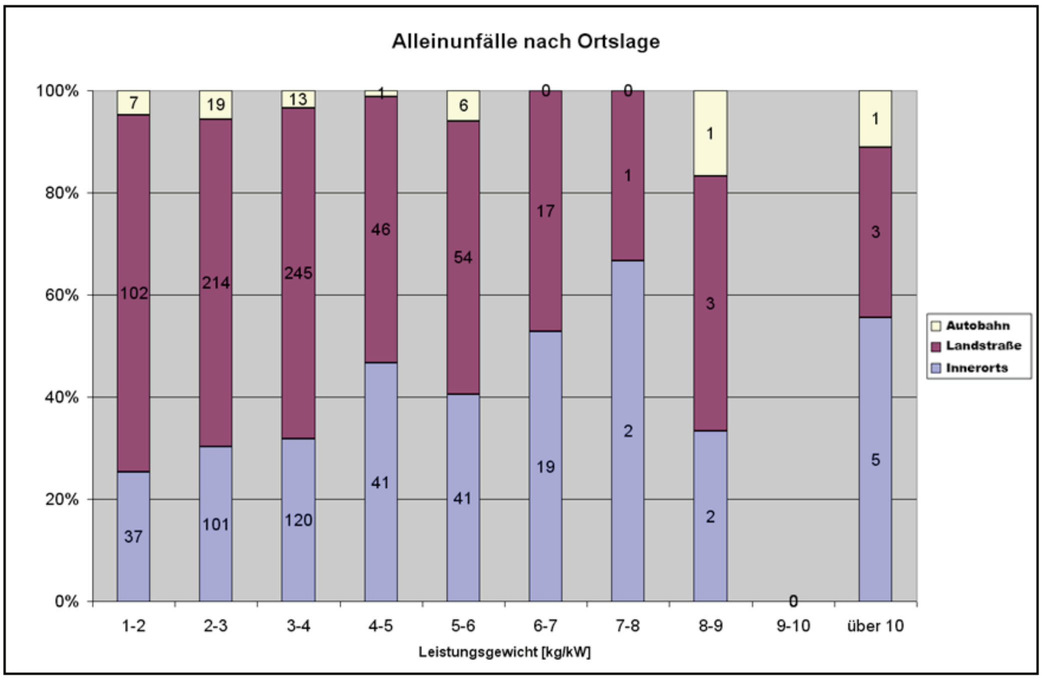


Abbildung 4-7: Alleinunfälle nach Leistungsgewicht und Ortslage

Ein Zusammenhang mit der Verletzungsschwere kann nicht dargestellt werden, da die meisten berichteten Unfälle ohne oder mit leichten Verletzungen geschehen sind. Nur ein kleiner Teil der Fälle beinhaltet schwer verletzte Personen. Getötete Motorradfahrer sind in der Datenmenge nicht enthalten. Eine statistische Auswertung, bezogen auf die Verletzungsschwere, führte zu keinen relevanten Aussagen.

5 Unfallgeschehen aus Sicht der Fahrzeugtechnik

Die Unfallforschung der Deutschen Versicherung führt eine detaillierte Unfalldatenbank, die unter bestimmten Gesichtspunkten aus den gemeldeten Schadensfällen der versicherten Personen gespeist wird. Mit 1.304 Einzeldatensätzen steht eine umfangreiche Datenbasis zur Auswertung zur Verfügung. Pro Datensatz sind zum Thema Motorrad bis zu 141 Merkmale abgelegt. Es wurden ausschließlich Unfälle mit Personenschaden und einem Schadenaufwand von mindestens 15.000€ berücksichtigt, wodurch die hohen Unterschiede in den Unfallschweren (vgl. Abschnitt 3) zu erklären sind.

Durch die starke Spezialisierung der im Abschnitt 3 abgeleiteten Konstellationen durch Örtlichkeit, Unfalltyp und Unfallart sind die Häufigkeiten in den Datensätzen der Fahrzeugtechnik deutlich herabgesetzt. Für eine Auswertung (Abschnitt 5.1 und 5.2) werden nur solche Konstellationen herangezogen, bei denen mehr als 30 Fälle auftreten. Für die detaillierte Auswertung werden daher die Unfallkonstellationen der Abschnitte 3.4, 3.5, 3.6 und 3.7 näher betrachtet.

5.1 Verletzungsschwereverteilung

Die Verteilung der MAIS-Werte[2] (Abbildung 5-1) zeigt, dass es bei Vorfahrtunfällen außerhalb geschlossener Ortschaften an Einmündungen vermehrt zu tödlichen Unfällen und sehr schweren Verletzungen kommt.

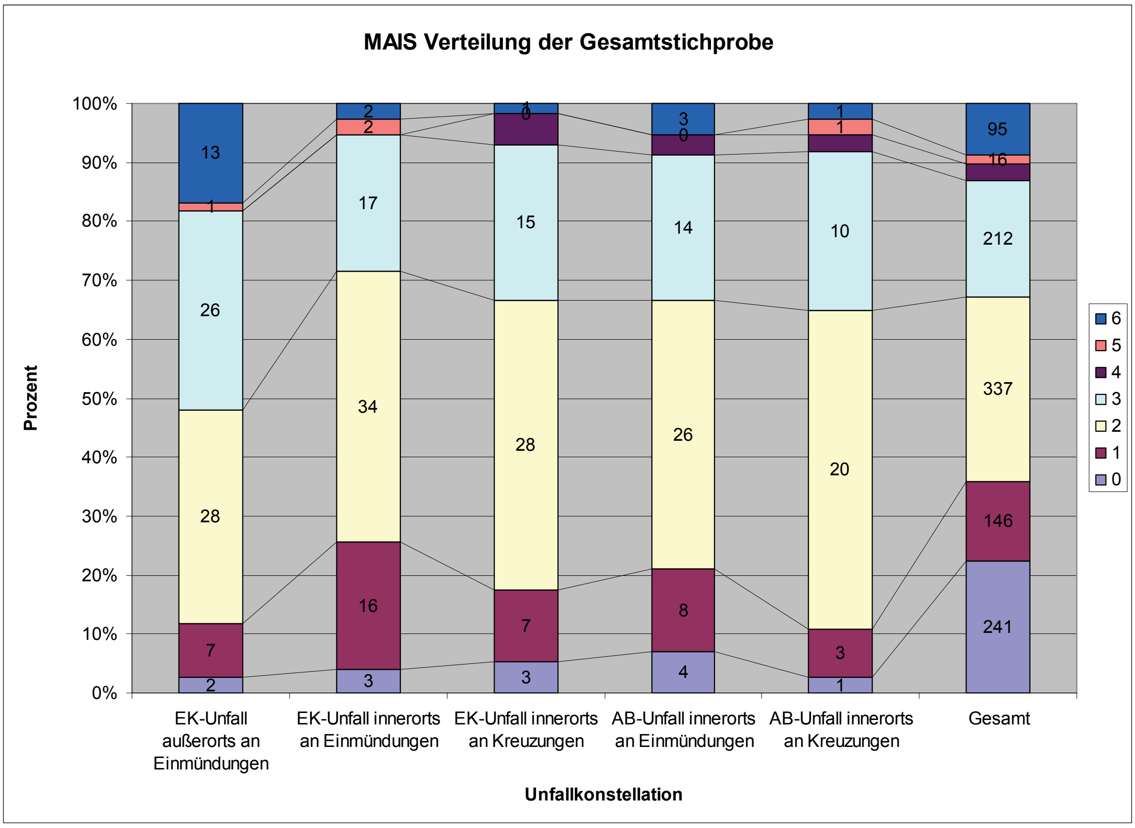


Abbildung 5-1: MAIS Verteilung über die gewählten Unfallkonstellation für die GDV-Stichprobe

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[2] **M**aximaler **A**bbreviated **I**njury **S**cale Wert: International anerkannte Ordinalskalierung der Verletzungsschwere für sieben Körperregionen (Kopf, Hals, Thorax, Abdomen, Wirbelsäule, Extremitäten, Körperoberfläche) von 0 bis 6. Wichtigstes Kriterium ist die von der Verletzungsschwere ausgehende Lebensbedrohung. Der Grad der Lebensbedrohung ist nichtlinearprogressiv und reicht von AIS 0 = unverletzt (Letalitätsrate 0,00%) über AIS 3 = schwer, nicht lebensgefährlich verletzt (Letalitätsrate 2,91%) bis AIS 6 = maximal verletzt (Letalitätsrate 100%). (Appel, 2002)

5.2 Leistungsgewicht und Alter des Fahrers

[Elliot et al. 2003] beschreibt in einer britischen Studie, dass der einflussreichste Faktor auf das Unfallszenario das Leistungsgewicht der betroffenen Motorräder sei. Es vereint mehrere technische Eigenschaften des Motorrades, die das Beschleunigungsvermögen des Fahrzeugs beschreiben. Hubraum und Nenndrehzahl haben direkten Einfluss auf die maximale Leistung eines Verbrennungsmotors. Zudem erlaubt ein leichteres Motorrad bei gleicher Leistung eine höhere Beschleunigung, der Wert des Beschleunigungsvermögens steigt mit sinkender Leistungsgewichtzahl [kg/kW]. Zur besseren Vergleichbarkeit werden Leistungsgewichtklassen gebildet, die eine gleich große Anzahl von Fällen vorsehen (Tabelle 5-1).

Tabelle 5-1: Einteilung der Leistungsgewichte in 10 gleich große Klassen

Leistungsgewichtklasse [1]	**Leistungsgewicht [kg/kW]**
1	bis 2,6
2	über 2,6 bis 3,1
3	über 3,1 bis 3,8
4	über 3,8 bis 4,71
5	über 4,71 bis 5,9
6	über 5,9 bis 7,6
7	über 7,6 bis 9,3
8	über 9,3 bis 13,4
9	über 13,4 bis 15,6
10	über 15,6

Aufgrund der geringen Fallzahlen (Abbildung 5-3) ist jedoch in der Verteilung der Leistungsgewichtklassen keine eindeutige Trennschärfe der Verletzungsschwere über den Unfallkonstellationen zu erkennen (Abbildung 5-2).

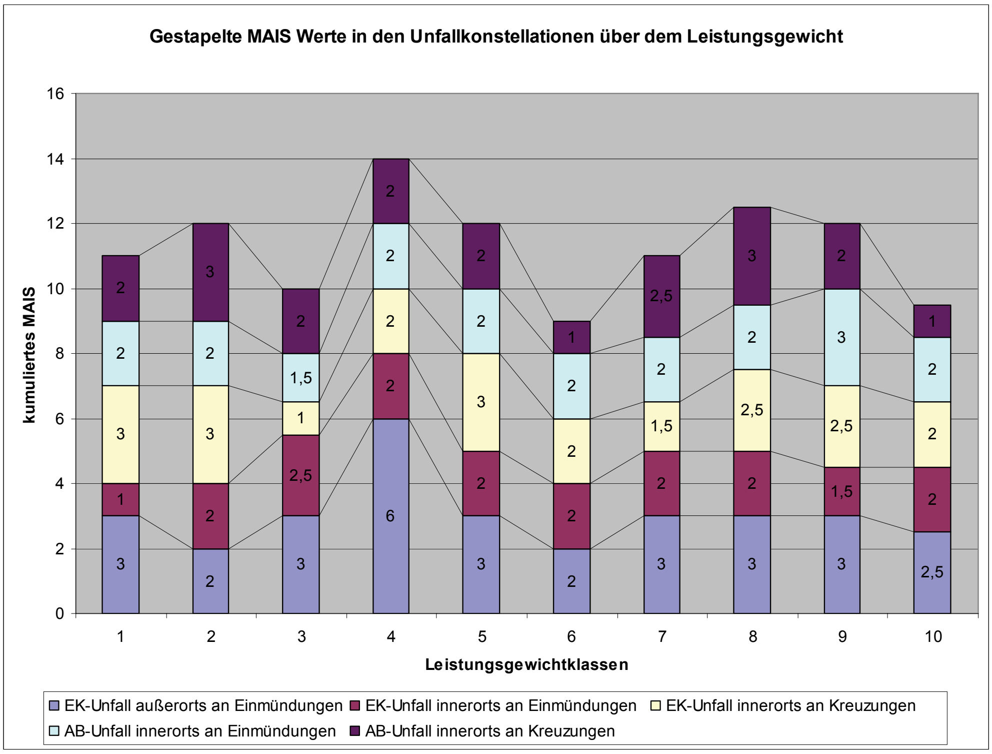

Abbildung 5-2: MAIS Werte der Leistungsgewichtklassen in den Unfallkonstellationen

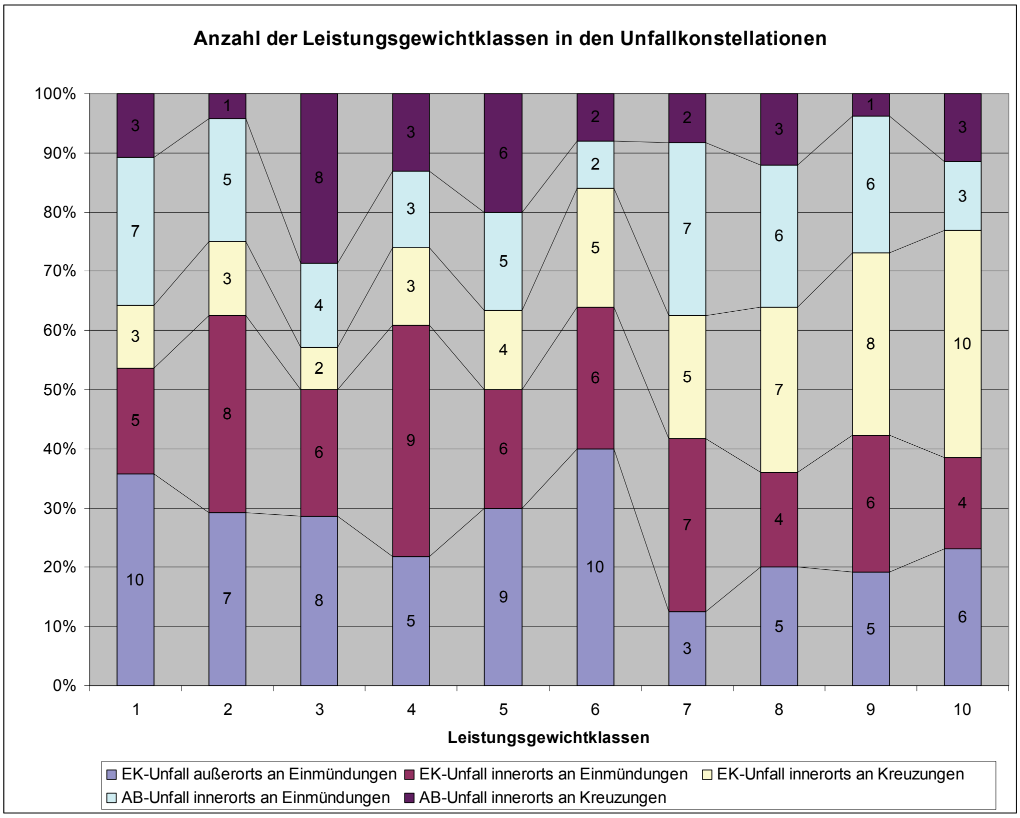

Abbildung 5-3: Anzahl der Leistungsgewichtklassen in den Unfallkonstellationen

Erst die Isolierung derjenigen Fälle im Datensatz, die nach Ortslage und Hauptschuldigkeit des Motorradfahrers unterscheiden, zeigt, dass das Leistungsgewicht Einfluss auf die Verletzungsschwere nimmt (Abbildung 5-4). Fahrer von Motorrädern mit einem hohen Beschleunigungsvermögen haben außerorts bei selbstverschuldeten Unfällen ein erhöhtes Verletzungsrisiko.

Erklärt werden kann es dadurch, dass das mögliche Beschleunigungsvermögen vom Motorradfahrer genutzt wird, wenn es zur Verfügung steht und zu risikobereiterem Fahren verleitet. Im Datensatz der Motorradfahrerbefragung ist ein eindeutiger Zusammenhang zwischen Einstellung zur Beschleunigung eines Fahrzeugs, den Verstößen im Straßenverkehr und den Verletzungsschweren zu erkennen (vgl. Abschnitt 4.3). Ist der Motorradfahrer nicht der Hauptverursacher einer Kollision, so hat das Leistungsgewicht keinen direkten Einfluss auf den Unfallhergang. Ist er der Hauptunfallverursacher – durch das Beschleunigungsvermögen des Motorrades verleitet – auf einem bestimmten Streckenabschnitt, so hat das Leistungsgewicht direkten Einfluss auf die Schwere des Unfalls. Alleinunfälle des Motorradfahrers sind in diesem Zusammenhang nicht auffällig, da sie großteils ohne jegliche Kollision ablaufen. Der Motorradfahrer wird in der Regel auf die Straße oder neben die Straße in unbefestigtes Gelände geschleudert, was zu weniger schwerwiegenden Verletzungen führt. Auch sind Verletzungen der Fahrer von leistungsstarken Motorrädern mit geringem Gewicht durch Unfälle innerorts nicht auffällig höher als die der weniger spurtstarken Einspurfahrzeuge, da durch die im Vergleich zu außerorts geringeren Geschwindigkeiten im Mittel geringere MAIS-Werte erreicht werden.

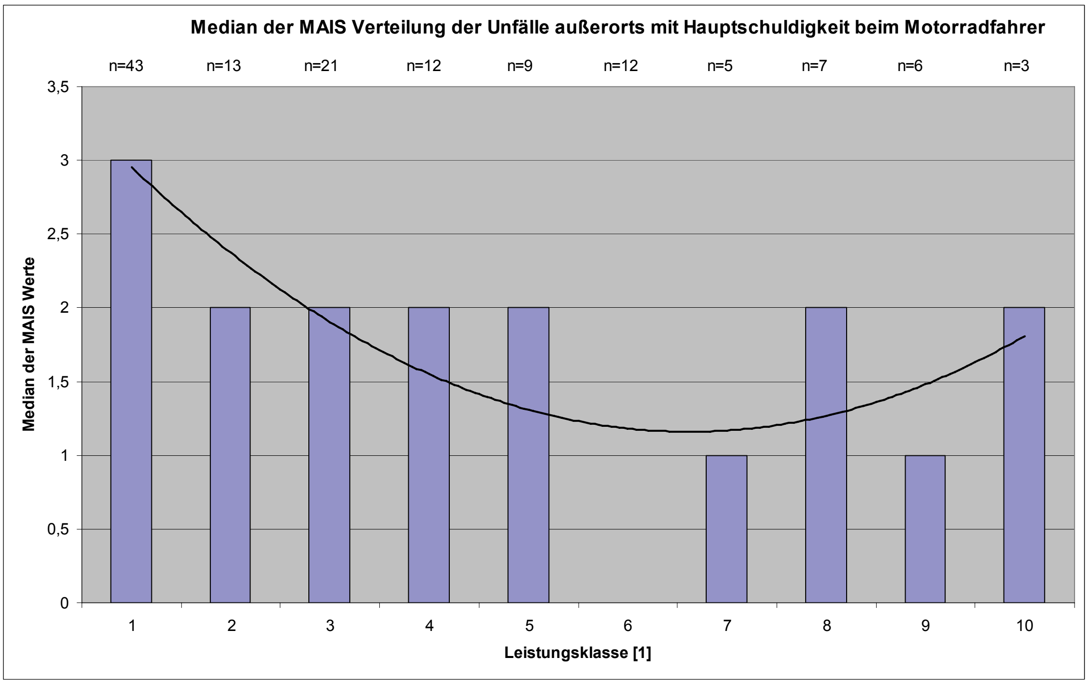

Abbildung 5-4: Verletzungsschwere über Leistungsgewicht außerhalb geschlossener Ortschaften mit Hauptschuldigkeit PTW

Anhand einer Varianzanalyse aller Unfälle außerorts wurde der Zusammenhang zwischen der abhängigen Variablen – der Verletzungsschwere (MAIS) – und mehreren unabhängigen Variablen geprüft. Dabei handelt es sich um die Ortslage, die Schuldigkeit des Motorradfahrers, das Alter des Motorradfahrers, und das Leistungsgewicht des Motorrades. Für die unabhängigen Variablen *Leistungsgewicht* und *Alter* wird eine reduzierte Anzahl an Klassen gebildet (Tabelle 5-2 und Tabelle 5-3).

Tabelle 5-2: Altersklassen

Altersbereich	**Klasse**
unter 18 Jahre	1 (n=10)
18 bis 25 Jahre	2 (n=18)
26 bis 40 Jahre	3 (n=34)
über 40 Jahre	4 (n=25)

Tabelle 5-3: Leistungsklassen

Leistungsgewicht $\left[\frac{kg}{kW}\right]$	**Klasse**
unter 2,75	1 (n=16)
2,75 bis 4,13	2 (n=31)
4,13 bis 9,42	3 (n=24)
Über 9,42	4 (n=16)

Die o.g. unabhängigen Variablen erklären zusammen 42,6% der Gesamtvarianz der Verletzungsschwere des Motorradfahrers.

Dabei hat das Leistungsgewicht einen signifikanten Einfluss auf die Verletzungsschwere (p=0,000). Das Leistungsgewicht hat einen Einfluss von 16% auf die Gesamtvarianz der abhängigen Variablen „Verletzungsschwere“ ($\eta^2 = 0{,}16$). Mittels Post Hoc Test zeigt sich, dass nur Klasse 1 eine signifikant höhere Verletzungsschwere aufweist als die übrigen Klassen. Die Klassen 2 bis 4 unterscheiden sich in der Verletzungsschwere nicht. Dies bedeutet, dass Fahrer von Motorrädern mit einem Leistungsgewicht unter 2,75 kg/kW höhere Verletzungsschweren erleiden.

Die Unfallart hat ebenfalls einen signifikanten Einfluss mit $\eta^2 = 0{,}163$. Sie kann jedoch zur Reduzierung der Verletzungsschwere nicht beeinflusst werden.

5.3 Einfluss weiterer Merkmale des Motorrades

Die Analyse der UDV Unfalldatenbank zeigt, dass technische Eigenschaften am Motorrad keinen nachweisbaren Einfluss auf die Verletzungsschwere eines Motorradfahrers haben. So mindert z.B. das

Vorhandensein von Seitenkoffern an den Einspurfahrzeugen nicht signifikant die Verletzungsschwere der unteren Extremitäten. Mit und ohne Koffer haben die betroffenen Motorradfahrer zu ca. 20% MAIS 3+ Verletzungen an unteren Extremitäten. Der zusätzliche Freiraum im Falle eines Sturzes hat so keinen positiven Einfluss auf die Verletzungsschwere. Auch die Lenkerform hat keinen direkten Einfluss auf die Verletzungsschwere. Fahrer eines Motorrades mit einem niedrigen Lenker haben zwar eine niedrigere MAIS-Verletzungsschwere als Fahrer von Motorrädern mit mittel hohen Lenkern, doch ist in diesem Fall nicht die reine Lenkerhöhe ausschlaggebend, sondern das Leistungsgewicht des Fahrzeuges. Der Korrelationskoeffizient zwischen Leistungsgewichtklasse und Lenkerhöhe liegt hochsignifikant bei 0,482.

Als „Faustregel" gilt, dass Unfälle außerorts einen im Mittel um eins höheren MAIS-Wert aufweisen als Unfälle innerorts. Zudem steigt die Verletzungsschwere, wenn der Motorradfahrer in die Fahrerseite des Unfallgegners fährt, auch um einen MAIS-Wert im Mittel. Die geringsten Verletzungsschweren sind so innerorts bei Unfällen mit mehr als einem Beteiligten zu verzeichnen, bei denen es zu keiner Kollision kommt.

Der häufigste Unfallablauf bei Unfällen mit mehr als einem Beteiligten ist die stabile Fahrt auf der Geraden oder in einer Kurve mit der aufrechten Kollision im Anschluss (Abbildung 5-5).

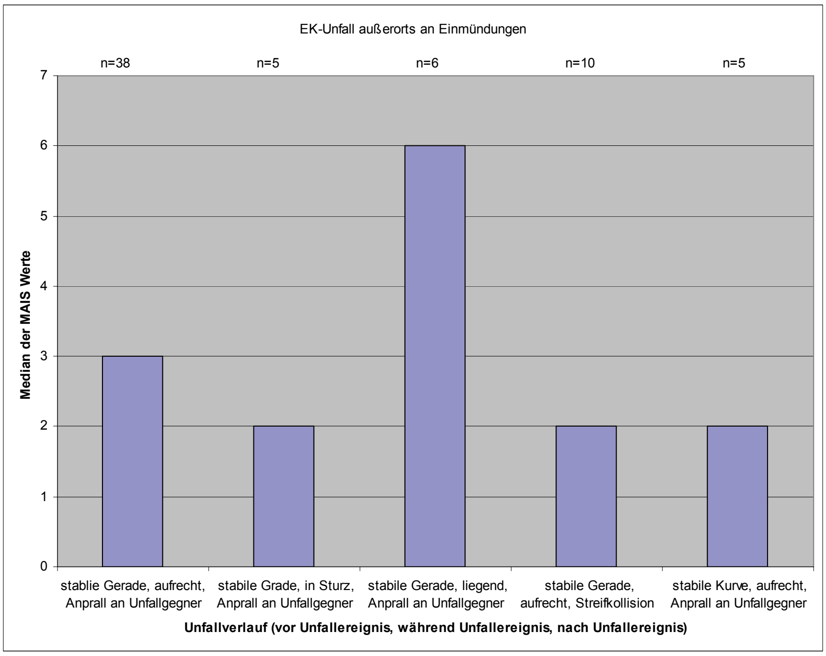

Abbildung 5-5: Unfallhergang exemplarisch am Beispiel EK-Unfall außerorts an Einmündungen

Rutscht das Motorrad jedoch vor der Kollision weg, so ist die Verletzungsschwere höher, weil weniger kinetische Energie abgebaut wird als bei einer vom Fahrer initiierten Gefahrenbremsung. Bei der aufrechten Kollision sind Kopf und Thorax am höchsten belastet, da der Motorradfahrer häufig auf die steife Dachkante des Unfallgegners prallt (Abbildung 5-6).

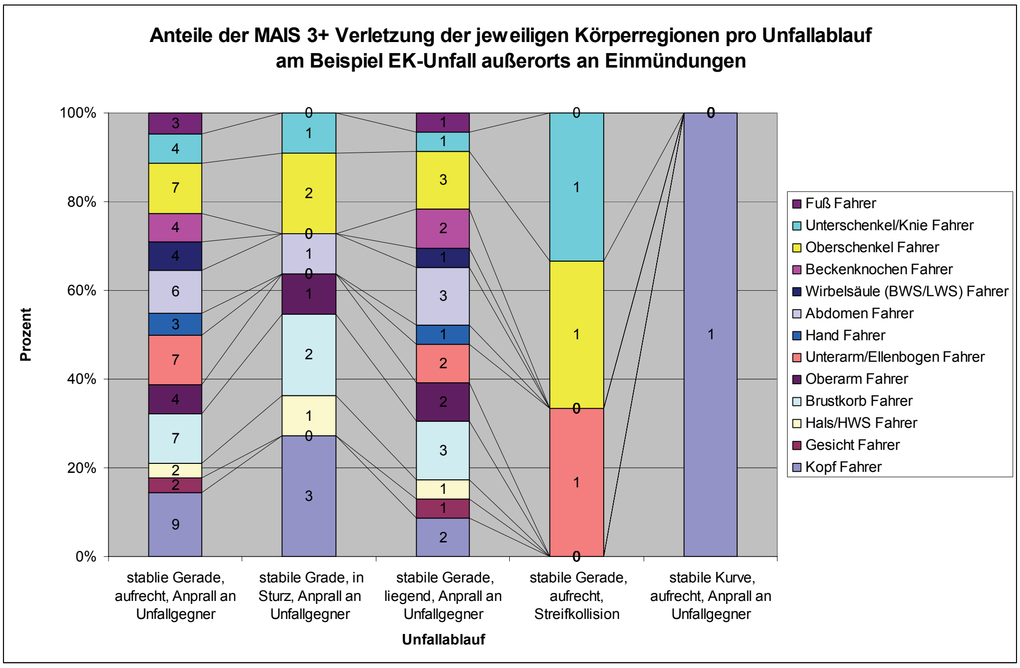

Abbildung 5-6: Anteil der MAIS 3+ Verletzungen der jeweiligen Körperregionen pro Unfallablauf

Auch ein Überfliegen des Unfallgegners durch den Motorradfahrer führt zu geringeren Verletzungsschweren. Der Weg des Energieabbaus ist dabei wesentlich länger und das Belastungsniveau kann somit geringer ausfallen. Der gezielte Überflug ist jedoch nicht zu favorisieren, da nie sichergestellt werden kann, ob ein Überflug gelingt und hinter dem Unfallgegner genügend Platz zur Verfügung steht. Alleinunfälle sind in der Datenbasis weniger schwerwiegend. Sie verlaufen großteils ohne Kollision und so kann die kinetische Energie durch ungestörtes Rutschen abgebaut werden.

Der Motorradtyp als technisches Merkmal des Motorrades hat wiederum keinen signifikanten Einfluss auf die Höhe der MAIS-Werte. Fahrer von Sportmaschinen sind im Allgemeinen schwerer betroffen, doch kann dies wiederum durch die niedrigeren Leistungsgewichte in dieser Motorradklasse erklärt werden. Sportmaschinen haben in der Datenbasis eine mittlere Leistung von ca. 73 kW. Chopper haben dagegen durchschnittlich eine Leistung von 31,5 kW.

6 Fazit und Ausblick

Die Ergebnisse der verschiedenen Fachdisziplinen zeigen ein deutliches Bild des Motorrad-Unfallgeschehens. Motorradfahrer sind keine unschuldigen Opfer im Straßenverkehr. Der Motorradfahrer muss mit den Fehlern anderer rechnen. Ihm muss klar sein, das nicht jeder Autofahrer die Dynamik und das große Beschleunigungsvermögen eines Zweirades richtig einschätzen kann. Demzufolge sind Fahrertrainings notwendig, die vor allem mental und nicht ausschließlich bei der Beherrschung der Maschine ansetzen. Hier muss das Erlernen des vorausschauenden Fahrens im Mittelpunkt stehen.

Straßenseitig zeigte sich u.a. die Notwendigkeit von separaten Linksabbiegespuren und Ampelphasen. Darüber hinaus sind motorradfreundliche Schutzplanken mit energieaufnehmendem Unterzug die wirksamste Lösung für Unfälle, die durch Abkommen von der Fahrbahn gekennzeichnet sind. Weiterhin scheinen Straßenschäden und Gleisanlagen innerorts ein beträchtliches Risiko für Fahrer von motorisierten Zweirädern darzustellen.

Fahrzeugseitig sind die Möglichkeiten für eine Verbesserung der Situation eher beschränkt. Es zeigt sich deutlich, das dass ABS der wichtigste technische Helfer beim motorisierten Zweirad ist. Nur durch eine kontrollierte, sichere Bremsung kann genügend Bewegungsenergie abgebaut werden, um die Verletzungsschwere zu reduzieren. Weiterhin zeigt sich, dass das Leistungsgewicht des Zweirades einen signifikanten Einfluss auf die Verletzungsschwere der Aufsassen hat. Auf der Seite der passiven Sicherheit ließen sich keine eindeutigen Anknüpfungspunkte für Verbesserungen finden, da es herstellerseitig bisher kaum Bemühungen in diesem Bereich gab. Mit Ausnahme des ABS gilt dies auch für die aktive Sicherheit. Möglicherweise ist die Kombination aus bereits realisierten Zweiradkonzepten zur Erhöhung der aktiven Sicherheit (Abbildung 6-1 links) und der passiven Sicherheit (Abbildung 6-1 Mitte) ein Denkmodell, das zu einem sichereren Zweirad führt (Abbildung 6-1 rechts). Der Denkansatz wird getragen durch eine Crashzelle mit gurtgesichertem Fahrer und Energie aufnehmender Front sowie zwei Rädern an der Front, die höhere Bremskräfte übertragen können und die Stabilität des Fahrzeugs erhöhen beziehungsweise die Sturzgefahr verringern, ohne das zweiradtypische Fahrverhalten zu vernachlässigen.

Abbildung 6-1: Denkmodell zur Erhöhung der Sicherheit von motorisierten Zweirädern (rechts) abgeleitet aus bereits realisierten Fahrzeugen (Quellen: Piaggio (links), BMW (Mitte), UDV (rechts).

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The Value of an Exclusive Motorcycle Lane in Mix Traffic: Malaysian Experience

Der Nutzen einer speziellen Motorradspur im Gesamtverkehr: Erfahrungen aus Malaysia

A study based on report submitted by Road Safety Research Centre, Faculty of Engineering, PUTRA University of Malaysia

Subramaniam Munusamy
Research Director, Organisation of Vehicle and Road Safety Malaysia
(OVARoad Safety Malaysia)

Abstract

The key road safety problem in developing countries of ASEAN is motorcyclist safety. Motorcycle is popular mode of personal transport and formed as the major road user in these countries. Studies had proved that segregation or exclusive motorcycle lane is the best engineering intervention to protect two-wheeled transport against collision over four wheeled transport. Acknowledging these benefits, the Malaysian government adopted a policy to provide exclusive motorcycle lane along several new highway and existing government owned highway(Federal highway- linking Kuala Lumpur-Shah Alam-Klang)

In Malaysia, motorcycles represented more than halves of all registered vehicle population. Owing the fact, motorcyclist contributing almost 70% accidents, in which around 60% of these accidents caused by other four-wheeled vehicles in the mix traffic condition. This alarming figure warrants the government to identify and implementing several road safety measures that targeted motorcyclist. An effective engineering approach to tackle this problem by segregating these vulnerable road users from other motorized traffic by introducing exclusive motorcycle lanes in several existing and every new roads in Malaysia.

A study was conducted based on analysis of reported accident cases and observation at exclusive motorcycle lane along the stretch of Federal Highway connecting KL-Shah Alam-Klang for the period of 12 months. The fatal accidents involving motorcycles plummeted significantly from 6 cases to one case during the observation period. To further investigate the above observation, an analysis of relative vulnerability of motorcycles before and after the introduction of an exclusive motorcycle lane shows that the relative vulnerability for single motorcycle accidents was slight reduction from 0.98 to 0.95. This study also indicated that the rear end and side-swipe collision also dropped significantly. Overall, the introduction of an exclusive motorcycle lane have significant impact reducing the accidents and fatalities to motorcyclist particularly the long term reduction about 39% However, the reduction was not sufficient enough to bring about significant reduction in overall casualties, particularly slight injuries.

Kurzfassung

Die Sicherheit der Motorradfahrer stellt das Schlüsselproblem im Straßenverkehr der Entwicklungsländer im Verband Südostasiatischer Nationen (ASEAN) dar. Das Motorrad ist ein sehr beliebtes und inzwischen das hauptsächliche Fortbewegungsmittel auf den Straßen dieser Länder. Studien haben ergeben, dass eine Trennung, bzw. eine separate Fahrspur für Motorräder der effektivste Eingriff ist, um einspurige Fahrzeuge vor Kollisionen mit zweispurigen Fahrzeugen zu schützen. Diese Vorzüge anerkennend hat die malaysische Regierung eine Richtlinie verabschiedet, nach der entlang neuer und bereits bestehender staatlicher Schnellstraßen separate Motorrad-Fahrspuren gebaut werden sollen. (Federal highway – Linking Kuala Lumpur-Shah Alam-Klang)

In Malaysia sind mehr als die Hälfte aller registrierten motorisierten Fahrzeuge Motorräder. Dabei sind sie in annähernd 70% aller Verkehrsunfälle verwickelt, wobei ungefähr 60% dieser Unfälle von Zweispurfahrzeugen im herkömmlichen, gemischten Straßenverkehr verursacht wurden. Diese alarmierende Zahl bewog die Regierung dazu, geeignete Wege zu finden und umzusetzen, die Verkehrssituation und -sicherheit von Motorradfahrern zu verbessern. Ein effektiver Ansatz, diesem Problem zu begegnen, ist die Trennung der schutzlosen Motorradfahrer vom restlichen Verkehr, indem man einige bestehende Straßen nachträglich um separate Motorrad-Fahrspuren ergänzt und beim künftigen Bau von Straßen in Malaysia eine solche Fahrspur einplant.

Basierend auf der Auswertung der gemeldeten Unfälle sowie einer zwölfmonatigen Überwachung der separaten Motorrad-Fahrspur entlang eines Abschnitts der staatlichen Schnellstraße Kuala Lumpur-Shah Alam Klang wurde eine Studie durchgeführt. Im Untersuchungszeitraum fiel die Zahl der tödlichen Unfälle beträchtlich von sonst sechs auf einen Todesfall. Um die Untersuchung weiter auszuwerten, wurde die relative Verletzungshäufigkeit der Motorradfahrer vor und nach der Einführung der separaten Motorrad-Fahrspur analysiert. Dabei zeigt sich, dass die relative Verletzungshäufigkeit bei Motorrad-Alleinunfällen leicht zurückging, von 0,98 auf 0,95. Diese Studie zeigt außerdem, dass die Kollisionen durch Auffahren und seitliches Streifen in ihrer Zahl signifikant gesunken sind. Insgesamt hat die Einführung einer separaten Motorrad-Fahrspur einen maßgeblichen Einfluss auf die Reduzierung von Unfallzahlen und Getötetenzahlen insbesondere die langfristige Reduzierung beträgt 39%. Jedoch war die Reduzierung nicht hinreichend genug, die Gesamtzahl der Unfälle signifikant zu reduzieren, insbesondere gilt dies für die Zahl leichter Verletzungen.

The Value of an Exclusive Motorcycle Lane in Mix Traffic: Malaysian Experience

Introduction

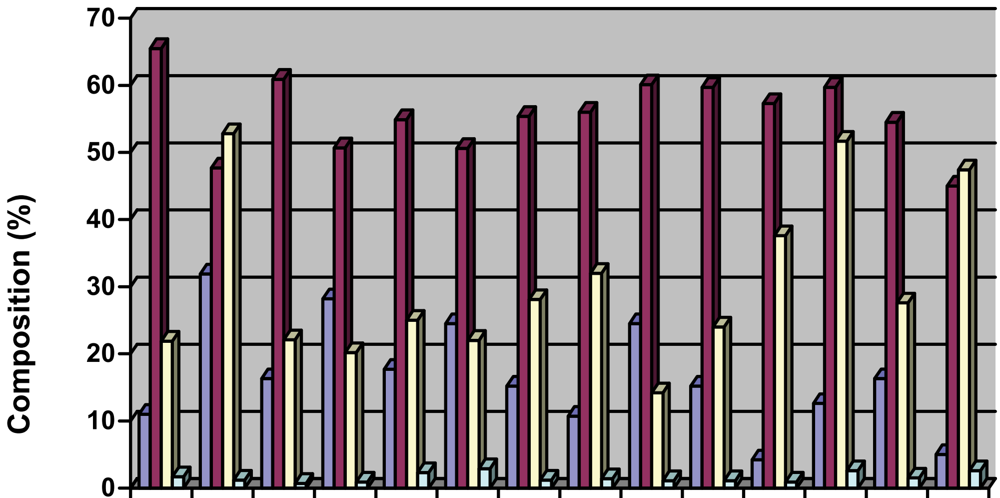
The key road safety problem in developing countries of ASEAN is motorcyclist safety. Motorcycle is popular mode of personal transport and formed as the major road user in these countries. Studies had proved that segregation or exclusive motorcycle lane is the best engineering intervention to protect two-wheeled transport against collision over four wheeled transport. Acknowledging these benefits, the Malaysian government adopted a policy to provide exclusive motorcycle lane along several new highway and existing government owned highway(Federal highway- linking Kuala Lumpur-Shah Alam-Klang)

In Malaysia, motorcycles represented more than halves of all registered vehicle population. Owing the fact, motorcyclist contributing almost 70% accidents, in which around 60% of these accidents caused by other four-wheeled vehicles in the mix traffic condition. This alarming figure warrants the government to identify and implementing several road safety measures that targeted motorcyclist. An effective engineering approach to tackle this problem by segregating these vulnerable road users from other motorized traffic by introducing exclusive motorcycle lanes in several existing and every new roads in Malaysia not all the new roads implementing, specially private concessionaires.

Mix Traffic Condition

Since the last two decades, the number of registered motorized two-wheelers (motorcycles and scooters) has been increasing tremendously. In 1979, the number of registered motorcycles was 1.19 million and the figure had reached four folds to about 5.36 million compare to 8 million today. Although total number of registered motorcycle has increased tremendously, registered motorcycles rate per 100,000 vehicles in total has been decreasing over the recent years. A study conducted by OVARoad Safety Malaysia revealed that this phenomena was mainly due to proportionally decreasing popularity of motorcycle as a result of risk nature consideration among the motorists. This factor had also completely rejects the Road Transport Department’s claim for motorist switch over to passenger cars due to life style change. Ironically, vehicle ownership trend in Malaysia seeming a complex trend over the last 3 years as number of registered passenger cars are decreasing mainly due to increasing fuel price. Number of newly registered motorcycles per 100,000 passenger cars has gone high from 78,500 motorcycles in 2005 to 115,500 motorcycles in 2007.

Motorcycles and other registered vehicles proportion varies from 35% to 65%, depending on urbanization level of certain area. In less urbanized state such as Perlis (North of Malaysia) motorcycles amount for more than three quarter of the total registered vehicles in that state. Meanwhile, in the urbanized states such as Kuala Lumpur, only one third of registered vehicles are motorcycles. However, exclusive motorcycle lanes are only available in several roads of Klang Valley (KL, Petaling Jaya, Shah Alam & Klang) due to higher motorcycle traffic composition compare to other less developed region.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Motorcycle	11	31,9	16,3	28,2	17,7	24,5	15,2	10,7	24,5	15,2	4,2	12,6	16,3	5
Passenger car	65,5	47,7	60,9	50,7	54,9	50,6	55,4	56	60,1	59,7	57,3	59,7	54,5	45
Truck/Lorry	21,9	52,8	22,1	20,2	25	22	28,1	32	14,2	24	37,6	51,7	27,6	47,4
Bus	1,7	1,2	0,7	0,9	2,3	2,9	1,2	1,4	1,1	1,1	0,9	2,6	1,5	2,6

Location

1. Johor Bahru- Ayer Hitam
2. Johor Bahru-Endau
3. Seremban- Kuala Lumpur
4. Butterworth-Taiping
5. Ipoh Kampar
6. Alor Setar-Sungai Petani
7. Kuantan-Maran
8. Bukit Iban-Rompin Interchange
9. Kuala Terengganu-Kuantan
10. Kota Bahru-Kuala Krai
11. Kota Kinabalu-Papar
12. Tawau-Semporna
13. Kuching-Serian
14. Bintulu-Miri

Graphic: Traffic Composition (%) by type of vehicle at 14 selected stations, Malaysia, 2007

The periodic observational data of Ministry of Public Works Malaysia on traffic composition in selected locations shows that motorcycle composition varies from 4% to 30% depending on urbanization and social status of the road users. This situation indicates that motorcyclist exposed to extreme risk of coalition with 90% to 70% of other larger vehicles on the road.

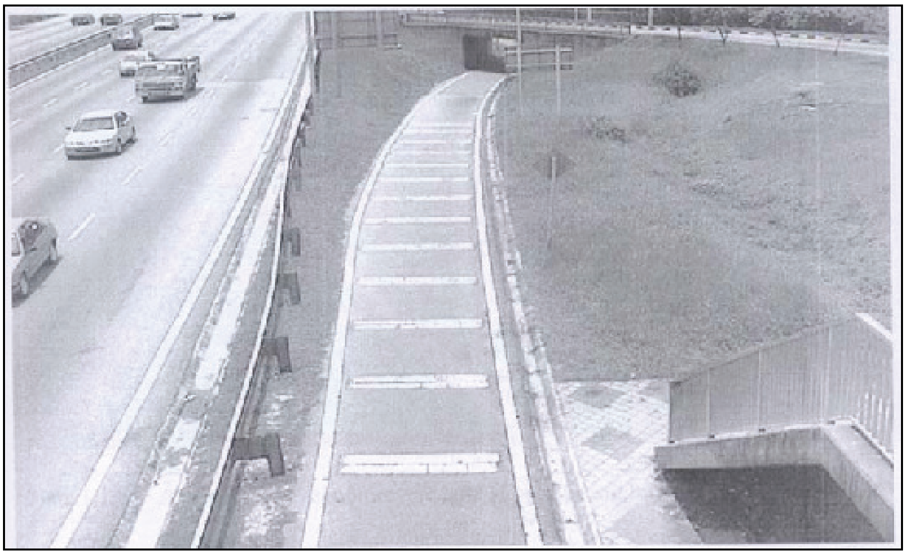
The 1st exclusive motorcycle lane in Malaysia was introduced along the Federal Highway, with support from World Bank Project in early seventies. Perhaps, this could be the world's first ideas of exclusive motorcycle lane to tackle the rising motorcycle accidents in Kuala Lumpur. In 1992, a private company, PLUS was carried out extension work of the lane. This extension was a part of an improvement program to the existing two-lane expressway connecting the Subang International Airport – Shah Alam-Klang.

What is Exclusive Motorcycle Lane?

Exclusive Motorcycle lane is a main term for special lane for the two wheeled vehicles such as motorcycles, scooters, and bicycles. In some parts of the whole expressways and highways in Malaysia, there is an additional lane designated for motorcycles. These lanes are usually about half the width of a normal lane on the North-South Expressway connecting main cities of northern and southern states) and are positioned on the extreme left side of the main carriageway for each direction of travel. These special lanes are found in Shah Alam Expressway, Butterworth-Kulim Expressway, Federal Highway, Guthrie Corridor Expressway, Putrajaya-Cyberjaya Expressway and all major highways in Putrajaya. Motorcycle lanes have a special shelter places that provide protection and shelter for motorcyclists against heavy rains. Usually, most motorcycles shelters are located below overhead bridges, but some motorcycle shelters may be special booths in motorcycle lane. On Malaysian federal roads, the motorcycle lanes are placed at the extreme left side of each direction and only separated from the main lanes by black-and-white stripes to enable motorcyclists to overtake slower motorcycles and to turn right to exit the road.

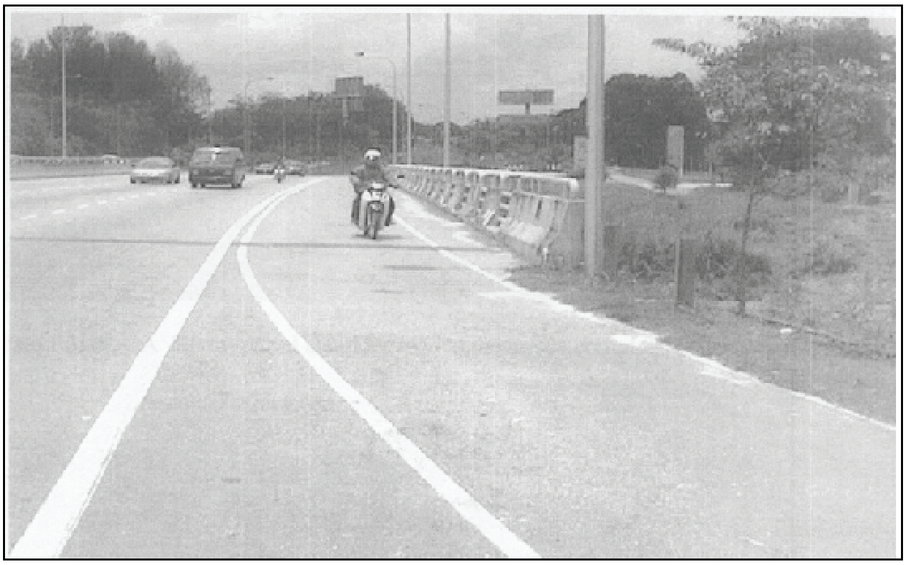
Type of Motorcycle Lane

1) Exclusive motorcycle lane: referring to a complete separate ride-way build for the sole use of motorcyclist which separates motorcyclist from other larger motorized vehicle on main drive-way.



Separate ride-way along Federal Highway, Route 2. (Picture: Radin Umar,Law Teik Hua)

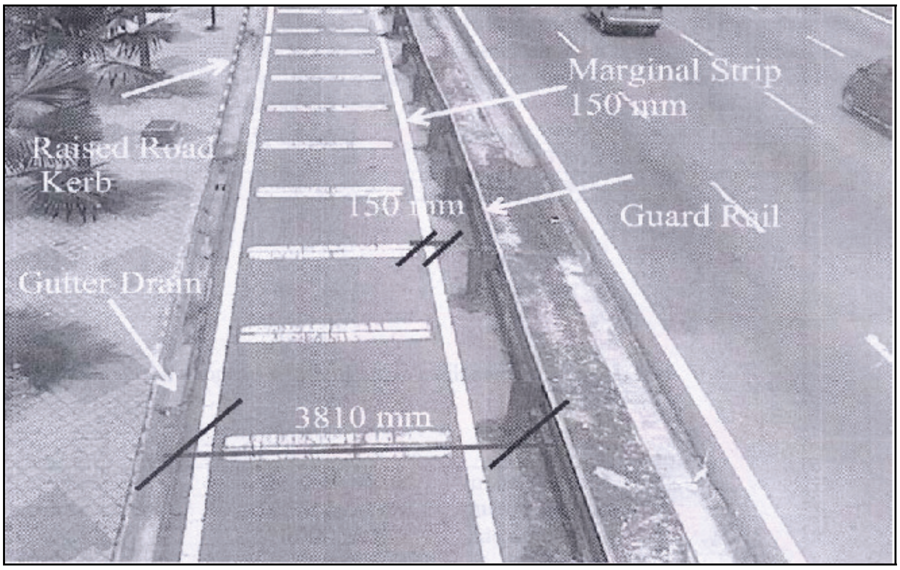
2) Inclusive motorcycle lane: refers to specially assigned motorcycle lane within the left side carriageway of an existing wide-drive way. There are also some form of physical barrier or pavement marking to separate these two-wheeler from four-wheelers to ensure safety and comfortability of motorcyclist.



Inclusive/non-exclusive motorcycle lane along Federal Highway towards Subang International Airport. (Picture: Radin Umar,Law Teik Hua)

Physical Determination Criteria

A later study “Determination of Comfortable Safe Width in an Exclusive Motorcycle Lane” by Law T.H and Radin Umar revealed certain physical criteria to consider for the safety and comfort of motorcyclist. Although there was a general guide by Public Works Department, Ministry of Works Malaysia, this study had disclosed several specific engineering standards to assess design criteria of an exclusive motorcycle lane. The physical characteristics of the common exclusive motorcycle lanes were recorded to determine 3 main variables, Distance of motorcyclist to his nearest rider on left and right (near guardrail), centre distance ratio between two riders while overtaking. The results recommended that an exclusive motorcycle lane needs a control width 3.81m (inclusive marginal stripe 0.38m at both edge) for two riders travel side by side comfortably at a speed of 70km/h (Enforced speed limit for exclusive motorcycle lane).

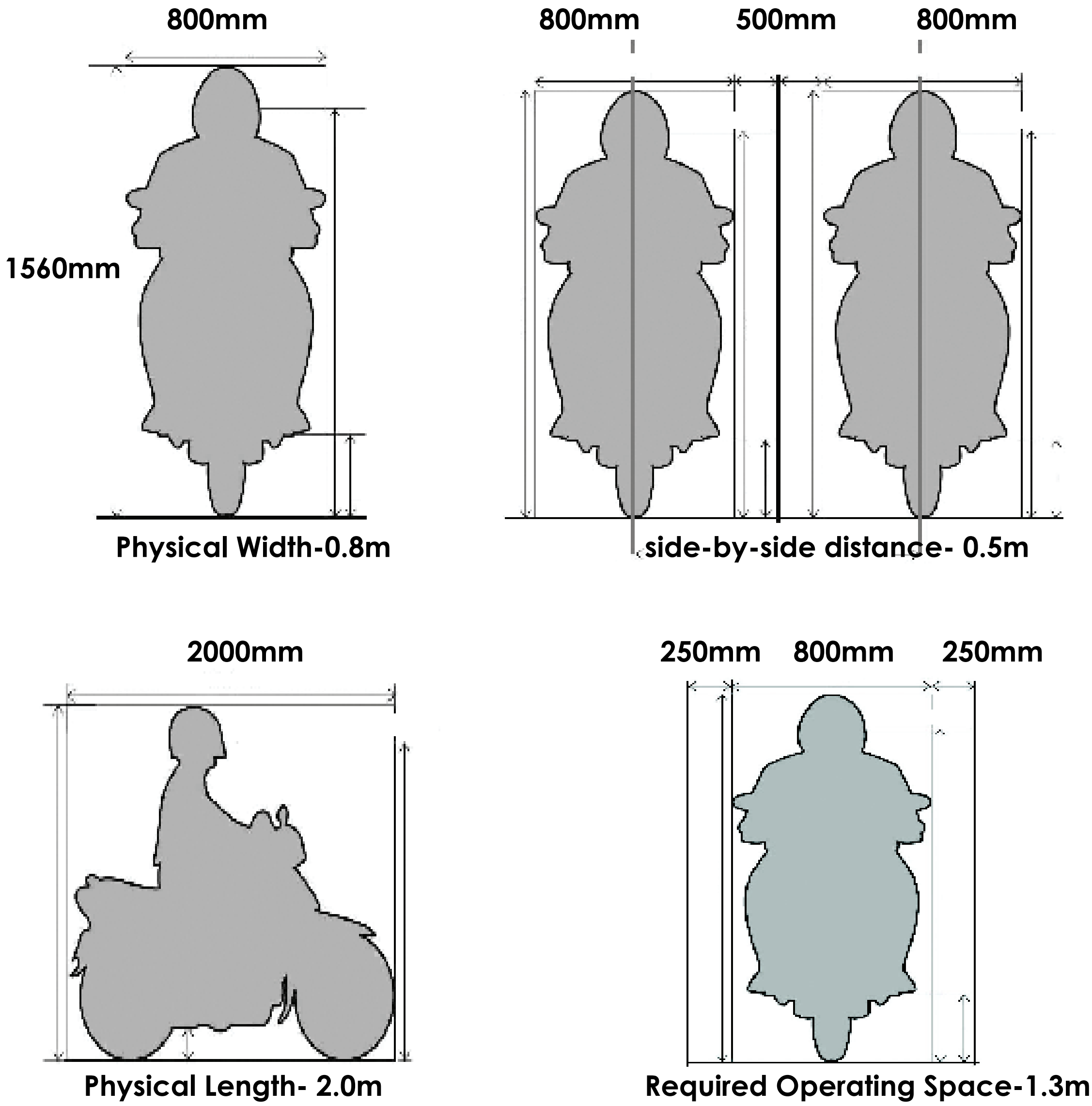


Picture: Recommended control width for an exclusive motorcycle lane.

Motorcycle Physical Criteria

This section will highlight some basic characteristic of the key components of motorcycle-traffic system in Malaysia, i.e the design of the motorcycle-vehicle, motorcycle-rider unit space requirement, motorcycle riding manner along the motorcycle lane. These components interact with each other to form the motorcycle traffic system.

It was found that 99% of the motorcycle population in Malaysia comprises those of small and medium sized type motorcycles with engine capacity below 150c.c. Due to its small nature, these motorcycles does not require much space for maneuvering.. A static motorcycle measured about 0.8m in width and 2.0m in length, and occupies a physical space of 1.6m2. This indicating that a lane width must be greater than 1.6m to allow two motorcyclist to overtake. A motorcyclist required a certain amount of operating space to ride along in motorcycle path. Results suggesting that at a motorcycle flow rate at average speed of 60km/hr, a typical motorcyclist needs effective lane width' between 0.9m and 1.7m of width to operate. Hence, the "effective lane width' for two motorcyclist are above 1.8m wide. Beside that, this study also found that motorcyclists tend to form themselves into more than one-line within the lane wider than 1.7m irrespective of peak or non-peak condition. This was influenced by available space within the lane that allow motorcyclists overtake safely.



Picture: Radin Umar, The Value of Exclusive Motorcycle Lanes to Motorcycle Accidents and Casualties In Malaysia. RSRC UPM.

The Exclusive Motorcycle Lane

1) Impact on Accident Severity and Casualty Injury along the track

This study was based on analysis of reported accident cases and observation conducted at exclusive motorcycle lane along the stretch of Federal Highway connecting KL-Shah Alam-Klang. The data were collected on monthly series for the period of 12 months.

The fatal accidents involving motorcycles plummeted significantly from 6 cases to one case during the observation period. The detailed investigation of this fatality found that the victim was killed in a single motorcycle accident (not a collision with other vehicle). No fatalities has so far been observed for the multiple motorcycle accidents during that period. In contrast, the analysis for the serious accidents on the other hand revealed that serious accidents and hospitalized cases had increased from 4 cases to 9 cases. Due to drop in total accidents, these changes were not statically significant.

Table1.Before and After Analysis of Accident Severity & Injury

Accident Severity	Before Intervention	After Intervention
Fatal Accidents	6	1
Serious Accidents (Hospitalised)	4	9
Minor Injury (out patient treatment)	120	131
Damage	43	6
Total Accidents	**155**	**122**
Total Casualties	**130**	**141**

2) Analysis of relative vulnerability of Motorcyclist

To further investigate the above observation, an analysis of relative vulnerability of motorcycles before and after the introduction of an exclusive motorcycle lane. This index was computed from the ratio of casualties to accidents and reflecting the probability of injuries sustained. From the analysis, it can be seen that the relative vulnerability for single motorcycle accidents was slight reduction from 0.98 to 0.95. however, casualties involving multiple motorcycles has increased slightly due to human factor.

Table2. Relative Vulnerability of Motorcyclists before and after intervention

Type of Accident	Before Intervention	After Intervention
Single Motorcycle Accidents	41	40
Single Motorcycle Casualties	40	38
Relative Vulnerability	**0.98**	**0.95**
Multiple Motorcycles Accidents	114	72
Multiple Motorcycles Casualties	90	103
Relative Vulnerability	**0.79**	**1.43**

3) Effect on collision type

The break down of collision type shows that the majority of accidents (approx 49%) are the side wipe accidents. This is followed by off-road accidents (30%), rear end accidents (15%) and other (10%). The analysis indicated that the rear end and side-swipe collision dropped significantly.

Table3. Breakdown of collision Types Before and After Intervention.

Collision Type	Before Intervention	After Intervention
Side-Swipe	76	55(49%)
Rear-End	32	16(15%)
Off-Road	37	34(30%)
Others	10	7
Total	**155**	**112**

Conclusion

Overall, can be concluded that the introduction of an exclusive motorcycle lane have significant impact reducing the accidents and fatalities to motorcyclist. The long term reduction was about 39% (Radin,1995) and supported further by another study (Radin and Barton, 1997). However, the reduction was not sufficient enough to bring about significant reduction in overall casualties, particularly slight injuries. The reason could be due to change in the collision mechanism of the vulnerable motorcyclist. The mechanism transformed from typical two wheeled- four wheeled collision to motorcycle-motorcycle collision. This has resulted in the vulnerability rates.

Recommendations

The study by Associate Professor Ir.Radin Umar (1995) suggested that more focus must be given to reduce the overall accidents, particularly multiple side accidents along the track. This can achieved by

1) Blackspot identification at selected accident-prone areas along the track
2) Route based analysis on collision characteristic
3) Area-wide injury control strategies.

Since the multiple motorcycle accidents particularly the side-swipe accidents form the major casualties, further segregation and traffic management along the tracks may help to further reduce possible collision particularly during the busy hours. Appropriate centre lane marking is strongly recommended in section wider than 3 metres. This will provide positive information to riders and hence encouraging better lane discipline and vehicle positioning along the track. Due to lack of centre lane marking, riders are free to move around and squeeze into any available space to overtake slower motorcycles that are frequently observed riding on the middle of the track.

In section where the road geometry is tight such as at the curves, a solid double-line centre marking should be provided. In addition, “No Overtaking” sign must be placed to avoid risk of collision. In sections where effective lane widths are smaller that 3.2 metres and lane widening is not possible such as approaching to under-ground tunnels or under pass, riders are recommended to ride in single file by placing a sign “Form One Lane”

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The Initial Rider Training project –
Developing a European approach to the
Initial Training of Motorcyclists

Die Entwicklung eines europäischen Modells
für die Fahrschulausbildung von Motorradfahrern

Aline Delhaye
Secretary General at the Federation of
European Motorcyclists' Associations (FEMA)

John Chatterton-Ross
Director EU Public Affairs
Fédération Internationale de Motocyclisme

Abstract

The Development of a European Approach to the Initial Training of Motorcyclists Project, TREN-SUB-2003-S07.30333, known as the Initial Rider Training Project, has considered the widely acknowledged problems of pre-licence rider training in Europe being widely variable in quality and or availability. The IRT Project has addressed one of the main problems affecting the quality of initial rider training, namely the concentration on machine control skills to the detriment of hazard awareness and rider attitude and behaviour. The relationship between newly qualified rider overconfidence, failing to recognise hazards and take risks and pre licence training that has overly focussed on machine control skills, has been recognised for a long time.

Working with acknowledged experts covering a wide range of motorcycling, academic and road safety interests, the resulting IRT model European initial rider training programme can deliver machine controls skills in the context of their relevance to the hazardous environment of today's roads, with an understanding of the rider having a primary responsibility for his or her own safety. The IRT model European programme offers a real improvement to much of the pre licence training presently available to riders within the European Union.

The modular structure and pedagogical approach of the IRT model European initial rider training programme can also offer a real improvement to the availability of initial rider training. Whilst it has been primarily developed to be used in a structured training environment, it can also be utilised in a range more informal training situations. It will offer real assistance to the family member or friend, or the motorcycle club or safety organisation, seeking to impart good, safe riding skills, often in circumstances where professional training is not available or is of poor quality.

In support of these main aims the IRT Project has considered the very innovative area of e-Coaching and the contribution that it could make to improving initial rider training, particularly in the context of exposing riders to virtual hazardous situations without putting them in any way at risk. The work undertaken concluded that an e-Coaching approach as envisaged within the report of the Hypermedia Unit of Tampere University of Technology, does have the potential to make a major contribution to the safety of riders of motorcycles and scooters.

Kurzfassung

Bei der Entwicklung eines europäischen Models im Hinblick auf die Fahrschulausbildung von Motorradfahrern, TREN- SUB-2003 –So7.30333, bekannt als das „Initial Rider Training Project“, wurden die allseits bekannten Probleme der Fahrausbildung in Europa, die sich in ihrer Qualität widerspiegeln, sofern eine Fahrschulausbildung in jedem Land vorhanden ist, in Betracht gezogen.

Das IRT-Projekt behandelt eines der Hauptprobleme, welches die Qualität der Fahrausbildung betrifft: die Konzentration auf die Fertigkeiten zur Steuerung des Motorrads in der Ausbildung zum Nachteil des Gefahrenbewusstseins und der Einstellung und dem Verhalten des Motorradfahrers. Die Beziehung zwischen jungen Führerscheinabsolventen mit übermäßigem Selbstvertrauen und fehlender Gefahreneinschätzung sowie einer Fahrausbildung, welche sich nur mit den benötigten Fertigkeiten beschäftigt, ein Motorrad zu steuern, wurde bereits vor langer Zeit erkannt.

Die modulare Struktur und die pädagogischen Betrachtungsweisen der Fahrausbildung des IRT bieten eine starke Verbesserung in Bereich der Verfügbarkeit der Fahrausbildung. Während es in erster Linie für den Einsatz einer strukturierten Fahrschulausbildung entwickelt wurde, kann es auch für kostenfreie informative Trainingssituationen genutzt werden. Das Programm bietet gerade Familienmitgliedern oder Freunden, Clubs oder Verkehrssicherheitsorganisationen gute Ansätze, Informationen dort weiterzugeben, wo Ausbildung qualitativ reduziert oder gar nicht vorhanden ist.

Zur Unterstützung dieser Hauptzielsetzungen wurde weiterhin überlegt, den innovativen Bereich des e-Coachings in das IRT zu integrieren, um Motorradfahrer realen Risikosituationen auszusetzen, ohne sie dabei in Gefahr zu bringen. Die bislang unternommen Untersuchungen kommen zu dem Schluss, dass hinsichtlich des angestrebten e-Coachings (mit Unterstützung des entsprechenden Fachbereiches der Tampere Univeristät) das Potenzial besteht, einen wichtigen Beitrag für die Sicherheit von Motorrad- und Rollerfahrern zu leisten.

The Initial Rider Training project –

Developing a European approach to the

Initial Training of Motorcyclists

Rider training, a shared concern

The initial training of motorcyclists, that is the training required for a rider to be able to satisfy the national authorities that he or she is sufficiently safe and competent to be awarded an A category licence, is a concern shared by many interests: legislators, academics, road safety experts, training providers, the manufacturers and retailers of motorcycles and scooters and, of course, those who ride them and want to ride them and the organisations that represent these various interests.

Riding a motorcycle with an acceptable level of safety requires skill, knowledge, a focused attitude and conscious behaviour. Motorcycle research overwhelmingly recognises that human behaviour is the most common cause of crashes. No one should start riding a motorcycle without having undertaken structured, relevant and cost-effective basic training.

The need to better understand

In the mid-1990's FEM (one of the two organisations, the other being EMA, which would combine in 1998 to form FEMA) became concerned about the quality and effectiveness of training. This led to an approach to the European Commission to secure their support and cooperation for a study to examine, from the perspectives of the rider, initial rider training in Europe. This became the first Initial Rider Training Project.[i]

The project had three main objectives: first to identify what the national training arrangements were and whether they were compulsory or voluntary; second to examine recent academic research on rider training; and third to survey riders themselves regarding their assessment of the training that they had received.

When the Project reported in 1997, it concluded that pre-licence rider training in the then 15 EU Member States varied widely, ranging from the very extensive and expensive to the virtually non-existent. Whilst it was expected to find these differences reflected in national accident statistics, no clear evidence of training, where it existed, resulting in fewer motorcycle accidents could be found. Examination of current or recent research into motorcycle training was also very interesting. First it was surprising how little motorcycle specific research there was. Second was that training itself could be part of the problem.

In addressing the third objective a total of 247 riders from Belgium, Finland, Great Britain Greece and the Netherlands were interviewed to ascertain what their evaluation of the training they had received. In fact only 43% had received any formal, paid for, training, with 57% saying they had taught themselves or had been shown by a friend. Of those who had taken formal training over 60% said that they found riding around obstacles was the least useful aspect of their training. When asked what they had found to be the most common hazards faced when riding over 40% said other vehicles drivers, over 30% said poor road surfaces with 17% saying weather conditions. Yet when subsequently asked what had been missing from their training over 25% said poor road surfaces and 18% said riding in poor weather conditions. Most surprisingly of all was that nearly 20% of riders surveyed said that braking techniques had been missing.

Doing something about it: The 2nd Initial Rider Training project

Developing a European Approach to the Initial Training of Motorcyclists (IRT2) project had four objectives: First to identify the elements of a model European IRT programme; second to consider how to apply these in different demographic, social and economic circumstances; third to consider how the essential elements could be developed into a comprehensive and cost-effective European IRT initiative; and fourth, to evaluate e-Learning (or e-Coaching) for training, especially in hazard awareness and attitude and behaviour.

The first three objectives became largely a single task. A Supervisory Board of experts from a range of disciplines was established. They agreed to develop a programme with three elements, theoretical, machine control and traffic interface.

The Supervisory Board established an Instructors' Working Group of five highly qualified instructors and it is their expertise that developed the IRT programme.

First, to develop a *Theoretical element* covering more than the rules and regulations of the road environment. (Signs road markings etc). – To prepare for the practical training. Second, a *Machine control element* addressing the skills and knowledge needed to control a motorcycle of scooter safely. Third a *Traffic Interface element* to equip the new rider to develop machine control skills in the context of real life traffic situations. [ii]

The Instructors' Working Group sought to ensure that in all elements the skills and knowledge were presented in the context of understanding the road hazards, and the importance of attitude and behaviour in avoiding and managing these.

The IRT programme: The theoretical element

The Supervisory Board knew how often existing training in this area was limited. It decided seven theoretical aspects were needed: Road regulations; Road signs and markings; Machine mechanics and dynamics; Helmets and appropriate clothing; Social responsibilities; Impairment; Hazard awareness; and Attitude and behaviour. It decided theory should come before Machine control was taught. If followed, this will result in better respect for the rules of the road.

The IRT programme: The 'machine control' element

A programme of machine control skills was developed: Machine familiarity; First movements; Gears, brakes and direction: Steering and counter steering; Low speed manoeuvring; and Hazard management.

These aspects were then developed, with emphasis on hazard awareness and attitude and behaviour, and the exercises required. These were structured on a "single sheet" for each subject.

For the training to be effective the instructor would need more information than could be contained on a "single sheet". Accordingly instructors' notes were written.

The IRT programme: The 'traffic interface' element

Applying machine control skills to riding safely includes: Positioning in traffic; Distance and speed; Curves and bends; Junctions; Overtaking; Motorways; Anticipation; Riding together; and Journey planning.

The Instructors working group tested these, on a training ground with simulated road junctions, and on public roads. Particular attention was given to hazard awareness and attitude and behaviour.

The role of the instructor: learning by example

The Instructors' working group agreed that a rider should only be trained by an experienced and competent motorcyclist. Instructors must be trained and qualified. With road training the instructor should be riding too. Attempting to train by monitoring from in a car is unacceptable.

The IRT programme: The e-Coaching element

An IRT Project objective was to evaluate, "e-Learning" (e-Coaching) in developing hazard perception. e-Coaching utilises software for a personal computer. This could be supplied to the two million initial riders in the European Union. As motorcycle accidents have high social and personal costs, the small investment is strongly recommended.

An e-Coaching programme could fulfil the following goals:

- Experience of hazardous riding scenarios at no-risk context and to receive feedback.
- Transfer to real-life situations.
- A self-learning process
- To access riders, and other who do not receive hazard perception training elsewhere.
- Appeal to the gaming generation while remaining accessible to other computer users.

Conclusions from the Hypermedia Unit of Tampere University of Technology are that[iii]:

- e-Coaching is useful for training hazard perception and good behaviour. It exposes students to hazardous situations without danger to anyone. Extreme events can be simulated until the trainee can handle the situation safely. Observing the performance of the trainee and giving immediate feedback is easy. A useful supplement to existing training.
- An attractive training method for young trainees who often use computers.
- PC hardware seems more suitable for the IRT e-Coaching programme than the video game consoles due to wider availability. Personal computers also link to the Internet, which can be used to create communal collaboration among the users, reinforcing the learning process.
- It is recommended that the programme is distributed via a website since this is an ideal way to distribute the software to the initial rider trainees in Europe. The website also functions as a base of operations for the communal collaboration aspects.
- The IRT e-Coaching programme itself consists of two "modes": In a level-based mode the trainee completes a series of levels with randomly generated traffic situations with increasing difficulty. In the exercise-based mode the user can select an interesting aspect of riding, and the exercise then contains traffic situations related to this aspect. Before and after every level or exercise a briefing and debriefing is held.

The IRT programme: A modular approach for differing social and economic circumstances

Project partners believe that the IRT programme will make a significant improvement to the safety of riders. It could be adopted as a national syllabus by Member States. Benefits could also apply where commercial or voluntary training providers are working without national guidelines.

Although the partners do not advocate relying on a friend, or relative, as the ideal way of learning to ride, they accept that there are still many Member States that lack formal training on any scale. In a European Union of 29 states that will remain the case for some time to come. In those circumstances we believe that the model European IRT programme also has a lot to offer. It can give to the friend, or relative, an overview of what needs to be trained.

Finally where national training arrangements exist, the model European IRT programme also can have a value. If offers a comparator syllabus to assess existing training.

The IRT programme: a solution for the implementation of the 3rd Driving Licence Directive

Following the development of IRT programme, the motorcycle community (ACEM, FEMA, FIM), along with the partners of the projects (Vägverket the Swedish national road traffic authority and IVV the international driving instructors´ organization), recommend that the IRT as a basis for developing a practical and effective approach to training riders to obtain a licence.

As the proposal for the Third European Driving Licence Directive progressed through the legislative process it became apparent to the Supervisory Board that its definition of progressive licensing would be limited.

The Supervisory Board recognised that if the IRT model European initial rider training programme continued to refer to different licence categories and show their training requirements, it would cause confusion. Accordingly they revised the matrix. In its final form the training requirements specified in Annexe 6 to the Directive ignore a rider's previous training and experience. Nonetheless the IRT Supervisory Board is hopeful that a review of Annexe 6 could result in the logic of the IRT Project's modular approach being reflected in future European legislative requirements.

In so doing the Supervisory board wish to stress that the IRT model European initial rider training programme remains modular in its structure and as such it would also allow for additional programmes, to meet specific circumstances to developed. For example a programme for riders who were returning to motorcycling after a long period of absence could be constructed from the elements of the model IRT programme.

Translating the syllabus:

Since the report was presented to the EU Commission it has become clear that for this work to have any impact on the implementation of the 3rd Driving Licence Directive the syllabus must be available in more than just English. The project team faced the problem that once a report is presented in an official EU language there is no role for the internal translation services of the EU in making it more widely available.

This has been partly addressed by professional translations of the syllabus being commissioned by the FIM into French and Spanish as an additional contribution. A rolling programme of translations into other major EU languages is under consideration.

Additional translations will assist the EU in its external programmes to countries outside Europe. A key benefit of this work is that it is not culturally specific. The work was conducted by a multinational team of experts. As the United Nations has succeeded in internationalising traffic signs the syllabus content needs little if any modification to make it applicable worldwide.

Conclusions

Riding a motorcycle or scooter offers freedom and flexibility for many people. It is fun and can be exciting. It has to be recognised however that the rider is vulnerable and even if the rider is not at fault, as is the case in the majority of accidents, without the benefits of the range of passive safety measure available to drivers they are more likely to be hurt.

The IRT model European initial rider training programme in its present Theoretical, Machine control and Traffic interface three element form, offers to the new rider the best chance of meeting the challenges and recognising and managing the hazards that will be met. The addition of a fourth e-Coaching element could further and significantly improve the situation.

The conclusion and recommendations of the IRT Project are in no way seeking to advance any vested interests. Their intent is only to make future riders of motorcycles and scooters better trained and safer.

More information on the Initial Rider Training project on http://www.initialridertraining.eu/

[i] First Initial Rider Training Project – *The views and the need of the Rider* (1997) http://www.initialridertraining.eu/docs/1997_IRTFinalReport.pdf

[ii] Initial Rider Training Manual http://www.initialridertraining.eu/docs/2007_IRTManual_ppt%20version.pdf.pdf

[iii] E-coaching Evaluation Report http://www.initialridertraining.eu/docs/2007_E-coachingEvaluationReport.pdf

Integrating the Honda SMARTrainer with MSF RETS For Improving Hazard Perception

Die Beurteilung des Nutzens und der Effektivität des Honda-Fahrsimulators zur Verbesserung der Risikowahrnehmung

Sherry Williams, Lora Perez, Tim Buche
Motorcycle Safety Foundation (MSF), USA

Abstract

Reducing rider risk is one of the most important challenges for the Motorcycle Safety Foundation (MSF). MSF continues to promote safe riding by increasing awareness of individual riders to road conditions and the behavior of other road users. *Hazard perception* is a process whereby a rider notices the presence or possibility of a change in the riding environment and takes appropriate action.

Honda's SMARTrainer (Safe Motorcyclist Awareness & Recognition Trainer) is a traffic situations simulator on a special frame with actual motorcycle controls as the user interface. It gives potential riders, new riders, and experienced riders opportunities to develop hazard awareness and other skills in simulated traffic scenarios with situations they typically might face in city streets, suburbs or highways. It does not recreate the feel of a real motorcycle, nor is it intended to replace on-bike training. The SMARTrainer does provide a safe and ethical venue in which students can begin to develop their skills before they're exposed to hazardous situations in the real world with no prior awareness or practice.

American Honda partnered with the MSF to ensure the quality of instruction provided with the SMARTrainer, engaging MSF to design, develop, and pilot-test training and support materials; and also to develop a comprehensive SMARTrainer RiderCoach Guide.

Based on its ongoing analysis, feedback from nearly 200 RiderCoaches and RiderCoach Trainers, and its assessment of the SMARTrainer as utilized by the military for returning soldiers, MSF has fully embraced a full range of SMARTrainer applications and will continue to integrate it into the RETS system and RiderCoach certification training. The SMARTrainer is not a substitute for traditional training, but it does offer benefits that enhance and support student learning when it is used in conjunction with RETS and a trained RiderCoach.

Kurzfassung

Die Verringerung von Risiken für Motorradfahrer ist eine der wichtigsten Herausforderungen für die Motorcycle Safety Foundation (MSF). Die MSF fördert sicheres Motorradfahren durch die Erhöhung des Sicherheitsbewusstseins, insbesondere unter Berücksichtigung des Straßenraums und des Verhaltens anderer Verkehrsteilnehmer. Die Gefahrenwahrnehmung ist ein Prozess, bei dem ein Fahrer eine mögliche Änderung in seiner Umgebung wahrnimmt und rechtzeitig die richtigen Maßnahmen ergreift.

Hondas SMARTrainer (Safe Motorcyclist Awareness & Recognition Trainer) ist ein Simulator für das Training von Verkehrssituationen mit motorradtypischer Bedienung. Er bietet, Fahranfängern wie routinierten Motorradfahrern die Möglichkeit, in simulierten Verkehrsszenarien ein Gefahrenbewusstsein und Gegenmaßnahmen zu entwickeln. Hierbei handelt es sich um typische Situationen, denen Fahrer in der Stadt, auf Außerortsstraßen sowie auf Autobahnen begegnen. Der Simulator soll weder das Gefühl eines echten Motorrades generieren noch die praktische Fahrausbildung auf dem Motorrad ersetzen. Der SMARTrainer bietet eine sichere Gelegenheit Fertigkeiten zu erwerben, bevor gefährliche Situationen im wahren Verkehrsgeschehen real werden.

American Honda kooperierte mit der MSF, um die Qualität des Unterrichts mit dem SMARTrainer inklusive Lehrmaterial zu sichern und um ein Test-Training zu entwickeln und umzusetzen. Darüber hinaus war ein SMARTrainer Trainer-Handbuch zu entwickeln.

Ausgewertet wurden Ergebnisse von nahezu 200 Fahrtrainern und Ausbildern von Fahrtrainern sowie deren Beurteilung des SMARTrainers. Basierend auf den laufenden Analysen hat die MSF eine große Palette von SMARTrainer Anwendungen zusammengetragen und wird fortfahren, die Erkenntnisse in das RETS-System (Rider Education and Training System) und die Fahrtrainer-Ausbildung zu integrieren. Der SMARTrainer ist kein Ersatz für die konventionelle Ausbildung, aber er kann die Ausbildung von Motorradfahrern unterstützen und vertiefen, wenn er in Kombination mit RETS und trainierten Fahrlehrern eingesetzt wird.

Integrating the Honda SMARTrainer with MSF RETS
For Improving Hazard Perception

The Motorcycle Safety Foundation's (MSF) mission is to make motorcycling safer and more enjoyable by ensuring access to lifelong quality education and training for current and prospective riders, and by advocating a safer riding environment. One way of reducing rider risk is to develop an increasing awareness of hazardous road conditions and the inappropriate behavior of other road users, and to demonstrate a rider's response to such situations. This paper will review why hazard awareness perception is key to crash avoidance, how the Honda SMARTrainer (Safe Motorcyclist Awareness and Response Trainer) was designed to improve hazard awareness, and further, how the MSF is incorporating this tool into the comprehensive Rider Education and Training System (RETS). Finally, we will report on one application of the MSF materials to a small sample of participants.

Background

The MSF defines *hazard perception* as a process whereby a rider notices the presence or possibility of a change in the riding environment and takes appropriate action, by changing speed, lane position, or path of travel. Haworth, Mulvihill, Wallace, Symmons, and Regan from the Monash University Accident Research Centre (MUARC) define a *hazard* as "any permanent or transitory, stationary, or moving object in the road environment that has the potential to increase the risk of a crash," and they define *hazard perception* as, "The process whereby a road user notices the presence of a hazard," (2005). These are similar definitions; both include the process of first perceiving a hazard before an action, or response to the hazard, can take place and a crash can be avoided. According to Wallace, Haworth, and Regan, also from MUARC, "Hazard perception and responding is more important for riders than car drivers, because riders cannot rely on other road users seeing them and because the severity of the consequences of failures of hazard perception and responding are greater for riders," (2005). Moreover, riders are more adversely affected by hazardous road and environmental conditions than car drivers.

Perhaps one of the most complete models of hazard perception for motorcyclists is the four-factor model suggested by Grayson, Maycock, Groeger, Hammond, and Field: "This model starts with the necessary component of detecting that a hazard is present, and where failure to detect the hazard will have the consequence of increasing risk to potentially serious levels. Having detected the hazard, the driver or rider needs to appraise the level of threat in the hazard. Once an operator has decided that a hazard must be responded to, he/she must decide what response is appropriate in the circumstances, and finally even if the correct course of action is selected, the rider/driver must implement that course of action correctly," (2003). Perceptual errors are the root cause for most crashes, a statement supported by results in the Motorcycle Accidents In-Depth Study (MAIDS) report: "The cause of the majority of PTW (powered two wheeler) accidents collected in this study was found to be human error," (2004). When an individual does not correctly perceive hazardous environmental and/or other-driver events, that person will not be able to make an accurate responsive judgment.

The MAIDS project team investigated 921 accidents in France, Germany, Netherlands, Spain, and Italy using the Organisation for Economic Co-operation and Development's (OECD) methodology for investigating accidents (2004). They also gathered information from 923 non-accident riders from the same areas to serve as a control population. In 50 percent of the 921 accident cases studied for the MAIDS report, driver error was the main contributing factor for accidents. As may be assumed, much of the time drivers failed to see or perceive riders (70 percent). Significantly, drivers that also had a motorcycle license were less likely (26.4 percent) to commit perceptual errors, perhaps due to the fact that their perceptual base makes it more likely that they would see motorcyclists. This shows that automobile drivers who are also motorcycle riders are less likely to be involve in accidents where they fail to see motorcyclists. Therefore, it is important to help motorcyclists improve their perceptual awareness in an inherently hazardous situation.

Riders represented 37 percent of the accidents caused by human error. Although, the rider percentage was lower than drivers, it is still significantly high. In 90 percent of the crashes studied in the MAIDS study, environmental and other-driver hazards were directly in front of the rider prior to the accident. This suggests that the rider made a fatal perception error, and/or the rider was unable to respond in time, after perceiving the hazard. Hazard awareness training would be key in giving the motorcyclist more time to respond to environmental hazards. Increasing hazard perception is a key area to improve if a rider is to have more time to initiate a crash avoidance maneuver. As a testament to this, the Australian motor vehicle department requires passing a hazard perception test as an integral part of attaining a motorcycle license.

Why use simulators?

One of the safest ways to teach hazard perception is with the use of a motorcycle traffic situations simulator. In a related application, simulators have been used as a more ethical approach vs. putting impaired drivers on the road to test the effects of alcohol or drugs on drivers (Montgomery, F. H., Leu, Montgomery, R.L., Nelson, 2006; Silber, et al., 2005). The Motorcycle Safety Foundation developed the "Riding Straight" module which uses FatalVision[SM] goggles to simulate the effects of intoxication. The University of Michigan Transportation Institute developed and tested a computer-based virtual reality, driving simulator on 86 college students called the "Road Ready Teens" video game. Researchers slowed reaction times in the computer simulator to create a drunk driving condition rather than having participants actually drink alcohol. Both instances illustrate a tool that simulates an effect in a safe and ethical way to educate young people about drinking and driving. In much the same way, it is also more ethical to use a traffic situation simulator to expose a novice motorcycle rider to a hazardous traffic situation.

A situation simulator would also be a safe and appropriate method for improving car drivers' awareness of motorcyclists. A simulator environment would allow motorists to experience the traffic environment from the seat of a motorcycle. This application may approximate the MAIDS finding where automobile drivers who also rode a motorcycle were less likely to commit perceptual errors. This type of intervention with motorists may create the increased awareness that motivates them to look more consciously for motorcyclists.

Pollatsek, Fisher, and Pradhan (2006) used a multi-screen automobile simulator to test whether younger drivers have more difficulty recognizing potential riding environment hazards due to their inexperience as drivers. In a comparison between younger and older drivers, this study showed that a simulator can be used to help younger drivers practice spotting potential environmental risks, and, therefore, reduce risk out on the roads. They postulate that, "Drivers can be trained to attend selectively to potentially threat-containing areas of the roadway and thereby minimize their risks in a simulated environment," (Pollatsek et al., 2006).

Another application of simulator technology is to expose students incrementally to the kind of hazardous situations they will face in real life. For example, a beginning student would start with written materials and educational videos in a classroom. The next steps of the student's education would increase in difficulty, such as with the use of a computer simulator (Wallace et al.). These researchers describe this process as incremental transfer learning (2005). The model of incremental transfer learning states, "Learners transfer skills that they have acquired in relatively simple environments to more complex environments."

For example, in a class of novice riders, the program may begin by teaching students how to operate the basic controls of a motorcycle, such as the brakes, clutch, and throttle. Once a student becomes comfortable with the controls, the program may move to simple riding situations and progressively increase the level of difficulty. As a student progresses, he or she will be ready to take the skills learned on a simulator and eventually apply them to training on an actual motorcycle.

In addition to giving rudimentary instruction on the controls of a motorcycle, simulators can provide feedback to instructors about their students' riding abilities. Wallace et al. found this to be an important aspect to using motorcycle simulators as well: "Simulators provide instructors with access to detailed information about student performance that can assist with the diagnosis of rider errors," (2005). In addition, a simulator can inform a student of his or her weaknesses. Thus, using a simulator is a safe way to present hazardous situations to students in order for them and their instructors to be informed about their specific abilities. They can experience conditions such as simulated night riding with mixed traffic on a simulator before being exposed to this environment in the real world with no prior awareness or practice.

Due to the costly nature of high-end, reality-based motorcycle simulators, they are generally not used for training purposes. Most of them function as tools for research, while the more affordable, fixed-base motorcycle simulators tend to be used for student training purposes.

The Honda SMARTrainer

To help encourage safe riding and reduce risk, Honda introduced a motorcycle traffic situation simulator that has become known as the SMARTrainer. The purpose of the SMARTrainer is not to recreate the feel of a real motorcycle, nor is it intended to supplant on-bike training. The Honda SMARTrainer is essentially a traffic simulation program designed to operate using a special frame with actual motorcycle controls as the user interface. The goal is to give potential riders, new riders, and experienced riders opportunities to develop their skills in simulated traffic scenarios with typical hazards they might face in city streets, suburbs, or highways.

The combination of specialized software with actual motorcycle controls makes it possible to navigate the on-screen motorcycle (or scooter) through various scenarios presenting the rider with real-world situations and hazards he/she might encounter. How a rider perceives and responds to these hazards is measured and assessed electronically. The SMARTrainer software then provides feedback on rider responses to the hazards during replay that is supplemented with printed advice and safety-oriented suggestions.

The MSF SMARTrainer Curriculum

In 2005, American Honda approached the MSF to develop training materials and implementation guidelines for the SMARTrainer and engaged the MSF to distribute this educational safety tool to certified training sites. As the exclusive developer and supplier of the SMARTrainer in the U.S., Honda partnered with MSF in this important project to ensure the quality of instruction provided with the SMARTrainer. Honda subsequently engaged the MSF to design and develop the pilot test training and support materials for the SMARTrainer, with the objective that students have a positive and meaningful experience that improves their hazard awareness in traffic conditions.

The original software programming for the SMARTrainer had been developed and used in many global markets when Honda approached MSF about distribution in the U.S. The initial research included an assessment of what changes would be required for adaptation to the North American market. A thorough review by MSF and Honda staff members resulted in modifications related to American road signage, wording, and the inclusion of specific MSF messages aimed at rider safety.

Initial training design began with a needs assessment that resulted in a self-directed approach centered around a student activity guide that was to be used in Honda Powerhouse dealerships. The addition of a Facilitator Handbook with each unit meant that each dealership would designate a trainer who would be able to successfully guide customers through the proper operation of the SMARTrainer.

To validate the appropriateness of this concept among the general population, the student activity guide and accompanying facilitator guide were pilot tested with a varied sample (12 persons) that included: experienced riders, new riders, recent Basic RiderCourse (BRC) graduates, pre-BRC students and motorists (non-riders).

Research produced two major findings. First, results indicated that the student materials contained too much detail regarding operation of the unit, and second, students reported difficulty following and learning in a non-supervised mode. Further, and more telling, observations of pilot test activity supported the need for an MSF-certified and specially-trained RiderCoach to be involved with the student during training, rather than just the confirmation of activity completion at the conclusion of each module. Subsequently, the notion of a self-directed activity guide was abandoned in favor of a SMARTrainer RiderCoach Guide in the hands of a specially-trained and certified RiderCoach. At this point, engaging a RiderCoach to supervise the SMARTrainer participant became a component that is included in the final Honda Agreement with its dealers.

However, the SMARTrainer is not simply a passive teaching device. Its powerful playback features facilitate immediate participant feedback and make the SMARTrainer an effective tool in the hands of a RiderCoach trained in SMARTrainer use. As the pilot test research reveals, combining an MSF-certified RiderCoach with the SMARTrainer and its array of coaching options creates the most effective learning environment. RiderCoaches, through their sixty-plus hours of training, are already focused on developing competencies to allow them to manage a learning environment that develops rider knowledge, skill and judgment. They have embraced the principle of developing each rider as much as possible through individualized coaching to achieve course objectives. The high-challenge, low-threat learning environment that they are taught to establish in the on-bike training courses also applies readily to the SMARTrainer application. The RiderCoach must choose the appropriate approach for each student and must provide individualized feedback and guidance that enable the

SMARTrainer modules to transcend the “how-many-times-can-I-crash” scenario of some simulated driving/riding machines. The RiderCoach knows that developing crash avoidance skills depends on implementing specific strategies for effectively managing risk in traffic. This perspective, pervasive in the MSF curricula, would be difficult to fully implement without a specially-trained RiderCoach providing the immediacy of pertinent feedback.

The SMARTrainer RiderCoach Guide, as a supplement to the MSF RiderCoach Guide, is based on the same principles, strategies, tactics, and techniques found in the MSF menu of courses. Use of adult learning principles ensures a consistent training style that offers the best possible learning experience for the rider. The SMARTrainer Guide leverages the robust nature of the device as a sophisticated tool, directing RiderCoaches to work with riders of varied experience levels, from the first-time beginner to experienced riders. SMARTrainer applications can also extend to large group presentations and teaching opportunities.

Safety messages are at the core of the MSF mission and are part of all education and training offerings. These include, but are not limited to: concepts such as SEE[SM], RiderRadar[SM], Ladder of Risk, Safety Oval, and lane positioning. In addition, modules contain learner-based questions that provide opportunities for an interactive debriefing with the rider, exploring topics such as protective gear, carrying passengers and cargo, and a variety of riding strategies, procedures, and techniques.

In addition to student preparation materials for RiderCoaches, MSF incorporated a detailed section from the Honda SMART Course Guide. This section contains a detailed explanation of each riding scenario, complete with scene objectives, situation descriptions, and key points of instruction related to recognition, judgment, operations, and control. It also includes advice for using specialized features such as the unique multi-eye system. The materials include a chart with a complete array of each hazard scene showing whether it is present in each course along with its objectives and key points of practice. An additional chart cross-references the hazardous situations with the course number. These tools allow a RiderCoach to choose a course appropriate to the rider’s needs. Another tool for the RiderCoach is a section that provides three coaching procedures, each focused on a different setting and purpose, “Traffic School,” “BRC Pre-School,” and “Public Safety Event.” In the special training for RiderCoaches, emphasis is placed on being prepared to use the SMARTrainer consistently and accurately, thus enhancing the hazard awareness of riders.

Key elements of RiderCoach SMART training include: in-depth knowledge of the capabilities and limitations of the SMARTrainer; all operational aspects of the SMARTrainer software; adequate knowledge of all courses and scenarios, particularly those that are evaluated automatically by the SMARTrainer; and the ability to deliver training in a variety of settings and conditions. The

SMARTrainer RiderCoach Guide is a valuable reference for the complete operation of the device at all training levels, from learning the controls for beginner riders to sharpening hazard awareness in experienced yet complacent riders. Using the basic functions as well as the complementary tools, in-depth analysis is available through the replay functions of the SMARTrainer.

MSF has fully embraced the SMARTrainer as a valuable tool in supporting its mission of rider safety. At the State Motorcyclists Safety Administrator (SMSA) Conference in Buffalo, New York in 2007, the SMARTrainer experience was provided to nearly 200 RiderCoaches and RiderCoach Trainers. A conference workshop presented the full range of SMARTrainer capabilities including the replay modes and a demonstration of tools for assessing rider perception and decision-making. With feedback from these front line stakeholders, the MSF concluded that the SMARTrainer is a valuable tool for improving rider safety, and continues to pursue further integration with its current Rider Education Training System. The primary focus of MSF's effort has been to develop RiderCoach-guided curriculum that will clearly set the SMARTrainer apart from traditional simulators that could easily be viewed as video games. For the MSF, the SMARTrainer RiderCoach Guide has become the fulcrum for integrating the SMARTrainer into the RETS system and RiderCoach certification training.

Integration of the SMARTrainer into MSF RETS

The MSF Rider Education and Training System (RETS) is composed of a flexible set of in-depth curricular programs that provide a wide choice of training options for motorcyclists. Within this system, education and training form a lifelong learning path and offer continuous, real-time improvement. Categories of offerings include Learn to Ride Classes, Return to Riding Classes, Ride Better Classes, Classroom Only Programs, and Online Programs.

The SMARTrainer Class is listed as a component of the RETS under Ride Better Classes, and will also be with other courses and the Host-an-Event series modules in the MSF literature. With the SMARTrainer's wide range of instructional options, the class could be listed under several categories. For example, the SMARTrainer has been used successfully as a remedial tool to help students master clutch and throttle coordination. With the absence of balance issues, such students are able to concentrate on their areas of weakness more effectively. Returning riders would benefit significantly from time on the SMARTrainer as they would become more sensitized to hazards in the common riding environment, which have likely changed since their initial riding experience.

SMARTrainer's role relative to MSF RETS goals

The mission of MSF RETS is to create the most effective motorcycle rider education and training system to support an increasingly safe riding environment in which responsible motorcyclists enjoy riding to the fullest. Four goals support this mission: 1) Comprehensive Model — a dynamic program that packages education and training courses into interconnecting building blocks, each containing a specific set of core skills and competencies; 2) Custom-Tailored for Riders — stand-alone yet interrelated modules so participants can select courses to create a personalized education and training program with instruction matched to particular interests and skill levels; 3) New Opportunities for Rider-Coaches — enhances professionalism in rider education and training by adding opportunities for RiderCoach and RiderCoach Trainer development and giving increased responsibility, visibility, and recognition; and 4) Flexibility for Jurisdictions — complements existing programs by offering options to respond to emerging countermeasures such as graduated licensing, rider improvement programs and online learning opportunities.

The SMARTrainer represents an additional dynamic component to RETS that meets each of these four goals. It is a flexible and effective tool for potential riders and riders with all levels of experience, and can provide these opportunities regardless of the weather or time of year. The safety renewal opportunities are endless.

Safety renewal, a term first coined by MSF, describes the process in which an individual is exposed to multiple learning experiences that focus on crash avoidance skills, risk management, and safety strategies as countermeasures, which affect change in attitude or intention and, subsequently, behavior. If a motorcyclist is involved in a variety of learning experiences over time, with no artificially imposed breaks between beginning and experienced courses (required waiting period and/or miles ridden requirements), the likelihood of the individual mastering the various cognitive and motor skills necessary for accident prevention should increase. Furthermore, renewal training periodically reminds the rider of salient safety issues, which should increase a rider's level of safety awareness and risk assessment. The SMARTrainer Class is a component of the MSF RETS that could be repeated multiple times in different courses to continually improve hazard awareness and perception.

MSF will continue working on improvements to the SMARTrainer RiderCoach Guide to ensure the highest quality training possible during the installation of the units in all settings. As more is learned during the initial implementation phase of the SMARTrainer, updates will be made to the materials to insure viability and greatest benefit for improved rider safety.

The military has taken a keen interest in the SMARTrainer, particularly in its efforts to influence attitudes toward safety and riding habits of active duty personnel who are returning after significant time out of the United States. This unique population offers MSF a chance to reacquaint individuals who have not ridden in some time and are reentering traffic conditions with safety messages and the need for skill development.

Case Study Application

At present, with fewer than 50 units in operation, results of training are limited. To evaluate the application of this tool to the MSF training system, we observed a setting where the SMARTrainer was utilized in the optimum way, both as an introduction to motorcycle controls and as a refresher course for experienced riders. The SMARTrainer, along with a fully-trained RiderCoach, was placed on two U.S. Navy aircraft carriers where it was put to the test by more than 40 service men and women. MSF surveyed the participants about the effectiveness of a stationary traffic situation simulator for teaching hazard perception.

An MSF RiderCoach assisted each student during use of the SMARTtrainer. The SMARTrainer allowed the RiderCoach to adapt the lesson content to the student's experience and skill level. For those who were non-riders, their session focused on learning the motorcycle controls and completing the practice course only. Those participants who were riders completed the practice run and then worked through a different course as a baseline. All experienced students rode one of the six "city" courses. Each riding scenario lasted from five to ten minutes. At the conclusion of each scenario, a color print-out provided the rider with immediate feedback on each scenario and showed the results of the rider's actions. Using this print out and the replay function, the RiderCoach provided verbal feedback.

A total of 43 students completed feedback forms that included 36 closed and open-ended questions. The scale ratings for questions on the feedback forms were from 1 to 7, with 1 corresponding to "Very Strongly Disagree" and 7 denoting "Very Strongly Agree." The questions fell into six categories. The first section included questions about students' perceived value and the overall effectiveness of the SMARTrainer. Students were then asked about their perceived improvement in understanding and awareness of hazard perception. The third group of questions had students rate themselves on individual preparedness, self-assessment of limitations, and level of trust in other road users. The next section inquired about students' personal experience with the playback feature of the SMARTrainer and the effectiveness of the RiderCoach. The fifth group of questions asked students which features of the SMARTrainer they valued most and least. Finally, the last group of questions were about demographics and the grade received for their performance. (A copy of the feedback questionnaire is located in Appendix A.)

Over half of the participants were male and the majority of the sample was between 21 and 34 years of age. Of the 26 participants who did not own a motorcycle, 22 were planning to buy a motorcycle. There were 18 students who had a motorcycle license and rode regularly, 16 of whom owned a motorcycle. Participants' self-assessed riding ability was distinguished in five different groups: 16 participants rated themselves "Experienced, Average Riders", five said they were "Experienced, Expert Riders", eight checked "Experienced, New Riders", one student reported "No Experience, New Rider", and eight participants had "No Experience, Non-Riders". Lastly, five students did not rate their riding abilities. For the purpose of reporting means and percentages for rating questions, the non-riders and the non-responders were excluded. Thus, the percentages reported below and the means in Appendix B represent the ratings of those who are riders of any experience level (N=30). Percentage agreement indicates a response in one of three categories, "Agree," "Strongly Agree," and "Very strongly agree."

We found several benefits with using the SMARTrainer motorcycle traffic situations simulator; benefits which seem to enhance and support student learning rather than substituting for anything in traditional training. For example, students best learn hazard perception in incremental steps or through the model of incremental transfer learning as suggested by Wallace et al. (2005). In this model, "It is assumed that skills are learned in stages, with improving performance as the learner moves from *knowledgeable*, to *prepared*, to *trained*, to *skilled*, to expert." One of the first steps a novice rider generally needs is to learn how to operate the motorcycle controls (i.e. clutch, gas, brakes, etc.), and we found that the SMARTrainer was a useful tool to support this kind of early learning.

Our survey included eight riders who had no riding experience. Although many of these participants only rode the practice course, they found the SMARTrainer to be a valuable tool for learning how to operate the SMARTrainer's motorcycle controls. For example, one rider said, "It was a great way to learn the basic concepts of motorcycle riding. You learn the position of the bike as far as braking, shifting, starting … " Another participant expressed, "It's a good tool for new, inexperienced riders. I would rather get some familiarization on the trainer than going out and purchasing a new motorcycle with no experience and wrecking it." Thus, some of the students surveyed felt they benefited by starting with the very first step in learning to ride a motorcycle. Having the SMARTrainer to practice on allowed them to do so in a safe environment. Our survey results showed that this feature was very important to our students, with 100 percent agreement with the statement, "Overall, working with the SMARTrainer is a valuable way to experience hazardous situations safely."

These preliminary results support the position that using the SMARTrainer is a safer, more ethical way for training novice riders before they get on a motorcycle and risk bodily injury, expensive vehicle damage, or environmental harm. MUARC concurs with this concept, noting, “Motorcycle simulators allow a rider to experience a wide range of hazards in a safe and instructor-supervised environment,” (Wallace et al., 2005). Along with the benefit that the novice riders learned motorcycle controls on the SMARTrainer, the experienced students in our survey felt the SMARTrainer was a valuable learning tool to experience hazardous situations safely and to improve motorcycle safety. Of the experienced riders in our survey, 100 percent agreed that the SMARTrainer helped them experience an increased awareness and understanding of the traffic environment and hazardous situations.

One of the most valuable features of the SMARTrainer is its ability to train experienced riders to perceive risk more appropriately. Many of the students surveyed made statements such as, “It’s an effective tool that exposes riders to most potential hazards.” For the survey question that stated “Experienced increased awareness of the nature of potential hazards in a traffic environment,” 100 percent of students who had motorcycle experience agreed, reflecting the ability of the SMARTrainer to help improve hazard perception among experienced riders. Another student stated, “It’s a good tool to make you aware of the hazardous situations that are usually taken for granted or go unaccounted for.” For example, over 97 percent of the experienced riders agreed they, “Experienced increased understanding of perceptual errors a rider might make while riding.”

In addition to enhancing hazard perception, the SMARTrainer helped improve the existing riding skills of experienced students. One experienced student stated, “It is a very cool tool to learn and sharpen my skills. Thank you!” Our survey results reflected this outcome, as 100 percent of the students agreed, “The SMARTrainer playback feature helped me understand how a rider SHOULD react after recognizing danger in an accident or hazardous situation.” Another student said, “Even though I am an experienced rider, it is a great tool to help with traffic awareness.” According to Grayson et al., “Drivers differ in accident liability because they differ in ability at an individual level – abilities to detect and recognize potential hazards, and abilities to respond appropriately to those hazards,” (2003). Therefore, the SMARTrainer is a valuable tool to teach learners at whatever level they may be at, in the Grayson et al. four-factor model.

The survey also revealed some feedback from younger riders between 18 and 21 years of age. One such participant, who stated that he had no experience and was a non-rider, said that the SMARTrainer, “Helps you think before you act and watch others with more caution.” Knowing that younger, inexperienced drivers have more difficulty appreciating high risk information in the environment (Pollatsek et al., 2006), the SMARTrainer can be a valuable tool to help younger riders practice detecting risking situations in their riding environment.

As a result of using the simulator, each student was informed of his or her weaknesses. A survey respondent stated, “Accident avoiding was shown as my weak area. This program helped me see this weakness in my riding.” The results from our case application indicate that experienced riders felt that the SMARTrainer not only broadened their knowledge of potential traffic hazards, but also enhanced their ability to predict hazards before they happened. For example, 100 percent of the students surveyed agreed with the statement, “Overall, I feel the SMARTrainer has raised my awareness of traffic patterns.” In addition to showing students their own riding weaknesses, the SMARTrainer allowed a coach to learn their students’ weaknesses and identify what areas each student needed to work on.

There are limitations to using a stationary simulator, namely the lack of real-world replication. The SMARTrainer is a stationary, traffic situations simulator in which students do not experience tilt, vibration, or propulsion. Therefore, the life-like sensory feedback from this simulator is limited. In our survey, 30 students, who were experienced riders, expressed that the riding experience was unrealistic. For example, one student stated, “The only drawback is the lack of feedback (sensory) from the bike. No vibration, no leaning, no thrust ... “ In addition, just 85 percent (a lower percentage when compared to other ratings) agreed they, “Experienced increase awareness of when other vehicles and road users may be in a motorcycle’s blind spot.” The results suggest that because the SMARTrainer lacks real-life sensory input and is a stand-alone, stationary apparatus, experienced riders did not get the overall feeling of where they may be in relation to another vehicle.

The MSF found that having a RiderCoach involved to support learners while they trained was essential for students to receive the full benefit of learning on a simulator. The advantage of immediate RiderCoach feedback cannot be overstated. The playback feature allows the student to replay the ride fully, using eye-view tools to enhance the viewing perspective, as soon as he/she completes the course. Our survey revealed the importance of having a RiderCoach nearby, as 74 percent agreed with the statement, “I could have learned equally as much using only the SMARTrainer’s automated replay feedback.” (a lower percentage when compared to other ratings This result was significantly lower among experienced riders, who received the full benefit of immediate RiderCoach feedback.

The RiderCoach supervising the event expressed one anecdotal finding. He noted that when a hazard approached unexpectedly on the screen or when the motorcyclist crashed, the SMARTrainer rider exhibited a visceral effect. When reviewing the ride, the motorcyclist was able to recall that affect. Compare this effect to a video tape, where the viewer might see a rider exhibit poor judgment and say, “Yes, that was a mistake, but I would never do that.” When viewing the playback, the RiderCoach emphasized that the picture on the screen IS the rider. Thus, the shortcomings found in stationary simulators can be compensated for with other techniques used in motorcycle training, such as Rider-

Coach feedback and first-person perspective. Not surprisingly, 100 percent of students agreed that, “Overall, the SMARTrainer has value as a tool to impact motorcycle safety.”

Next Steps

Driving and riding simulators have been used in a variety of settings, both for training and research. Through the collaboration of Honda and MSF, the SMARTrainer is an example of a mechanical tool that has been transformed into a complete learning module. By using certified RiderCoaches who use their knowledge of adult learning, motor skills, and traffic safety principles, and providing them with substantial guidance through a professionally developed teaching guide, the SMARTrainer experience is augmented significantly. Respondents are in nearly complete agreement about its high value and effectiveness.

Future steps for the development of the SMARTrainer include testing its placement in a multi-pronged curriculum sequence. Some developers recommend placing SMART before the BRC, particularly for those students who have no experience with a clutch mechanism. In our initial focus group, several students had experienced difficulty with clutch-throttle control when taking the BRC. When they used the SMARTrainer, with the balance issue out of the picture, they were able to concentrate on and master the friction zone process. On the other hand, others advocate using the SMARTrainer as the perfect bridge between the BRC and riding in traffic. By simulating traffic situations, the trainer allows the novice rider to gain more confidence and to learn what to expect from other road users when riding in traffic.

The SMARTrainer is the perfect addition to a safety renewal perspective. It constitutes a significant learning event in a relatively short period of time that can be varied to meet the needs of students at any RETS level: Learn to Ride, Returning to Ride, or Ride Better. The feedback feature of the SMARTrainer gives students immediate feedback about weak areas. The assessment, using an A-D grade, has the potential to instill competition during a public event. And by riding safer, the performance grade rises. The result: riders who are more aware of potential hazards and begin to look for them in the real-world of riding.

By applying its contemporary techniques and theory-driven curriculum-development approach to the SMARTrainer effort, the Motorcycle Safety Foundation has transformed this sophisticated tool into an essential, and effective element of a comprehensive Rider Education and Training System.

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Appendix A: SMARTrainer Survey Feedback Instrument

Motorcycle Safety Foundation SMARTrainer critique

Please help the Motorcycle Safety Foundation evaluate the SMARTrainer by providing feedback on your experience. Please provide as much detail as possible in your comments.

If you are a non-rider, you may not feel able to respond to all questions. In this case, circle the NA for "Not Applicable."

Circle the number corresponding to your response to each question.

Overall Evaluation		Very Strongly Disagree						Very Strongly Agree	
1	Overall, working with the SMARTrainer is a valuable way to experience hazardous situations safely.	1	2	3	4	5	6	7	NA
2	Overall, the SMARTrainer has value as a tool to impact motorcycle safety.	1	2	3	4	5	6	7	NA
3	Overall, the SMARTrainer is an effective way to reproduce traffic situations.	1	2	3	4	5	6	7	NA
4	Overall, the riding environment shown in the SMARTrainer is similar to my expectations and/or experiences with the riding environment.	1	2	3	4	5	6	7	NA
5	Overall, I feel the SMARTrainer has raised my awareness of traffic patterns.	1	2	3	4	5	6	7	NA

5A. Add any additional comments on your overall evaluation.

Which, if any, of the following outcomes do you feel you experienced?									
6	Increased awareness of the nature of potential hazards in a traffic environment	1 Definitely NOT	2	3	4	5	6 Definitely, YES	7	NA
7	Increased ability to predict hazards hidden in traffic environment	1 Definitely NOT	2	3	4	5	6 Definitely, YES	7	NA
8	Increased overall safety awareness or alertness toward potential hazards	1 Definitely NOT	2	3	4	5	6 Definitely, YES	7	NA
9	Increased awareness of when a motorcycle may be in the blind spot of other vehicles	1 Definitely NOT	2	3	4	5	6 Definitely, YES	7	NA
10	Increased awareness of when other vehicles and road users may be in a motorcycle's blind spot	1 Definitely NOT	2	3	4	5	6 Definitely, YES	7	NA
11	Increased understanding of Importance of acquiring a wide range of information from the traffic environment	1 Definitely NOT	2	3	4	5	6 Definitely, YES	7	NA
12	Increased understanding of perceptual errors a rider might make while riding	1 Definitely NOT	2	3	4	5	6 Definitely, YES	7	NA
13	Increased understanding of the danger of assumptions when making judgments about traffic patterns	1 Definitely NOT	2	3	4	5	6 Definitely, YES	7	NA

13A. What aspects of your riding do you believe the SMARTrainer experience will impact the most? WHY?

Continued on Back --->

Motorcycle Safety Foundation SMARTrainer critique

Additional Areas	Very Strongly Disagree						Very Strongly Agree	
14 I feel I am better prepared to ride in traffic after using the SMARTrainer.	1	2	3	4	5	6	7	NA
15 The SMARTrainer helped me self-assess my capabilities and limitations.	1	2	3	4	5	6	7	NA
16 The SMARTrainer caused me to reconsider my level of trust in other road users and pedestrians.	1	2	3	4	5	6	7	NA
17 The SMARTrainer playback feature helped me understand what may have caused an accident (or hazardous event).	1	2	3	4	5	6	7	NA
18 The SMARTrainer playback feature helped me understand how a rider SHOULD react after recognizing danger in an accident or hazardous situation.	1	2	3	4	5	6	7	NA
19 The SMARTrainer Coach's feedback added more value to the trainer's automated replay feedback.	1	2	3	4	5	6	7	NA
20 I could have learned equally as much using only the trainer's automated replay feedback after my rides.	1	2	3	4	5	6	7	NA

21 My "performance grade" for my baseline ride was: _______________; For my second ride was: _________________

For non-riders only:

22. The SMARTrainer helped me learn the controls of a motorcycle.	1	2	3	4	5	6	7	NA
23. The SMARTrainer gave me a realistic feel for the clutch mechanism of a motorcycle.	1	2	3	4	5	6	7	NA
24. The SMARTrainer experience has influenced my decision to purchase a motorcycle.	1	2	3	4	5	6	7	NA

24A. In what way has this experience influenced your decision to purchase?

25. What is the most valuable feature of the SMARTrainer?

26. What feature was least beneficial?

27.What, if any, additional activities, coaching or feedback would have made your SMARTrainer experience more valuable?

28. Please share any additional comments you may have.

Demographics

29. Do you currently own a motorcycle? Yes NO
29A. If no, do you plan to buy one? Yes NO

30. Do you currently ride a motorcycle regularly? Yes NO
30A. If yes, estimated # of miles you ride annually: ______________

31. What style and engine size is the motorcycle you ride **most often** / or plan to buy?
☐ Traditional ☐ Cruiser ☐ Sportbike ☐ Dual Purpose ☐ Touring
Engine CC size: _____________ cc

32. Do you have a motorcycle license endorsement? Yes NO
32A. If yes, for how long? _____ years_____ months

33. Age
☐ 18- 21 ☐ 21-24
☐ 25-34 ☐ 35-44
☐ 45-64 ☐ 65 or Over

34. Gender
☐ Male
☐ Female

35. Which of the following best describes your riding ability?
_____ No experience, Non-rider
_____ No experience, New rider
_____ Experienced, New rider
_____ Experienced, Average rider
_____ Experienced, Expert rider

36. Have you taken any motorcycle training or safety courses? Yes NO
36A. If yes, specify courses below:
_____ MSF Dirtbike School
_____ MSF Basic RiderCourse
_____ Other, non-MSF ----> Specify, ______________________
_____ MSF ScooterSchool
_____ MSF Experienced RiderCourse
_____ None of the above ______________________

Appendix B: Statistical Means

Overall measures	**6.5**
Overall, working with the SMARTrainer is a valuable way **to experience hazardous situations safely**.	6.8
Overall, the SMARTrainer has **value as a tool** to impact motorcycle safety.	6.6
Overall, the SMARTrainer is an **effective way to reproduce traffic situations**.	6.4
Overall, the riding environment shown in the SMARTrainer is **similar to my expectations** and/or experiences with the riding environment.	6.2
Overall, I feel the SMARTrainer has **raised my awareness of traffic patterns**.	6.5
Experience measures	**6.4**
Experienced **increased awareness of the nature of potential hazards** in a traffic environment.	6.6
Experienced **increased ability to predict hazards** hidden in traffic environment	6.4
Experienced **increased overall safety awareness or alterness** toward potential hazards	6.4
Experienced increased awareness of when a motorcycle may be **in the blind spot of other vehicles**	6.3
Experienced increased awareness of when **other vehicles and road users may be in a motorcycle's blind spot**	6.4
Experienced increased understanding of **importance of acquiring a wide range of information from the traffic** environment	6.4
Experienced **increased understanding of perceptual errors** a rider might make while riding	6.5
Experienced increased understanding of **the danger of assumptions when making judgments** about traffic patterns	6.4
SMARTrainer Playback Feature	
The SMARTrainer **playback feature helped me understand what may have caused an accident** (or hazardous event).	6.4
The SMARTrainer playback feature **helped me understand how a rider SHOULD react after recognizing danger** in an accident or hazardous situation.	6.6
The SMARTrainer **Coach's feedback added more value** to the trainer's automated replay feedback.	6.4
I could have learned equally as much **using only the trainer's automated replay feedback**.	4.7
Personal Assessment	
I feel I am **better prepared to ride in traffic** after using the SMARTrainer.	6.1
The SMARTrainer **helped me self-assess my capabilities and limitations**.	6.2
The SMARTrainer caused me to **reconsider my trust in other road users** and pedestrians.	6.3

N = 30 riders with any level of motorcycle experince

The quality seal of the German Road Safety Council

Das Qualitätssiegel des Deutschen Verkehrssicherheitsrates e.V.

Hartmut Kerwien
Dr. Kerwien – Forschung-Beratung-Training

Jürgen Bente
Deutscher Verkehrssicherheitsrat (DVR)

Abstract

The EU-ADVANCED project [01/] has already identified opportunities for the introduction of an EU-wide quality seal for driver safety training. Sanders [02/] reported on the initial draft concepts to create an EU quality seal. According to these concepts, the seal should be voluntary, issued for a limited period of time, and course-specific; it should also represent a progressive, tiered system, have a scientific basis, and be able to supply independent consumer information.

Based on these requirements, the German Road Safety Council began planning the introduction of a quality seal for practical driving programmes. Based on the ADVANCED project and other studies regarding the quality and effectiveness of driver safety training, the quality seal was introduced to the sponsors and members of the German Road Safety Council in 2007 after completing several stages of development. The result is a quality seal that incorporates the following quality aspects: Content, method, training and continuing education for trainers, and quality assurance. The quality aspects are based on various quality categories and criteria. The purpose of the seal is to provide the customer with an easily recognisable symbol as an orientation aid, as well as indicating that a defined standard of quality and a legitimate program with the core goal of "improving road safety" can be expected. It is issued for practical driver training programmes on suitable training courses, practical driver training programmes in public road traffic, and mixed programmes, as well as seminars in combination with one of these three forms. The quality evaluation is conducted for one specific program version offered by a provider; it is based on a "five-star system" using a list of defined elimination criteria.

The structure and the evaluation system for the quality seal are introduced, and the guidelines used to issue the seal as well as experiences collected during the process of issuing the seal are also presented.

Kurzfassung

Das EU-ADVANCED Projekt [01/] zeigte bereits die Chancen für die Einführung eines EU-weiten Siegels für Fahrsicherheitstrainings auf. Sanders [02/] berichtete über erste grobe Rahmenvorstellungen zur Schaffung eines EU-Qualitätslabels. Das Label sollte nach diesen Vorstellungen freiwillig sein, wissenschaftlich fundiert sein, zeitlich begrenzt vergeben werden, ein fortschreitendes, abgestuftes System darstellen, kursspezifisch sein und eine unabhängige Verbraucherinformation liefern können.

Der DVR begann mit der Maßgabe dieser Anforderungen in der Folgezeit die Planungen für die Erstellung eines Qualitätssiegels für fahrpraktische Programme. Auf der Basis des ADVANCED-Projekts und weiterer Studien zur Qualität und Wirksamkeit von Fahrsicherheitstrainings wurde nach dem Durchlaufen mehrerer Entwicklungsstufen das Qualitätssiegel im Jahre 2007 den Kostenträgern und den Mitgliedern des DVR vorgestellt. Das Ergebnis ist ein Qualitätslabel, das aus den Qualitätsdimensionen Inhalt, Methode, Aus- und Fortbildungssystem für Trainer und Qualitätssicherung besteht. Die Qualitätsdimensionen bauen auf verschiedenen Qualitätskategorien sowie Qualitätskriterien auf. Das Siegel soll dem Kunden ein einfach zu erkennendes Zeichen als Orientierungshilfe bieten und darüber informieren, dass er mit einer definierten Qualität und einem seriösen Angebot mit dem Kernziel „Erhöhung der Verkehrssicherheit“ rechnen kann. Es wird vergeben für fahrpraktische Trainingsangebote auf geeigneten Übungsplätzen, fahrpraktische Trainingsangebote im öffentlichen Straßenverkehr sowie Mischvarianten daraus und für Seminare in Kombination mit einer der drei vorgenannten Formen. Die Qualitätsbewertung wird jeweils nur für eine spezifische Trainingsvariante eines Anbieters durchgeführt und erfolgt mit Hilfe eines „Fünf-Sterne- Systems“, wenn eine Liste definierter Ausschlusskriterien geprüft wurde.

Es wird die Struktur und das Bewertungssystem des Qualitätssiegels vorgestellt sowie über die Vergaberichtlinien und über Erfahrungen mit der Siegelvergabe berichtet.

Das Qualitätssiegel des Deutschen Verkehrssicherheitsrates e.V.

Einleitung

Qualitätssiegel für Produkte oder Dienstleistungen sollen primär Verbrauchern bzw. Kunden eine Orientierung bei der Wahl eines Angebots liefern. Dem Anbieter erlaubt ein solches Qualitätssiegel auf der anderen Seite, die Qualität seines Angebots nach außen zu verdeutlichen. Ungünstige Prüfergebnisse können den Anbieter darüber hinaus motivieren, die Qualität seines Angebots zu verbessern.

In Deutschland werden Weiterbildungsangebote im Bereich Verkehrssicherheit häufig von Betrieben oder den Unfallversicherungsträgern bezuschusst, wenn die jeweilige Maßnahme zum Ziel hat, Unfälle zu vermeiden und sicheres Verhalten zu erzeugen. Aus diesem Grund ist es verständlich, dass diese Kostenträger sichergestellt haben wollen, dass es sich bei solchen Angeboten um qualitativ hochwertige Maßnahmen handelt. Ein interessierter Verkehrsteilnehmer sollte ebenfalls auf den ersten Blick erkennen können, welche Trainingsangebote seinen Bedürfnissen am ehesten entsprechen.

Ein Qualitätssiegel für fahrpraktische Trainings und Programme sollte deshalb deutlich zu erkennen geben, dass es sich bei dem Angebot um eine Maßnahme handelt, in der die Verkehrssicherheit zentraler Bestandteil ist und dass es sich um ein qualitativ hochwertiges und seriöses Angebot handelt, in dem neueste Erkenntnisse zur Durchführung von Trainings berücksichtigt werden.

Zur Entwicklung des DVR-Qualitätssiegels

Die Basis zur Entwicklung des Qualitätssiegels lieferte eine umfassende Literaturrecherche. Hierzu gehörte zunächst die Inspektion etablierter Qualitätssiegel, um einen Überblick über mögliche Bewertungsschemata und Vergabeformen zu erhalten. Darüber hinaus wurden Testprozeduren für verschiedene Produkte und Dienstleistungen zu Rate gezogen.

Zur inhaltlichen Ausgestaltung des Qualitätssiegels wurde zunächst die Arbeit von Fastenmeier und Gstalter [03/] inspiziert, in der ein Schema entwickelt wurde, um Sicherheitstrainings zu klassifizieren und nach ihrem Nutzen zu bewerten. Die Entwicklung dieses Schemas beruhte auf teilnehmenden Trainingsbeobachtungen und auf Analysen von Evaluationsstudien über Verkehrssicherheitstrainings. Die daraus abgeleiteten Beschreibungs- und Beurteilungskriterien bestanden aus einer Reihe von als sinnvoll erachteten Lernzielen sowie Kriterien zur Didaktik und Methodik der Trainingsmaßnahmen.

Einen weiteren wichtigen Grundstock für die Qualitätssiegelentwicklung lieferte das EU-ADVANCED-Projekt [01/], welches zum Ziel hatte, Empfehlungen für die Gestaltung von freiwilligen und obligatorischen Sicherheitstrainings für Auto- und Motorradfahrer zu erarbeiten. Grundlage bildete dort neben den obligatorischen Literaturrecherchen ein elektronischer Fragebogen, der europaweit an Trainingsanbieter geschickt wurde, um ein Bild über die Rahmenbedingungen, Zielgruppen, Lernziele, Kursmethoden und Inhalte der verschiedenen Maßnahmen zu erhalten. Darüber hinaus hatte die EU-Projektgruppe verschiedene Trainings in den Ländern Europas besucht. Die Empfehlungen der Projektgrupe zu den Inhalten der Kurse basierten auf einem hierarchischen Modell des Fahrverhaltens [z.B. 04/, 05/,] bzw. auf der so genannten GDE-Matrix [06/].

Den hauptsächlichen Anteil zur inhaltlichen Ausgestaltung des Qualitätssiegels sowie zu methodisch didaktischen Durchführungskonzepten lieferten allerdings die bereits existierenden Sicherheitstrainings und Sicherheitsprogramme, die nach den Richtlinien des DVR (Deutscher Verkehrssicherheitsrat) durchgeführt werden.

Eine erste Sammlung von Kriterien wurde in einer Expertenrunde (Working Group Inhalte und Qualitätssicherung des DVR) mehrfach diskutiert und ergänzt, so dass das Qualitätssiegel mittlerweile in Deutschland und auch in angrenzenden Ländern etabliert ist. Es ist so konstruiert, dass nicht nur bestehende Maßnahmen mit dem Siegel versehen werden können, sondern auch neue, innovative Ansätze in der praktischen Verkehrssicherheitsarbeit eine Chance erhalten.

Folgende Angebote können mit dem Qualitätssiegel versehen werden:

- Fahrpraktische Trainingsangebote auf geeigneten Übungsplätzen
- Fahrpraktische Trainingsangebote im öffentlichen Straßenverkehr
- Kombinationen von fahrpraktischen Angeboten im öffentlichen Straßenverkehr und auf geeigneten Übungsplätzen
- Seminare in Kombination mit einer der drei vorgenannten Formen
- Seminare unter Einbeziehung moderner Fahrsimulatoren

Das Qualitätssiegel beantragen können alle Institutionen und Personen, die Verkehrssicherheitsangebote mit fahrpraktischen Teilen anbieten. Das Siegel wird dabei für das Programm und nicht für die Institution bzw. Person vergeben.

Die Ausgestaltung des DVR-Qualitätssiegels

Den Kern des Qualitätssiegels bilden eine Liste von Ausschlusskriterien sowie die vier Qualitätsdimensionen „Inhalt“, „Methode“, „Aus- und Fortbildung für Trainer“ und „Qualitätssicherung“. Zusätzlich wird ein Wahlbaustein für den Trainingsplatz angeboten, der vom Antragsteller gesondert beantragt werden kann.

Ausschlusskriterien

Bei Erfüllung nur eines Kriteriums der Ausschlussliste kann das Qualitätssiegel nicht vergeben werden. Dies ist beispielsweise der Fall, wenn es sich bei der Maßnahme um ein reines Fertigkeitstraining handelt, wenn die Maßnahme deutlich sportliche Ambitionen hat, wenn es keine Übungsvariationen gibt, die das Gelingen trainierter Verhaltensweisen schwieriger werden lassen, wenn fahrpraktische Übungen losgelöst von realen Straßenverkehrssituationen durchgeführt werden, wenn das Training ausschließlich mit der Methode der Instruktion durchgeführt wird oder wenn die Trainer nicht ausgebildet bzw. regelmäßig fortgebildet werden. Darüber hinaus müssen bestimmte Kriterien für das Übungsgelände eingehalten werden. So darf es beispielsweise keine spitzen, scharfkantigen Einrichtungen auf dem Trainingsgelände geben, die für Motorradfahrer gefährlich werden können und es müssen ausreichende Sturzräume zur Verfügung stehen.

Qualitätsdimension Inhalt

Die Kriterien dieser Dimension betreffen unter anderem die Notwendigkeit eines Realitätsbezugs der Übungen zum realen Straßenverkehr. So wird beispielsweise der Unterschied zwischen den idealtypischen Verhältnissen beim Bremsen auf dem Übungsgelände und in der Realität (verschmutzte Fahrbahn, Regennässe, Glätte, Rollsplitt etc.) thematisiert. Desweiteren sind Kriterien beinhaltet, die den psycho-physischen Zustand des Fahrers mit seinen Auswirkungen auf Wahrnehmung und Verhalten und die Rolle von Einstellungen, Motiven und Emotionen auf das Fahrverhalten betreffen. Darüber hinaus werden die Themen Arbeits- und Gesundheitsschutz, Risikobewusstsein und Risikovermeidung sowie vorausschauendes Fahren und Notmanöver berücksichtigt.

Qualitätsdimension Methode

Fahrpraktische Trainings sollten teilnehmer- und problemorientiert gestaltet werden. Die Wünsche, Interessen und Bedürfnisse der Teilnehmer sollten bei der Planung und Durchführung des Trainings berücksichtigt werden. Im Sinne einer modernen Erwachsenenpädagogik sollten Trainingsteilnehmer die Möglichkeit erhalten, selbst nach Lösungsstrategien für Fahrprobleme zu suchen und diese Strategien dann auch auszuprobieren. Dabei ist darauf zu achten, dass eine Methodenvielfalt angewendet wird mit einem sinnvollen Wechsel zwischen Instruktion, Moderation, Selbst- und Fremdbeobachtungsaufträgen, Gruppenarbeit, Lehrgespräch, Einsatz von Medien etc.

Qualitätsdimension Aus- und Fortbildungssystem für Trainer

Anhand der Kriterien dieser Qualitätsdimension wird überprüft, inwiefern es für die Trainer der Maßnahme fixierte Eignungskriterien gibt und wie die Traineraus- und Fortbildung ausgestaltet ist.

Qualitätsdimension Qualitätssicherung

Ein Anbieter sollte für die entsprechende fahrpraktische Trainingsmaßnahme einen ansprechenden „Pre-Sales-Service" besitzen. Er sollte beispielsweise telefonisch erreichbar sein und es sollte eine ausführliche Beratung am Telefon stattfinden. Dabei sollte der Kunde freundlich und wertschätzend behandelt werden. Darüber hinaus wird überprüft, ob es ein System der internen Information und Kommunikation gibt, festgelegte Verantwortlichkeiten und Zuständigkeiten sowie ein funktionierendes Beschwerde- und Reklamationsmanagement. Desweiteren sollte es Maßnahmen zur Wirkungs- und Nachhaltigkeitsmessung geben wie beispielsweise regelmäßige Teilnehmerbefragungen oder gar wissenschaftlich fundierte Evaluationsstudien. Einen weiteren Themenpunkt stellt die Informationsweitergabe an die Trainer und auch Teilnehmer dar. Es wird beispielsweise geschaut, ob die Trainer schriftliche Hintergrundinformationen zu verkehrspädagogischen bzw. verkehrspsychologischen erhalten oder inwiefern es für das Trainingsangebot Teilnehmerbroschüren gibt, in denen die wichtigsten Inhalte des Trainings beschrieben sind.

Wahlbaustein Trainingsplatz

Neben dem Antrag auf Erteilung des Qualitätssiegels für ein Programm kann ein Anbieter auch die örtlichen Rahmenbedingungen der Kursdurchführung prüfen lassen. Dieser Antrag ist freiwillig.

Das Bewertungssystem berücksichtigt, dass die technische Ausstattung eines Trainingsgeländes hinsichtlich der pädagogischen Sinnhaftigkeit sowie des Realitätsbezugs betrachtet wird. Besonders honoriert werden diejenigen Platzbedingungen, die ein Durchführen von Manövern mit höheren Geschwindigkeiten gestatten. So ist beispielsweise das Bremsen aus einer Geschwindigkeit von mehr als 80km/h mit einem anderen Eindruck beim Trainingsteilnehmer verbunden als eine Bremsung aus Tempo 50. Gerade bei modernen Fahrzeugen sind zum Teil höhere Geschwindigkeiten notwendig, um Grenzsituation zu erleben. Dieses Erleben, dass moderne Fahrzeugtechnik auch Grenzen hat, ist einer der zentralen Punkte bei einer Trainingsdurchführung. Dies darf natürlich nicht zu einer Gefährdung von Mensch und Fahrzeug führen.

Für den Out- und Indoorbereich der Trainingsbedingungen gibt es jeweils zwei Qualitätskategorien, die die technische Ausstattung sowie das Trainingsgelände bzw. die Raumfunktionalität betrachten. Übergreifend wird die Lernumgebung überprüft.

Bewertungssystem

Die Bewertung der Kriterien erfolgt mit Hilfe einer Checkliste mit den Antwortmodi „nein“, „eher nein“, „eher ja“ und „ja“. Die Auswertung erfolgt durch eine spezielle Software, die die Punkwertungen intern verrechnet und als Ergebnis den jeweiligen Erfüllungsgrad für jede Dimension ausweist. In den Dimensionen „Inhalt“, „Methode“, „Aus- und Fortbildung für Trainer“ und „Qualitätssicherung“ muss jeweils ein Erfüllungsgrad von 40 Prozent erreicht werden. Über alle vier Qualitätskategorien hinweg muss ein Erfüllungsgrad von mindestens 60 Prozent existieren.

Für den Wahlbaustein „Trainingsplatz“ werden fünf unterschiedlich gewichtete Kategorien verrechnet, in denen jeweils ein Erfüllungsgrad von 20 Prozent erreicht werden muss. Pro 20 Prozent Erfüllungsgrad wird ein Stern vergeben. Bei einem Erreichungsgrad von mehr als 90 Prozent wird die maximale Anzahl von 5 Sternen vergeben.

Vergabeverfahren

Eine Antragstellung kann jederzeit formlos schriftlich erfolgen. Dem Antragsteller wird dann die Kriterienliste zugesendet. Danach reicht der Antragsteller seine schriftlichen Unterlagen auf der Grundlage der Kriterienliste ein. Diese Unterlagen werden auf formelle Vollständigkeit hin gesichtet. Die schriftlichen Unterlagen werden dann an zwei Mitglieder der unabhängigen Qualitätssiegelprüfkommission gesendet, die zu der eingereichten „Schriftform“ Stellung beziehen. Nach einer positiven Beurteilung der Unterlagen beobachten die beiden Prüfer das fahrpraktische Training vor Ort, um Aussagen darüber machen zu können, ob das Training auf der Grundlage des eingereichten Konzeptes durchgeführt wird. Beide Prüfer verfassen im Anschluss unabhängig ihre Stellungnahmen und Bewertungen. Über einen Konsensfindungsprozess einigen sich beide Prüfer auf ein abschließendes Urteil. Nach positiver Prüfung wird das Qualitätssiegel verliehen und das Training auf der Internetseite des DVR (www.dvr.de) aufgelistet. In der Folgezeit werden regelmäßige Qualitätskontrollen durchgeführt. Der Auftraggeber erhält eine regelmäßige Zusammenfassung der Prüfergebnisse durch den DVR.

Abschließende Bemerkungen

Das Instrument zur Erfassung der Kriterien ist mittlerweile an einigen höchst unterschiedlich ausgestalteten Trainingsmaßnahmen überprüft worden. Es zeichnet sich durch eine hohe Sensitivität aus. Gute und weniger gute Maßnahmen lassen sich sehr gut identifizieren. Die Prüfer kommen in der Regel zu konkordanten Urteilen. Von den Prüfergebnisse lassen sich eindeutige Verbesserungspotenziale für Trainingsmaßnahmen ableiten.

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MYMOSA – Towards a virtual motorcycle rider for realistic simulations of motorcycle manoeuvres

MYMOSA – Ein virtueller Motorradfahrer für die realistische Simulation von Motorradfahrmanövern

Claudio Brenna
University of Firenze, Dipartimento di Meccanica e Tecnologie Industriali (DMTI), Florence, Italy

David Moreno
CAE division, LMS International, Leuven, Belgium

Ioannis Symeonidis; Gueven Kavadarli
Biomechanics Group, Institute of Legal Medicine, Ludwig Maximilian University, Munich, Germany

Kurzfassung

Die Multibody-Simulation ist ein hervorragendes Instrument, um Motorradfahrdynamiken analysieren und verstehen zu können. Die Häufigkeit ihrer Nutzung ist in letzten Jahren sehr schnell angestiegen. Abgesehen von dem mathematischen Fahrzeugmodell ist ein virtueller Fahrer notwendig, um das Motorradfahren zu simulieren. Dies liegt in der „instabilen Natur" von Einspurfahrzeugen, die die Simulation insbesondere bei „Open-Loop-Manövern" erschwert.

Das Problem, einen virtuellen Motorradfahrer zu entwickeln, wurde in der Literatur bereits behandelt. Die meisten der vorgeschlagenen Kontroll-Algorithmen erfüllten jedoch ihre Bestimmung, ohne die physiologischen Grenzen des Fahrers in Betracht zu ziehen. Die Ziele der hier aufgeführten Forschungsergebnisse zeigen eine erste Entwicklung eines *realistischen virtuellen Motorradfahrers*, der auf Experimenten und der simulatorischen Umsetzung zusammen mit einem detaillierten Multibody-Modell eines Motorrades basiert.

Besondere Akzente wurden darauf gelegt, das Fahrermodell so einfach wie möglich zu gestalten, um den späteren Steuerungsentwurf zu vereinfachen. Dazu wurden reale Fahrerbewegungen unter Laborbedingungen mit der „Motion Analysis Technik" gemessen. Um für die spätere Analyse gültige Datensätze zu erhalten, waren an diesem Experiment mehrere freiwillige Probanden beiderlei Geschlechts mit unterschiedlichen Fahrerfahrungen und verschiedener Statur beteiligt.

Der virtuelle Fahrer steuert die Richtungen des Motorrades mittels eines Drehmoments am Lenker sowie seiner Körperbewegung. Für die derzeitige Forschung wurde der Oberkörper des Fahrers durch ein stehendes Pendel modelliert. Hinsichtlich der Längsdynamiken wird das Motorrad über Brems- und Antriebsmomente gesteuert, die über ein einfaches Kettenmodell auf das Hinterrad übertragen werden. Erste Ergebnisse des entwickelten virtuellen Motorradfahrers werden am Ende dieses Beitrages präsentiert.

Abstract

Multibody simulation is a very powerful tool that can provide a great help to understand and analyze motorcycle dynamics. Indeed, its application in this field has grown very fast in the last years. However, apart from the mathematical model of the vehicle, a virtual rider is essential in order to properly simulate a motorcycle. This is due to the unstable nature of two-wheeled vehicles, which makes them very difficult to simulate by using open-loop maneuvers.

The problem of developing a virtual rider for motorcycles has already been covered in literature but most of the proposed control algorithms achieved their purpose without considering the physiological limits of the rider. The objective of the research activities presented here are the preliminary development of a *realistic virtual rider* based on an experimental campaign and its subsequent simulation together with a detailed multibody model of a motorcycle.

Special emphasis was put on making the rider model as simple as possible to facilitate the posterior design of the controller. Real rider movements were measured under laboratory conditions by means of the Motion Analysis technique. Several volunteers with different riding experiences, gender and anthropometry were involved in the experiments in order to provide a valid dataset for the analysis.

The virtual rider controls the direction of the motorcycle by means of both a torque on the handlebars as well as the movement of his body. For the present research, the upper part of the rider's body was modeled by means of an inverted pendulum. With regard to the longitudinal dynamics, the motorcycle is controlled by means of the brake torques and by the engine torque, which is transmitted to the rear wheel by means of a simplified model of the chain. First results of the developed virtual rider are presented at the end of this paper.

MYMOSA – Towards a virtual motorcycle rider
for realistic simulations of motorcycle manoeuvres

1. Introduction

The simulation of a motorcycle accident is quite a complex task because of its highly interdisciplinary nature, i.e. it involves different approaches such as multibody, finite elements, control theory, experimental data from real scenarios, etc. Because of this reason, a rigorous and well defined methodology is necessary to link all these approaches in the most efficient way. This mentioned methodology is being developed within the MYMOSA project (MRTN-CT-2006-035965), a research network financed by the Sixth Framework Program (Marie Curie Actions) of the European Union.

The general objective of this research project is the improvement of PTW (Powered Two Wheelers) safety and rider's safety, leading to a significant reduction of injuries and fatalities of motorcyclists. This objective will be reached by cooperation of researchers from top universities, research institutes and companies and the collaborative generation of multidisciplinary know-how (motorcycle dynamics, accidentology, accident dynamics, biomechanics), development of simulation tools, predictive models and new protective equipment concepts and new safety vision through the implementation of integrated safety (new devices, sensors, control systems). For further info, please visit www.mymosa.eu. The results presented in this paper correspond to the first stages of the development of a virtual rider and a detailed motorcycle model.

In the field of motorcycle simulation, the development of a realistic virtual rider is a challenging topic because the rider plays a very important role. Unlike cars, where the driver uses the steering wheel just to keep the vehicle within the lane limits, motorcycle riders must also stabilize the motorcycle by using the handlebar and the movements of their body. These movements are usually considered secondary but, since the rider's mass is comparable to the motorcycle's mass, they may have a great influence on the dynamic behavior of the motorcycle under certain circumstances such as evasive or emergency maneuvers. It becomes therefore important to take into account the rider movements in the development of new safety systems for motorcycles.

The problem of developing a virtual rider for motorcycles has already been covered in literature but most of the proposed control algorithms achieved their purpose without considering the physiological limits of the rider, which are essential in order to obtain realistic results. Only a detailed experimental activity can give information about human being's capabilities. The objective of the first part of this work is the development of a *realistic virtual rider* based on an experimental campaign done in the Institute of Legal Medicine of the Ludwig Maximilian University (Munich).

From the control point of view, the strategy proposed in [1] to compute the steering torque was taken as a starting point and then extended in order to take into account also the movements of the rider's upper body.

2. Experimental setup

The experimental campaign was carried out by means of *motion-capture.* Motion-capture or motion-tracking started as a photogrammetric analysis tool in biomechanics research in the 1970s and 1980s as a tool to measure displacements, velocities and accelerations of the several limbs that compose the human body. Afterwards it expanded into education, training, sports and recently computer animation for cinema and video games as the technology matured. This technique is based on markers that identify the points of interest on the body. All volunteers wear markers near each joint that allow identifying its motion by measuring the positions and angles between the markers. Acoustic, inertial, LED, magnetic or reflective markers, or combinations of any of these, can be tracked. By using the trajectory of these markers, it is possible to fully reconstruct the movement of the human limbs. For the experiments described below, an optoelectronic motion capturing system with reflective markers and 8 Falcon cameras registering at 120 Hz were used.

The experimental setup is shown in Figure 1, where one volunteer fitted with all the markers is sitting on the motorcycle. Two of the Falcon cameras can be observed in the background. Each volunteer wore sixteen markers carefully positioned so that enough information was available to reconstruct the position of each limb's centre of mass at every recorded frame. By neglecting the compliance of the limbs, the position of three non-aligned markers is enough to reconstruct the 3D movement of any limb.

Four markers were placed for each arm; one on the wrist to point out where the arms starts, another two on the elbow to identify both its rotation axis and the end of the forearm, and the fourth one on the shoulder in order to identify the end of the upper arms.

In order to define the torso's centre of mass, a set of four markers was used. Two markers were placed on its upper part, one on the sternum and the other on the back spine at the height of the sternum. The other two markers were placed on the left and right greater trochanter of the femur. The last two markers were also used to check the relative movement between the motorcycle saddle and the pelvis.

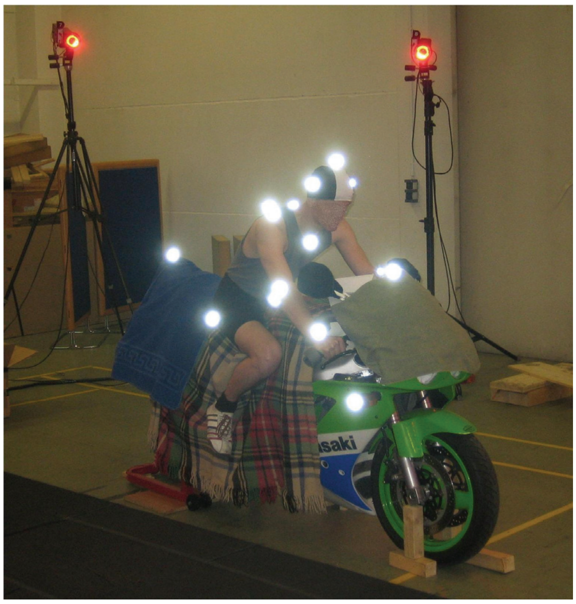

Figure 1: Experimental set-up with some of the markers highlighted

For the head three markers were used, one on the top of the head and the other two on the sides.

The distribution of the markers described up to now is symmetric so an additional marker was added to allow the software to recognize the orientation of the rider during the post process.

The reconstruction of the motion was done by using all the markers described above together with anthropometric relationships found in literature [2].

The position of both the centre of gravity of each limb and its mass were defined by using statistical data. Before starting the experimental activity, the anthropometric measures of each volunteer were collected in order to calculate the torso's length and the position of the centre of gravity of the head. Finally, at every frame, the centre of mass of the rider's upper body was computed as the centre of gravity of all the limbs.

The motion of the rider on the motorcycle is greatly influenced by the riding position, i.e. it depends on the position of the saddle with respect to the handlebar and foot rests. Because of this reason, two different motorcycles were used for the experimental campaign. A sport motorcycle (Kawasaki ZXR 750) and a touring motorcycle (BMW F650GS Dakar). The first one is a sport bike where the position of the fuel tank reduces the freedom of the rider while he/she leans laterally. On the other hand, the second bike is usually considered more comfortable and most of the motorcyclists felt less restricted since they were able to move easily.

All the measurements were performed in a laboratory due to the limitation imposed by the recording setup; the measurement range covered by the eight cameras was not big enough to record a real maneuver with the motorcycle in motion. Both motorcycles were fixed to the ground in the upright position with zero roll and steering angles. The brackets used to fix the motorcycle were rigid enough to keep the motorcycle immobilized during the experiment.

Table 1: Volunteers characteristics

Weight [kg]	Stature [cm]	Gender	Experience
53	167	Female	Normal
52	165	Female	Normal
62	174	Male	No experience
79	184	Male	Expert
73	183	Male	Expert

Five volunteers took part in the experiments, three males and two females with different experience in motorcycle riding (see Table 1). Two of them were very experienced riders since they have ridden motorcycles for many years and also during long trips. Two volunteers had normal experience; they sometimes use motorcycles. One of the volunteers had no experience. Before the beginning of the experiment, each volunteer was asked to sit on the motorcycle and take confidence with it. They also received a detailed explanation of all the procedures of the experiment. Their basic anthropometric data was collected according to [2] and they put on a tight non reflective dress. After these steps, they were asked to perform, as fast as possible, a lateral movement on one side and then on the other side till coming back to the normal riding position. A special emphasis was put on the explanation of the protocol so that the volunteer was fully aware of the purpose of the experiment. Each volunteer fulfilled 6 repetitions per motorcycle with the aim of studying the repeatability of the movements.

3. Evaluation and analysis of results

The trajectories of the markers on the volunteers' body and on the motorcycle were tracked using the Eva Real Time software. The definition of the virtual markers (i.e. the centers of gravity and other useful points that were not directly registered) and the full data analysis were done in Matlab. Firstly, the raw data was filtered by means of a second order Butterworth filter with a cut-off frequency of 5 Hz. Then, by using the anthropometric relationships described in [2], both the mass and the position of each limb's centre of mass were calculated. With this data available, it was easy to compute the full motion of the centre of mass of the upper part of the rider's body.

It is worth noting that the main focus of this research was to create a rider model as simple as possible with the aim of facilitating the design of the control algorithm for the virtual rider but, at the same time, it had to be detailed enough to capture the most important features of a human rider.

First efforts were focused on obtaining the set of data that characterizes the limits of a human rider. For this purpose, displacement, velocity and acceleration of the centre of gravity of the upper part of the rider's body (from now on, it will be designed as CG) were analyzed.

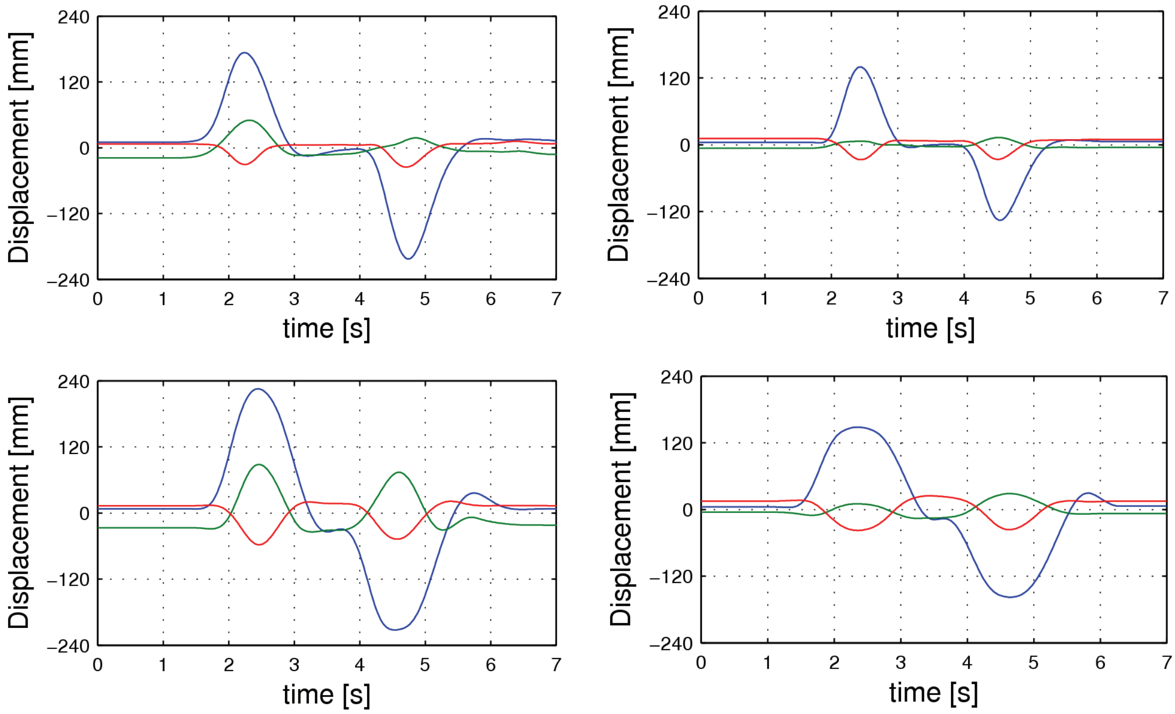

Figure 2: Rider's upper body CG displacement. x (blue), y (green) and z (red).

The graphics shown in Figure 2 correspond to the experiment described in section 2: first the rider leans to the left, then he/she comes back to the initial position and repeats the movement towards the opposite side; always trying to do it as fast as possible with the maximum amplitude. The left column depicts some results from volunteers D and A on the touring motorcycle while the right column shows the same volunteers on the sports motorcycle. By comparing these two columns, it can be clearly observed the difference between the amplitude of the rider's movements (above all in the lateral direction *x*) when he/she changes from a touring to a sport motorcycle. More precise information can be obtained from Tables 2 and 3, where the maximum values for all the volunteers are summarized. All volunteers performed 6 repetitions of the experiment on each motorcycle; mean and the standard deviation are reported in Tables 2 and 3. The units are *mm* for displacements, *mm/s* for speed and mm/s^2 for the acceleration.

Table 2: CG maximum values (touring motorcycle)

Vol.	d_x	σ_x	d_y	σ_y	d_z	σ_z
A	**240**	2	**120**	5	**83**	4
B	**141**	5	**32**	3	**17**	1
C	**195**	5	**137**	11	**63**	5
D	**191**	9	**64**	3	**39**	2
E*	**285**	13	**118**	12	**107**	14

Vol.	v_x	σ_{vx}	v_y	σ_{vy}	v_z	σ_{vz}
A	**483**	8	**296**	2	**189**	10
B	**438**	22	**101**	7	**87**	6
C	**438**	26	**297**	40	**164**	41
D	**484**	30	**142**	5	**110**	6
E*	**821**	39	**339**	28	**388**	36

Vol.	a_x	σ_{ax}	a_y	σ_{ay}	a_z	σ_{az}
A	**1680**	68	**1288**	54	**961**	66
B	**2705**	106	**623**	76	**688**	32
C	**2008**	253	**1326**	218	**912**	245
D	**2038**	102	**672**	24	**722**	70
E*	**3900**	109	**1800**	90	**2578**	158

Table 3: CG maximum values (sports motorcycle)

Vol.	d_x	σ_x	d_y	σ_y	d_z	σ_z
A	**151**	3	**32**	1	**48**	2
B	**132**	5	**13**	1	**33**	1
C	**165**	9	**35**	3	**54**	5
D	**152**	10	**19**	2	**38**	3
E*	**189**	5	**42**	2	**101**	3

Vol.	v_x	σ_{vx}	v_y	σ_{vy}	v_z	σ_{vz}
A	**308**	8	**83**	5	**116**	1
B	**598**	37	**65**	11	**152**	11
C	**435**	22	**94**	25	**135**	18
D	**439**	20	**47**	7	**115**	8
E*	**652**	28	**132**	11	**370**	20

Vol.	a_x	σ_{ax}	a_y	σ_{ay}	a_z	σ_{az}
A	**1150**	37	**334**	45	**498**	38
B	**5034**	370	**683**	148	**1626**	210
C	**1730**	167	**402**	153	**699**	103
D	**2185**	125	**329**	110	**859**	85
E*	**3451**	211	**888**	114	**3196**	198

As can be confirmed from Tables 2 and 3, all five volunteers performed a more reduced lateral displacement on the sport motorcycle. On the other hand, the touring motorcycle allowed them to do a wider movement. With regard to the maximum velocity, most of the volunteers moved faster on the touring bike. However, both for the maximum velocity and maximum acceleration, a strict order between both motorcycles was not found; especially in the acceleration case, where the percentage of volunteers was almost balanced between the sport and the touring motorcycles.

From now on the analysis will be mainly focused on the lateral direction *x*. The movement of the rider's CG along this direction exerts the biggest influence on the motorcycle's behavior as compared to the other two directions. The reason is that the lateral displacement of the rider's CG shifts the center of gravity of the system out of the symmetry plane of the motorcycle; generating therefore and additional roll moment that tends to lean the motorcycle. Another important reason is the effect of the rider's lateral acceleration with respect to the motorcycle, which generates a reaction force that tends to lean the motorcycle in the opposite direction. This effect helps to start a turn as described in [3].

* The results of this volunteer were not considered for the statistical analysis because it is suspected that one of his markers was partially unstuck and therefore it would lead to wrong results.

In the x axis, the repeatability (i.e. the similitude between different trials of the same person) of the movements is very good as can be observed in Tables 2 and 3. The standard deviation for the position is always smaller (with respect to the mean) than 5%, closer to 6 % for the velocity and under 13 % for the acceleration. Of course, these maximum values change considerably from one person to another. The highest ratios among volunteers are shown in Table 4.

Table 4: Ratios of max/min values among volunteers for both motorcycles

Vol.	touring	sport
position	1.7	1.25
velocity	1.1	1.9
acceleration	1.6	4.4

The set of data described above can be use to limit the maximum displacement, velocity and acceleration of the virtual rider. However, even respecting those values, the virtual rider could still perform non-realistic movements. It is also necessary to limit the maximum frequency with which the rider moves.

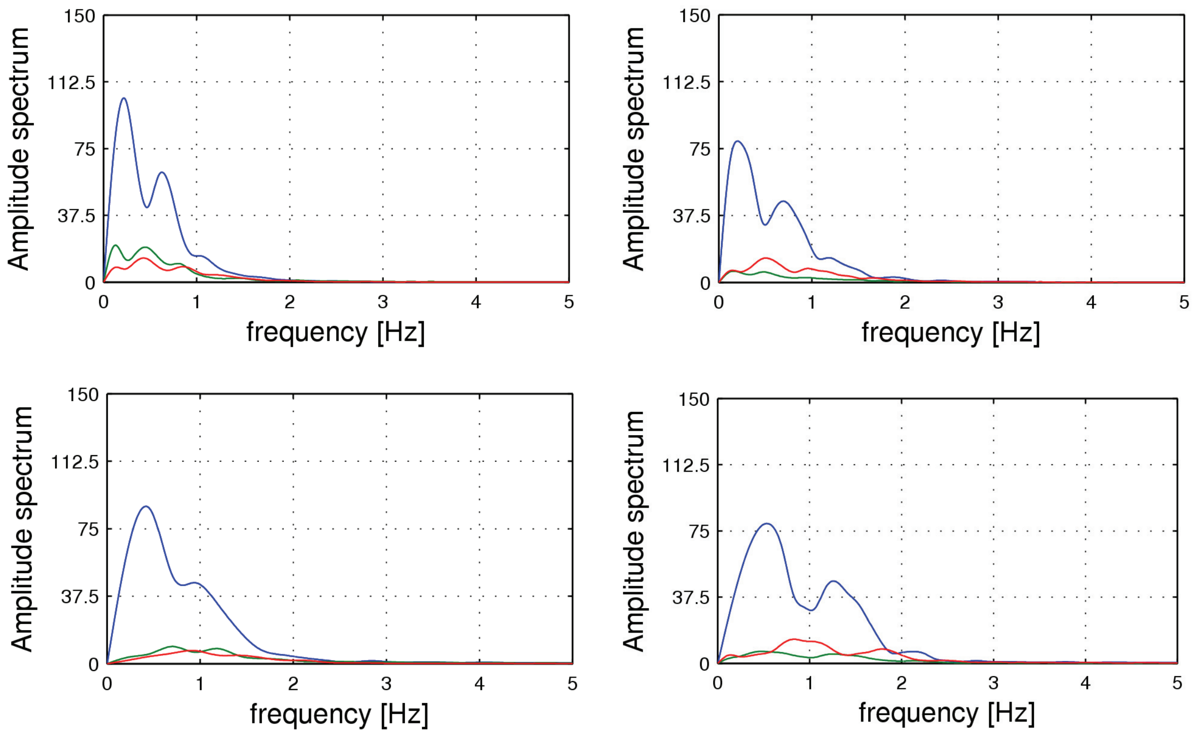

Figure 3: FFT of the rider's CG displacements: x (blue), y (green) and z (red).

The FFT (Fast Fourier Transform) was used in order to find out the maximum frequency component of the rider's movements. Since each volunteer performed several repetitions of the experiment, for each frequency, the maximum amplitude among all the trials was selected. The results are shown in Figure 3 for volunteers D (first row) and B (second row). As in the previous figures, the left column depicts the results of the volunteers on the touring motorcycle while the right column depicts the results obtained on the sport motorcycle. The mean values of the signals were removed before the FFT analysis. The following table summarizes the results:

Table 5: Maximum frequencies considered for the rider's movement [Hz]

Vol.	touring	sport
A	1.31	1.27
B	1.86	2.27
C	1.29	1.45
D	1.39	1.58
E*	1.82	2.00

As it is shown in Table 5, none of the volunteers exceeded the frequency of 2.3 Hz during the experiments. The limits shown in Table 5 can be taken into account in both the multibody model and the mathematical model for the control design by means of a filter. For instance, as in [4], a second order differential equation can be used:

$$\frac{d^2y(t)}{dt^2} + 2\xi\omega\frac{dy(t)}{dt} + \omega^2 y(t) = x(t) \qquad [1]$$

where x is the input of the filter (i.e. the output of the controller) and y is the control action that is introduced to the motorcycle-rider system in order to control the movement of the upper part of the rider's body. By combining the limits shown in Table 2 and Table 3 with the filter described above, it is possible to better reproduce the real behaviour of the rider. It is worth noting that this approach is just an approximation since each frequency component should be limited separately instead of using a low-pass filter. However, this option would complicate excessively the design of the controller and will not be considered for now.

All the results described up to now correspond to the movement of the upper part of the rider's body. However, the main control action is exerted to the handlebar and needs to be limited as well. Nowadays there are some ongoing experiments within the MYMOSA consortium to measure the required rider's properties for this purpose. Results will be published in the future.

Model of the upper part of the rider's body

Once the set of data that characterizes the limits of the human rider was obtained, the research focused on defining a simple model of the upper part of the rider's body. Since it had to be used both in the control design and in the multibody model, it was considered to be very important to limit the number of degrees of freedom of the model. The main limitation came from the control part since the more detailed the rider model is, the more complicated the design of the controller becomes. Therefore, the following question arose: which set of bodies could be used to model the rider's upper body in a simple but accurate way?

The answer to this question came in a very natural way after observing the 3D trajectory of the CG. In Figure 4, the blue line shows the projection of the trajectory on the transversal plane of the motorcycle, while the green curve depicts the trajectory of the virtual point placed between the trochanter's markers. The black triangle represents the middle point of the saddle and was used as the reference point of the rider's model.

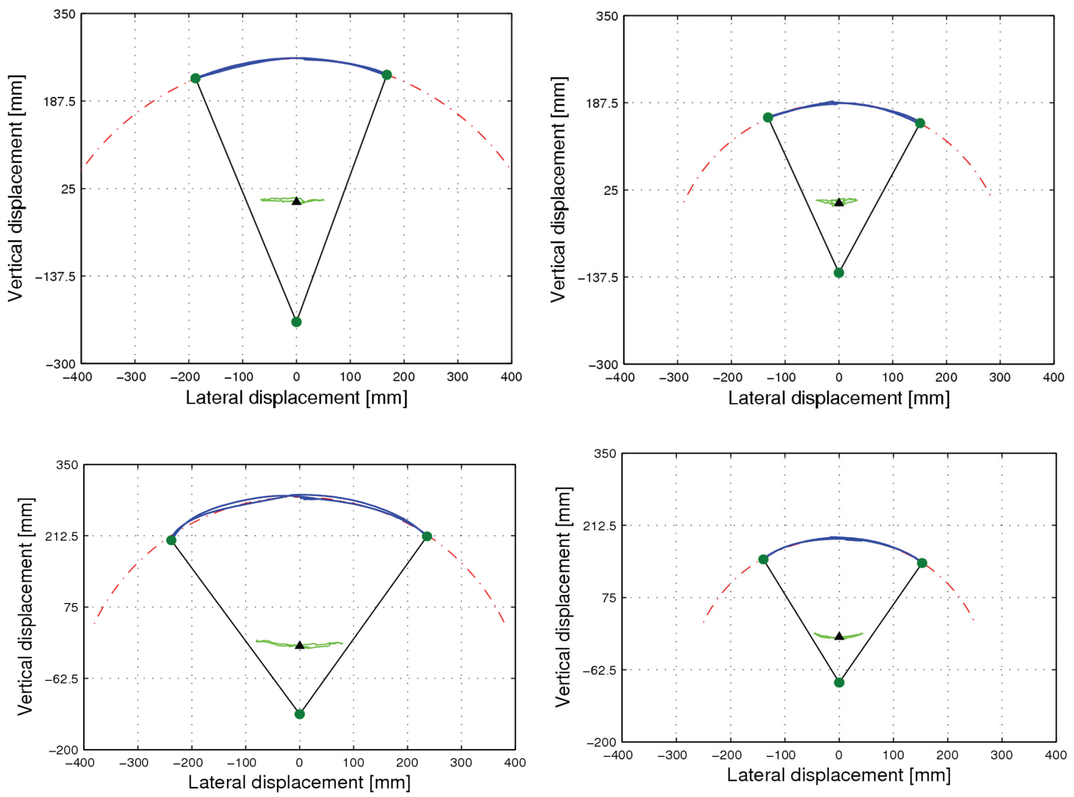

Figure 4: CG trajectory projected on the frontal plane for riders D & A on both motorcycles.

Table 6: Results for the touring and sports motorcycle respectively

Vol.	$\overline{R}$	σ_R	$\overline{a}$	σ_a	$\overline{\alpha}_{max}$	σ_α	$\overline{\alpha}_{min}$	σ_α
A	**417**	9	**-130**	9	**35**	1	**-33**	1
B	**509**	39	**-252**	41	**15**	1	**-14**	1
C	**411**	58	**-149**	60	**25**	5	**-32**	4
D	**462**	16	**-196**	15	**22**	1	**-24**	1
E	**413**	24	**-66**	25	**38**	3	**-40**	3

Vol.	$\overline{R}$	σ_R	$\overline{a}$	σ_a	$\overline{\alpha}_{max}$	σ_α	$\overline{\alpha}_{min}$	σ_α
A	**262**	13	**-74**	13	**36**	2	**-33**	4
B	**289**	17	**-130**	20	**26**	2	**-26**	3
C	**280**	16	**-127**	15	**34**	4	**-37**	3
D	**303**	13	**-118**	13	**28**	1	**-28**	2
E	**236**	6	**-5**	9	**52**	3	**-52**	1

As it is shown in Figure 4, the trajectory of the CG can be approximated very well by an arc of a circle (red discontinuous line). An optimization algorithm was used to compute the parameters of the circle (i.e. its radius R and the distance from its center to the middle point of the saddle a) that minimize the quadratic error between both curves, real and approximated. This algorithm was applied to all the repetitions performed by each volunteer. In Figure 4 some of these repetitions are shown. The left column depicts the results for volunteers D and A on the touring motorcycle while the right column shows the same volunteers on the sports motorcycle. As it was already commented in point 3, all the volunteers adopted a more compact position on the sport motorcycle. In fact, the radii of the trajectories on the right column are clearly smaller. The numerical results are presented in Table 5, where the maximum leaning angles α (which are considered positive toward the right) are also shown. The repeatability of the experiment was good for all the volunteers since, as can be observed in the Table, the standard deviation of the radius is quite small with respect to its mean value.

Considering the good results obtained by the fitting algorithm, an inverted pendulum was chosen to model the lateral movements of the rider. The pendulum was linked to motorcycle's main frame through a revolute joint and the mass of the upper part of the rider's body was lumped at its end.

4. The virtual rider

In this section, the mathematical model of the virtual rider is described. Its main objective is to make the motorcycle follow a predefined path with a given speed profile. However, the motorcycle is an unstable system [5] and the controller must also stabilize it to achieve its purpose.

The first part of the section is focused on the algorithm used to compute the relative position of the motorcycle (and its derivatives) with respect to the reference path. This algorithm provides the controller all the information needed to correct the path error. Afterwards, the different terms used to compute the control actions (steering torque, rider's leaning angle, throttle and braking signal) will be introduced. The strategy proposed in [1] to compute the steering torque will be taken as the starting point and then extended in order to take also into account the movements of the rider's upper body.

4.1 Relative position of the motorcycle wrt the reference path

In order to make the motorcycle follow a predefined path, it is necessary to know its relative position with respect to the path for each integration step. Some authors [6] compute directly the distance between the motorcycle and the points of the reference path in order to find the closest point. However, the method of the curvilinear coordinates [7] has proved to be more efficient and simple. This method will be used for the simulations shown next.

Basically, the position of the motorcycle is described by a set of curvilinear coordinates s, n and ϑ. Where s is the travelled distance along the reference path, n is the lateral error and ϑ is the relative angle between the path and the motorcycle. These coordinates are obtained by projecting the motorcycle velocity vector on the reference path and then integrating the resulting terms. The resulting equations are:

$$\kappa(s)\left(\frac{\partial s}{\partial t}\right)=\dot{\psi}-\left(\frac{\partial \vartheta}{\partial t}\right) \quad [2]$$

$$\left(1-n\kappa(s)\right)\left(\frac{\partial s}{\partial t}\right)=u\cos(\vartheta)-v\sin(\vartheta) \quad [3]$$

$$\left(\frac{\partial n}{\partial t}\right)=v\cos(\vartheta)+u\sin(\vartheta) \quad [4]$$

where $\dot{\psi}$ is the yaw velocity of the motorcycle and $\kappa(s)$ is the curvature of the reference path as a function of the travelled distance s. This set of equations have been implemented in Simulink to be run simultaneously with the multibody model in Virtual.Lab Motion [8] and the rider model, also implemented in Simulink.

4.2 Thrust/Braking force

A PID with *look-ahead* is used to control the speed of the motorcycle. Here the term look-ahead [1,9] means that the control action (i.e. the thrust or braking force) needed to follow a predefined speed profile is computed based on the difference between the actual speed of the motorcycle and the desired speed at a future point (i.e. the look-ahead point) which travels a distance L_A ahead of the motorcycle.

This distance is used to anticipate the response of the system so it starts accelerating/braking before the motorcycle reaches the reference point, which is always moving ahead of the motorcycle. Therefore, in order to imitate the behavior of a real rider, L_A must increase with the speed of the motorcycle u and decrease with the curvature of the road κ.

$$L_A = f(u,\kappa) = \frac{a_0 + a_1 u + a_2 u^2}{1 + b_1|\kappa| + b_2 \kappa^2} \quad [4]$$

Equation 4 shows the expression adopted, where the coefficients a and b were set in order to obtain a stable response of the motorcycle. In this version of the controller, the speed profile is pre-computed before the simulation and therefore it is completely uncoupled with the lateral dynamics.

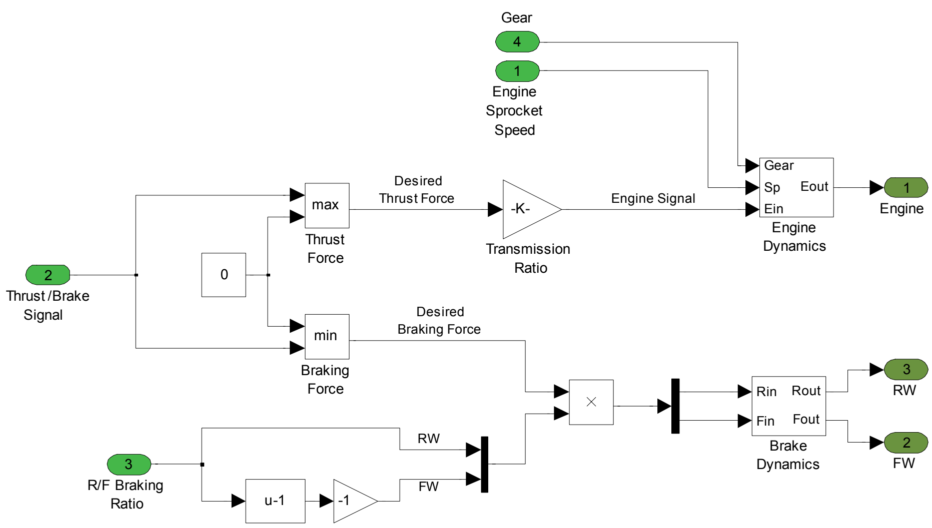

Figure 5: Distribution of the control signal (brake/thrust)

The output of the longitudinal controller is a single signal and, before introducing it to the multibody model, it must be split in three different components since the motorcycle has three inputs for the longitudinal control: thrust, front brake and rear brake. Since riders usually do not brake and accelerate at the same time, it is easy to distinguish between the thrust and braking forces. On one hand, when the control action is positive the control force is applied by the chain and, on the other hand, when it is negative the force is applied by the brakes. As it is shown in Figure 5, this is implemented in Simulink by comparing the signal to zero by means of two max-min blocks.

At this point, the braking force must be distributed between the front and rear brakes. This is done by introducing a new control action, the rear/front brake force distribution (R/F braking ratio in Figure 5). In order to simplify the design of the controller, this ratio was considered constant for the present study.

The block engine dynamics simply limits the maximum power that the engine can supply depending on the speed and the gear engaged. Finally, the block brake dynamics includes a first order dynamic model to better reproduce the behavior of real riders when using the braking system.

4.3 Steering torque

The main objective of the lateral dynamics controller is to stabilize the motorcycle so that it follows a certain path. In order to avoid the fall of the motorcycle, the controller should be able to balance the motorcycle's centrifugal and gravitational forces. For that purpose, the roll angle derived from the steady-state equilibrium condition [5] will be used as the main reference of the controller.

$$\phi_{reference} = \arctan\left(\frac{ma_c}{mg}\right) = \arctan\left(\frac{u^2\kappa(s)}{g}\right) + \phi_{rider} \qquad [5]$$

where u is the longitudinal speed of the motorcycle, κ is the curvature of the reference path, both computed at the look-ahead point, and ϕ_{rider} represents the effect of the rider displacement on the equilibrium angle. A first approach could be the following PD (proportional-derivative) controller:

$$\tau_1 = P_\phi(\phi_{reference} - \phi(t)) + D_\phi \frac{\partial \phi(t)}{\partial t} \qquad [6]$$

where u is the torque exerted on the handlebars, P_Φ is the proportional constant and D_Φ is the derivative constant of the PD controller. However, additional terms are needed to correct the path error.

Thus, by using the output variables of the tracking algorithm, a new PID control action can be computed as

$$\tau_2 = P_n n(t) + I_n \int n(t)dt + D_n \frac{\partial n(t)}{\partial t} \qquad [7]$$

in order to correct the path error. Where n is the lateral deviation of the look-ahead point with respect to the desired path. If some instability appears, other terms can be used to smooth them. For instance, the following term will act as a steering damper, which helps to reduce the destabilizing effect of the wobble mode.

$$\tau_3 = D_\delta \frac{\partial \delta(t)}{\partial t} \qquad [8]$$

Finally, the control torque that is applied to the motorcycle results from the addition of all the torques described above.

4.4 Control law for the rider's upper body motion

The leaning angle of the rider's upper body, which has one DOF with respect to the main frame of the motorcycle, was computed by means of two different terms as shown in Eq. 2. The first term of this equation makes the rider lean proportionally to the roll angle of the motorcycle and the second acts when the curvature changes, for instance, when entering or leaving a curve.

$$\alpha = P_\alpha \phi(t) + f_{rider}(\dot{\kappa}(s)) \qquad [9]$$

For instance, in a turn with constant radius, the second term of Eq. 2 acts first to make the rider lean into the curve. During this movement, the rider's lateral acceleration generates a reaction force that tends to lean the motorcycle in the opposite direction. This effect helps to start a turn as described in [3]. Once the motorcycle has already entered in the turn, the second term keeps the rider leant. This lateral displacement of the rider's CG shifts the center of gravity of the system out of the symmetry plane of the motorcycle, which generates and additional roll moment. Thus, the required roll angle of the motorcycle decreases. Finally, the first term will be active again to bring the motorcycle back to the upright position.

The block diagram shown in Figure 6 was introduced before the motorcycle-rider system to limit the control actions exerted by the virtual rider on the system. The saturation block is used to limit the amplitude of the control signals while the low-pass filter restricts their frequency content.

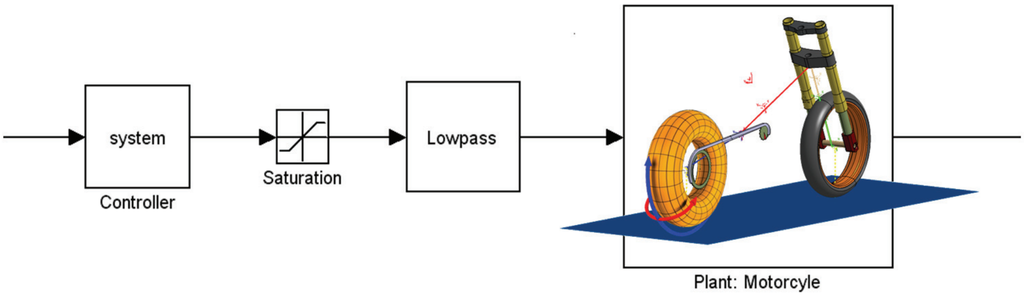

Figure 6: Structure used to limit the control signal

In this case, as shown in Eq. [9], the upper part of the rider's was controlled by the angle α . Therefore, the scope of scheme shown in Figure 6 was to limit the amplitude of the angular displacement and its frequency content. Other schemes could be designed to take into account a more detailed set of the rider's limits described in section 3.

5. The multibody model of the motorcycle

As it is shown in Figure 7, the developed motorcycle model is composed of six rigid bodies: the front wheel, the lower part of the fork, the upper part of the fork (including the handlebars), the front frame (including the engine and the fuel tank), the swinging arm and the rear wheel.

With this configuration, the motorcycle model has a total of eleven degrees of freedom that can be decomposed in the following way: six from the front frame (3 coordinates of the centre of mass together with the roll, pitch and yaw angles), one from the steering angle, two corresponding to the rotation of the wheels and another two from the suspensions.

As explained in the previous sections, the virtual rider has one degree of freedom with respect to the front frame. This means that the actions that the rider exerts to control the direction of the motorcycle are a torque on the handlebars and the movement of his torso. This approach is valid for the most common maneuvers. With regard to the longitudinal dynamics, the motorcycle is controlled by means of the brake torques and by the engine torque, which is transmitted to the rear wheel by means of the chain. A proper modeling of the chain force is very important since it influences the load distribution during acceleration and braking, reducing or increasing the rear normal force available for traction. This means that it is not enough to model the engine as a torque applied on the rear wheel, it is also necessary to include the chain force in the model.

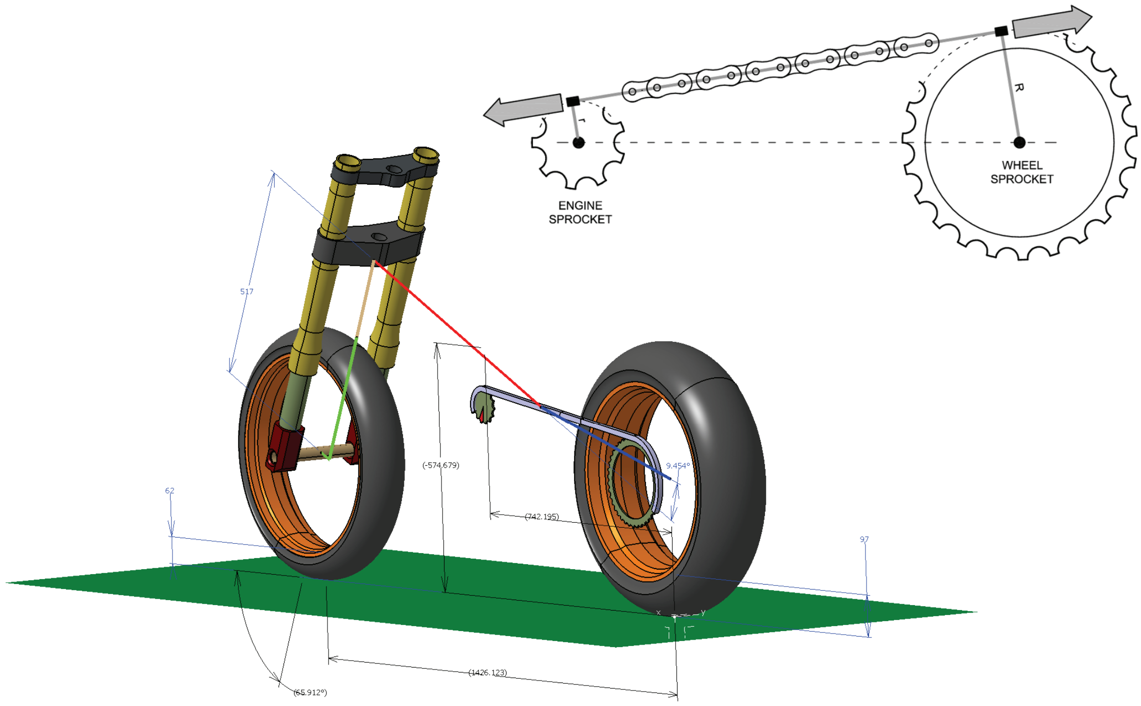

Figure 7: Schematic of the multibody model of the motorcycle and simplified model of the chain

A detailed model of the chain's dynamic behavior would slow down the simulations considerably without improving the results. Because of this, the simplified model shown in Figure 7 is used. With this model, the chain force is applied in the proper direction and the chain effect (i.e. force that pulls the chain when the suspension moves) is also taken into account.

A subassembly composed of three massless elements and four kinematic constraints is used to ensure the tangency condition between the chain and both the engine and the rear wheel sprockets. As it is shown in Figure 7, the links r and R are connected through revolute joints (black circles) to the front frame and to the swinging arm respectively. They represent the line that connects each contact point with its corresponding sprocket centre and therefore the chain must be always perpendicular to them. This condition is ensured by linking the chain and the links R-r by means of two prismatic joints (black rectangles). By using this subassembly, the contact points between the chain and the sprockets are always known and it becomes relatively easy to model the chain as a kinematic relationship or as a force element.

The first option is easy to implement since it is enough to add two more kinematic constraints to the chain subassembly in order to enforce the ratio between the speed of the chain and the angular speed of the sprockets. By using this approach, one can control directly the torque applied by the engine. However, it presents an important drawback. When the chain gets compressed, it transfers the reaction force to the engine sprocket and this does not make sense from a physical point of view since the real chain is not able to transfer any force when compressed. This problem can be overcome by using a force element acting between the contact points. In this case, the input would be the chain force exerted by the engine.

With regard to the tires, it is worth noting that they are a crucial factor for the accuracy of motorcycle simulations. In this work, the response of both tires is modeled by means of the LMS Complex Tire, which takes into account three components of force and three components of torque in the normal, longitudinal, and lateral directions. These reactions are not considered independent. The tangential reactions at the tire/ground interface depend on the normal force and the friction ellipse is used to limit the magnitude of the net tangential force. Well established empirical relations [9] are used to compute the force/torque in these directions as a function of the normal force, sideslip and rotational slip. The values of all the parameters were taken from [10].

6. Results

Next, three sets of results are shown. Firstly, the open loop behavior of the motorcycle will be introduced in order to understand what the counter-steering maneuver is. Secondly, a closed loop maneuver will be simulated without considering the movement of the rider's body. And finally, the same maneuver will be simulated taking into account the movement of the rider according to the model describe in the section 4.4. Both cases, with and without the movement of the rider, will be compared at the end of this section.

6.1 Open loop results

Before showing the results of the virtual rider, it is interesting to observe the open-loop behavior of a motorcycle. A priori, it could seem obvious that a clockwise torque on the handlebars would make the motorcycle turn right. However, the behavior of a motorcycle is counterintuitive; to turn right the rider first must turn left. The result of a clockwise step torque on the handlebar is presented in Figure 8.

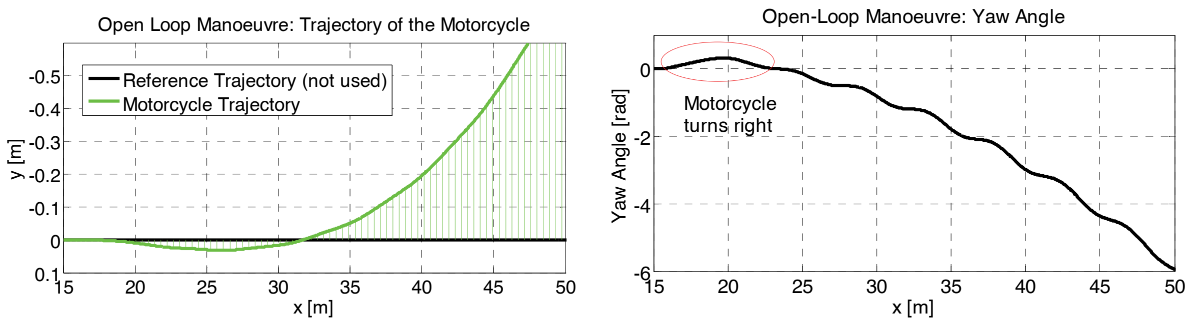

Figure 8: Open-loop results

Initially, as a result of the applied torque, the motorcycle tends to turn right. At the same time, due to the centrifugal force, the motorcycle leans to the left. Once the motorcycle is slightly leant in this direction, the leaning torque overcomes the steering torque and the motorcycle starts cornering to the left as shown in Figure 8. More details about the counter-steering behavior can be found in [3]. This phenomenon must be taken into account when setting up the controller gains for the closed-loop simulations.

6.2 Closed-loop results

Figure 9 shows the closed-loop results for the reference path shown in the graphic 9.a. The path is composed of several stretches. Firstly there is a straight stretch to let the motorcycle stabilize in the upright position. Next there is a turn to the right followed by a turn to the left. Finally the same path is repeated symmetrically; first to the right and then to the left. The reference speed was set to the constant value of 22 *m/s*. The gains for equations 4-9 were set by following an iterative process until the results fulfilled the requirements.

As it is shown in a), the path followed by the motorcycle fits quite well the reference except for the exit of the second curve where the overshot reaches a value of 5 m. It is interesting to see in b) how the torque on the handlebars is mainly due to the proportional term of equation 6 (i.e. the term that takes into account the difference between the actual and the desired roll angle) when the motorcycle is cornering. In c) the roll angle is shown. As stated before, a deviation with respect to the steady conditions is needed. This is due to different reasons, firstly this maneuver is not stationary and secondly the roll angle of the motorcycle is also influenced by the other terms of the controller like, for instance, those introduced to correct the path error. Finally, Figure d) shows the steering angle during the maneuver. Before starting the first curve, the counter steering maneuver can be clearly distinguished. However, in the other turns this effect is not so obvious.

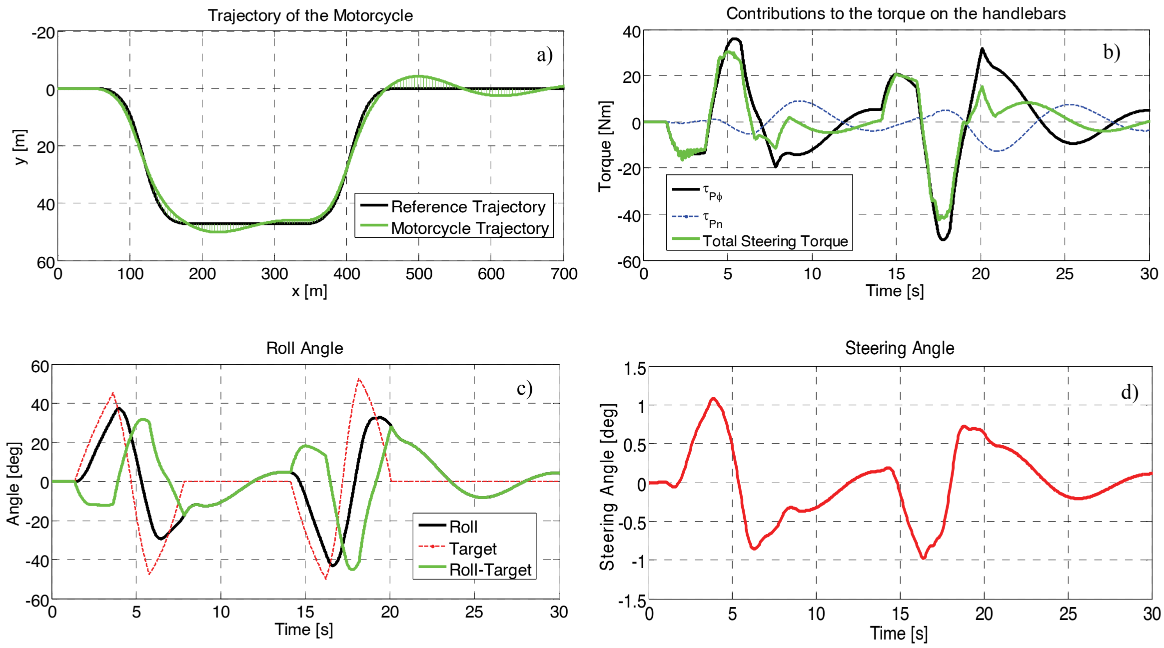

Figure 9: Closed-loop results without considering the rider's movements

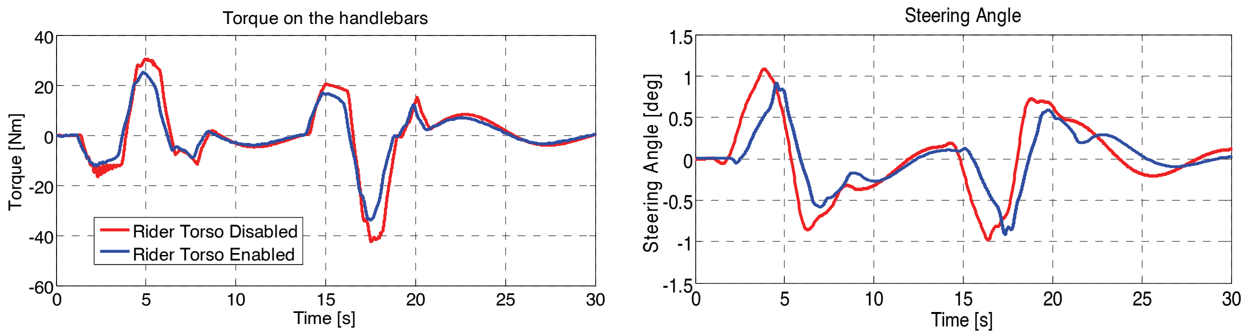

Figure 10: Effects of the rider's movement

Figure 10 shows a comparison between the results obtained without considering the movement of the upper part of the rider's body (red lines) and those obtained considering it (blue lines). As can be observed, the movement of the rider facilitates the maneuver; the required torque is smaller when the rider is active. Also the steering angle decreases in this case.

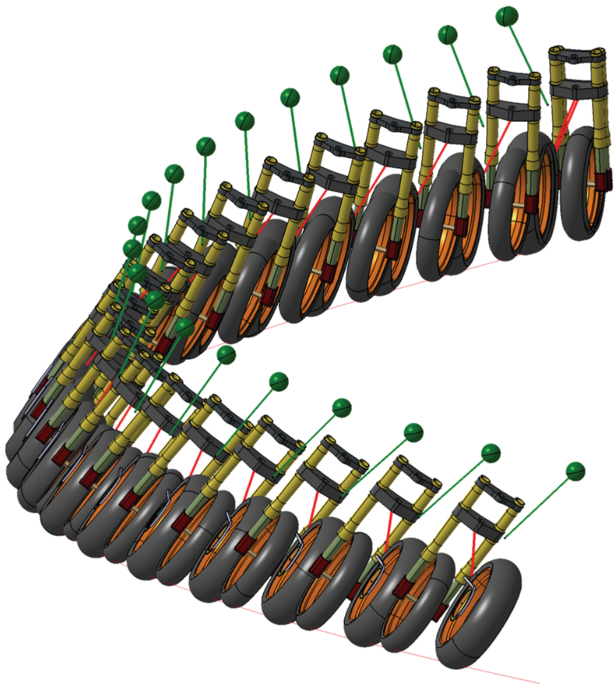

Figure 11. A snapshot of the model making the first turn to the right.

A snapshot of the animation is depicted in Figure 11. Only the first turn to the right is shown. During the first part of the trajectory the rider leans into the curve and then it leans to the opposite side in order to bring the motorcycle back to the upright position and start turning to the left.

It is worth noting that no limits were imposed to the steering torque since no experimental data was available when the simulations were performed. Nowadays there are some ongoing experiments within the MYMOSA consortium to measure the required rider's properties for this purpose.

7. Conclusions

In this work, two parts can be clearly distinguished. First, an experimental study of the rider's upper body motion was carried out. For this purpose, data coming from five volunteers on two different motorcycles was analyzed. This first part was focused on defining a simplified rider model that could capture the most important features of a human rider. Firstly, a set of limits that characterizes the human rider was identified in terms of displacement, velocity, acceleration and frequency. And secondly, the trajectory of the riders (as they move laterally) was successfully approximated by an arc of a circle. Numerical and graphical results were presented at the end of this section.

The second part of this research was focused on the simulation of the motorcycle-rider system. A multibody model of system was developed in LMS Virtual.Lab Motion and co-simulated together with a control algorithm (i.e. the virtual rider) defined in Simulink. A maneuver composed of several stretches was successfully simulated; first without considering the movement of the upper part of the rider's body and then by considering it. Both cases were compared at the end of this section proving that the movement of the rider reduces the steering torque needed to make a certain turn.

This model will be improved in the future by introducing also the human limits on the steering torque.

One important drawback of the presented controller is the difficulty of finding the coefficients for equations 4 to 9, which are not constant but depend on the curvature, the motorcycle's speed and also on its acceleration.

8. Acknowledgements

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Analysis of the thorax rider protection using a new safety system: numerical approach

Numerisches Modell zur Analyse des Thorax-Schutzes bei Gebrauch eines neuen Schutzsystems

Y. Godio; L. Thollon; C. Brunet
Laboratory of Biomechanics and Applications, Faculté de Médecine Nord,
Université de la méditerranée, Marseille, France

S. Bidal
Altair Development France, Marseille, France

Kurzfassung

Eine von der National Highways Traffic Safety Administration (NHTSA) unterstützte Studie begutachtete 1981 rund 4.500 Motorradunfälle, die sich im Bereich Los Angeles ereigneten. Gemäß dieser Studie wurden die meisten tödlichen Verletzungen durch Beschädigungen des Kopfes und des Brustraums verursacht.

Die hier vorgestellte Arbeit fokussiert sich auf die Verwendung einer numerischen Simulation, um mögliche Rippenbrüche bei einem Motorradunfall vorauszusehen und das neue Sicherheitssystem eines in der Jacke integrierten Airbags zu bewerten.

Unterschiedliche Simulationen wurden durchgeführt (Pendel-Teilsystem-Prüfungen mit Post Mortem Human Subjects (PMHS); Gewicht des Aufprall-Prüfkörpers=12kg). Dabei ging es um die Beurteilung des Einflusses verschiedener Faktoren:

- Aufprallgeschwindigkeit des Pendels mit drei unterschiedliche Aufprallgeschwindigkeiten (3,33 4,33 und 5,33m/s).
- Aufprallbereich mit unterschiedliche Aufprallpunkten
- Unterschiedliche Aufprallarten des Pendels (Pendel trifft senkrecht auf, Pendel trifft quer auf).

All diese Prüfungen erfolgten mit und ohne Airbagjacke mit HUMOS (Dummy: Human model for safety). Für jede Versuchsanordnung wurden die Belastung und die Zeitkurve des Pendels analysiert und ein Verletzungsprotokoll geführt.

Die Studie zeigt, dass die Belastung durch das Pendel kein geeignetes Kriterium ist, um Rippenbrüche vorauszusagen. Ebenso verdeutlicht die Studie, dass das integrierte Airbagsystem die Sicherheit der Motorradfahrer steigert. Tatsächlich wurden bei keinem der mit Airbags durchgeführten Versuche Verletzungen festgestellt.

Der nächste Schritt der Studie wird in der Simulation realer Motorradunfälle (nach dem Accidentology-Ansatz) bestehen. Zweck dieser Simulation ist die Analyse über das Verhalten des Motorradfahrers beim direkten Aufprall auf einen Pkw.

Abstract

A study sponsored by NHTSA in 1981 examined nearly 4,500 motocyclist crashes occurring in the Los Angeles area. This study showed than the most deadly injuries were located on chest and head.

The presented paper focuses on the use of the numerical simulation to predict rib fractures in case of motorcyclist accident and to evaluate a new safety system: an airbag integrated in a jacket.

Different simulations were performed according to experimental tests (pendulum subsystem tests with PMHS; impact mass = 12 kg) to evaluate the influence of various parameters: three different impact velocities (velocity = 3.33, 4.33 and 5.33 m/s), variation of the impact zone, use of different types of impact (perpendicular and lateral position of the pendulum).

For all the tests, we performed simulations with and without airbag positioned on the HUMOS model. For each configuration test, we analysed the load versus time curve of the pendulum and we performed an injury report to evaluate ribs fractures.

Through this study it appears that the load applied by the pendulum can't be used as an injury criterion to predict rib fractures. The study also showed that the airbag system increases the security of the motocyclist. Indeed, for each simulations test, performed with airbag, no injuries were noted when the airbag was used.

The next step of the study will consist in simulating real motorcyclist accidents based on accidentology approach. The aim will be to analyse the motocyclist behaviour in case of direct impact on a car.

Keywords: Finite Element Model, Human, Motorcycle, Trauma, Safety, Crash

Analysis of the thorax rider protection using a new safety system: numerical approach

Introduction

A study performed by INRETS [1], in 2007, describes injuries of motorized two-wheelers injured in a road crash between 1996 and 2003 and recorded by the Rhone Road Trauma Registry in France. Through this study, it seems than 50% of severely injured riders sustained severe chest injuries and 44.8% suffer from severe head injuries.

Krauss in 2002 showed that little safety system have been made to reduce the severity of thoracic injuries in motorcycle crashes, compare to the head with the safety helmet [2].

However, the development of new safety system for the thorax requires a standardisation to evaluate thoracic injuries in case of motorcycle before to analyse the benefit of this safety devices.
In this aim, some studies were performed to develop injury criteria. After acceleration tolerance studies by Stapp [3, 4] and force tolerance studies by Patrick [5, 6], compression criterion appeared as better according to Kroell [7, 8] who performed a large number of frontal chest impacts (using a 152 mm diameter rigid pendulum), and found a better correlation of AIS with chest compression (r = 0.730) than with maximum plateau force (r = 0.524).

So, if human tolerance of the chest to blunt impact was initially dedicated to protect unbelted drivers involved in frontal crashes and later to understand the interaction between the belt and the ribcage, some recent studies focused on the development of new safety systems in case of motorcycle accidents.
In this context, the study presented is a part of a PREDIT project, PROMOTO ("Improved Protection Motorcyclists by a vest with Integrated Airbag") where the objectives are to analyse motorcyclist accidents, to perform experimental and numerical tests for different motor crash configurations and to test a new airbag system directly integrated in the motorcyclist jacket.
This paper focuses on the use of the simulation to predict rib fractures and to evaluate the airbag system. The human model used is the Radioss® HUMOS model, developed and validated from the HUMOS European project.

Materials and Methods

The aims of this study are

- To develop the knowledge of vulnerable body segments in case of motorcycle accident,
- To evaluate the benefit of a new safety system in terms of injuries reduction.

The numerical study was performed in two steps:

- A first analysis to understand the injury mechanisms observed in these types of accidents.
- Simulations focusing on the benefit of a new safety system.

For both approaches, we used a finite element human model, HUMOS (HUman MOdel for Safety), based on a car driver 3D reconstruction [9, 10].

Description of Humos Model

For all the tests, we performed simulations with and without airbag positioned on the HUMOS model. The HUMOS model is a 50th percentile European human model, in height and weight. This model was developed between the years 1998 and 2001, in the framework of a European Project gathering software and automobile manufacturers, research institute and universities.

The HUMOS model used for our study is validated locally for each anatomical part through subsystem tests and globally through sled tests, as detailed in [11, 12].

Description of simulation Procedure

First step

The simulations were based on the experimental tests performed at the LBA, pendulum tests with PMHS (impact mass = 12 kg). We performed two types of tests:

- Impacts at three different impact velocities (3.33, 4.33 and 5.33 m/s) on the lower sternum, using the pendulum in a perpendicular position,
- Impacts at 5.33 km/h on the lower, middle and upper sternum, using the pendulum in a parallel position

These tests allowed estimating the possibility to use the applied load as an injury criterion, (figure 2 and 3).

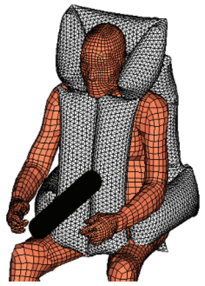

Figure 2: Perpendicular pendulum position

Figure 3: parallel pendulum position

Second step

We performed simulation tests with and without the new safety system (airbag) inflated on the humos model, based on those described below.

1st configuration:

- Impact speeds 3.33, 4.33 and 5.33 m/s (12, 16, 19 km/h)
- Impact area: lower sternum
- Impactor: flat pendulum (mass = 12 kg and diameter = 76 mm) perpendicular to the impact area (figure 2)

2nd configuration:

- Impact speeds: 2.78, 5.56, 8.33, 11.11 m/s (10, 20, 30, 40 km/h)
- Impact area: upper sternum
- Impactor: same flat pendulum (mass = 12 kg and diameter = 80 mm) lateral to the impact area (figure 3)

For both the approaches, the criterion used to evaluate the thoracic injuries was the AIS [13]. The current FMVSS 208 is based on Kroell results which were analyzed by Neathery [14]. These studies allowed determining the percentage of chest depth and compression for a 50th percentile male and the corresponding AIS values

The AIS can be computed using the percentage of chest compression: AIS = -3.78 + 19.56 C. This calculation method was used in the current study.

The correspondence between AIS and ribs fractures is detailed here after [15]:

AIS: rib fractures

AIS 1: 1 rib fracture

AIS 2: 2-3 rib fractures

AIS 3: > 3 on one side, =< 3 on other side

AIS 4: > 3 rib fracture on both sides, flail chest

AIS 5: bilateral flail chest

Description of simulation with airbag

For the simulations with airbag, each run was performed in two steps.

- 1st step – inflation of the airbag: Firstly, we pre-positioned the airbag based on the CAO provided by manufacturers, not inflated, around the human model. During airbag inflation (60ms) the airbag shape is controlled in order to cover the whole HUMOS external surface, particularly the thoracic part.

- 2nd step – impact simulations: Numerical simulations were performed like those described in the first step. The aim of this approach is to evaluate the benefit of a safety system for the different tested configurations without airbag (figure 4b).

Results

First step: Simulations without airbag

Influence of impact speed for the perpendicular pendulum position (Table 2)

For v = 3.33 and 4.33 km/h, we noted no injury (ASI = 0) for respectively an applied load of 1940 and 2208 N.

At v = 5.33 km/h, we observed rib fractures ‘AIS = 1.2) qwith an applied load of 2572 N.

This injury report has been obtained for quite low impact speeds; the higher impact speed in this step is 5.33 m/s (< 20 km/h).

Influence of impact area on the sternum, at v= 5.33 m/s for the lateral pendulum position (Table 3)

The tests were performed at v = 19 km/h. We observed no injury for the impact on the middle and lower sternum with respectively an applied load of 5201 and 4640 N.

For the test with impact on the upper sternum, we noted a more severe injury report (AIS = 1.45) for an applied load of 4444 N.

We can notice an AIS increase for the upper sternum impact configuration compared to the two other cases. Moreover, the load level applied on the model also increases for lateral pendulum configurations compared to perpendicular pendulum impact simulations.

Second step: Evaluation of the new safety system

1^st^ configuration

The load level measured on the impact pendulum worth being studied, for the 3 speeds, in simulations with airbag (figure 6). We observed a decrease of the applied load of 32% and 21% respectively for impact speeds of 12 km/h and 16 km/h with the airbag system. For an impact speed of 5.33 m/s, the resulting decrease is only about 1.5%.

Concerning the sternum deflection measured for each impact speed, a decrease can also be observed with airbag: around 10 mm of maximal deflection instead of more than 40 mm for impact speed inferior to 20 km/h without any protection system (figure 7).

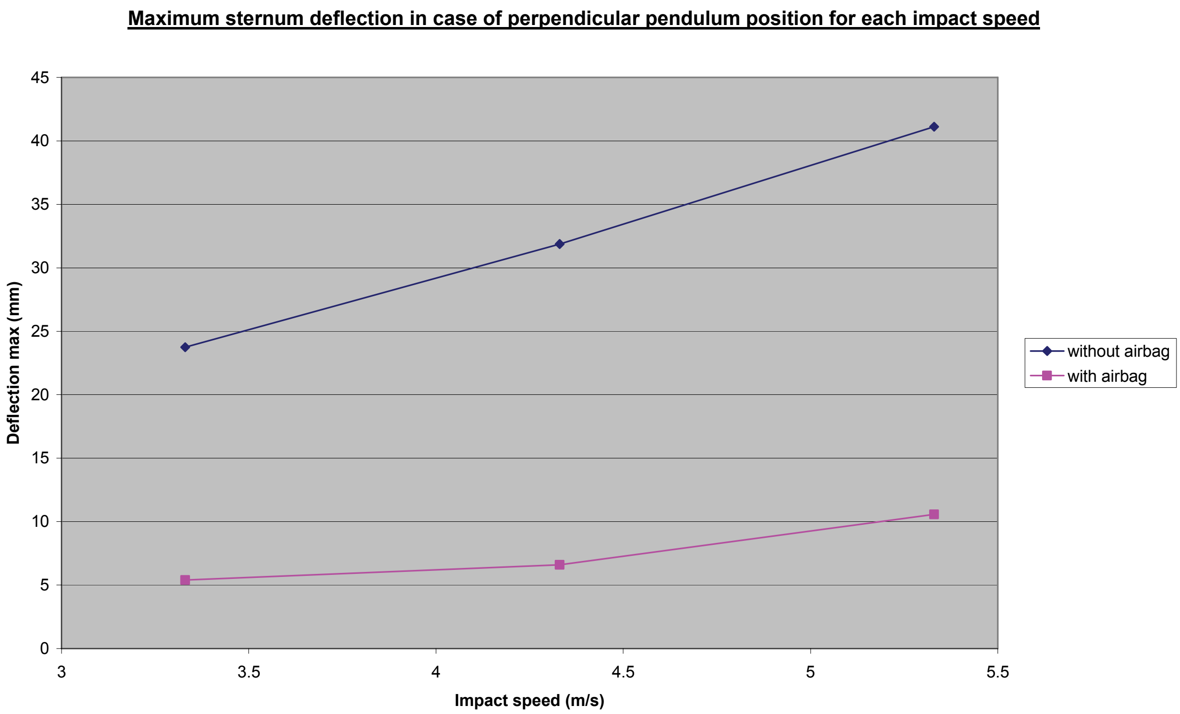

Figure 7: Comparison rib deflection versus impact speed, in case of perpendicular pendulum position, with and without airbag

By using AIS scale for each test, low impact speeds (<4.5 m/s) lead to similar injury reports with or without airbag. For higher impact speeds (5.33 m/s), the AIS increased up to 1.3 without airbag, whereas it is always null with airbag (figure 8). Injury level remains minor in all cases (AIS 1).

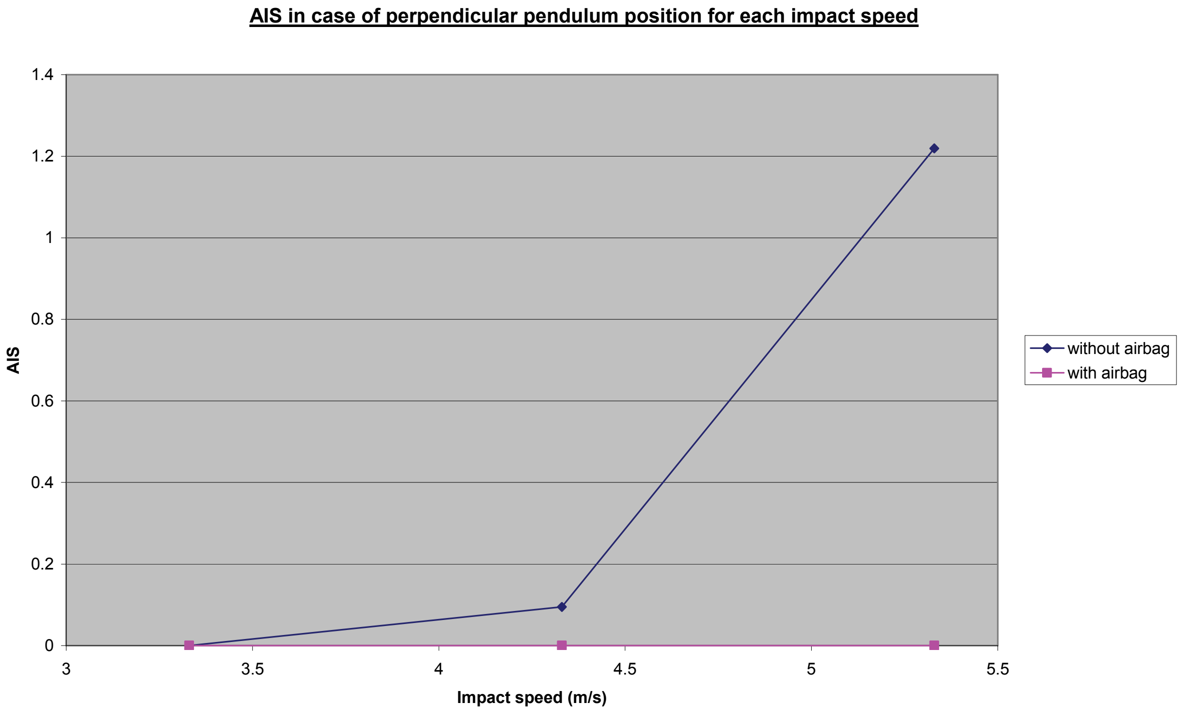

Figure 8: Comparison AIS versus impact speed, in case of perpendicular pendulum position, with and without airbag

2nd configuration

With airbag, the applied load level decreases of 50%, 32% and 31% for impact speeds of 2.78 m/s, 5.56 m/s end 8.33 m/s respectively (figure 9). At a speed of 11.11 m/s, the observed load reduction is only about 5%.

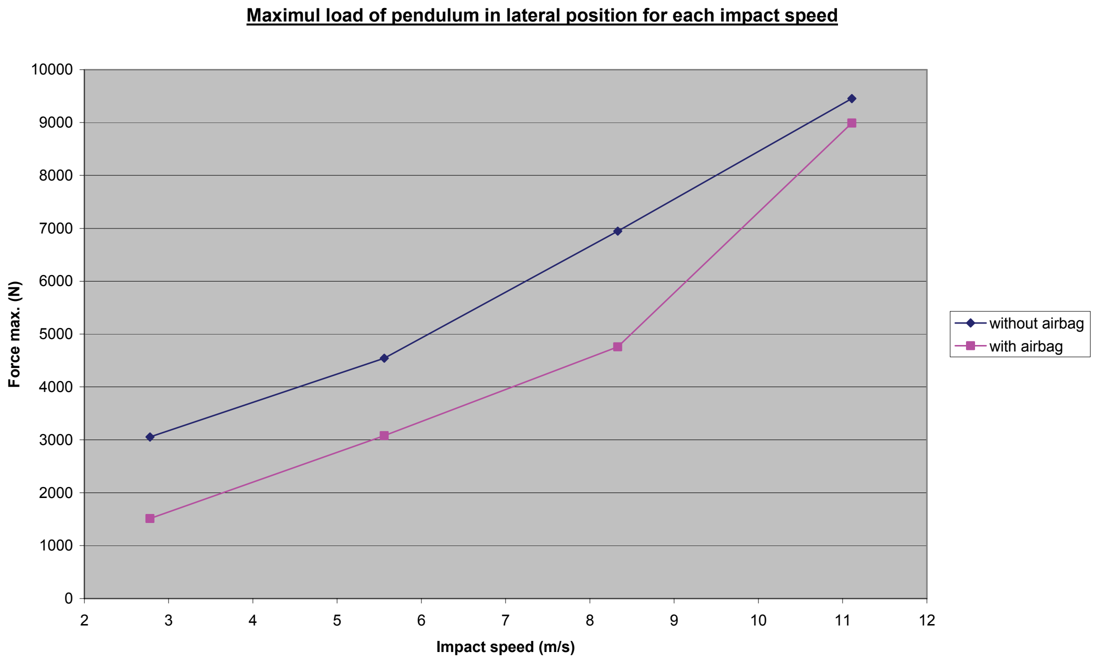

Figure 9: Comparison load versus impact speed, in case of lateral pendulum position, with and without airbag.

As for perpendicular pendulum tests, a reduction of the sternum deflection is observed (figure10) when the airbag system is used, at speeds up to 30km/h. With airbag the maximal deflection remains inferior to 10mm whereas it raises 40mm during a 30km/h impact if no safety system is worn.

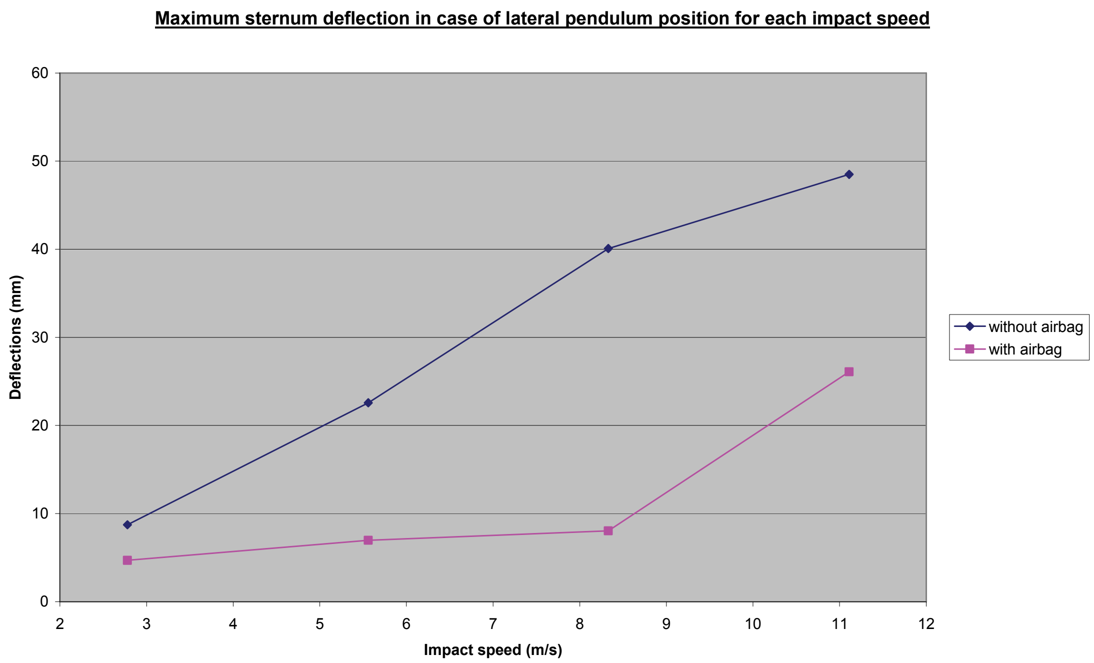

Figure 10: Comparing sternum deflection versus impact speed, in case of lateral pendulum position, with and without airbag

For a 30km/h impact, if no safety system is worn, the impact induce major injuries (AIS 5+), whereas no injuries are observed with airbag (AIS=0) (figure 11).

For the 40km/h impact with airbag, injuries are reported (AIS=1.8) but it is interesting to notice again the difference in terms of severity: the airbag allows reducing the AIS from 5 (bilateral flail chest) to 1.8 (1-2 rib fractures). It confirms that such a safety system can allow avoiding life threatening injuries, or at least reduce to minor fractures.

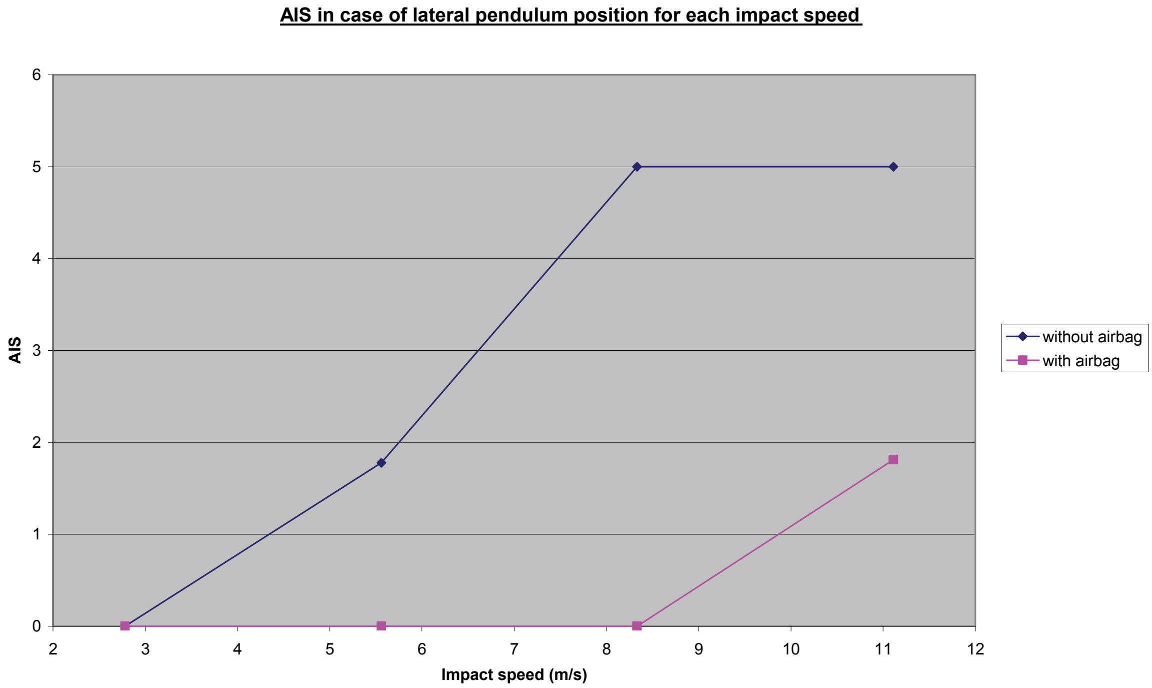

Figure 11: Comparing AIS versus impact speed, in case of lateral pendulum position, with and without airbag.

Discussion

First step: Simulations without airbag

From the results, we observed that the decrease of the applied load does not induce a more severe injury report as expected, the injury severity is reduced for the 2nd configuration tests (AIS 0 instead of AIS 1.2 for the 1st configuration), despite an approximately 80% increase of the applied load in configuration 2 (F=4639) compared to configuration 1 (F = 2572 N).

In case of lateral impactor configuration, with impacts on the 3 levels of sternum (lower, middle and upper), for the same load range (around 4% of variation) we observed a more severe injuries in case of upper sternum impacts (F = 4444 N; AIS = 1.45) compare to low sternum impacts (F = 4639 N; AIS = 0).

So through this first approach it seems that the maximum force level measured during impact can not be considered as a good injury criterion. This result is also detailed by Kroell [8, 9] who performed a large number of frontal chest impacts.

Second step: comparison of simulation with and without airbag, for the two configurations described in the materials and methods

1st configuration

These tests were performed in the same configuration as those carried out in the first approach but for these tests an airbag was used in order to check its contribution in term of reduction of the injury assessment.

As we could note it previously, the load level is strongly decreased when an airbag was used as safety system. Indeed, the airbag makes it possible to dissipate the impact energy and thus to minimize the load applied on the rib cage. This results in a very positive injury assessment since no injury was observed when the airbag was used.

2nd configuration

The aim of this second series of tests was first of all to be able to compare results with previous ones, for weak loading ranges, but also to load more severely the airbag, until an impact speed of 11.11 m/s (approximately 40 km/h).

Two observations can be done concerning the sternum deflection:

- At 30km/h with airbag, we noted a decrease of 80% compared to the case without airbag (deflection lower than 10 mm with airbag),
- At 40 km/h with airbag, we observed an increase of 300% compared to the case described above (impact speed = 30 km/h, with airbag). However, a decrease of the sternum deflection about 47% was measured as compared to the case without airbag.

Thus, following this second series of tests, with and without airbag, a first report arises. Within the framework of this type of load, closer to a real accident situation for the two wheels motorized (impact speed ranging between 30 and 40 km/h, larger impact surface on the body segments), the airbag fully plays its role: large decrease of the sternum deflection resulting in a very positive injury assessment: AIS = 0 up to 30 km/h and AIS < 2 in the case of impact at 40 km/h. It should be noted that these impact speeds are in agreement with the impact speeds estimated by Hurt [2]. Indeed, the median pre-crash landing speed was estimated to 29.8 mph, and the median crash landing speed closed to 21.5mph (35 km/h).

Conclusion

The objectives were first to evaluate the use of the applied load on the chest as an injury criterion, and secondly to develop and evaluate a digital model of airbag jacket based on an existing prototype. According to our results, the load applied on the chest as unique injury criterion raises strong limitations.

The benefits of using of an airbag jacket as a new protection system were also assessed, as it could significantly reduce the sternum deflection and the injury gravity (from AIS=5 without airbag to AIS=2 with the airbag jacket).

Future Work

The next steps of this study will consist in:

- performing subsystem tests in order to evaluate the airbag benefit in terms of injuries reduction (impact on the backside and lateral side of the motorcyclist, use of different impacting objects with different impact angles to simulate an impact on the sidewalk, B-pillar, etc.),
- simulating real motorcyclist accidents based on an accidentology approach. The aims will be to analyse the motorcyclist behaviour in case of direct impact on a car (frontal and lateral impact).

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Testing of two different motorcycle garments with integrated airbag in real crash conditions

Test zweier verschiedener Motorradkombis mit integriertem Airbag unter realen Crash-Bedingungen

Alessandro Bellati

Andrea Ambrogi

DAINESE S.p.A., Italy

Abstract

As a leading manufacturer of protective clothing for motorcycle and dynamic sports, DAINESE is continuously searching new solutions to increase the safety of its products. With regards to passive safety several investigations have been carried out with the aim of incorporating airbag systems within motorcycle garments for riders.

The requirements of a system designed to protect a professional rider in the context of a race track differ greatly from those of the average rider within the context of an urban environment. In the first scenario the most likely type of incident involves falling and sliding off the track, while in the latter, it is a collision with a vehicle or an obstacle. For this reason two different prototypes of garments with embedded airbags have been developed and tested.

In this paper the outcome of two real life tests on race track (a front and a rear lowside), together with a real impact between a scooter and a car (crash configuration 114) are presented and discussed. A leather suit equipped with an airbag worn by a professional rider and an airbag jacket fitted to a dummy have been respectively tested.

The objective of this study is to show the possibility of a successful implementation of such technology within future motorcycle rider equipment, with the long term objective of a more integrated safety solution.

Kurzfassung

Als einer der führenden Hersteller von Schutzbekleidung für Motorradfahrer und dynamische Sportarten ist Dainese kontinuierlich auf der Suche nach neuen Lösungen, um die Wirksamkeit seiner Produkte in Sachen Sicherheit zu erhöhen. Mit Blick auf den Bereich der passiven Sicherheit wurden Untersuchungen durchgeführt die darauf abzielten, ein Airbagsystem in einen Motorradfahreranzug (Motorradkombi) zu integrieren.

Die Anforderungen an ein solches System hinsichtlich des Schutzes eines professionellen Motorradrennfahrers auf der Rennstrecke unterscheiden sich gravierend von den Anforderungen an einen durchschnittlichen Motorradfahrer im Kontext der städtischen Verkehrsumwelt. Im ersten Fall (Rennstrecke) bestehen die Stürze am häufigsten aus dem Fallen und Rutschen auf der Strecke, während im zweiten Fall (normaler Straßenverkehr) meist Kollisionen mit einem Fahrzeug oder Hindernis das Unfallgeschehen bestimmen. Aus diesem Grund wurden zwei verschiedene Bekleidungs-Prototypen mit integrierten Airbags entwickelt und getestet.

In diesem Beitrag werden die Testergebnisse beider Systeme präsentiert und diskutiert: Zum einen der Test auf der Rennstrecke (Wegrutschen des Vorder- und Hinterrads) durch einen Profifahrer, der einen mit Airbag bestückten Lederanzug trägt und zum anderen der Zusammenstoß zwischen einem Motorroller (Scooter) und einem Pkw (Crash-Konfiguration 114). Hierbei wurde ein mit einer Airbagjacke bekleideter Dummy eingesetzt.

Das Ziel dieser Studie besteht darin, die Möglichkeit einer erfolgreichen Einführung solcher Technologien mit Blick auf die zukünftige Ausstattung von Motorradfahrern zu untersuchen, die zunehmend in integrierten Lösungen einzelner Komponenten besteht.

Testing of two different motorcycle garments with integrated airbag in real crash conditions

Introduction

Enhancing the passive safety of motorcycle is a big challenge because this topic is complex and tests are of difficult repeatability. Recent studies [1] have contributed to create common understanding of how motorcycle users are exposed to injuries in different body parts, but the picture is still far from been completely clarified, because taking into account all the possible variants is highly demanding. With respect to other issues, motorcycle has a much more wide range of applications. Motorcycle is not only a transportation mean but can be utilized also as a fun vehicle utilized for racing in the race-track. Common sense suggests that street use condition and track condition are very different, and so are the needs of the different user.

A specific characteristic of motorcycle accidents is the significance of cases in which the motorcycle is the only vehicle involved. These kind of events can account for more than one third of the total fatalities. Even when colliding with some obstacles there are still a significant percentage of all cases in which the impact happens after the motorcycle has already capsized. These characteristics suggest that a proper safety approach should follow the rider even when he fall off from the motorcycle.

Moving the focus to injured body parts, the topic depends strongly on the type of crash scenario. In track use the most injured body parts are: feet, hands, and collarbone; impacts are rare, instead sliding and tumbling are the most common kind of crash, as consequences of lowside and highside motion [2] [3] [4]. In case of street use those parts are substantially different: mostly head, legs, torso and neck; direct impact with other vehicle and obstacles are in fact the most relevant source of injury [1].

Any of the cases, even if lower extremities injuries are the most frequent, the severity is generally not very high, while head and thorax injuries in many cases can prove fatal. A meaningful effort for enhancing the passive safety of the rider could, therefore, focus on augmenting the protection of the specific areas depending to the utilization. That is the reason why the interest for airbag technology applied also on motorcycle is strongly increasing [5][6][7][8].

Airbag technology applied to the garment can prove especially helpful in extending the limited protection offered by traditional clothing, but at the current development level, comfort topics and protection issues are still heavily colliding each other. The more the protection wanted, the more the air volume and the weight needed, ending in obtaining a substantially more cumbersome gear. For this reason the more challenging part of the task is trying to find the optimal compromise between comfort and protection. A system too bulky, even if very protective, risks not to be perceived by the user as a benefit, and this may prove to be true indeed, because of the reduction in the freedom of movements of the rider. Focusing on a particular protection area it could prove helpful for tuning correctly the level of comfort to the level of added protection needed. With this aim, our research department developed two different solutions one for the race use, and one for the urban utilization.

Maybe in the future it will be possible to solve both the needs with just one device, but at the current development these are the more flexible solutions.

For realizing a working system, different steps have to be taken. Activation time is critical for inflating the airbag before a collision occurs. At the same level of importance it is realizing an adequate airbag restraint system, able to protect the rider in different conditions. Finally bag dimension and inflation have to be explored and tested in many different configurations, and tuned to the particular need. An open issue remains evaluating the effectiveness in real conditions considering all the aspects together: deployment, robustness, safety. Our goal since the beginning was to be able to reduce damage from both primary (with other vehicle) and secondary (with ground and other objects) impacts, and so we worked in the direction of the maximum possible time reactivity of the systems.
Field test could prove a correct approach to solve such a complex topics, and this article wants to present the feasibility test of these two different systems.

Racing Solution

The bag shown in the following figures Fig. 1, Fig. 3, and Fig. 5 is a 37 litres prototype that protects mostly the shoulders and the neck area. The bag deploys from the aerodynamic appendix of the leather suit, opening some automatic buttons. Full inflation process takes around 30ms. After inflation, the complete bag and the hump appendix can be removed in about 5 seconds, simply pulling two strips, like a parachute. The triggering device is constituted by a full inertial platform equipped with 3 gyrometers, 3 accelerometers and a GPS sensor. The electronics is completely suit-contained and it is not connected by any means with the bike. The hardware, realized by 2D GmbH, is very compact and lightweight. The triggering command is given when the sensor recording acceleration and rotational speeds overpass a combined value that is defined within a pre-defined risk evaluation function, which has been selected analyzing the data of many different riders in real condition races [9].

The test has been realized in the Adria international racetrack by the 19th of December 2006. The test involved a front lowside fall and a real lowside fall. A stunt rider was hired and he was asked to perform two crash-leading maneuvers, brake-locking the front and the rear wheel in the same corner. The corner was filmed with high speed cameras that recorded the whole maneuver. The bike was adequately modified for reducing the hazard to the rider and the stunt man was fully equipped with the maximum level of protection.

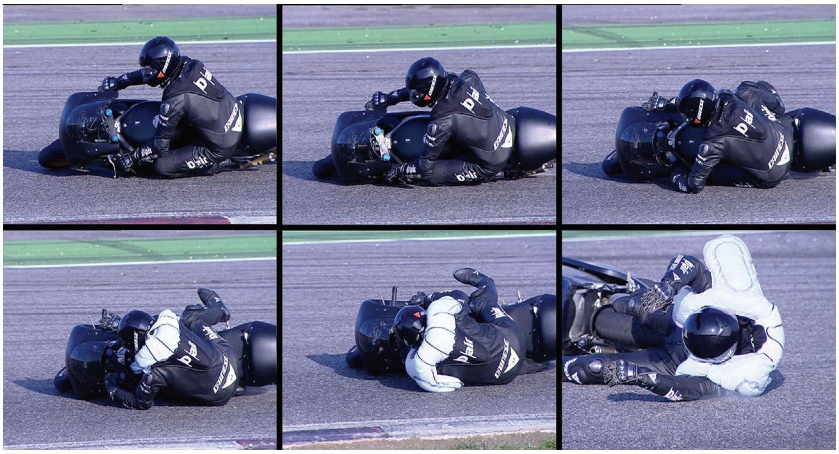

Fig. 1 – airbag inflation process during front lowside

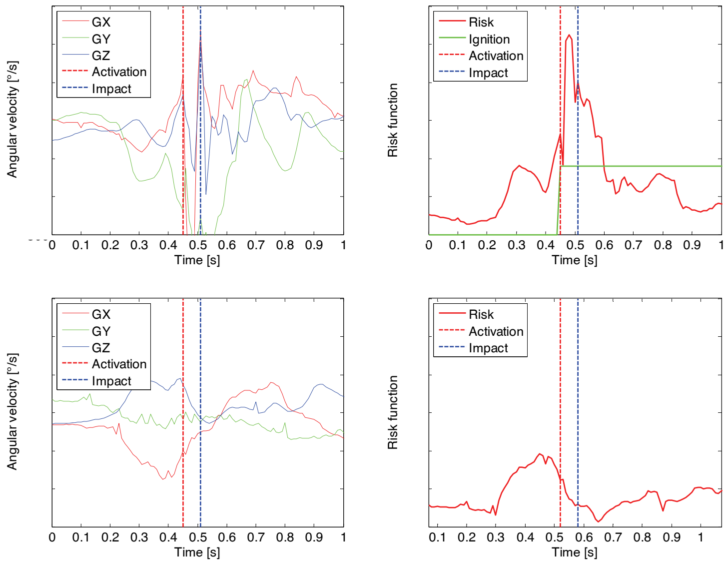

Fig. 2 – sample data caming from the recorder front lowside; up: rider; down: motorcycle

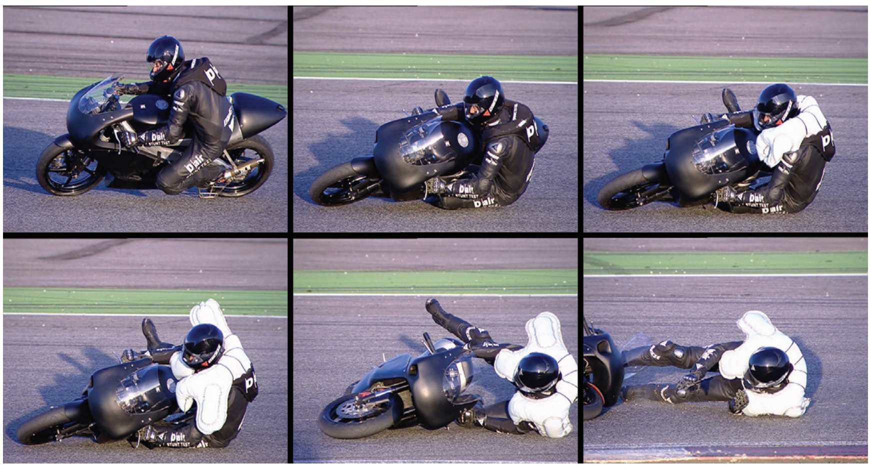

Fig. 3 - airbag inflation process during rear lowside

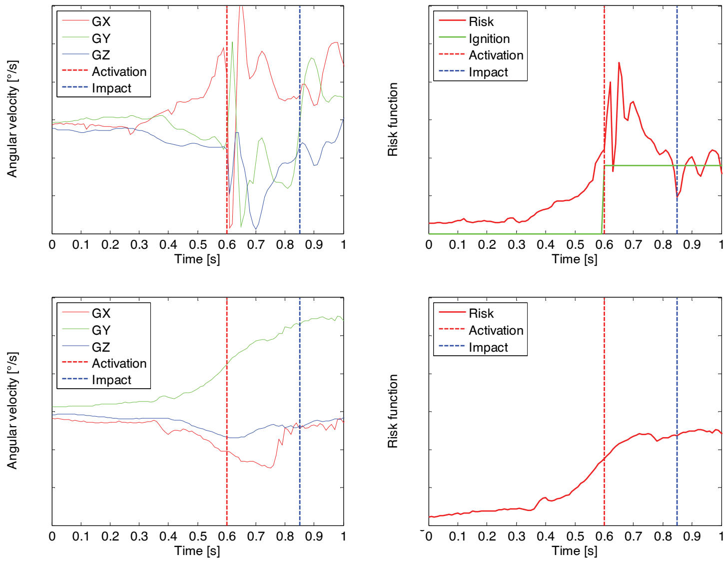

Fig. 4 - sample data coming from the recorder rear lowside; up: rider; down: motorcycle

How it's visible from picture of the test results in Fig. 1 and Fig. 3, the system deployed correctly before direct contact between the rider and the ground. Data in Fig. 2 Fig. 4, reports the pattern of the rotational speeds of the bike and the rider, and a parallel sample of the risk function evaluation data, showing the moment of the inflation and the real contact with the ground.

Moving towards physical results, the neck/head area, the bag avoided the direct impact between the helmet and the terrain thus reducing possible head trauma. The material of the bag resisted also to the abrasion of the asphalt during the first stages of the impact. Very important in such a test is also the word of the tester that was able to retrieve directly the first sensations. The stunt man reported a very soft contact with the ground, and he was almost unaware of the opening of the bag, at least in the frenzy of the crash. The stunt man sustained no injury also because the fall was quite soft, but nevertheless perceived positively the intervention of the bag.

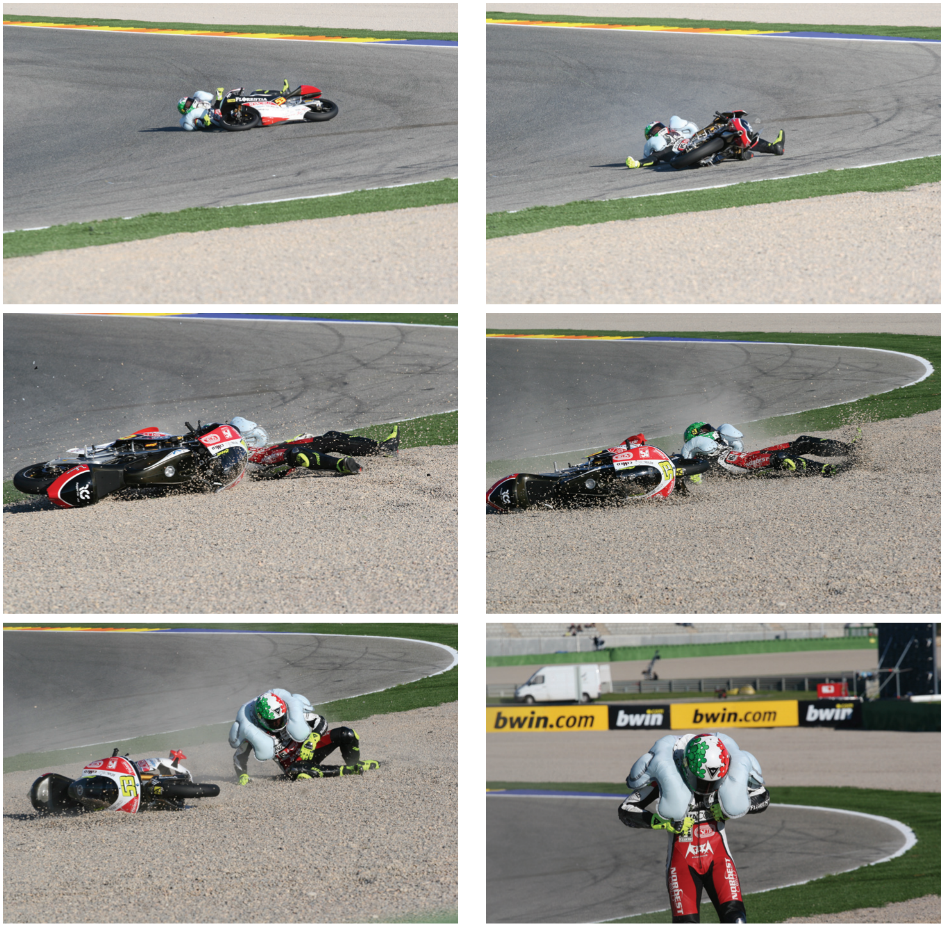

Fig. 5 – Real deployment during Valencia 2007 motoGP

Talking about user feelings, we can also cite Simone Giorgi Grotzkyj (Italian champion 2005) who utilized the airbag leather suit during the 2007 Valencia MotoGP. He reported that he perceived the sliding as "falling on an inflatable seat", describing the feeling to be accompanied by the bag from the bike to the ground.

Going in deep with the topics, some questions could arise about the real benefits of such a bag intervention to the overall dynamic behaviour of the rider. This initial experience created an occasion for reflecting on the real need of the system for enhancing the protection. Experience of riders indicates, that triggering is not necessary in any kind of fall and it is preferable just in case of more violent crashes, leaving things unchanged in case of little slides. For most riders in fact simply sliding away in case of slight fall, it is perceived as a much more "natural" way for exiting from the track, and it also give the opportunity to rejoin immediately to the race without loosing the short but precious time for detaching the system. This particular need emphasizes the usefulness of an electronic system instead of a more traditional "pull the cable" inflator means. With a properly tuned electronics it is possible to distinguish between the different kinds of fall and thus deciding whenever it is appropriate to trigger the system or not.

As a final remark we can say that testing in competition is a very severe and useful kind of test for such a system, because all the different parts are together stressed out, and also serves as a parallel test for misuse avoidance.

Street Solution Test

The prototype tested, was an airbag jacket, without sleeves, filled internally with two folded airbags of toroidal shape. Having two different separate chambers, it offers some redundancy. The bag deploys around the wearer, opening calibrated stitching. The bags protect the back and the torso, also giving some additional protection at the level of the neck and the hip. The system fires upon impact and it is controlled by a set of accelerometers positioned on the bike. The overall inflation process take around 30ms depending on environment temperature; in time for protecting from primary impact.

The presented test was carried out at the Neumünster Dekra crash test center, on 2008 February. During the test the dummy hit the opposing vehicle at a speed of 48Km/h in configuration ISO13232 114 [10]. The system autonomously deployed, upon impact. The inflation sequence shown in Fig. 6 documents how the overall process developed correctly, with enough time gap for providing protection upon both primary and secondary impacts. The time showed in the right corner of each picture is referred to the contact of the front wheel with the switch on the ground, visible under the scooter.

Interesting, for what concerning the secondary impact, the test showed a substantial bouncing of the dummy on its back during contact with the ground, suggesting a softer contact with the ground.

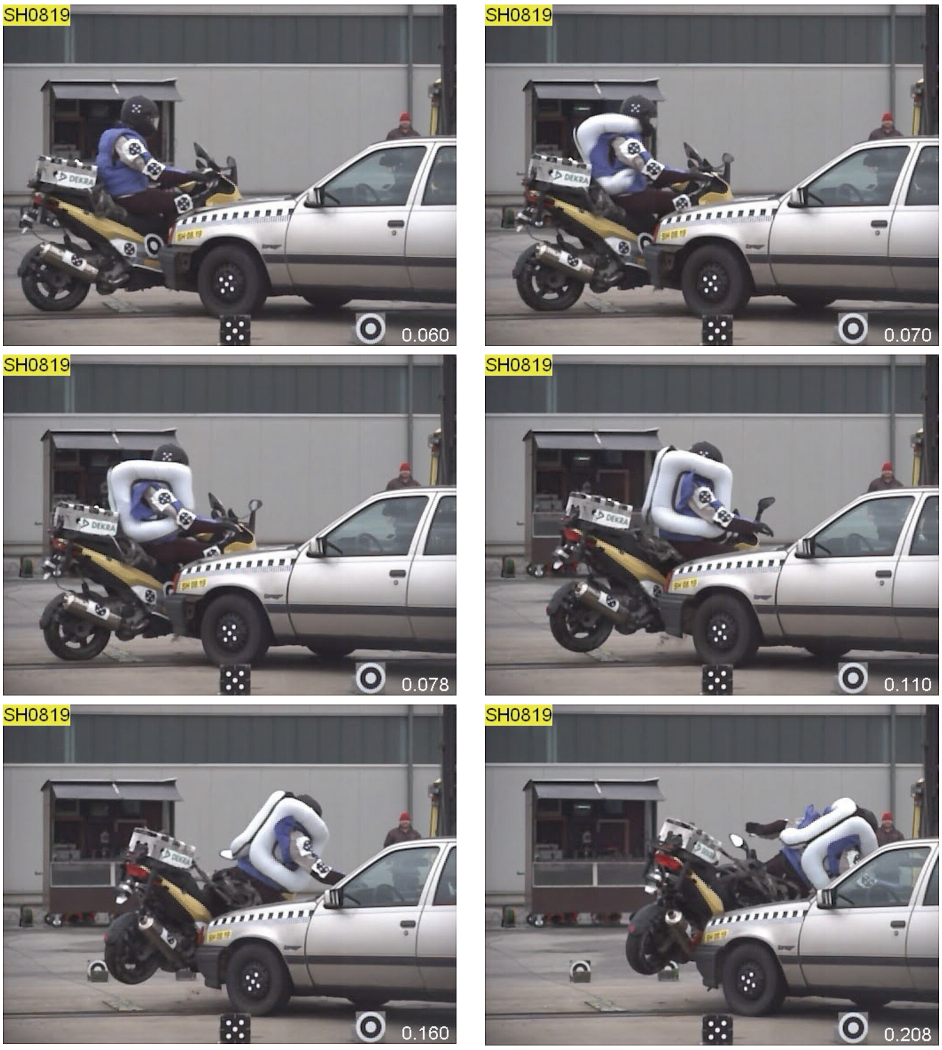

Fig. 6 - D-air street: test sh0819 inflation sequence

Dummy results SH 08.19

Dummy loads secondary impact

	Limit*)		Actual value		Criteria fulfilled?
Head					
HIC	1000		177		yes
Res. head acceleration a3ms	80.0	g	63.89	g	yes
Neck					
Neck tension force Fz (0 ms)	3,3	kN	0,44	kN	yes
Neck tension force Fz (35 ms)	2,9	kN	0,2	kN	yes
Neck tension force Fz (60 ms)	1,1	kN	0,1	kN	yes
Neck shear force Fx (0 ms)	3,1	kN	1,1	kN	yes
Neck shear force Fx (35-45 ms)	1,5	kN	0,3	kN	yes
Neck shear force Fx (60 ms)	1,1	kN	0,2	kN	yes
Neck bending moment Mby (y-axis)	57,0	Nm	65,64	Nm	no
Chest					
Chest deflection	50,0	mm	4,02	mm	yes
Viscious criterion	1,0	m/s	0,1	m/s	yes
Femurs					
Femur force Fz left (0 ms)	9,07	kN	3,7	kN	yes
Femur force Fz left (10 ms)	7,58	kN	2,2	kN	yes
Femur force Fz right (0 ms)	9,07	kN	3,4	kN	yes
Femur force Fz right (10 ms)	7,58	kN	3,4	kN	yes

*) Limits according to ECE-R 94 (2006-03-30)

DEKRA Configuration 114

Fig. 7 – crash report of the test, with indicated biomechanical limits

Fig. 8 – Crash test outcome

How it is shown in Fig. 8 sequence, the helmet after the crash is only slightly damaged because it is kept separated from the terrain by the rear bag. Of course in those kind of tests, the variability is very high even within the same test condition, and so it is difficult to obtain similar values in multiple tests. Nevertheless it was demonstrated that is possible to trigger such a system correctly upon impact and that the inflation time is compatible with the primary impact at the reference speed at which the test was realized. Talking instead about injury reduction, the results have a more limited interpretation. Even following the norm [10] variability of those parameters is very high and so it is difficult to understand the real improvements in safety. Looking at the recorded data, the only biomechanical limit [11] that was over passed during the test was the one relative to the neck longitudinal bending. This results helped us in understanding for example that a more high neck protection could rise the protection of the head and the neck. An other result looking at the first frame of the crash movie, is that the shape of the bag, could help in the deflection of the rider from a colliding trajectory with the opposing vehicle, thus reducing the chances of a critical impact in the first steps of the crash.

Future Protection Considerations

The final goal for these thematic is to create a protective system with no compromise, lightweight, protective and attractive for the user. We believe that air-protection technology could shortly became a safety standards for the added needs of the upcoming market. For this reason our research department is currently continuing to explore new solutions for airbag integration focusing on the best safety and comfort compromise possible.

A system flexible and adaptive is the challenge for the future and in that direction we are moving, trying to satisfy all the needs with just one device. Protection can still be augmented, providing that the activation and inflation processes were found to be consistent. Looking at a bridge with motorcycle manufacturer, integration of intelligent garment with on-board airbag technology placed on the bike should be encouraged, giving the possibility to the obtain even better protection performance. Future issues will be considering correctly the topics of the additional passenger and the interaction between the different airbag systems. Looking things from this prospective communication should be strongly encouraged, and a common standard should be developed.

Conclusions

In this paper two different tests, realized on the basis of two completely different approaches, were presented. Outcome of the tests gave space to some interesting insight on safety of inflatable garment. Both the prototypes successfully passed the activation test giving proof of the their feasibility, confirming the correctness of the precedent studies.

The final aim is of course enhancing the safety of the riding experience, but the correct approach is still matter of discussion.

The protection and the optimal design should be additionally investigated for finalizing those preliminary studies in a robust and well developed product able of sustain the safety needs of the upcoming motorcyclists.

Acknowledgements

Thanks to the stuntman Mr Claudio Pacifico who successfully performed the necessaries tests, to Piaggio for providing vehicle support for testing, to 2D Data-recording GmbH for the hardware and the technical support, to all the teams the helped the data acquisition campaign.

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APROSYS SP4: Advanced testing procedures for protective measures on rider equipment and road furniture

APROSYS SP4: Neuartige Testverfahren für Schutzmaßnahmen an Fahrerausrüstung und Straßenausstattung“

Steffen Peldschus, Erich Schuller
(Ludwig-Maximilians-Universität München)

Begoña Pérez Magallón, David García, Alberto Mansilla (CIDAUT)

Marco Pierini, Niccoló Baldanzini (University of Firenze)

Samuel Bidal (Altair Development France)

David Manzardo (Dainese)

Violaine Tinard, Rémy Willinger (Université Louis Pasteur Strasbourg)

Abstract

Within the European research project APROSYS SP4 several initiatives were undertaken to improve the safety for motorcyclists. Impact test standards and procedures, that have been revised or are being proposed for the first time, are presented in this paper.

One of the objectives in APROSYS SP4 is the development of advanced personal protective equipment. The current version of the ECE R22 regulation on helmet testing was reviewed. Several issues for improvement in a medium-term perspective have been identified as well as an advanced evaluation procedure for the long-term.

A test protocol was defined for the testing of the effectiveness of a thorax protector for occupants of powered two-wheelers. The protocol was implied in the assessment of different design variants of such a protector by means of numerical simulation before manufacturing a prototype for physical testing.

Another objective of the project is the development of guidelines for a European impact test standard on motorcyclists' protection by roadside safety barriers. The focus of this work is on the sliding impact after the separation of rider and two-wheeler. Using crash simulation with human models it was shown that loading of the thorax is a crucial problem in the proposed impact configurations. Already existing test procedures do not include any appropriate assessment for that. It was therefore concluded that new measurements for the physical tests need to be developed. The tests will serve for the development of improved barrier systems.

Kurzfassung

Im Rahmen des Europäischen Forschungsprojektes APROSYS SP4 wurden verschiedene Initiativen gestartet, um die Sicherheit von Motorradfahrern zu verbessern. Anpralltest-Normen und -Verfahren werden im vorliegenden Beitrag beschrieben.

Eine der Zielsetzungen von APROSYS SP4 ist die Entwicklung moderner persönlicher Schutzausrüstung. Die aktuelle Version der ECE-R22-Richtline für Helmtests wurde analysiert und verschiedene Ansätze zur mittelfristigen Verbesserung wurden dabei herausgestellt.

Ein Testprotokoll zur Bewertung der Wirkung eines Thoraxprotektors für Aufsassen motorisierter Zweiräder wurde definiert. Das Protokoll wurde angewendet für die vergleichende Bewertung verschiedener Designvarianten eines solchen Protektors mit Hilfe der numerischen Simulation, bevor Prototypen für experimentelle Verfahren hergestellt wurden.

Ein weiteres Projektziel ist die Entwicklung von Richtlinien für eine europäische Anpralltestnorm an Straßenschutzeinrichtungen zum Motorradfahrerschutz. Der Fokus der Untersuchungen liegt auf dem rutschenden Anprall nach der Trennung der Aufsassen vom Fahrzeug. Mit Hilfe der Crash-Simulation konnte gezeigt werden, dass die Thorax-Belastung einen kritischen Punkt bei den vorgeschlagenen Anprallkonfigurationen darstellt. Bereits bestehende Testverfahren beinhalten keine angemessene Bewertung dafür. Daraus wurde gefolgert, dass neue Messverfahren für experimentelle Tests zu entwickeln sind. Diese Tests werden der Entwicklung verbesserter Schutzeinrichtungssysteme dienen.

APROSYS SP4: Advanced testing procedures for protective measures on rider equipment and road furniture

Introduction

Crash simulation using Finite-Element human models was shown in the last years to be an applicable tool for the simulation of injury mechanisms. This paper describes the potential for application of such simulation methods to the field of motorcycle passive safety, where the availability of specific PMHS test data and crash test dummies is limited. The human model HUMOS2 and the ULP human head finite element (FE) model (see figure 1) were used for this work. Simulation techniques were applied to the investigation of different problems within the European research project APROSYS SP4.

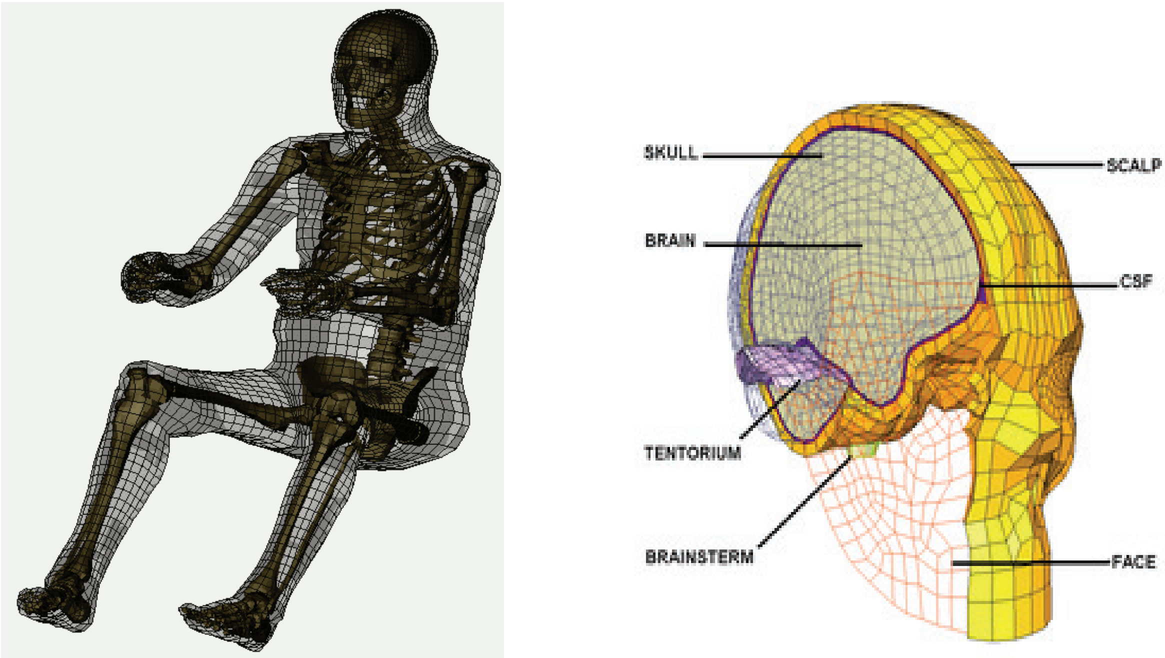

Figure 1: HUMOS2 model (left) and ULP head FE model (right)

Helmet impact testing

A comparison between real accident impact conditions (COST 327 report [1]) and impact conditions described in the ECE R22 standard has been performed. Real impact conditions in terms of velocity are more severe than the impacts in R22. At the light of this result, it seems reasonable to propose more stringent values for the R22 impact scenarios. In order to couple real impact velocities with R22, very stringent values for impact speed should be necessary (for example, 12 m/s in some impact points).

These initial velocities are really too stringent to apply to existing type helmets. The impact speeds combined with the chosen injury criteria cannot result in a feasible helmet design, given the current material and design restrictions. A mid-term proposal for amending the R22 has been done (Tables 1 and 2), considering not too strict conditions but reducing the accepted limit values for the injury criteria (HIC, linear and rotational accelerations).

A most rigorous set of conditions describing in a more realistic way the real accidents is proposed for the long term (Tables 1 and 2), once the materials technologies can afford tougher helmets.

As a complement for the long-term proposal, other innovative injury criteria are proposed. These new criteria consist in using a finite element numerical head model to translate the outcomes from the R22 tests (accelerations) in real injuries by means of injury risks. The use of such head models substitute the commonly applied HIC criteria and makes more realistic predictions of the injuries that would be sustained by the rider's head according to the impact scenarios. However, this is a sophisticated tool which requires some time to be widely used. Its implementation is foreseen for the next years. The underlying principles for this approach are explained hereafter.

Table 1 – Impact velocities proposed to improve R22 proposal in the mid and long term

Impact point	R22	Mid-term proposal	Long-term proposal
P	7.5 m/s	6 m/s	6 m/s
R	7.5 m/s	7.5 m/s	12 m/s
X	7.5 m/s	7.5 m/s	12 m/s
B	7.5 m/s	7.5 m/s	12 m/s
S	5.5 m/s	6 m/s	6 m/s

Table 2 – Injury criteria proposed to improve R22 proposal in the mid and long term

Criteria	R22	Mid-term proposal	Long-term proposal
HIC	2400	2200	1000 / Advanced Biom. Criteria at Tissue Level
Linear acc.	275 g	250 g	150 g / Advanced Biom. Criteria at Tissue Level
Rotational acc.		10 krad/s^2	8 krad/s^2 / Advanced Biom. Criteria at Tissue Level

Improvement of human head injury risk assessment in future test standards

At present thresholds concerning helmet performance are set at HIC 2400, which is a quite high value under a biomechanical point of view. Currently, in the automotive environment, maximum authorized HIC values are in the range of 1000-1500 for linear front or occipital impact. In addition, HIC does not distinguish front and lateral directions and, even more important, does not take into account rotational acceleration of the head.

First attempts in this later direction are proposed within SP4 but the rough 10 krd/s^2 proposed is a quite rough value which does not take into account impact duration or impact direction. Some proposals for rotational acceleration limits can be found in the literature, but they are strongly dependent on time and direction, so that today there is no single limit known. Moreover, it is well known that impacts typically conduct simultaneously to both linear and rotational acceleration.

Within the Integrated Project APROSYS, the subprojects SP4 "Motorcycle Accidents" and SP5 "Biomechanics" established a close interaction. Within SP5, improved head injury criteria to specific injury mechanisms have been defined taking into consideration the time evolution of both linear and rotational acceleration. These improved head injury criteria based on head modelling are the base of the present proposal for helmet standard test evolution.

It has been shown within SP5 that state of the art head FE models became much more powerful injury prediction tools than HIC. So, the present proposal is to implement improved head injury criteria into a new helmet impact test procedure.

In the proposed approach the experimental head linear and rotational acceleration recorded with the head form under the specified impact conditions suggested within SP4 (see Table 3) will constitute the inputs which will drive the head FE model (see Figure 2). This computerized head model is used as a tool to compute the injury parameters related to three different injury mechanisms:

skull fracture,
sub dural haematoma and
neurological injury.

Based on the simulation of 68 well documented head trauma, tolerance limits have been identified within APROSYS SP5 (D5.1.1.B) with respect to a given injury mechanism. This establishes human head tolerance limits relative to three injuries i.e. skull fracture, subdural haematoma and moderate or severe neurological injuries with a risk of 50% as reported in Table 3.

Table 3. Improved head injury criteria based on head FE modelling.

Mechanical parameter	Skull strain energy	Minimum of CSF pressure	Brain Von Mises strain	
Injury	Skull fractures	Subdural or Subarachnoid haematoma	Moderate DAI (AIS 2)	Severe DAI (AIS 3+)
Criteria	865 mJ	-135 kPa	25%	35%

In summary, this methodology makes possible to predict head injury risks by means of a coupled experimental-numerical testing approach based on improved model based head injury criteria.

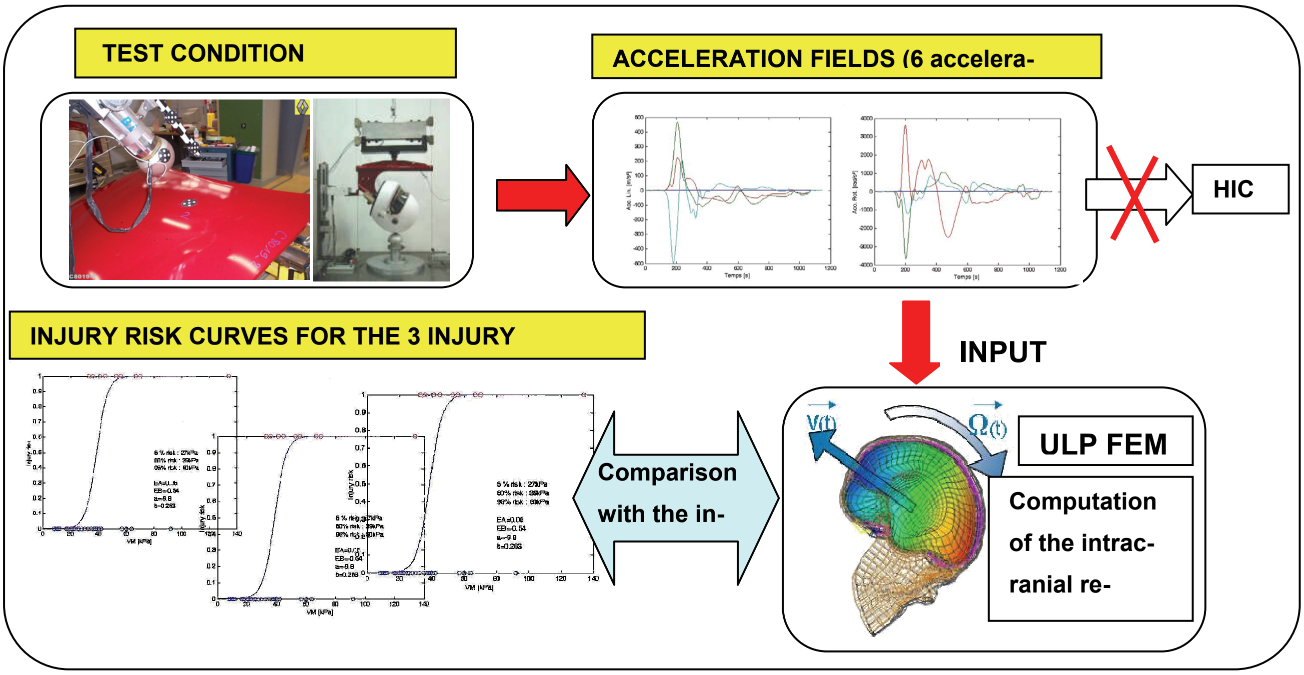

Figure 2: Schematic view of the long term proposed helmet test procedure : The coupled experimental-numerical approach considers the recorded linear and rotational headform acceleration as the input of the head FE model, in charge of the later to compute head injury risk.

Virtual Impact Testing of a Thorax Protector

Crash simulation with the HUMOS2 model was also applied to the development of advanced personal protective equipment for motorcyclists. Different design variants of a thorax protector were assessed by means of numerical simulation before manufacturing a prototype for physical testing. The thorax protector (see figure 3) was meshed using only BRICK elements (100238 nodes and 54972 elements).

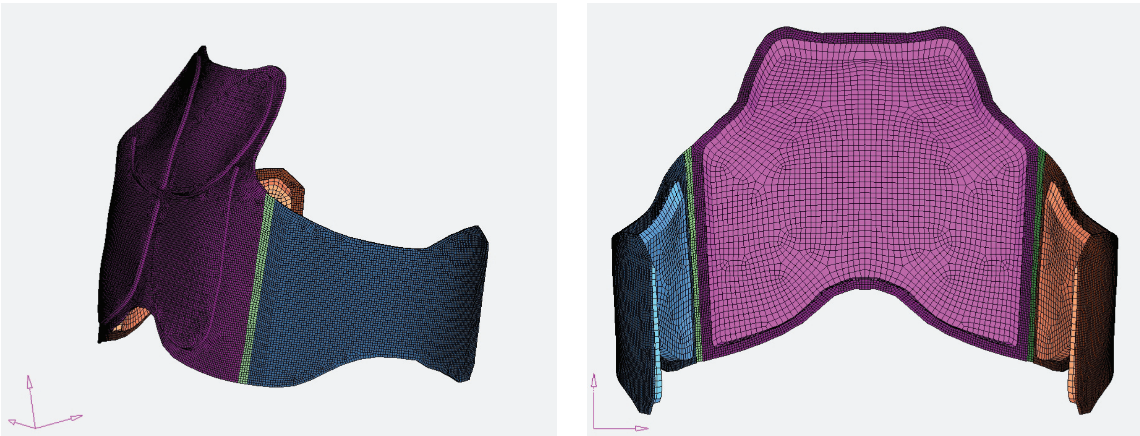

Figure 3: Thorax protector final mesh

Two types of scenario were simulated: a frontal impact and a lateral impact of HUMOS 2 model by a cylindrical impactor. For each of them two different speeds were used for the impactor: 5 m/s and 10 m/s. Each case was simulated with and without the thorax protector.

The impactor is a rigid cylinder with:

Diameter = 15,2cm

Weight = 23,4 kg

Frontal impact

In such an impact scenario, a chest compression greater than 20% is indicating an onset of rib fractures and a chest compression greater than 40% a flail chest (totally instable chestwall).

Referring to the injury criteria table, benefits of thorax protector are obvious. However, in each case it does not allow to change the kind of injuries which can be seen.

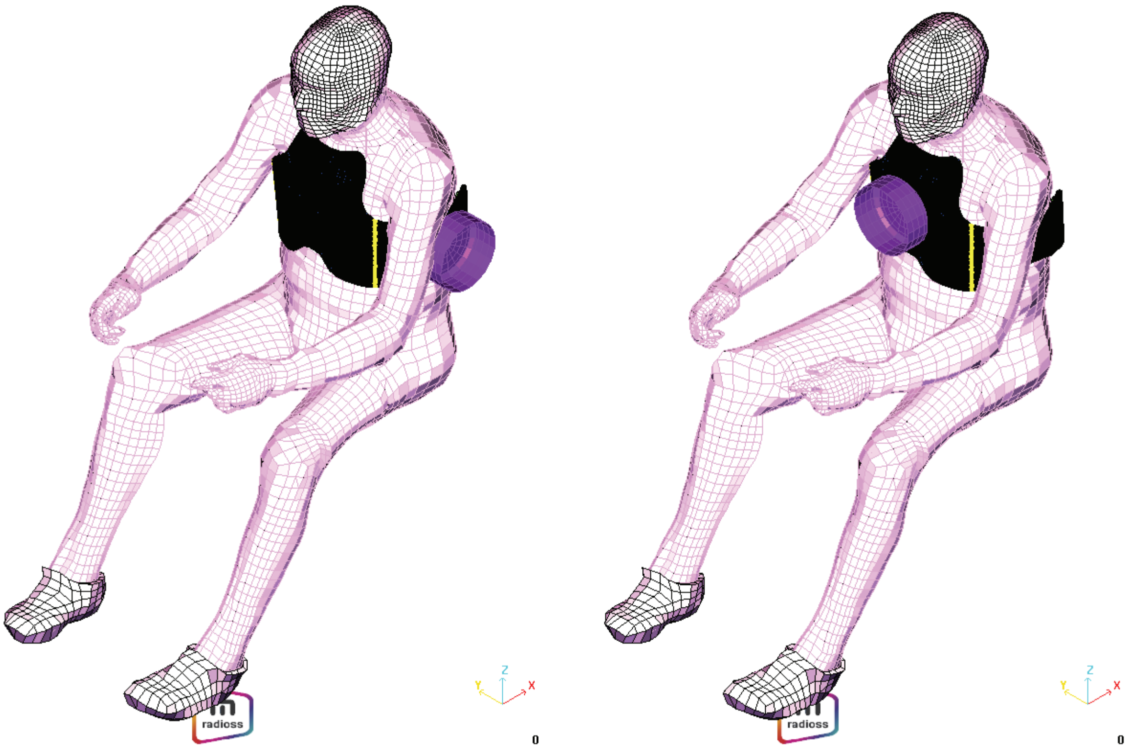

Figure 4: Impact configurations – lateral (left) and frontal (right)

Table 4: Frontal impact - Injury criteria values

FRONTAL IMPACT	Chest compression	Chest deflection
5 m/s – without protector	27 %	46.5 mm
5 m/s – with protector	20 %	34.5 mm
10 m/s – without protector	71 %	120 mm
10 m/s – with protector	51 %	85.8 mm

Lateral impact

In a scenario of lateral loading by impact, a half thorax compression of 20% is indicating a risk of 50% of sustaining an AIS 3+ injury. The impact was simulated with the impactor hitting the side of the thorax directly, without the upper arm clamped in between.

Referring to the injury criteria table, benefits of thorax protector in lateral impact are not as obvious as in frontal impact. Its protection is really effective for high speed. However it does not allow to change the kind of injuries which can be seen.

Table 5: Lateral impact - Injury criteria values

LATERAL IMPACT	**Half thorax compression**
5 m/s – without protector	**27 %**
5 m/s – with protector	**29 %**
10 m/s – without protector	**61 %**
10 m/s – with protector	**56 %**

Honeycomb stiffness effects

Honeycomb stiffness impact was virtually changed by scaling down E, G and Yield functions values in the material definition. Two virtual honeycomb were defined, the first one with a scale factor equal to 1/2, the second one with a scale factor equal to 2/3.

Frontal impact was simulated again with a cylindrical impactor at 10m/s and a virtual honeycomb (scale factor 1/2). The results were compared to the other frontal 10 m/s impacts, with and without thorax protector.

Table 6: Design variants - Injury criteria

FRONTAL IMPACT	**Chest compression**
10 m/s – without protector	**71 %**
10 m/s – with protector	**51 %**
10 m/s – with protector and virtual honeycomb	**53 %**

Even if the honeycomb is more easily compressed, thoracic compression is reaching the same level. So honeycomb stiffness variation seems to be useless. However it can be explained by the injury mechanism. The impact is so heavy that HUMOS 2 shows a total flail chest in left and right side of its ribs cage, even when the thorax protector is used. The bone being broken, only internal soft organs are resisting to the impact. The honeycomb low stiffness allows to slow the compression but do not protect of a heavy impact.

From the results it was concluded that a priority design requirement is assigned to impact force distribution rather than impact energy absorption.

Roadside Safety Barrier Testing

Unlike car occupants, the riders of powered two-wheelers can rather easily be injured by parts of the road infrastructure in the course of an accident. Once a rider has fallen on the road surface, the crash barriers mounted on the roadside constitute a potential impact obstacle for him. In order to mitigate the consequences of such an impact, devices have been designed in various European countries for the installation on a guardrail. Test procedures have been developed for the assessment of the effectiveness of such devices [2, 3].

These procedures imply the use of a crash-test dummy and the analysis of injury risks to head and neck. Using the HUMOS2 model and crash simulation it was analysed whether this kind of impact also causes a considerable loading of the thorax. It had previously been demonstrated that the HUMOS2 model can successfully be used to simulate injury mechanisms in a similar impact scenario [4]. The impact configuration is depicted in figure 5. The thorax load was analysed following the procedure that Kuppa et al. used for lateral sled tests with post-mortem human surrogates [5]. Simulating those sled tests with the HUMOS2 model gave maximum lateral thorax deflections of 52 and 64 mm at the mid-axillar height of ribs 4 and 8, respectively.

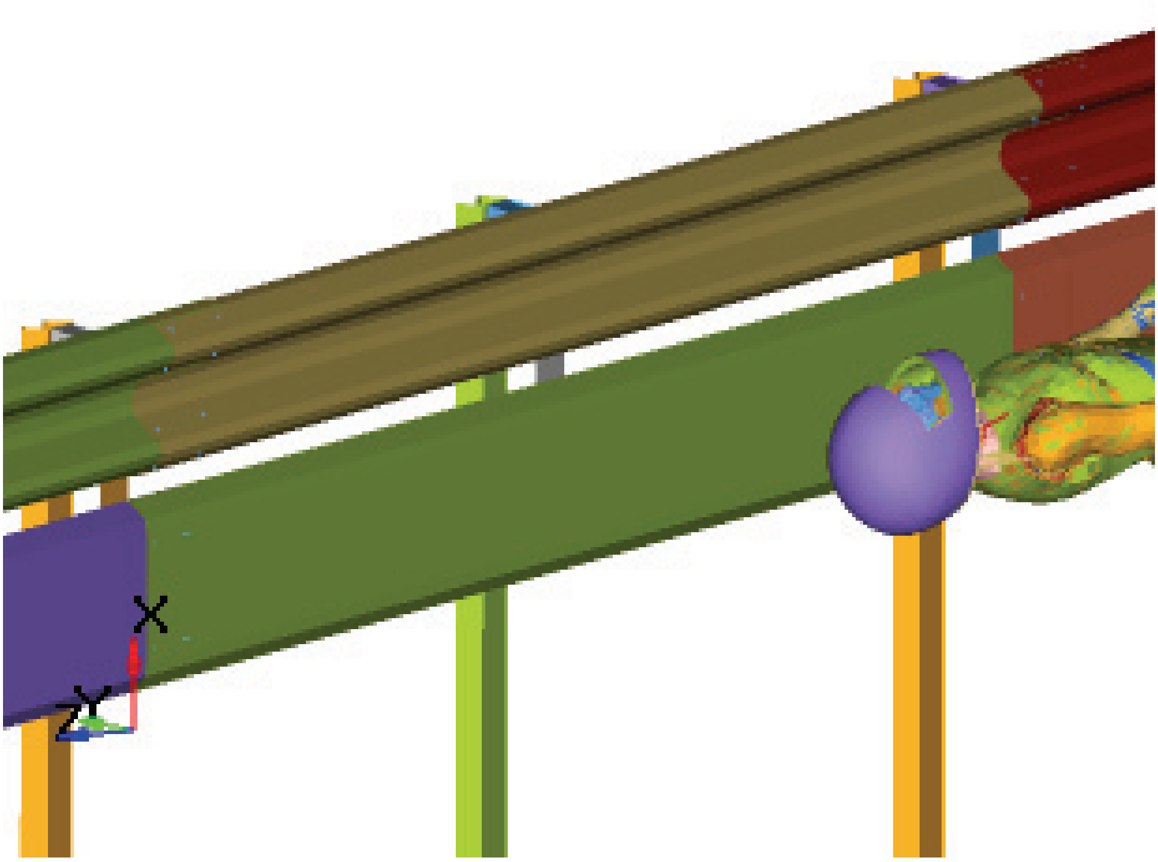

Figure 5: Impact configuration for roadside barrier test

For the sliding impact of the motorcyclist onto the roadside barrier maximum thorax deflections of 51 and 48 mm were simulated at the height of rib 4 and 8, respectively. The deflections of the thorax were found to be rather comparable in magnitude to the ones for the PMHS sled tests and the loading was therefore seen to be severe. An assessment of the thoracic injury risk is thus suggested for the definition of impact tests that serve the assessment of roadside barriers. This implies the development of new measurement methods to be used with crash test dummies for this kind of impact test.

Acknowledgement

The authors wish to acknowledge the support of HIASA and the ESI Group. Part of this work was funded by the European Commission within the APROSYS project under the 6th Framework Programme.

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Powered Two Wheelers compared with cars – Driving dynamics, fuel consumption and exhaust emissions in daily use

Motorisierte Zweiräder verglichen mit Autos – Fahrdynamik, Kraftstoffverbrauch und Abgasemissionen im täglichen Umfeld

Dipl.-Ing. Bertrand-Olivier DUCREUX
Transport and Mobility Department
ADEME (French Environment and Energy Management Agency)

Abstract

This ADEME study evaluates the progress made by two-wheeled vehicles since Euro 3 came into effect and compares it to late model passenger cars (Euro 4 auto compliant) by putting them both in similar, real, operating conditions.

The two modes of transport were compared on a "home-to-work" trip between the suburbs (Linas) and downtown Paris (Musée d'Orsay) at rush hour (arrival time in Paris: 8.30am). The study included all types of regulated pollutants for vehicles: local pollutants (unburned hydrocarbons HC, carbon monoxide CO, nitrogen monoxide and dioxide NOx) and greenhouse gases (CO2, CO and HC), and takes into account the differences in driving dynamics between the 2 and 4 wheeled vehicles when situated in the same traffic conditions.

Fifteen powered two wheelers from 125 to 1200cm3 (scooters and motorbikes) and three cars, have been measured on "real-world" cycles, and their environmental impact assessed.
The study highlights the differences of driving behaviour between PTW and cars (in France), the differences in emissions between the vehicle families, and clearly shows the consequences of different homologation procedures and thresholds between cars, small and bigger PTW (including results on WMTC test procedure).

Kurzfassung

Die ADEME-Studie untersucht den Fortschritt von motorisierten Zweirädern, seit die Euro 3 in Kraft trat im Vergleich mit den letzten Personenwagen (Euro-4-konform). indem man sie in gleiche Fahrsituationen versetzt.

Die zwei Arten von Transport wurden an einer „Haus-zur-Arbeit"-Fahrt zwischen Vorstadt (Linas) und Innenstadt Paris (Musée d'Orsay) während der Hauptverkehrszeit (Ankunft in Paris 8.30 Uhr) verglichen. Die Studie schließt alle Arten von Verschmutzung für Fahrzeuge ein: lokale Pollution (unverbrannte Kohlenwasserstoffe HC, Kohlenmonoxid CO, Stickstoffmonoxid und Dioxide NOx) und Gewächshausgase (CO2, CO und HC) und berücksichtigt die Unterschiede der Fahrdynamik zwischen Zwei- und Vierradfahrzeugen, wenn Sie sich in den gleichen Verkehrbedingungen befinden.

Fünfzehn motorisierte Zweiräder von 125 bis 1200 Kubikzentimeter Hubraum (Motorroller und Motorräder) und drei Autos wurden im „real-world"-Fahrzyklus und dessen Auswirkung auf die Umgebung gemessen.

Der Kernpunkt der Studie – die verschiedenen Fahrgewohnheiten zwischen motorisierten Zweirädern und Autos in Frankreich sowie die Unterschiede der Abgase zwischen verschiedenen Typen von Fahrzeugen – zeigt eindeutig die Konsequenzen der verschiedenen Verfahren zur Homologation zwischen Autos und kleineren oder größeren motorisierten Zweirädern (einschließlich der Resultate des WMTC-Testberichts).

Powered Two Wheelers compared with cars – Driving dynamics, fuel consumption and exhaust emissions in daily use

The context

Since 2000 and the first Euro regulation applying to powered two wheelers, ADEME (French Environment and Energy Management Agency) has been working to assess the PTW exhaust emissions. Older PTW (Euro1, Euro2) were thus studied in some former work released in 2000 and 2005[1]. As of 1 January 2007, all PTW of more than 50 cm^3 (therefore excluding mopeds) sold in Europe have to meet Euro3 emission standards (some derogations remaining in effect until end of 2007). This new step requires that manufacturers implement technical solutions (which have been proven in passenger car use), including fuel injection in most models, fuel mix regulators and three-way catalytic converters in exhaust systems.

Therefore, the implementation of Euro3, leading to deep changes in engine control features, justified resuming ADEME evaluations of the environmental performance of this category of vehicles.

Moreover, at the same time, the Paris City Hall got in contact with ADEME to join a workgroup about PTW emissions. This group brought together representatives of the municipality and from the world of two-wheel vehicles. The focus of the workgroup was not only to assess new Euro3 PTW emission levels, but also to quantify the differences in emissions and fuel consumption with cars, taking into account the peculiarities of PTW driving in the traffic. These expectations were asking for updates in current knowledge in PTW emissions compared to cars, as described in former articles[2].
The test program described below was created through exchanges with this work group. This ensured that it was representative and realistic from the riders' point of view.

Building the detailed study

The test program therefore seeks both to evaluate the environmental progress made by PTW after Euro3 implementation and to compare the results with those obtained by recent model passenger cars (Euro4 "for cars" compliant). However, as it had been done formerly in ADEME's PTW studies and as it was discussed with the PTW workgroup, the assessment was to be made in conditions as close as possible to the real use of cars and motorbikes, and not only on mandatory test cycle.

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[1] See on ADEME website :
http://www2.ademe.fr/servlet/getDoc?cid=96&m=3&id=23210&p1=02&p2=12&ref=17597
http://www2.ademe.fr/servlet/getDoc?cid=96&m=3&id=28529&p1=02&p2=12&ref=17597

[2] for interesting examples see :« The rising importance of two-wheelers emissions –a comparison to cars », M.Weilenmann & P.Novak, EMPA and « Comparison of real-world emissions from two-wheelers and passenger cas », A-M.Vasic & M.Weilenmann, EMPA

It was decided to compare the two families of vehicles under similar operating conditions from the driver's point of view: a home-to-office trip between the suburbs (Linas) and downtown Paris (Musée d'Orsay) at rush hour (arrival time in Paris: 8.30am).
This path includes highways, wide roads and urban streets with a wide range of congestion level along the way. The total distance is 31 km long and the trip should represent what a driver encounters as driving conditions when commuting to a big city.

As mobile emission measuring devices still cannot be embedded on PTW (too large, too heavy), the emission assessment had to be made on a roller test bench. A secondary advantage of this testing strategy is that it is then possible to "re-play" any test cycle on any vehicle if needed, remaining exactly in the same conditions (on the contrary, if measured "online" on the road, the results would become date-dependant because of traffic variations).

The next issue was therefore to build a sufficient knowledge of the driving dynamics of cars, small and bigger PTW (including both scooters with automatic transmission and motorbikes with clutch and gearbox), so that various test cycles can be built for the test bench.

"Real use" of motorcycles, scooters and passenger cars in the traffic

To build the test cycles, several trips were recorded simultaneously on the reference route for a car, a 600 cm^3 motorcycle and a 125 cm^3 scooter. For each of them, a skilled driver or rider familiar with his vehicle in the urban traffic was aiming at an arrival time of 8.30 am. Thus, the car and the two PTW were driving in the same traffic condition.
The vehicles had to adhere to speed limits, but the PTW were allowed to drive between lines of slow or stopped cars, as they usually do under normal driving conditions in France.
These simultaneous recordings were repeated five times, on successive days. The stored datas included time, speed, distance, engine rpm, throttle position and driver's comments about traffic congestion.

The speed profiles were then analysed (versus time and versus distance) to split them depending on the type of road and congestion level and the behaviour of every vehicle was studied. The comparison of each single vehicle, from one day to the others, showed a good consistency (average speeds, stops, congestion). Then, when compared to the other vehicles, it allowed us to extract a dynamics structure for each of the three vehicle types.

In particular, when analysing the average speeds of both PTW on every sector of the route, we noticed that they were quite close to each other. This result led to an average travel time of 43 minutes for the 600 motorbike, versus 44 minutes for the 125cm3 scooter.

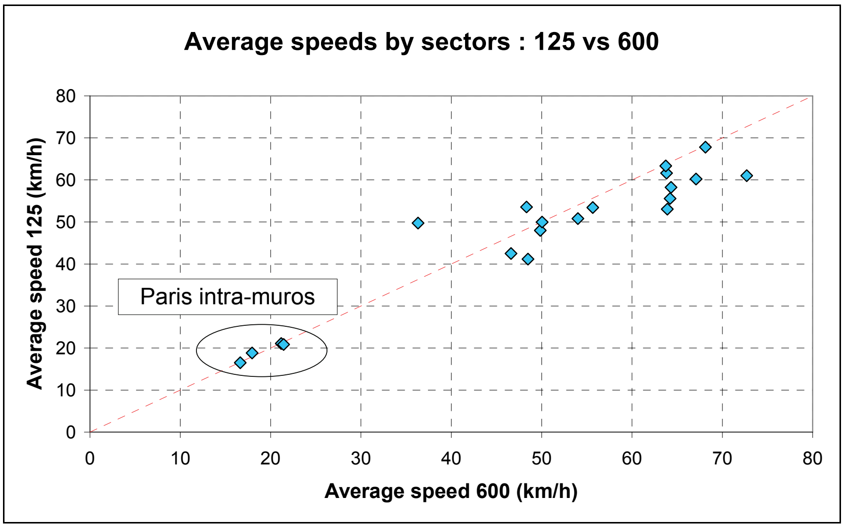

Fig. 1: 125 scooter and 600 motorbike average speeds

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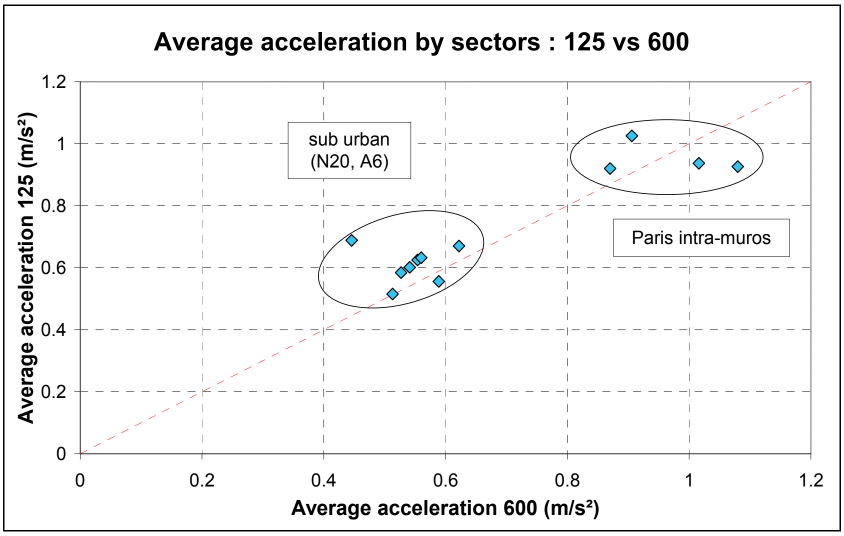


Fig. 2: 125 scooter and 600 motorbike mean positive acceleration

We can see on fig.1 that it's only on the faster sectors (average speed over 65 km/h) that the bigger motorbike took a slight advantage of its higher performance potential. As this type of traffic only represents a minor part of the total distance, the global travel time does not really benefit from this.

The small difference in driving dynamics between the two PTW is also noticeable on fig.2.
The average acceleration levels of both PTW do not appear to be as different as their engine's maximum power outputs are. This demonstrates that in urban and sub-urban traffic, the performance potential of bigger PTW is rapidly useless when congestion increases.

From this result, it was decided to consider all types of PTW as a single type of vehicle and therefore to build only one set of test cycles dedicated to PTW, regardless to their power output. It was considered that a cycle possibly leading to wide open throttle operation for smaller PTW was reflecting the real use.

Next to this PTW comparison, the same analysis was made on the car's recordings, resulting in an average travel time being twice the time for PTW: 88 minutes were needed on the road to reach the arrival point. PTW take a clear benefit of their lower size: riding between the car lanes they have to stop less often in the traffic jams. The car travel reflects the high congestion level along the way, due to the chosen peak hour.

Finally, extracting datas from the on-road recordings, two sets of test cycles were built, one for powered two wheelers and the other for cars. Each of these sets is describing the whole path, split in the following six phases: urban (with cold start 20°), "Nationale" road, fluid highway, congested highway, traffic jam and hot urban. The duration of some phases had to be adapted compared to real driving time, because of testing installation needs (limitation due to sampling bags volume, or requirement of sufficient sample size to ensure accuracy of analysis with CVS system). These slight modifications are later corrected to calculate the actual results on the real route.
The key feature of these cycles is that they describe the driving dynamics of both PTW and cars, while driving in parallel in the same conditions (traffic congestion, type of road, weather).
The main characteristics of these cycles are summarised in the following table:

Table 1: test cycles characteristics

	average speed (km/h)		duration (s)		distance (m)		average accel (m/s2)		max speed (km/h)		nb stop / km		stop time / km	
	car	PTW	car	PTW	car	PTW	car	PTW	car	PTW	car	PTW	car	PTW
urban cold	19.1	24.0	889	706	4706	4705	0.672	1.092	50.8	52.7	3.0	2.3	41	38
"Nationale" road	41.0	60.6	914	618	10408	10407	0.536	0.613	93.0	91.5	1.0	0.3	10	2
fluid highway	70.4	81.8	529	455	10341	10335	0.460	0.552	108.9	111.7	0.1	0.1	0	0
congested highway	12.1	44.0	994	466	3340	5700	0.626	0.388	48.6	57.4	6.6	0.2	75	1
traffic jam	4.3	7.5	820	472	989	988	0.625	0.641	31.0	37.8	18.2	10.1	433	103
urban hot	19.1	24.0	889	706	4706	4705	0.672	1.092	50.8	52.7	3.0	2.3	41	38

The cold and hot “urban” phases describe the same “speed vs time” profile.

The “traffic jam” is a very severe congestion due to road works, which we decided to keep in order to evaluate the emission control systems in such extreme conditions.

For practical reasons, cold urban + “Nationale” road + fluid highway are gathered in one single cycle called “Suburbs” and the three other phases build a second cycle called “City”.

We can make a few comments on the dynamics of these cycles, compared to the homologation cycles being in use in European homologation tests. As shown on fig.3, where average speed and acceleration are plotted, we can notice that ECE cycle is quite similar to urban real driving for cars and EUDC cycle is close to highway real driving for cars. However, as far as PTW are concerned, we clearly see that their behaviour in the traffic induces some important difference with cars and therefore with regulatory cycles.

The same figure also highlights the main differences between car and PTW “real-world” driving: average speeds are higher for PTW, whatever the context, but the average acceleration is more specific. The average acceleration for the PTW is much higher in urban cycle, whereas a bit closer to cars on roads, highway and in the heavy traffic jam. On the congested highway, PTW show a very low rate of acceleration. This is due to a typical traffic mode (in France) where cars are nearly stopped, moving with slow “stop-and-go” pattern, while PTW ride quite smoothly between the slow car lines, hardly braking and not often stopping .

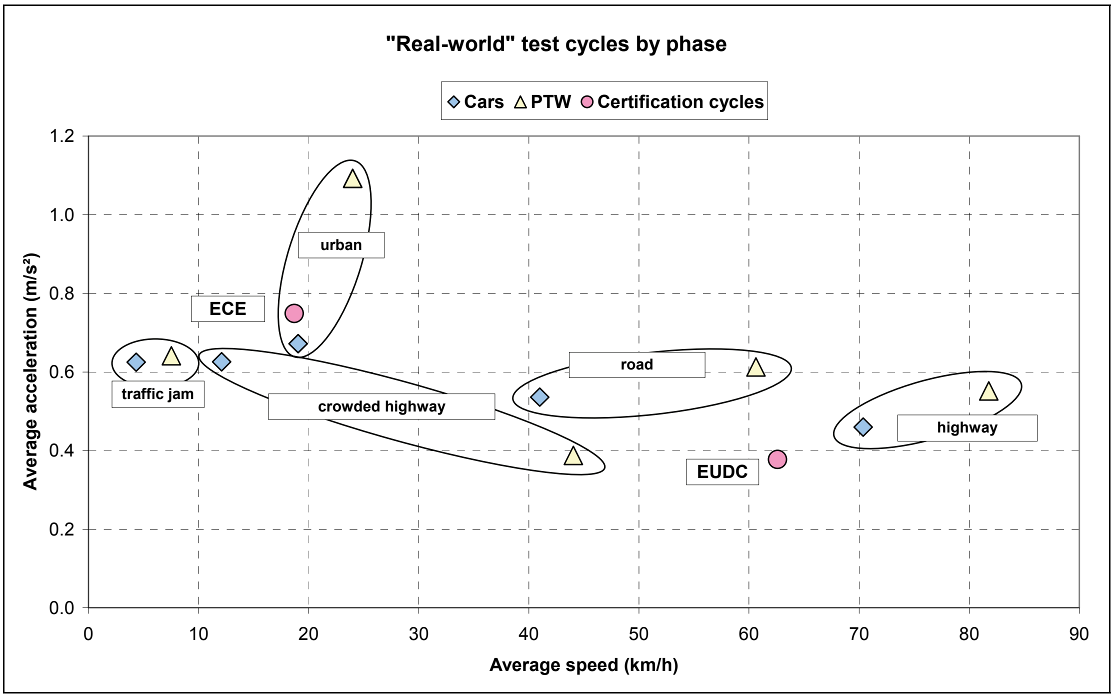


Fig. 3: « real world » test cycles dynamics compared to homologation cycles

In order for the travel time of cars to be representative of real commuting use, time spent looking for a parking spot is later added to the actual trip time (by a slight increase of cars "traffic jam" and "hot urban" phases distance). For this study and as it is usually the case in France, PTW were allowed to park on wide sidewalks: this enabled quasi-local and very quick parking. A recent PREDIT-ADEME research[3] showed that the average time spent looking for car parking (for commuter working in the "Musée d'Orsay" area) was 16 minutes at that time of the day. This still increases the time savings for the PTW user.

Homologation test cycles reminder

The current European homologation process includes, for motor vehicles, average exhaust emission measurements (type I tests).

Euro 4 compliant cars are tested with cold start (20°c) on the NEDC cycle, built with 4 elementary ECE and one EUDC cycle.

Euro 3 PTW under 150 cm3 (and over 50cm3) are tested with cold start (20°c) on 6 elementary ECE cycles.

Euro 3 PTW over 150 cm3 are tested with cold start (20°c) on 6 elementary ECE cycles and one EUDC cycle.

Euro 2 PTW were tested with hot start and on ECE cycle only (maximum speed = 50 km/h).

It might be reminded that Euro3 does not imply any durability requirement for emission control.

An harmonised test cycle for PTW has been defined and is part of the next evolutions planned for Euro regulation: the WMTC is also part of the present study.

Description of the test vehicles

For this program, 15 PTW and three cars have been measured. Their main characteristics are summarised in table 2. All the vehicles were lent by the manufacturers or their sales departments in France and the bigger motorbikes were complying with the maximum power limitation of the country (78kW).

Different categories of PTW have been tested, from 125cm3 to more than 1000 cm3 engines, and both motorbikes (with gearbox and clutch lever) and scooters (with CVT transmission) were included.

As far as cars are concerned, the choice was to pick up 2 gasoline cars (gasoline being the usual fuel for PTW) and one diesel car (without Diesel Particulate Filter) because of the diesel share in French

[3] PREDIT-ADEME « Le temps de recherche d'une place de stationnement », SARECO, February 2005.

cars sales (75% in 2007). As the study is aiming at daily use, the diesel car and one gasoline car were chosen from urban size with reasonable engine power. However, as some of the PTW are ranging up to 78kW and therefore to high performance, the second gasoline car is fitted with a bigger 6 cylinder engine with 155kW output and automatic gearbox. None of these latter vehicles can be quoted as optimised for urban driving, but all of them actually can be found inside French big cities…

Table 2: Main characteristics of vehicles

category	engine power	mileage	fuel system	test inertia	Euro level
trail 125	8 kW	507	carb	190 kg	Euro3
scoot 125	11 kW	1359	inj	190 kg	Euro 3
scoot 125	11 kW	3000	inj	240 kg	Euro 3
scoot 125	10 kW	1566	inj	240 kg	Euro 3
scoot 125	8 kW	4	carb	190 kg	Euro 2
scoot 250	16 kW	4013	inj	230 kg	Euro 3
scoot 400	25 kW	4255	inj	270 kg	Euro 2
scoot 400	29 kW	1585	inj	310 kg	Euro 3
roadster 600	72 kW	4259	inj	270 kg	Euro 2
roadster 600	72 kW	3321	inj	270 kg	Euro 3
roadster 600	53 kW	3750	inj	270 kg	Euro 3
sport/GT >= 950	78 kW	1623	inj	270 kg	Euro 2
sport/GT >= 950	78 kW	912	inj	270 kg	Euro 3
sport/GT >= 950	78 kW	209	inj	270 kg	Euro 3
sport/GT >= 950	74 kW	6111	inj	320 kg	Euro 3
urban gasoline	55 kW	1900	inj	1130 kg	Euro 4
urban diesel w/o DPF	66 kW	3643	inj	1250 kg	Euro 4
sedan V6 gasoline auto	155 kW	10353	inj	1700 kg	Euro 4

Taken from the manufacturer's press fleets, there is no reason to think that the test vehicles were specially tuned for our tests. Some mileages may appear quite low: this is due to the fact that most of them being Euro3 compliant, they were new models at the time of our tests, leading to short availability duration for each user (the Press and our test lab). It can be noticed that 4 Euro2 PTW were included to verify the consistency of emission results when compared to our former studies.

Laboratory measurement and tests performed

All measurements have been performed at the UTAC lab, where both PTW and cars emission test facilities are used for official European homologation. This was a guarantee for reproducible and calibrated measurements of regulated pollutants (CO, HC and NOx), of CO_2 emissions and of fuel mileage. Only the averaged results using the classical CVS system were recorded with no continuous online sampling.

Roller bench setting was made in accordance with the homologation files, for cars and for all the powered two wheelers (a few coast-down tests have also been made to check for consistency between these official settings and actual measured rolling resistance).
Every vehicle has been tested on several cycles:

For PTW:

- Euro3 test cycle (the whole cycle was measured including EUDC, even for PTW under 150 cm3), with preconditioning and "ambient start" (20°c) as in the European Directive,
- "real-use" PTW cycles (Suburbs and City) beginning with a 20°c start,
- WMTC cycle (here we made the difference between the PTW categories, not measuring the 3rd phase for small PTW unable to reach 130 km/h).

For cars:

- Euro4 test cycle (20°c start),
- "real-use" cars cycles (Suburbs and City) beginning with a 20°c start,
- The "urban" part of CADC cycle was already measured for further reference.

Every measurement has been repeated at least twice and sometimes more when the results were showing a high dispersion or considered as surprising.

Considering PTW gear shifting strategies, for "real-use" cycles it was left to the test operator practice, as it is the case for the Euro3 homologation procedure. For WMTC cycles, the shifting diagrams from available "version 9" excel file was used. Scooters were driven with no specific strategy: the CVT was controlling the transmission ratio on every cycle.
Cars shifting strategy was taken from the NEDC cycle for Euro4 compliance verification, and had been specified from the on-road recordings analysis for the real-use cycles.
The big 6 cylinder car with automatic transmission was tested in "Drive" mode.

First results: progress from Euro2 to Euro3

For each vehicle, its "Euro level homologation" compliance was assessed. The situation would not have been perfectly satisfactory for some PTW if they had been brand new; however due to the lack of durability requirement for Euro3 level, all vehicles were qualified as correct for the test campaign.
A quick overview of PTW progress between Euro2 and Euro3 on the real-world cycles is presented on fig.4, using their average emission factors on the whole path (in g/km):

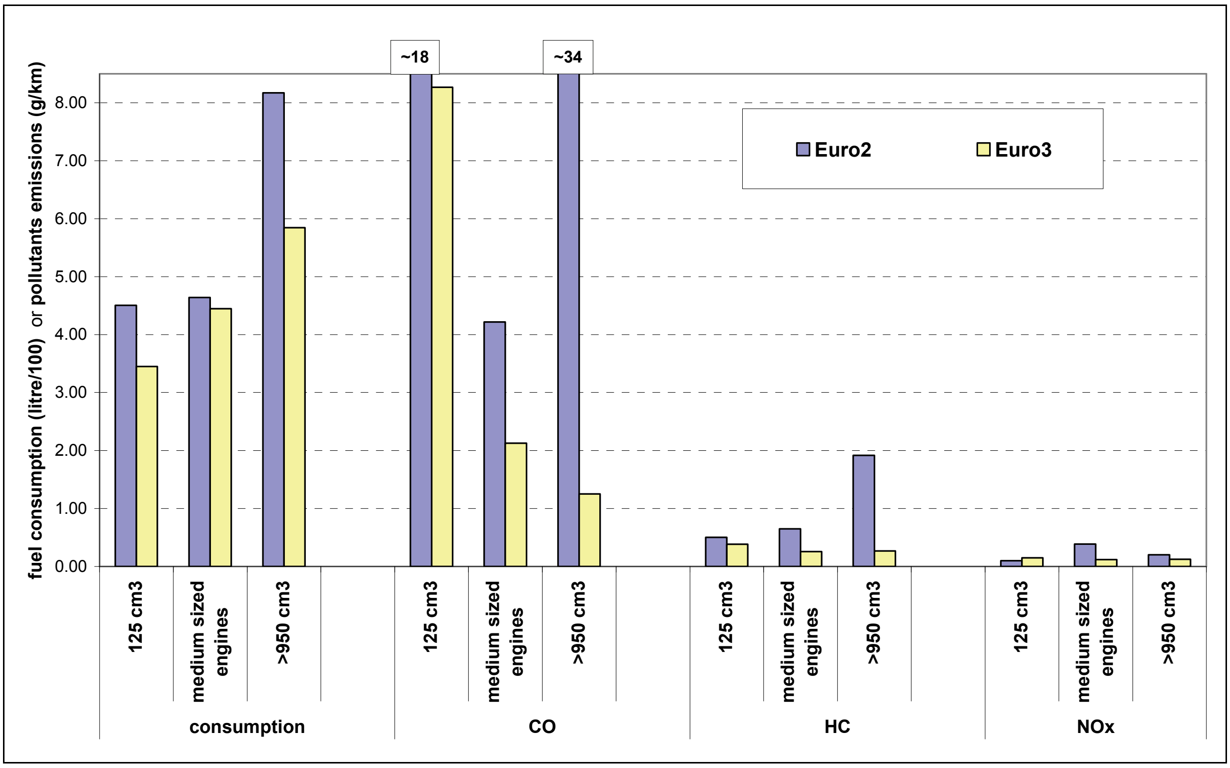


Fig. 4: Comparison of exhaust emissions and fuel consumption between Euro2 and Euro3 PTW

The four Euro2 PTW measured during the study had emission levels in line with (or slightly better than) previous ADEME studies (S. Barbusse, 2000 and 2005).

Euro3 PTW results, all of which were measured over the same real use cycle, showed clear improvements in pollutant emissions and fuel mileage for all categories:

- NOx emissions are below 0.16 g/km for 125 cm^3 and 0.12 g/km for larger engines (Euro3 limit is 0.15).
- HC emissions fall significantly, to less than 0.4 g/km for 125 cm^3 (Euro3 limit is 0.8 under 150cm3) and 0.26 g/km for larger engines (Euro3 limit is 0.3).

Note that our former 2005 results showed a level of (HC+NOx) of 1.5 g/km on average for 125 cm^3, and more than 5 g/km for some larger engines.

- CO emissions for motorcycles "> 125 cm^3" are below 2.1 g/km and are even better managed as engine size increased (average of 1.25 g/km for 1,000 cm^3 and over; Euro3 limit is 2.0).
- On the other hand, CO emissions for 125 cm^3 remain high (up to 8.3 g/km), particularly during extra-urban driving.

Note that 2005 results showed CO emission levels above 30 g/km for large engines and 12 g/km on average for 125 cm^3.

These values show that the PTW market has responded well to stricter regulations, since homologation thresholds are nearly met (with the noticeable exception of 125 cm^3 CO emissions) for the “real-use” cycles, which are stricter than current legislation.

Moreover, the reduction in CO and HC emissions after implementation of Euro3 has resulted in better fuel efficiency:

- A reduction in greenhouse gases (CO_2, HC, CO), from -7 to -25% depending on the engine size, (*82 to 140 g eqCO_2/km, for engine between 125 cm^3 and more than 1000 cm^3).*
- An improvement in fuel efficiency (l/100) of 20% for 125 cm3 PTW (*Euro3 average:3.5 l/100*), reaching 25% for engines greater than 950 cm^3 *(Euro3 average: 5.8 l/100)*
- A lower improvement in fuel efficiency (about 5 to 10%) for PTW of average engine size, especially since Euro2 references measured for the present study were already quite efficient (injection) *(Euro3 scooter average: 4.1 l/100 and roadsters 600: 4.8 l/100).*

These results, though globally positive, highlight some weakness in present Euro regulation, in particular for smaller capacities being homologated on the urban ECE cycle (max speed = 50 km/h). This leads to high CO level when driven on suburban roads, over 50 km/h.

Euro4 cars and Euro3 PTW comparison: exhaust emissions

Here we compare the total absolute quantity of pollutants emitted into the atmosphere (and of fuel used by the engine) during the complete trip (31.015 km for PTW), taking into account the car’s specific driving profile and the time spent looking for parking (due to this added “parking search”, the distance travelled by cars is higher than that of PTW; therefore average emission factors are not convenient indicators).

The average number of passenger per vehicle in Paris area has been evaluated to 1.1 for PTW and 1.18 for cars. Therefore, these values being quite close to each other, the following analysis is presented for one single vehicle and no correction is taken into account considering the occupation rate of vehicles.

These results are representative of reasonable driving style in heavy traffic conditions.

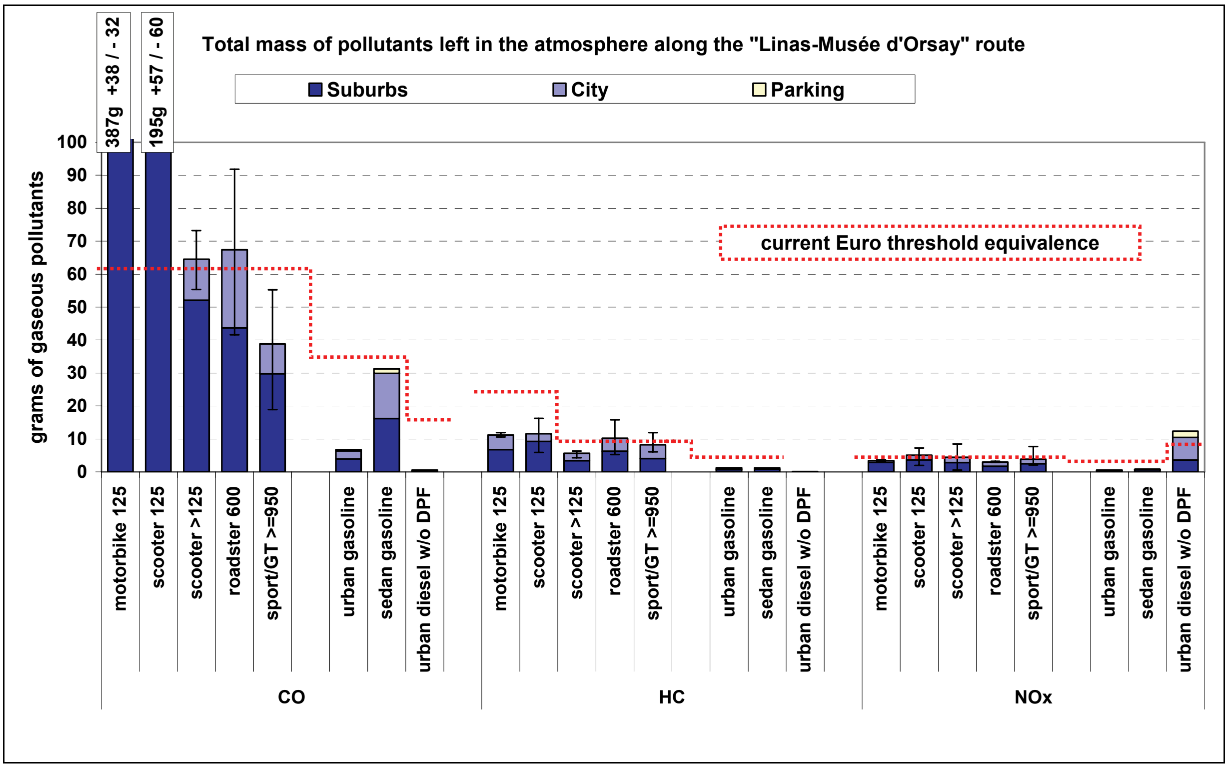


Fig 5: comparison of absolute pollutants mass emissions between Euro3 PTW and Euro4 cars

On fig.5, total amounts of pollutants along the way are plotted for every phase of the real use (Suburbs, City, and parking for the cars). Only Euro3 PTW are considered, the study aiming at "up-to-date" vehicles.

The dotted red lines correspond to the equivalence of the emission factors threshold of current Euro standards for every pollutant and for each vehicle category on its "real-use" cycle.
The dispersion bars show the measured fluctuations between the different tests and between the different PTW of each category (see table 2). The dispersion is mainly due to the differences between the various vehicles inside categories including more than one model.

- For 125 cm^3 vehicles, emissions of CO and HC remain 10 to 20 times higher than the average for Euro4 gasoline cars. Besides, it must be quoted that the 125 motorbike was equipped with a carburettor-fed engine, whereas all the 125 scooters where fuel injected.
- For larger engines:
  - CO emissions are two to three times higher than the average for Euro4 gasoline cars.
  - HC emissions are six times greater than those of Euro4 gasoline cars.

The difference between 125 cm^3 and larger engines is the consequence of lighter regulations for motorcycles under 150 cm3 than for motorcycles with larger engines (the 125 cm^3 standard measures emissions based on the ECE cycle only). Hence, the 125 cm3 PTW demonstrate CO emission factors being 2 to 4 times higher on the “Suburbs” than on the “City” real-use cycle.

- PTW NOx emissions are on average six times higher than those of Euro4 gasoline-powered cars. They are, however, less than half those of Euro4 diesel cars. Relatively low NOx emissions remains a noticeable performance of “4 stroke” PTW, despite the introduction of lambda regulation on Euro3 engines above 150cm3: increasing the air-fuel ratio from former rich mixture did not lead to a big increase of NOx. This might be due to the fact that high load phases (often the most NOx generating) for PTW engines, which correspond to acceleration phases in the context of our study, do not last long since average inertia of PTW remains quite low.

In order to complete this comparison, some simple calculations have been processed using the database of the Artemis project and the numerous car exhaust emission results on elementary cycles. Extracting emission factors on sub-cycles close to the different phases of our real-use cycles, it has been possible to obtain an estimation of the exhaust emission of older cars.
A Euro1 gasoline car would have emitted approximately 130 g of CO and 45 g of HC.
A Euro2 gasoline car would have emitted about 42 g of CO, 2.5 g of HC and 11.4 g of NOx.
A Euro2 diesel car would have emitted around 36 g of NOx.
It can be reminded that Euro1 for cars (1993) was the step justifying the fuel injection generalisation for gasoline cars, with 3 way catalysts and lambda regulation, thus corresponding quite well to the PTW Euro3 effect on big motorcycles.

The above estimations allow to position PTW exhaust emissions relatively to cars, as follows:

- 125 cm3 Euro3 PTW are worse CO emitters than Euro1 cars (1993), especially the carb-fed motorbike, but HC emissions are 4 times lower than Euro1 cars.
- Intermediate capacities PTW show better CO results, about half that of Euro1 gasoline cars (still 50% higher than Euro2), and HC 5 times lower than Euro1 cars (still 3 times higher than Euro2 cars).
- Bigger capacities PTW show CO emissions equivalent to that estimated for Euro 2 gasoline cars, and the same HC level than intermediate capacities (between Euro1 and Euro2 cars).
- For all Euro3 PTW, their NOx emission level is nearly half the one estimated for Euro2 gasoline cars, being therefore much better than that of diesel cars of any generation.

The shift in time between PTW and cars Euro regulation is here clearly highlighted. Nevertheless, all PTW have followed their regulation strengthening, as already demonstrated in the above Euro2/Euro3 comparison.

It also appears that taking into account the parking phase for cars is not an important penalty to their emission control performance: while the parking phase represents approximately 10% of the total distance, it represents about 6% of CO emissions and 3.6% of HC emissions. Only for the two urban cars did the parking phase represent 14% of NOx emissions with a high absolute level for the diesel car (average of 0.4g/km).

Euro4 auto and Euro3 PTW comparison: fuel consumption and greenhouse gases emission.

In accordance with former assessments of PTW exhaust emissions published by ADEME, the greenhouse effect of exhaust pollutant emissions is taken into account using Global Warming Potential values proposed by IPCC in 2001 (considered here are the minimum values of the proposal, i.e. GWP=1.15 for CO, 11 for HC, and 0 for NOx). This leads to a correction added to pure CO_2 emission, that could be considered as negligible for cars (due to very low CO and HC emissions when Euro4) but is still not so low for PTW. Emissions of greenhouse gases found on the chart (as "CO_2equ") includes CO and HC contribution to greenhouse effect.

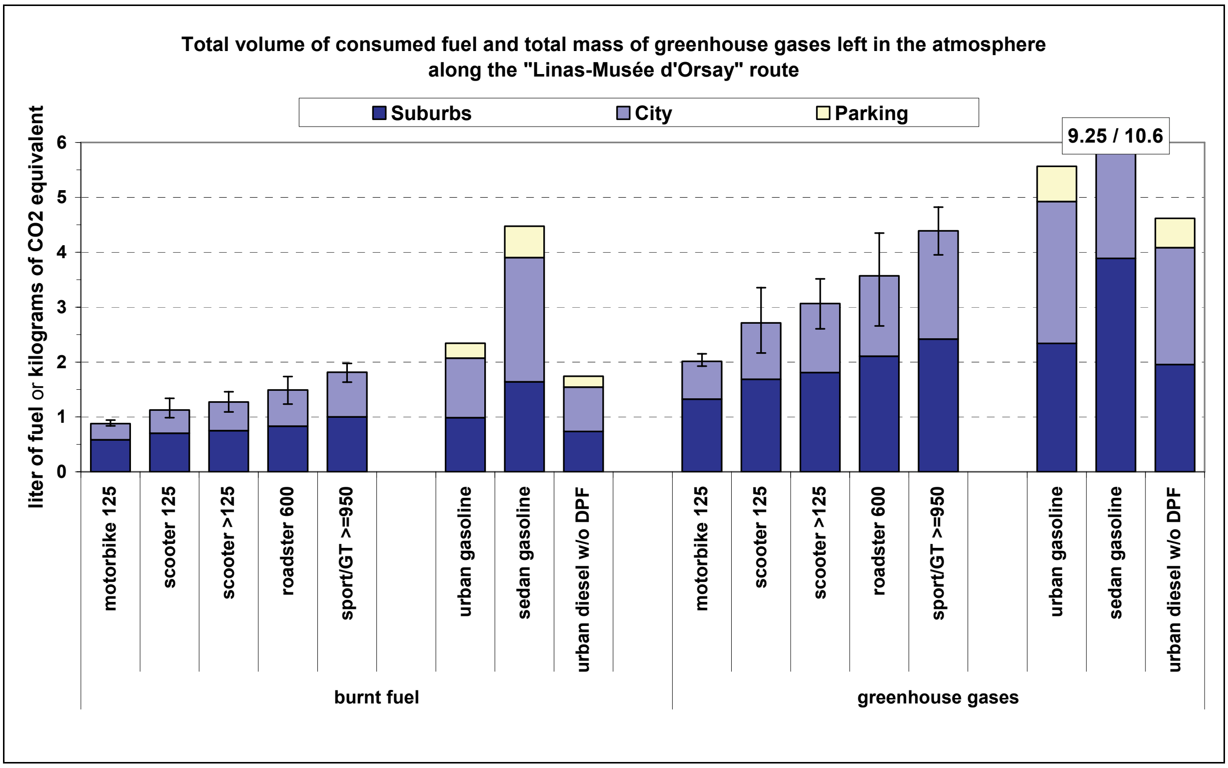


Fig. 6: Comparison of total consumed fuel and emitted greenhouse gases

- Globally, fuel consumption for Euro3 PTW is lower than that of the two gasoline-powered cars. Only the compact diesel car is a bit more fuel efficient than motorcycles with engines larger than 950 cm^3.
- The latter PTW (the most powerful of our test range) demonstrate high fuel consumption that can be close to that of small cars: this is confirmed by the feedback from big capacity PTW users.
- It appears clearly that the lower the PTW engine size, the lower the fuel consumption. 125 cm3 PTW are the more fuel efficient vehicles.

Moreover, a noticeable difference emerges between all the 125 scooters and the 125 motorbike. The possible technical factors are: the maximum output of the motorbike being lower than scooters (8kW vs 10 to 11 kW), the mass of the vehicle (conditioning the test inertia) of the motorbike being lower than the tested scooters (120kg vs 135, 155 and 160kg), but probably the main explanation comes from the gearbox allowing a better optimisation of the fuel consumption than the scooters CVT.

This particularly can be noticed in the urban phase where the motorbike consumption shows a much better level than the scooters (gear shifting strategy offers more degrees of freedom there than in faster suburban cycle). The management of 125 cm3 scooters transmission ratio appears to be tuned for good performance and driveability, but current technology still remains far from basic “eco-driving” behaviour (a CVT seldom leads to high engine load at low revs). Besides, it is well known that basic CVT transmission have a bad efficiency, as can be deduced from their cooling needs when driving.

Greenhouse gases emissions follow the same trend than fuel consumption. The only difference is that the diesel car emits more CO_2 than gasoline engines per liter of consumed fuel, leading to a global emission being slightly over the big capacities PTW average (with the car parking being taken into account).

Euro4 auto and Euro3 PTW comparison: energetic efficiency

In order to better understand the above results concerning fuel consumption, ADEME evaluated the energetic efficiency (conversion of the fuel into mechanical power) of each vehicle. A simple calculation along the real-use cycles, using the settings of the roller bench for each vehicle, gives the mechanical energy provided by their powertrains during each test. This mechanical energy results from the fuel conversion into power at the wheel, through the engine and transmission. Therefore, the ratio between this energy needed for the vehicle travel and the amount of consumed fuel, illustrates the energetic efficiency of the powertrain.

It must be highlighted that despite a false common idea, the energy needed to move a PTW is not only proportional to its mass. The average aerodynamic drag of a PTW is between 50 and 100% of a car's drag (C_d.A order of magnitude between 0.4 and 0.7m²) and rolling resistance of PTW tyres is about twice the resistance of car's tyres (about 15 to 20 kg/ton). The lower mass of PTW is a clear benefit for acceleration potential but fuel consumption is not reduced by the same ratio than mass. On the ADEME test cycles, the total average energy needed for PTW is between 50 and 60% of the tested cars.

The classification of the different vehicles according to their efficiency is presented on fig.7. Important factors such as Euro level, engine fuelling system, maximum power output and test inertia (closed to the "real-use" mass including the rider) are also reminded on the graph.

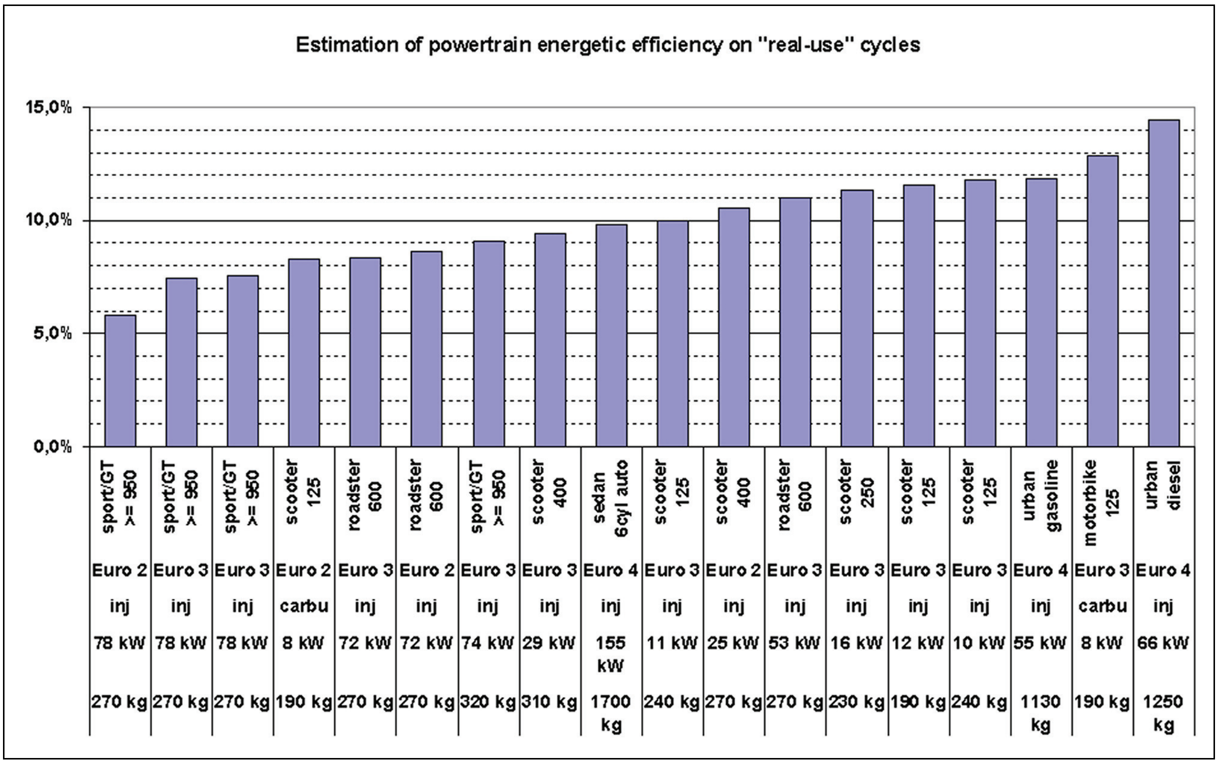


Fig. 7: Classification of estimated energetic efficiency

It appears that in daily urban and suburban use:

- The powertrains of small Euro3 PTW have fuel efficiencies comparable to that of compact gasoline car, the 125 motorbike even being slightly better than our reference urban gasoline car. Their light weight provides a significant reduction in fuel consumption as they require less energy than a car to move.

- The improvement of fuel use with Euro3 is also noticeable for all PTW categories, as Euro2 models are less efficient than Euro3 PTW of the same type and with similar power/mass ratio.
- The vehicles with large engines, which are not well-suited to the type of use studied here, are clearly less energy efficient. This is linked to their performance potential: the 210 HP car and the motorcycles with a high power/weight ratio, have significantly lower efficiency under these operating conditions. The strong decrease of engine efficiency when used at low loads is a well-known feature of internal combustion engines. This also explains why some large motorcycles have fuel mileages which are comparable to that of much heavier cars.

A quick look to the future: WMTC cycle

As a final result and to assess the consistency of WMTC with current Euro regulation, emission results and fuel consumption measurements of the Euro3 PTW have been compared on various test cycles: the ADEME "real-use", the WMTC, and the current Euro3 mandatory cycle.

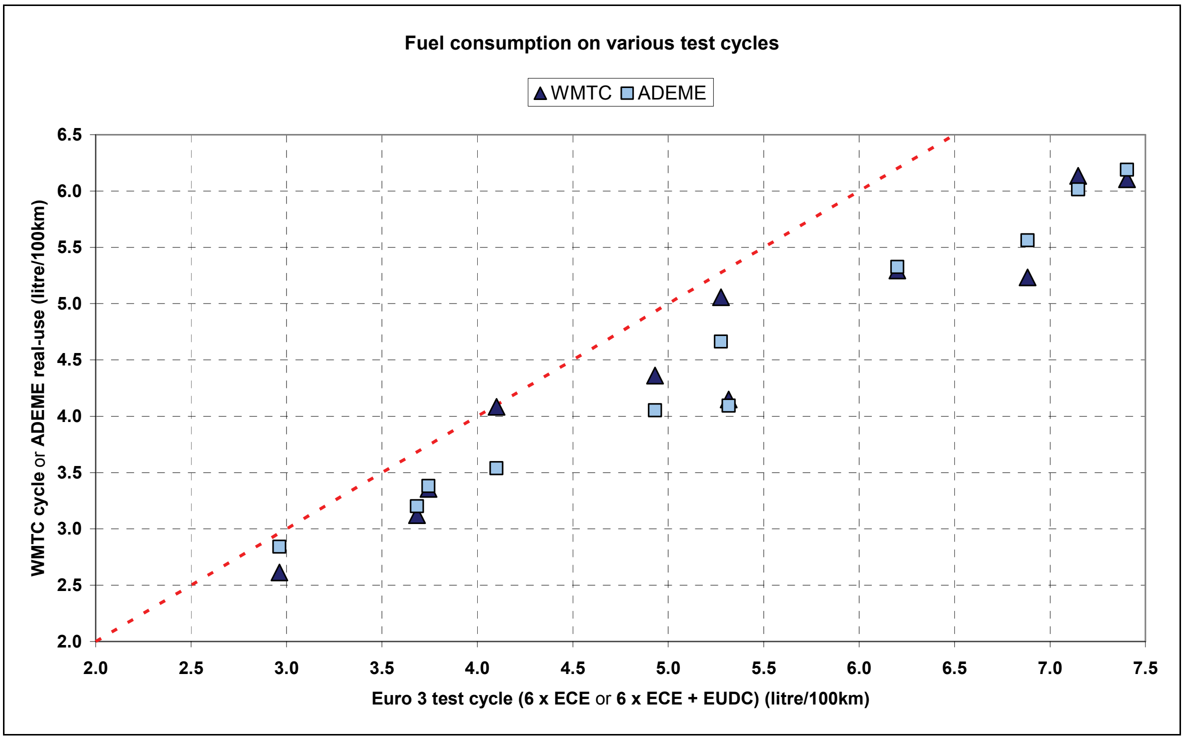


Fig. 8: Fuel consumption on WMTC, ADEME « real use », and Euro3 test cycles

Fig.8 clearly shows that fuel consumption on WMTC and ADEME cycles are lower than the values on Euro3 cycle (they are all under the "y=x" red dotted line). As ADEME cycles were built on a "real-use" basis and as WMTC results are globally very closed to ADEME's ones, it can be considered that WMTC introduction would lead to good consumer information with realistic fuel efficiency values measured during homologation.

As far as pollutant emissions are concerned, the situation is not so simple to analyse, as shown on fig.9.

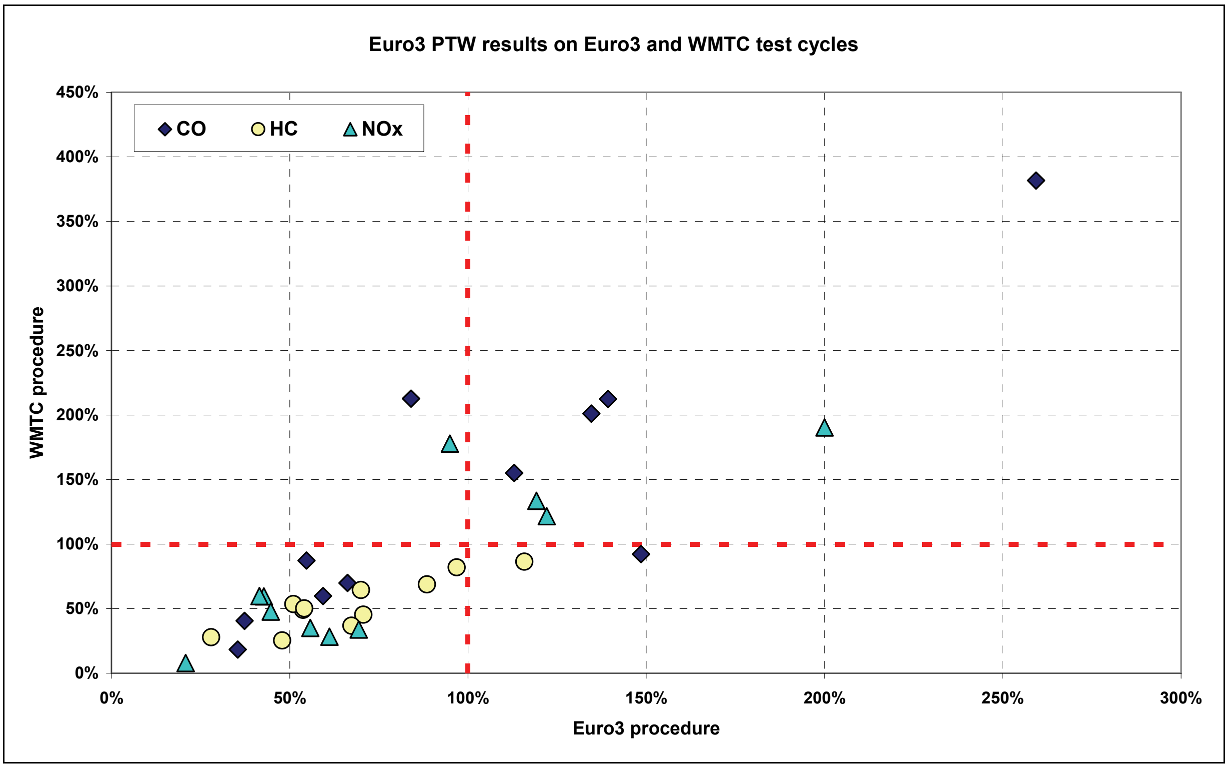


Fig. 9: Exhaust pollutants on Euro3 and WMTC test cycles

The tested PTW were tuned for Euro3, certainly not optimised on WMTC cycle. However, it appears that on the PTW of our sample:

- Average CO emissions are 80% higher on WMTC cycle than on Euro3 cycle (remaining globally lower than ADEME cycle results). Nevertheless, some CO values on the WMTC cycle are lower than on the Euro3 cycle.
- HC emissions on WMTC cycle are about 10% lower than on Euro 3 (but slightly lower than on ADEME cycle). All the tested PTW emit less HC on WMTC than on Euro3, with none of them failing the WMTC HC limit.

- NOx emissions do not show any clear trend, being strongly "fine-tuning"-dependant (through the accuracy of the lambda regulation).

For 4 out of 11 tested PTW, the results in WMTC conditions and in Euro3 conditions (cycle and emission thresholds) are "homologation compliant".
2 of the tested PTW are Euro3 compliant but fail in WMTC conditions (because of CO for the first one and NOx for the other).
One PTW is complying with WMTC procedure, but fails at Euro3 test (it's the only tested PTW over-emitting HC compared to its corresponding Euro3 limit).

The fact that some of the tested PTW still satisfy Euro3 despite their mileage and are moreover "WMTC compliant" demonstrates that obtaining a robust emission control is possible for PTW.

However, the various PTW complying with only one of the two sets of cycle and limits demonstrate that WMTC can not be described as systematically more severe than Euro3.
Consequently, WMTC must be associated with some durability requirement to ensure that it will lead to an effective further reduction of PTW exhaust emissions compared to Euro3 situation. This is one lack of Euro3 current regulation.

The second "gap in the law" in Euro3 is the non-representative ECE cycle used for PTW under 150 cm3 (which are commonly used above 50km/h). It is clear that WMTC cycle (reaching 95 km/h for category 2 PTW) will introduce a strengthening of the emission control requirements for 125 cm3, as it will be closer to real use. Associated with the durability, it should result in improving smaller PTW exhaust emissions.

Summary of findings

This study provides information on the current environmental status of powered two wheelers:

- Euro3 legislation has resulted in a clear improvement in PTW pollutant emission levels under real operating conditions, especially above 125 cm3.
- A substantial difference remains between the pollutant emission levels of powered two wheelers and those of recent model passenger cars, in real-use.

This is the result of a difference in the severity of automobile and motorcycle regulations: the strength of Euro3 for motorcycles (2007) is comparable to Euro1(1993) or Euro2(1997) for cars. The above emission analysis for Euro3 PTW shows results comparable to those of cars between 10 and 15 years old (still quite common on the road today).

- The high performance levels of motorcycles with powerful engines are not in contradiction with good management of pollutant emissions: our measurements show that they have among the best results for Euro3 PTW. However, a high power/mass ratio leads to an efficiency penalty increasing the fuel consumption.
- Euro3 PTW NOx emissions are significantly lower than those of diesel cars, even of the most recent models.
- The regulation for 125 cm^3 emissions (specific and less severe than that for larger engines) results in levels of CO which are significantly higher during their frequent actual extra-urban use. This particular point deserves special consideration by legislators in the near future given the increasing numbers of this type of PTW in Europe.
- The lack of durability requirements with Euro3 can be noticed with nearly half of the tested PTW not succeeding the homologation test after a few thousand kilometres.
- WMTC could be an efficient improvement of the current situation, provided that it includes a durability requirement. It would also lead to a good tool for consumer information concerning CO2 emissions and fuel consumption.
- Euro3 PTW greenhouse gas emissions are below those of the average automobile vehicles sold today (an average of 87 g/km for 125 cm^3 scooters compared to more than 130 g/km for a compact diesel car). The best car in the ADEME 2007 ranking (Smart ForTwo diesel) emits 88 g/km over the NEDC homologation cycle (urban and extra-urban cycle).
- Small Euro3 PTW demonstrate a good potential for low fuel consumption, taking profit from their small size and mass, and corresponding small engine.

Future expected regulatory changes will be able to address some of these issues. The introduction of the WMTC measurement cycle (World Motorcycle Test Cycle), the regulation of emission control durability, the reduction of emissions through evaporation and the requirement to measure CO_2 are currently under study by the European Commission. This must be taken as an interesting opportunity for PTW industry to offer greener vehicles, while increasing fuel prices and traffic congestion lead more people to consider PTW as a solution to their mobility needs.

Acknowledgements

The author wants to express thankful regards to the UTAC team for their help and dedication, to all the PTW and cars manufacturers implied in the test vehicles for their practical support, and to all the members of the Paris PTW workgroup for their comments, lively participation, and support: the members of the Paris City Hall, the DVD personnel, the CNPA motorcycle branch, the Association of European Motorcycle Manufacturers ACEM, the French Federation of Angry Bikers FFMC (affiliated to FEMA), the Couriers' CGT, Moto Magazine, the French Federation of Motorcycling FFM (affiliated to FIM), the Automobile Club of the West, the Moto Zen Association, the CERTU and the CETE of Center Normandy.

Higher Level of Motorcyclists' Safety by improved Road Infrastructure in Germany

Höhere Motorradsicherheit durch verbesserte Straßeninfrastruktur in Deutschland

Prof. Dr.-Ing. Jürgen Follmann
Hochschule Darmstadt, Fachbereich Bauingenieurwesen

Dipl.-Ing. Helmut Nikolaus
Leit. Regierungsbaudirektor a.D.
Leiter des FGSV- Gremiums „Motorradunfälle"

Abstract

During the past years, the number of traffic accidents in general is decreasing, thus mirroring a positive development. In contrast to this the number of severe accidents with involvement of motorcycles stays approximately constant. In 2007, 11.000 severely injured and 850 fatally injured motorcyclists had to be counted in Germany. Without an enormous increase in motorcyclists' safety the European aim for 2010 is presently not to be achieved.

From the three basic safety elements: man – vehicle – road, about 10-30 % (*according to MAIDS*) of the accidents are assumed to be accountable to infrastructure causes. Regarding the great potential capacity by the reduction of (fatal) injuries of motorcyclists, systematic improvements of road infrastructure are demanded as well as promising.

Motorcycle accidents with a high degree of injury severity are a major problem outside built-up areas. About 70% of all killed and 60% of all severely injured motorcyclists are involved in accidents there. Thus, the responsible institutions mainly focussed their safety activities on the so called "Motorcycle Routes".

With the help of pilot projects as well as the development of motorcycle-friendly safety devices by the competent road authority of North Rhine-Westphalia (*Straßen.NRW*), a new technical guideline was worked out. In 2003, a committee "Motorcycle accidents", as part of the German Road and Transportation Research Association FGSV, consisting of members of various German road authorities, representatives of police and safety institutions as well as universities and motorcycle associations, was founded and compiled the mentioned directive called: "Guideline on improving motorcyclists' safety outside build-up areas – MVMot 2007".

Firstly, the guidelines' content comprises, in addition to the present procedures, a special inquiry of motorcycle accidents. Themes covered reach from the investigation of problem areas (black spot management) up to the detailed analysis of motorcycle accidents and special influencing variables of road environment.

Secondly, appropriate measures with illustrations taken from practice have been collected.

It is differentiated between measures improving accident avoidance and measures reducing the crashworthiness. Measures improving accident avoidance include the influence on the drivers' operation characteristics, the clarification of trace design by means of road marking and signing, various constructive and operative measures improving the roads' environment and pavement conditions, clear

obstructed views, ease dangerous curve situations and intersection areas as well as focussed surfacechanges in order to decrease the number of accidents by speedreduction.
As parts of measures reducing the crashworthiness the creation of forgiving roadsides can be named; clearing and rearranging the road sides of operative equipment, shielding of obstacles as well as the use flexible equipment are only a few measures to be named. Particular importance is attached to the application of new motorcycle-friendly passive safety devices with the help of secondary rails.
Suggestions concerning methods of traffic supervision and prevention top off the contents.

These guidelines "MVMot 2007" were developed for the everyday safety work of the competent road authorities, police departments and accident-commissions of the state and local authorities.
By the presentation of the guidelines among experts with the collaboration of the Federal Ministry of Transportation, a key objective was reached: the guidelines' mandatory introduction in North Rhine-Westphalia, Bavaria, Baden-Wuerttemberg and Rhineland-Palatinate. Only with these mandatory specifications, the basis for a better chance of financing and realisation on site is provided.

Now, the next step to take is the implementation of the guidelines to the safety audits combined with the systematic professional training of the persons in charge of traffic safety. Above all there is a need of spreading the gathered knowledge also beyond the circles of experts way into politics, in order to increase the importance of motorcyclists' safety and thus guaranteeing the financing of safety devices for motorcyclists in Germany.

Kurzfassung

Die allgemeine Entwicklung der Verkehrsunfälle zeigt seit Jahren eine eindeutig positive Tendenz. Dagegen bleiben die schweren Unfälle mit Motorradbeteiligung nahezu konstant, so auch in 2007 mit 11.000 Schwerverletzten und 850 Getöteten. Deshalb erscheinen die europäischen Ziele bis 2010 ohne einen wesentlichen Zugewinn in der Motorradsicherheit derzeit nicht erreichbar.

Innerhalb der Sicherheitsgrundgrößen von Mensch – Fahrzeug – Straße kann ein Mitwirkungsanteil der Infrastruktur am Unfallgeschehen von etwa 10 bis 30% (n.MAIDS) angenommen werden. Unter Einbezug des bedeutenden Potenzials bei der Folgenminderung bei schweren Unfällen erscheinen systematische Verbesserungen an der Straßeninfrastruktur geboten und Erfolg versprechend.

Motorradunfälle mit schweren Folgen sind insbesondere ein Problem auf Außerortsstraßen, wo seit Jahren etwa 70% der getöteten und 60% der schwer verletzten Motorradfahrer verunglücken. So galt denn auch das Sicherheitsengagement der verantwortlichen Institutionen besonders den so genannten Motorradstrecken.
Nach Pilotversuchen sowie der Entwicklung motorradfreundlicher Schutzeinrichtungen durch die Straßenbauverwaltung NRW konnte 2003 innerhalb der „Forschungsgesellschaft für das Straßen- und Verkehrswesen" ein Gremium „Motorradunfälle" aus Mitgliedern aus Straßenbauverwaltungen, Verkehrsbehörden, Polizei, Sicherheitsinstituten, Hochschulen und Motorradverbänden gegründet werden, das ein technisches Regelwerk erarbeitete: das „Merkblatt zur Verbesserung der Verkehrssicherheit auf Motorradstrecken – MVMot 2007".

Die Inhalte des Merkblattes befassen sich zum einen – in Ergänzung der heutigen Verfahrensabläufe – mit der gezielten Unfallauswertung von Motorradunfällen, von der flächigen Sonderauswertung zur Ermittlung unfallauffälliger Stellen bis zur Detailanalyse des Unfallgeschehens und den besonderen Einflussgrößen der Straßensituation. Zum anderen sind geeignete Maßnahmen mit Darstellungen aus der Praxis zusammengetragen.

Differenziert wird hierbei nach Maßnahmen zur Unfallvermeidung, wie der Beeinflussung der Fahrweise und der Verdeutlichung des Fahrverlaufs mit Mitteln der Markierung und Beschilderung und nach straßenbaulichen und betrieblichen Maßnahmen zur Verbesserung des Fahrraums, der Fahrbahnoberflächen, der Sicht, der Kurvensituationen und der Einmündungsbereiche. Aber auch gezielte Oberflächenveränderungen zur Unfallreduzierung durch Geschwindigkeitsabbau stehen im Fokus.

Zu den Maßnahmen zur Unfallfolgenminderung zählen das Erreichen eines möglichst hindernisfreien Seitenraumes durch Beseitigen, Versetzen oder Abschirmen von Hindernissen sowie Verwendung

weicher Materialien bei Leiteinrichtungen. Eine besondere Bedeutung hat der Einsatz neuer motorradfreundlicher passiver Schutzeinrichtungen mit Unterfahrschutz bei unvermeidbar notwendigen Schutzmaßnahmen. Hinweise auf Methoden zur Verkehrsüberwachung und Prävention runden die Inhalte ab.

Dieses Regelwerk MVMot 2007 wurde für die Praxisarbeit der für die Verkehrssicherheit zuständigen Straßenbauverwaltungen, Verkehrsbehörden, Polizeidienststellen sowie Unfallkommissionen in den Ländern und Kommunen entwickelt. Nach Vorstellung des Merkblattes in der Fachwelt unter der Mitwirkung des Bundesministeriums für Verkehr wurde bereits ein entscheidendes Ziel erreicht, die verbindliche Einführung in den Ländern Nordrhein-Westfalen, Bayern, Baden-Württemberg und Rheinland-Pfalz. Erst diese verbindliche Vorgabe in der Aufgabenerfüllung schafft überhaupt eine höhere Chance der Finanzierung und Umsetzung geeigneter Maßnahmen vor Ort.

Bleibende Aufgabe ist die Implementierung in das verkehrstechnische Repertoire wie z.B. Sicherheitsaudit und Verkehrsschau/Betriebsaudit, verbunden mit einer systematischen Schulung der Verantwortlichen. Darüber hinaus gilt es, durch die Verbreitung der Erkenntnisse auch über die Fachwelt hinaus zur Erhöhung des Stellenwerts der Motorradsicherheit und deren Finanzierung in Deutschland beizutragen.

Höhere Motorradsicherheit durch verbesserte Straßeninfrastruktur in Deutschland

Inhalt

1. Einführung

Das Merkblatt zur Verbesserung der Verkehrssicherheit auf Motorradstrecken (MVMot 2007) wurde am 16.10.2007 im Rahmen eines Workshops zur Motorradsicherheit unter Schirmherrschaft des Bundesministeriums für Verkehr, Bau und Stadtentwicklung in den Räumen der Bundesanstalt für Straßenwesen vorgestellt. Dieser Workshop mit rund 200 Teilnehmerinnen und Teilnehmer zeigte das große Interesse und die hohen Erwartungen an dieses neue Regelwerk. Anwesend waren Vertreterinnen und Vertreter der Straßenbauverwaltungen, der Polizei, der Straßenverkehrsbehörden, der Motorradverbände sowie der Industrie aus Deutschland und Österreich.

Vorausgegangen war eine 4-jährige Arbeit mit 16 Sitzungen im Arbeitskreis „Motorradunfälle" des Arbeitsausschusses „Unfalluntersuchungen, Sicherheitsmaßnahmen" der Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV). Der Arbeitskreis hatte insgesamt 20 Mitglieder. Dabei waren u.a. vertreten die Straßenbauverwaltung der Länder Bayern, Hessen, Nordrhein-Westfalen und Rheinland-Pfalz, die Polizei bzw. Straßenverkehrsbehörden der Länder Baden-Württemberg, Hessen und Nordrhein-Westfalen sowie Automobil- und Motorradverbände. Die Leitung des Arbeitskreises lag bei Ltd. RBDir. a. D. Dipl.-Ing. Helmut Nikolaus, dem langjährigen Leiter des SBA Euskirchen / NRW.

Durch diese fachübergreifende Zusammensetzung wurden die verschiedenen Aspekte der Unfälle mit Motorradbeteiligung, Erfahrungen aus der Realisierung von Maßnahmen zur Verringerung der Anzahl der Unfälle sowie der Unfallschwere ebenso wie die besondere Situation des Motorradfahrens in das Regelwerk einbezogen.

Ausgehend von den Pilotprojekten und Entwicklungen bei der Straßenbauverwaltung NRW (SBA Euskirchen) wurden in begleitenden Untersuchungen an typischen Motorradstrecken vor allem durch die Straßenbauverwaltungen in Bayern, Hessen, Nordrhein-Westfalen und Rheinland-Pfalz grundlegende Daten zur Unfallanalyse, zu den Maßnahmen und zu ihren Wirkungen erarbeitet ((3), (5), (6), (7)).

Im MVMot 2007 werden konkrete Maßnahmen zur Verbesserung der Verkehrssicherheit in unfallauffälligen Bereichen von Motorradstrecken im Außerortsnetz aufgezeigt. Dabei werden spezifische Aspekte des Motorradfahrens bzw. des Unfallgeschehens erläutert, damit die Abhilfemaßnahmen situationsgerecht ausgewählt werden können. Hiermit sollen Motorradunfälle vermieden oder zumindest die Unfallfolgen verringert werden. Die Grundsätze des Merkblattes sind sinngemäß auch in anderen Bereichen des Streckennetzes anwendbar.

Das MVMot 2007 ergänzt die Merkblätter für die Auswertung von Straßenverkehrsunfällen - Teil 1: Führen und Auswerten von Unfalltypen-Steckkarten und Teil 2: Maßnahmen gegen Unfallhäufungen - der FGSV (2) und gibt Hinweise auf neu entwickelte motorradfreundliche Schutzeinrichtungen.

2. Ausgangssituation

Die anhaltend hohe Anzahl der schweren Motorradunfälle in Deutschland ist besorgniserregend. Während die allgemeine Entwicklung der Straßenverkehrsunfälle eine eindeutig positive Tendenz zeigt und die Anzahl der Verkehrsunfälle mit schwerem Personenschaden im Zeitraum von 1995 bis 2005 um rund 30% sank, blieb diese bei Unfällen mit Motorradbeteiligung (Motorradunfälle, motorisierte Zweiräder mit amtlichem Kennzeichen) jedoch nahezu konstant. Diese Entwicklung zeigt sich auch bei der Anzahl der Getöteten im Straßenverkehr (Bild 1). Ohne eine wesentliche Verminderung der Anzahl der getöteten Motorradfahrenden erscheint die europäische Zielsetzung der Reduzierung der Anzahl der Verkehrstoten von 2000 bis 2010 um mindestens 50% kaum realisierbar.

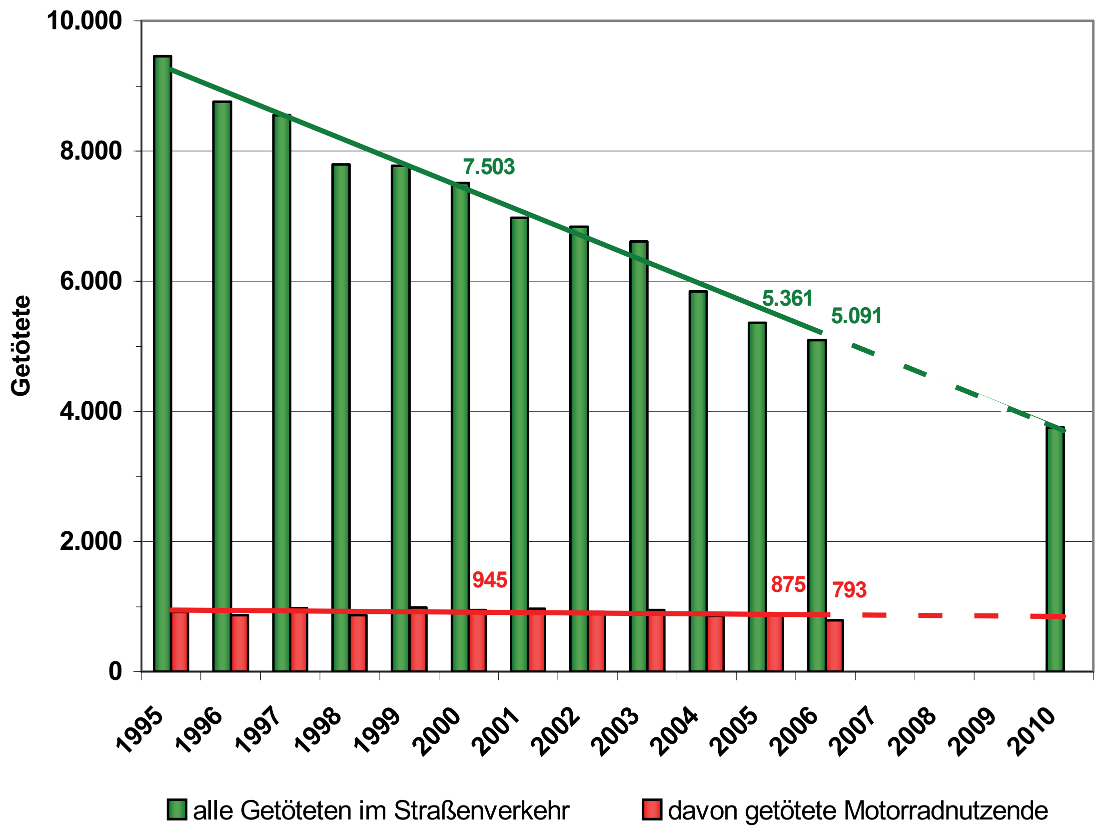


Bild 1: Getötete im Straßenverkehr
(Quelle: Deutsches Statistisches Bundesamt, www.destatis.de)

Motorradunfälle unterscheiden sich von anderen Unfällen deutlich. Allgemein ist das Risiko der Motorradnutzenden bei einem Verkehrsunfall getötet zu werden 12 Mal höher als das von Pkw-Insassen.

Über 2/3 der getöteten Motorradfahrenden verunglücken auf Landstraßen. Die Mehrzahl der schweren Motorradunfälle ereignet sich zudem in anderen Streckenbereichen als sonstige Verkehrsunfälle. Die unfallauffälligen Bereiche liegen überwiegend in kurvenreichen Strecken mit besonders hohem Motorradaufkommen, die im folgenden Motorradstrecken genannt werden.

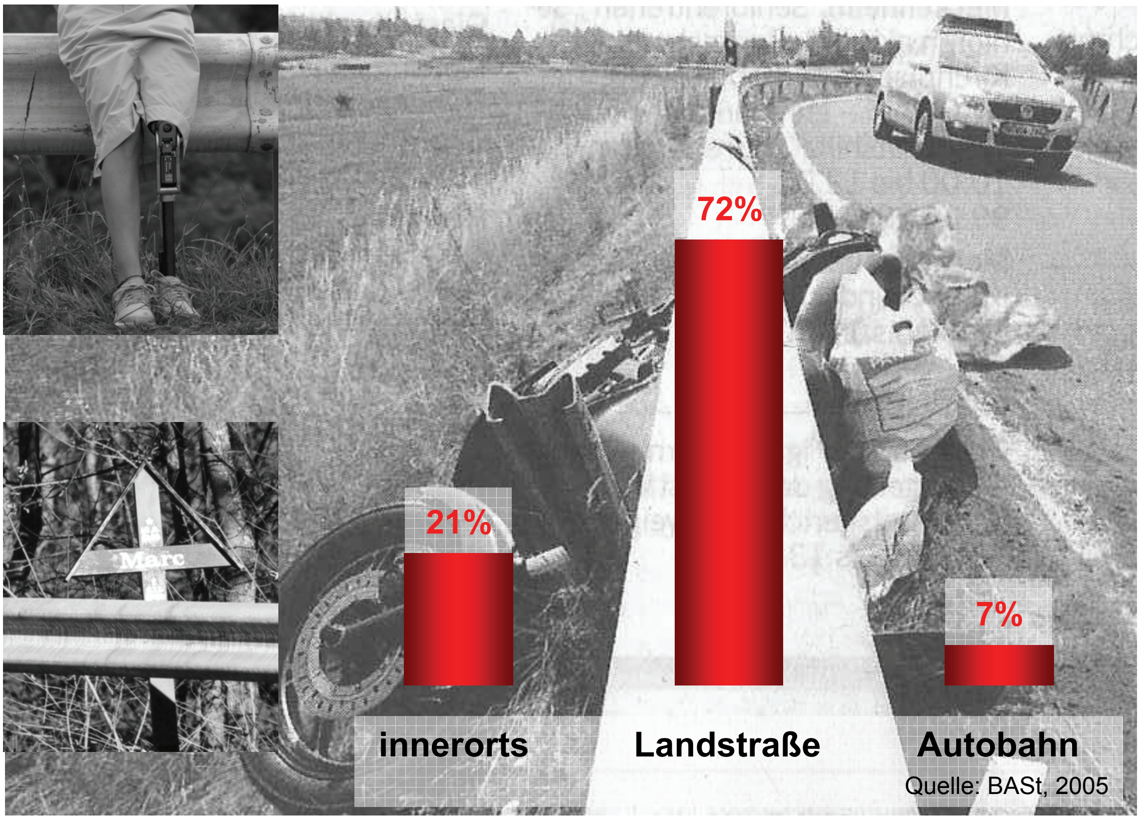


Bild 2: Motorradunfälle mit Getöteten nach örtlicher Lage

Die Situation der Motorradfahrenden unterscheidet sich in mehreren Punkten grundsätzlich von den Rahmenbedingungen der Pkw-Nutzenden. Dabei geht es im Wesentlichen um:

- die unterschiedliche Fahrphysik von Einspur- und Zweispurfahrzeugen,
- die besondere physische und psychische Beanspruchung beim Motorradfahren sowie
- das unterschiedliche Sichtfeld.

Die Überlagerung dieser Aspekte macht das Motorradfahren zu einer komplexen und anspruchsvollen Tätigkeit. Motorradfahrende sind deutlich intensiver in den Prozess der Fahrzeugführung eingebunden als Pkw-Nutzende. Sie sind empfindlicher gegenüber Störeinflüssen (z.B. schlechter Fahrbahnzustand, Bruch in der Linienführung, unvorhergesehene Verkehrssituationen) als andere Verkehrsteilnehmer.

Beim Motorrad gibt es keine schützende Karosserie. Technische Sicherheitseinrichtungen wie ABS, Anti-Schlupf etc. sind derzeit nicht Standard oder durch die spezifischen Eigenschaften des Motorrades nur bedingt einsetzbar.

Dem europäischen Aktionsprogramm zur Verkehrssicherheit folgend, besteht akuter Handlungsbedarf, dieser Verkehrsteilnehmergruppe besondere Aufmerksamkeit zu widmen.

Das Merkblatt befasst sich mit den Maßnahmen der Infrastrukturverbesserung zur Erhöhung der Motorradsicherheit. Die beiden weiteren Schlüsselgrößen zur Risikominderung des Motorradfahrens, nämlich die Beeinflussung der Motorradnutzer sowie die Entwicklungschancen in der Fahrzeugtechnik werden aufgezeigt.

3. Unfallauswertung

3.1. Ermittlung unfallauffälliger Stellen

Zunächst müssen diejenigen Bereiche ermittelt werden, bei denen aufgrund bestimmter Unfallauffälligkeiten Maßnahmen besonders Erfolg versprechend eingesetzt werden können. Die gezielte Bekämpfung der folgenschweren Unfälle mit Motorradbeteiligung kann allerdings nur begrenzt erfolgreich sein, wenn Verbesserungsmaßnahmen ausschließlich bei den üblicherweise betrachteten Unfallhäufungsstellen vorgesehen werden. Diese basieren auf Einjahres-Karten für alle Unfälle und Dreijahres-Karten für alle Unfälle mit (schwerem) Personenschaden. In dieser Betrachtung erfüllen die Unfälle mit Motorradbeteiligung nur selten die Kriterien einer Unfallhäufung. Trotz der vergleichsweise geringen Anzahl der Motorradunfälle weisen diese jedoch einen hohen Anteil bei den Getöteten und Schwerverletzten auf.

Zum Auffinden unfallauffälliger Stellen empfiehlt sich eine Untersuchung auf der Basis einer Unfalltypenkarte der Motorradunfälle mit schwerem Personenschaden über einen zurückliegenden Zeitraum von mindestens drei Jahren. entsprechend den Kriterien in Tabelle 1.

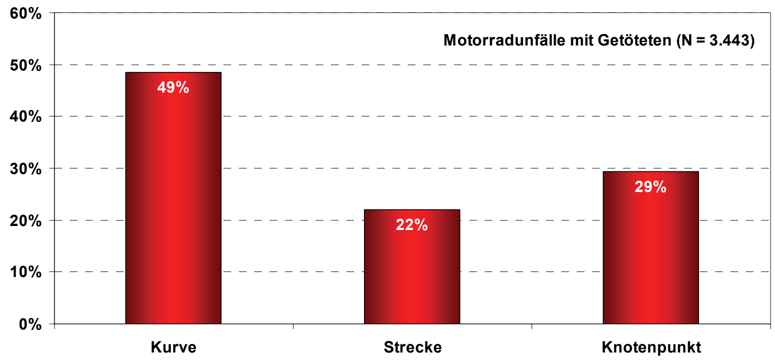
Tabelle 1: Kriterien für die Unfallauffälligkeit unter besonderer Berücksichtigung von Motorradunfällen

Betrachtungs-zeitraum	**Kriterium der Unfallauffälligkeit**
3 Jahre	mindestens 2 Motorradunfälle mit schwerem Personenschaden auf 300m: • in einer Kurve, • an einem Knotenpunkt oder • auf einem Streckenabschnitt.
Anmerkung: Bei einem Betrachtungszeitraum von 5 Jahren ist der Grenzwert auf mindestens 3 Motorradunfälle mit schwerem Personenschaden auf 300m anzuheben.	

3.2. Detailanalyse

Für die ermittelten unfallauffälligen Stellen ist in der bei örtlichen Unfalluntersuchungen üblichen Vorgehensweise zu prüfen, welche Verbesserungsmaßnahmen zielführend sind. Dabei sind für diese Bereiche nicht nur alle Motorradunfälle sondern auch alle anderen Unfälle im Betrachtungszeitraum einzubeziehen – unabhängig von deren Schwere. Nützliche Hinweise für erfolgversprechende Maßnahmen können auch aufgrund des Unfallgeschehens früherer Jahre gewonnen werden.

Das Ergreifen von Maßnahmen ist umso dringlicher, je schwerwiegender die jeweiligen Unfallfolgen (Anzahl der Getöteten und Schwerverletzten) sind und je eher durch eine Maßnahme schwerste Unfallfolgen verringert werden können.



In **Kurven** verunglückt nahezu die Hälfte der getöteten Motorradfahrenden. Ähnlich ist die Verteilung bei den Schwerverletzten.

Bei Abkommensunfällen verunglücken 86% der Getöteten durch Aufprall auf **Hindernisse** im **Seitenraum**.

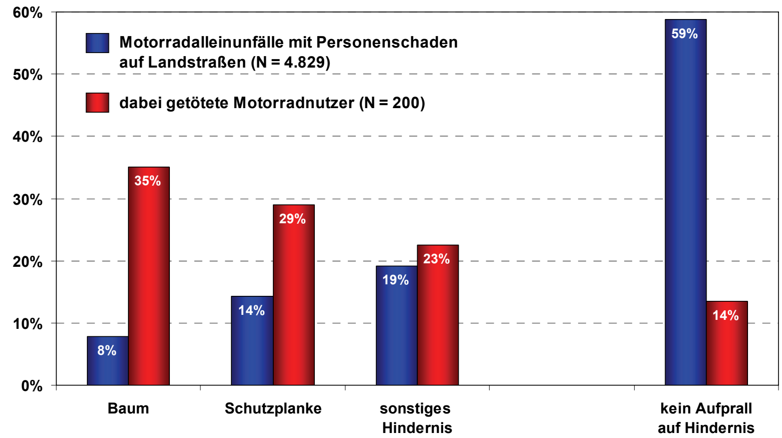


Bild 3: Gesamtauswertung der Unfälle mit Motorradbeteiligung über den Zeitraum von 2000 bis 2004 (1)

Bei der Detailanalyse ist für die Ermittlung von Verbesserungspotenzialen in der Verkehrssicherheit die Analyse der besonderen Ursache-Wirkungs-Zusammenhänge von Motorradunfällen von wesentlicher Bedeutung.

Grundsätzlich können mehrere Einflussgrößen im Unfallgeschehen maßgebend sein. So kann beispielsweise der Aufprall auf ein seitliches Hindernis die Unfallfolgen verschlimmern. Um diese besser deuten zu können, empfiehlt es sich, die Unfallsituation im auffälligen Bereich hinsichtlich verschiedener Einflussgrößen aufzutragen. Im Bild 4 sind wegen ihrer besonderen Bedeutung beispielhaft die Verteilung der Unfälle mit Motorradbeteiligung und Personenschaden über den Untersuchungszeitraum und der jeweilige Aufprall auf Hindernisse im Fahrbahnseitenraum herausgestellt.

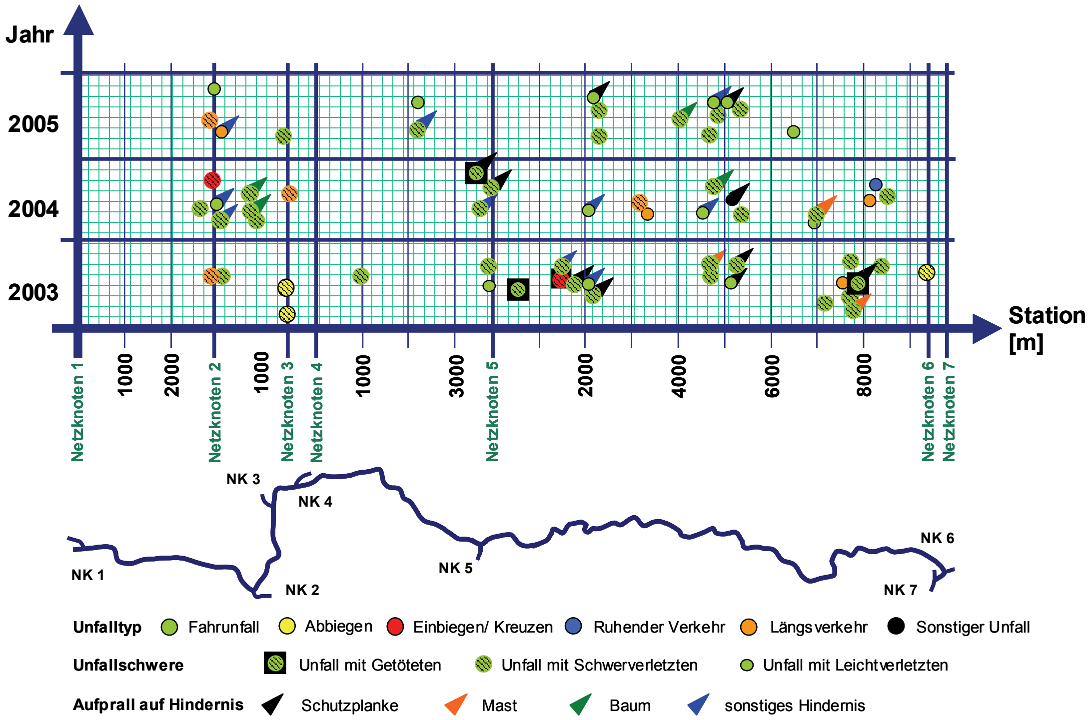


Bild 4: Motorradunfälle mit Personenschaden und bzw. ohne Aufprall auf ein Hindernis im Streckenverlauf

3.3. Besonderheiten des Unfallgeschehens

Für die Ermittlung von Maßnahmen ist es erforderlich, motorradtypische Unfallsituationen hinsichtlich relevanter Einflussgrößen und Ursachen zu analysieren. Unfallrelevante Einflussgrößen ergeben sind aus der topographischen Situation, der Linienführung, der Knotenpunktsgestaltung sowie dem baulichen und betrieblichen Zustand der Straße und des Seitenraums. Die Bilder 5 und 6 zeigen beispielsweise ungünstige Eigenschaften der Fahrbahnoberfläche bzw. Hindernisse im Seitenraum, an denen bei einem Aufprall oftmals schwere Unfallfolgen entstehen.

Hinzu können Verhaltens- und Fahrfehler der Unfallbeteiligten kommen, wie:

- überhöhte Geschwindigkeit an Kurven und Knotenpunkten,
- falsch bzw. zu spät eingeleitete Brems- und Lenkmanöver,
- Überholmanöver bei unzureichender Überholsichtweite,
- Hineinragen des Körpers in die Gegenrichtung,
- Übersehen von Abbiegeabsichten,
- Übersehen von bevorrechtigten Motorradfahrenden,
- Unterschätzen der Annäherungsgeschwindigkeit oder
- Fahrstreifenwechsel bei Ausweichmanövern.

Bild 5: Überraschend auftretende Unstetigkeiten in der Fahrbahn insbesondere in Kurven als Risiko

Bild 6: Hindernisse im Seitenraum von Kurven mit hohem Verletzungsrisiko bei Unfällen

4. Maßnahmenfindung

Bei der Auswahl von geeigneten Maßnahmen muss vor allem auf eine verbesserte Wahrnehmung des Straßenraumes abgezielt werden, um eine Anpassung des Fahrverhaltens insbesondere vor Kurven und Knotenpunkten zu erreichen. Zudem wird dringend empfohlen, bei der Festlegung von Maßnahmen auch die vor- bzw. nachgelagerten Streckenabschnitte zu berücksichtigen. Bei Gleichartigkeit der Streckenführung sollte eine einheitliche Ausstattung gewährleistet sein.

Ein besonderes Augenmerk gilt bei einspurigen Fahrzeugen auch der Oberflächenbeschaffenheit der Fahrbahn mit Blick auf Griffigkeitswechsel. Von besonderer Bedeutung ist zudem ein hindernisfreier Seitenraum insbesondere am Außenrand von Kurven.

Ein Erfolg versprechendes Maßnahmenkonzept setzt sich zusammen aus:

- verkehrsrechtlichen Maßnahmen (verkehrsregelnde Maßnahmen nach StVO wie Markierung und Beschilderung),
- straßenbaulichen und betrieblichen Maßnahmen (Umbau/ Erneuerung der Fahrbahn, Entfernung von Hindernissen, Installation passiver Schutzeinrichtungen etc.) sowie
- Verkehrsüberwachung und präventive Maßnahmen.

Straßenbauliche Maßnahmen sind vielfach nur langfristig umsetzbar. Häufig kann die Verkehrssicherheit aber durch schneller verwirklichbare Maßnahmen wie der Verbesserung passiver Schutzeinrichtungen und/oder Markierungen erhöht werden.

In Einzelfällen ist nur durch eine konsequente Überwachung der Verkehrsbeschränkungen eine angepasste Fahrweise zu erzielen.

Zur Entwicklung sinnvoller Maßnahmen zur Erhöhung der Verkehrssicherheit auf Motorradstrecken ist eine Abstimmung und Konkretisierung unter Einbeziehung aller Beteiligten (Polizei, Straßenverkehrsbehörde, Straßenbauverwaltung und gegebenenfalls Motorradverbände) erforderlich. Hierbei ist eine transparente und nachvollziehbare Aufbereitung des Ist-Zustands sowie des geplanten Soll-Zustands als Diskussionsgrundlage von besonderer Bedeutung. Diese sollte beinhalten:

- Darstellung der Unfalltypenkarte mit Kennzeichnung der Motorradunfälle des Untersuchungsgebietes über den Betrachtungszeitraum.
- Vergrößerte Ausschnitte der unfallauffälligen Bereiche mit Unfalldiagrammen und stichwortartige Beschreibung mit Fotos der Unfallstellen (Bild 7).
- Skizzenhafte Darstellung möglicher Maßnahmen (Bild 8).

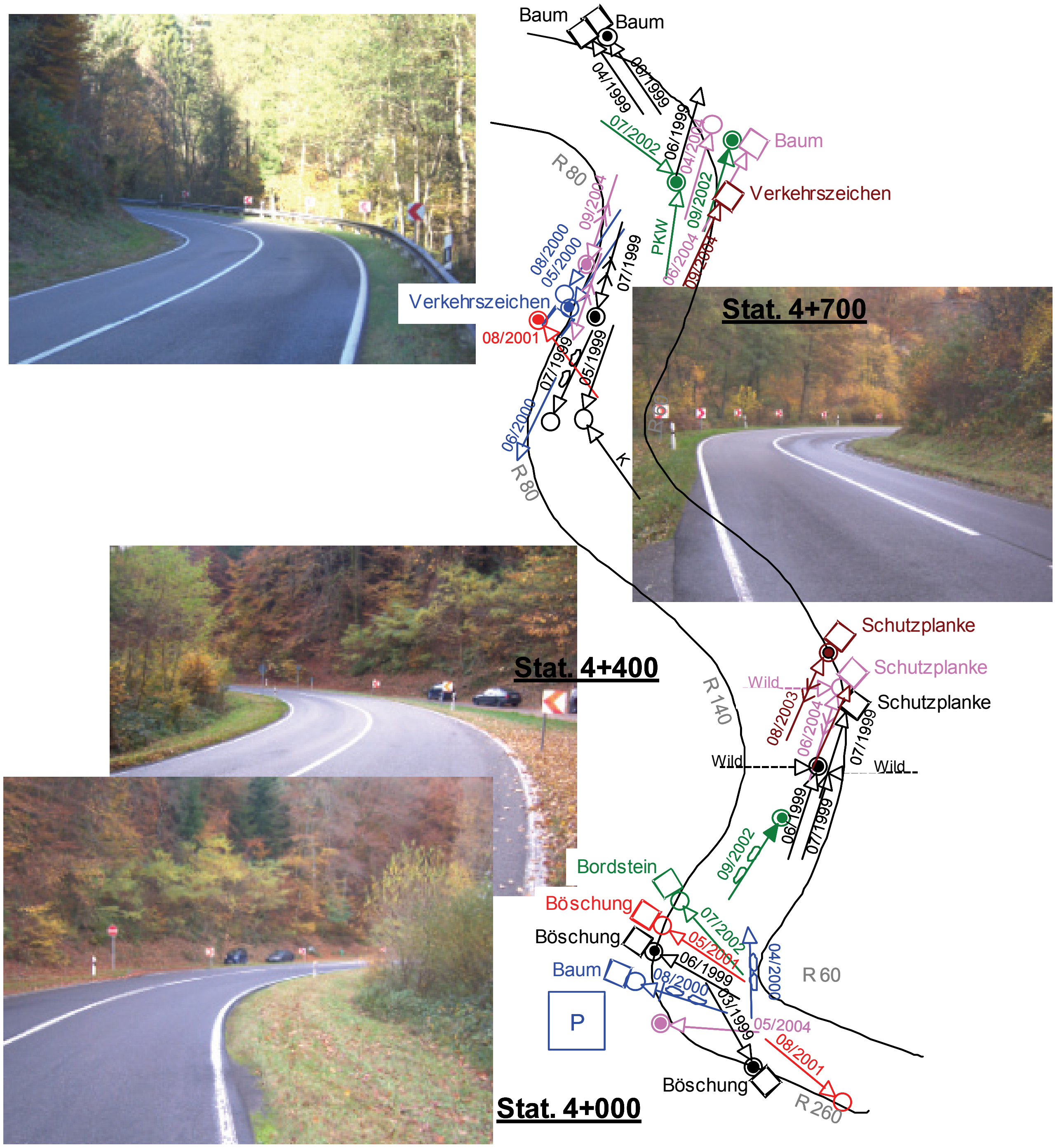


Bild 7: Unfalldiagramm mit detaillierter Darstellung von Besonderheiten

Bild 8: Skizzenhafte Darstellung von Maßnahmen

5. Maßnahmen

5.1. *Verkehrsrechtliche Maßnahmen*

Bei der Festlegung sollte den Wahrnehmungsbedingungen der Motorradfahrenden folgend diese Rangfolge eingehalten werden:

- Verdeutlichung der optischen Führung durch Fahrbahnmarkierung vor der Gefahrstelle beginnend,
- Unterstützung der optischen Führung durch senkrechte Leiteinrichtungen sowie
- Beschilderung durch StVO-Zeichen.

Markierung

Eine wesentliche Grundlage bei der Maßnahmenfindung sind die Trassierungsparameter des Streckenabschnittes, die über die jeweils gültigen Regelwerke beurteilt werden können. Bei unzureichender Sicht und ausreichender Fahrbahnbreite sollte in Kurven konsequent eine Fahrstreifenbegrenzung markiert werden. Eine durchgehende Fahrstreifenbegrenzung (StVO-Zeichen 295) untersagt das Überholen und Kurvenschneiden. Es wird empfohlen, die in Tabelle 2 zusammengestellten Grenzwerte einzuhalten.

Tabelle 2: Markierung der Mittellinie in Abhängigkeit vom Kurvenradius bei unzureichender Sicht (Bild: ASV Bensheim)

<table>
<tr><th>Kurvenradius</th><th colspan="2">Markierung Mittellinie</th></tr>
<tr><td>≤ 80 m</td><td>Fahrstreifenbegrenzung unbedingt erforderlich</td><td rowspan="3"></td></tr>
<tr><td>≤ 180 m</td><td>Fahrstreifenbegrenzung in der Regel erforderlich</td></tr>
<tr><td>> 180 m</td><td>Fahrstreifenbegrenzung nur in Sonderfällen erforderlich</td></tr>
<tr><td colspan="3">Die Fahrstreifenbegrenzung sollte mindestens 50 m vor Beginn der Kurve erfolgen. Details sind vor Ort festzulegen.</td></tr>
</table>

Die Wirkung kann durch eine Doppelmarkierung verstärkt werden. Bei ausreichender Fahrbahnbreite ist eine Aufweitung der Fahrstreifenbegrenzung auf mindestens 50 cm anzustreben, um eine größtmögliche Trennungswirkung der Richtungsfahrstreifen zu erzielen und um das Risiko des Hineinragens des Körpers in den Fahrstreifen der Gegenrichtung zu verringern.

Knotenpunkte sollen dem aktuellen Regelwerk entsprechen. Sie müssen gerade an Motorradstrecken gut wahrnehmbar sein, um die Aufmerksamkeit der Motorfahrenden gegenüber möglichem Fehlverhalten anderer Verkehrsteilnehmer zu erhöhen.

Schlecht oder gar nicht einsehbare Knotenpunkte beispielsweise hinter Kuppen und Kurven verschärfen für Motorradfahrende die Unfallgefahr. Hier sollten Knotenpunkte unabhängig von den Einsatzgrenzen nach dem Regelwerk möglichst Aufstellmöglichkeiten für Linksabbieger besitzen (Bild 9).

Bild 9: Linksabbiegerführung mit Aufstellbereich

Können keine Aufstellmöglichkeiten für Linksabbieger geschaffen werden und kann auch die Einsehbarkeit des Knotenpunkts nicht verbessert werden, sollte die Mittellinie in der Annäherung zumindest bis vor die Sichtbehinderung als Fahrstreifenbegrenzung (gegebenenfalls einseitig überfahrbar) markiert werden. Dies gilt auch für regelmäßig befahrene Zufahrten.

Auch an verkehrlich unbedeutenden Einmündungen (Wirtschaftswege, Parkplätze, ...) können Maßnahmen zur Verdeutlichung der Situation erforderlich werden, zumal gerade am Wochenende die verschiedenen Nutzergruppen verstärkt zusammentreffen.

Senkrechte Leiteinrichtungen

Senkrechte Leiteinrichtungen unterstützen die Längsmarkierungen. Sie verdeutlichen Änderungen des Straßenverlaufs oder Einschränkungen des Verkehrsraums. Insbesondere sollen sie vermitteln, dass:

- eine unerwartet enge Kurve folgt,
- sich die Krümmung der Kurve in deren Verlauf wesentlich ändert oder

- sich die Kurve weiter herumzieht als zunächst zu erwarten ist.

Senkrechte Leiteinrichtungen umfassen:

- Leitpfosten,
- (aufgelöste) Richtungstafeln sowie
- sonstige Leitelemente wie Schutzplankeneinsätze, flexible Leitbaken, Leitschwellen etc.

Als Leiteinrichtungen dienen vor allem Leitpfosten. Diese stehen in der Regel in Abständen von 50 m. Jedoch sollen auf jeder Straßenseite – in Krümmungen R < 200m auf der Kurvenaußenseite – mindestens immer 5 Leitpfosten sichtbar sein. Für Motorradstrecken kann darüber hinaus eine weiter verdichtete Aufstellung in Kurvenbereichen zweckmäßig sein, um allein stehende Richtungstafeln zu vermeiden bzw. zu ersetzen. Dadurch verringert sich die Gefahr schwerer Verletzungen beim Anprall auf den Pfosten und Aufstellvorrichtungen

Bild 10: Verdichtet gestellte, nachgiebige Leitpfosten vor einem Erdwall statt Richtungstafeln mit Stahlpfosten

Bei Richtungstafeln ist die Verletzungsgefahr durch deren Aufstellvorrichtung besonders zu beachten:

- Bei vorhandenen Schutzplanken sollten die Richtungstafeln möglichst dahinter aufgestellt werden. Die Montage auf bzw. unmittelbar hinter der Schutzeinrichtung birgt zusätzliche Gefahren bei aufrechtem Anprall.

- An Kurven mit sehr niedrigen Geschwindigkeiten (≤ 30 km/h, z.B. Spitzkehren) sollten die Pfosten von freistehenden Richtungstafeln, die nicht ersetzt werden können, mit Schaumstoff ummantelt werden.
- Auch bei sonstigen Schutzeinrichtungen wie Erdwällen sind notwendige Richtungstafeln nicht davor aufzustellen.

Desweiteren sollten als Leiteinrichtungen möglichst flexible Materialien (Kunststoffpoller) eingesetzt werden. Das MVMot 2007 enthält ein Schaubild zur Auswahl von Art und Umfang senkrechter Leiteinrichtungen auf Motorradstrecken.

Beschilderung

Verkehrszeichen sollten nur dort angeordnet werden, wo dies aufgrund der besonderen Umstände zwingend geboten ist. Eine ausreichende Akzeptanz ist nur dann gewährleistet, wenn der eindeutige Bezug zu einer sich von der übrigen Streckencharakteristik deutlich abhebenden Gefahrenstelle (z.B. Kurve, Einfahrt, Knotenpunkt) vorhanden ist.

Aufgrund der besonderen Orientierung der Motorradfahrenden auf die Fahrbahn ist eine Verdeutlichung von Gefahrstellen durch entsprechende Markierung (Warnlinie, Mittellinie als Fahrstreifenbegrenzung etc.) von besonderer Bedeutung.

Bei Motorradstrecken sollten möglichst keine Verkehrszeichen auf der Kurvenaußenseite, wegen der Verletzungsgefahr an den meist unvermeidbaren starren Aufstellpfosten angeordnet werden. Verkehrszeichen sollten gegebenenfalls hinter bestehende Schutzeinrichtungen versetzt werden.

Sonderschilder außerhalb der StVO alleine bringen nach den bisherigen Erfahrungen keine spürbare Verbesserung der Verkehrssicherheit.

5.2 Straßenbauliche und betriebliche Maßnahmen

Bauliche Maßnahmen wie Erneuerungsmaßnahmen des Fahrbahnoberbaus (z.B. Erhöhung der Querneigung) bzw. Ausbaumaßnahmen im Bereich von Kurven (z.B. Beseitigung von Krümmungssprüngen innerhalb von Kurven) sind meist mit hohen Investitionskosten verbunden. Deshalb sollte gerade bei einer Unfallauffälligkeit mit Motorradbeteiligung besonderes Augenmerk auf betriebliche Maßnahmen wie Schaffung hindernisfreier Seitenräume, Verbesserung der Oberflächenbeschaffenheit oder eine verbesserte Wahrnehmung des Straßenraums gelegt werden.

Dem hindernisarmen Seitenraum insbesondere in den Außenkurven muss das Hauptaugenmerk der Streckenprüfung gelten. Tabelle 3 gibt beispielsweise eine Übersicht von straßenbaulichen und betrieblichen Maßnahmen im Seitenraum. Diese sind im MVMot 2007 durch zahlreiche Bilder verdeutlicht.

Tabelle 3: Straßenbauliche und betriebliche Maßnahmen im Seitenraum

Problemsituation	**Maßnahmen**
Hindernisse neben der Fahrbahn (Bäume, Meilensteine, Streugutbehälter, Durchlassöffnungen, Straßenabläufe, Geländer, Fundamente, Beschilderung, etc.)	• Beseitigen oder Versetzen • Schutzmaßnahmen gegen Aufprall • Erdwälle als Alternative • Abdecken/ Schützen von Durchlässen • Zusammenfassen von Stationszeichen, Wegweisung, Rohrpfosten etc. möglichst auf einer Höhe • Aufstellen von Verkehrszeichen in Kurven außerhalb der Bereiche mit erhöhter Abkommenswahrscheinlichkeit
passive Schutzeinrichtungen (Geländer, Schutzplanken etc.)	• Beseitigen, falls keine Erfordernis • Gewährleisten der Funktionalität der erforderlichen Schutzeinrichtungen (Ergänzung und Ersatz)
Sichtfelder	• Beseitigen von Sichthindernissen zur: • Erkennbarkeit des weiteren Streckenverlaufs bzw. • Anfahrsicht für einbiegende Verkehrsteilnehmer (kleinere Silhouette des Motorradfahrenden)
Böschungen	• Verhindern von Geröll auf der Fahrbahn durch Böschungssicherung.
Bankette	• Auffüllen ausgefahrener Bankette und Härten, um Fahrbahnverschmutzung zu verhindern.
Hochborde	• Vermeiden, um Anprallunfälle, Aufprallverletzungen und Rückprall des Fahrzeuges zu verhindern • wenn erforderlich, möglichst niedrig ausbilden.

Schutzplankensysteme mit Unterfahrschutz

Ein besonderes Augenmerk gilt bei Motorradstrecken den Schutzplankensystemen. Diese sollen die Verletzungsfolgen von Unfällen vor allem für Pkw und Lkw möglichst gering halten. Motorradfahrende sind bei einem Sturz im Bereich von solchen Rückhaltesystemen einem mehrfach höheren Verletzungsrisiko als Pkw-Insassen ausgesetzt. So hat der Anprall des Körpers an den Schutzplankenpfosten meist schwerste Verletzungen zur Folge. Desweiteren besteht für Motorradfahrende beim Durchrutschen unter der Schutzplanke die Gefahr eines Anpralls an sekundäre Hindernisse (Bäume, Mauern etc.) oder eines Absturzes über steil abfallende Böschungen.

Durch einen Unterfahrschutz kann der Anprall auf scharfkantige Teile bzw. das Durchrutschen unter der Schutzplanke vermieden werden (Bild 11). Dabei sind an das System folgende Anforderungen zu stellen:

- Oberfläche ohne hervorstehende Konstruktionsteile,
- Spaltbreite zwischen Schutzplanke und Unterfahrschutz maximal 50 mm,
- Spaltbreite zwischen Unterfahrschutz und Oberkante Bankett maximal 50 mm,
- Abschirmung der Konstruktionsteile für aufrecht anprallende Motorradfahrende und
- Einsatz bei „Einfacher Schutzplanke“ (ESP) und „Einfacher Distanzschutzplanke“ (EDSP) auch in der Nachrüstung möglich.

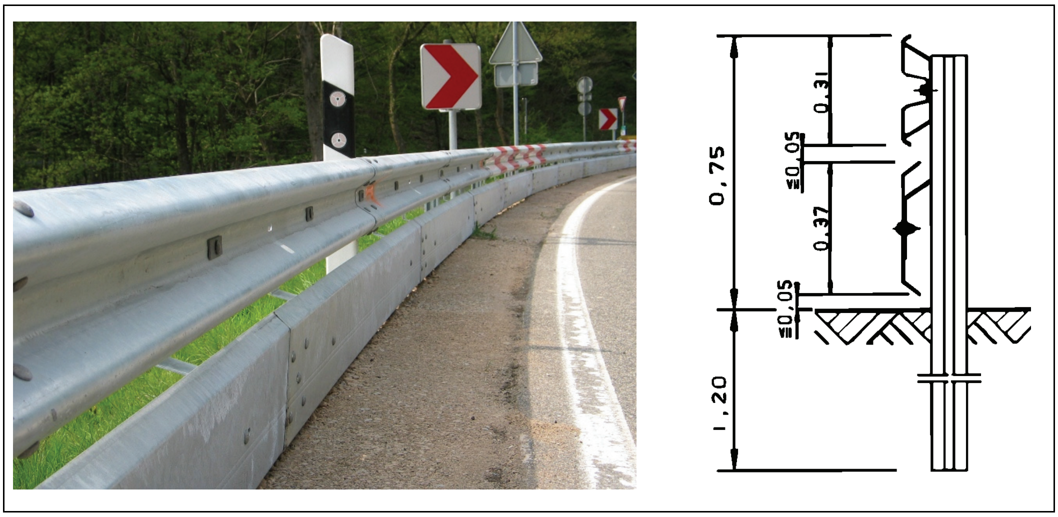


Bild 11: Unterfahrschutz „System Euskirchen“ bei einfacher Schutzplanke

Die Wirksamkeit des Unterfahrschutzes ist auch in der Praxis belegt (Bild 12).

Bild 12: Wirksamkeit des Unterfahrschutzes (Foto: Alexander Sporner)

Darüber hinaus ist in Vorbereitung das System Euskirchen$^{\text{Plus}}$. Dieses besitzt einen Schutzüberzug aus Lochblech, um das Verletzungsrisiko durch einen Anprall im oberen Systembereich zu minimieren (4).

Wesentlicher Vorteil des Systems Euskirchen/ Euskirchen$^{\text{Plus}}$ ist, dass bestehende Schutzeinrichtungen kostengünstig und mit geringem Montageaufwand nachgerüstet werden können.

Bei Ummantelung der Pfosten mit Schaumstoff (SPU) ist das Schutzpotenzial für Motorradfahrende deutlich niedriger als beim Einsatz von Unterfahrschutzvorrichtungen. Es empfiehlt sich, den Einsatz von SPU auf Stellen zu begrenzen, die mit niedrigen Geschwindigkeiten (≤ 30 km/h) befahren werden.

Eine Übersicht der straßenbaulichen und betrieblichen Maßnahmen im Fahrbahnbereich mit zahlreichen Bildern enthält das MVMot 2007. Dabei ist die Einrichtung von Fahrbahnteilern anstelle von Sperrflächen im Zuge der Verziehung und/oder der Rückverziehung der Linksabbiegestreifen an Knotenpunkten eine auch an Motorradstrecken positiv wirkende bauliche Maßnahme, da sie das Überholen und Kurvenschneiden in Knotenpunkten unterbinden. Hierdurch wird sowohl das Linksabbiegen und das Linkseinbiegen/Kreuzen gesichert.

Bild 13: Fahrbahnteiler als Maßnahme gegen Überholmanöver im Knotenpunkt

In Sonderfällen können Rüttelstreifen zur Durchsetzung der verkehrssicheren Geschwindigkeiten in Betracht gezogen werden. Diese Rüttelstreifen dürfen allerdings nur auf der Geraden vor Kurven eingesetzt werden. Zudem sollte noch ein ausreichender Sicherheitsabstand zum Bremsen vor der Kurve vorhanden sein. Um ein Umfahren zu verhindern, sind die Rüttelstreifen über die gesamte Fahrbahnbreite auszubilden.

In Deutschland liegen hierzu insbesondere positive Erfahrungen aus einem Modellversuch vor, der bereits im Herbst 2003 realisiert wurde (Bild 14). Zwischenzeitlich wurden weitere Rüttelstreifen erfolgreich umgesetzt. Eine Systemskizze zur Anordnung einer Rüttelstrecke enthält das MVMot 2007.

Bild 14: Verkehrssichere Geschwindigkeiten durch Rüttelstreifen

5.3 Verkehrsüberwachung und präventive Maßnahmen

Ziel der polizeilichen Maßnahmen ist es, die Verkehrssicherheit durch Einwirkung auf das bewusste sowie unbewusste Fahrverhalten von Verkehrsteilnehmern zu verbessern. Nur eine regelmäßige personelle und/oder technische Präsenz haben dauerhaften Einfluss auf das Verhalten von Verkehrsteilnehmern und wirken sich auch auf das Unfallgeschehen aus.

Im Gegensatz zur Geschwindigkeitsüberwachung im Pkw-Verkehr ist die Überwachung von Motorradfahrenden hinsichtlich der Erfassung und Verfolgung von Verstößen mit höherem technischen und personellen Aufwand (Anhaltekräfte) verbunden. Kernprobleme sind die Erfassung des Kennzeichens und die Identifikation des Fahrers.

Zur Unfallprävention können in Verkehrssicherheitsaktionen und nach Regelverstößen:

- die Kenntnisse über verkehrsgerechtes Verhalten vermittelt und vertieft werden,
- das Verantwortungsbewusstsein gegenüber anderen Verkehrsteilnehmern geschärft werden sowie
- die Notwendigkeit und Sinnhaftigkeit der am Ort durchgeführten Verkehrsüberwachungsmaßnahmen dargestellt werden.

6. Erfolgskontrolle

Um die Verkehrssicherheit auf einzelnen Streckenabschnitten zu erhöhen und vor Ort die beste Maßnahme zu realisieren, müssen Alternativen zielgerichtet bewertet werden können. Erfahrungsgemäß ist jedoch die Wirkung von Maßnahmen zur Verbesserung der Verkehrssicherheit sehr unterschiedlich. Mitunter entscheidet auch eine Vielzahl von Randbedingungen über die Akzeptanz und den Erfolg einer Maßnahme.

Zuverlässige Aussagen über die Wirksamkeit umgesetzter Maßnahmen erfordern eine regelmäßige Betrachtung auftretender Motorradunfälle an den relevanten Streckenabschnitten im Zeitraum nach der Einrichtung von Maßnahmen. Hierbei ist auch eine etwaige Verlagerung von Unfällen auf benachbarte Streckenabschnitte von Bedeutung. Dabei lässt sich eine konkrete Aussage über die Wirksamkeit erst nach einem Zeitraum von mindestens drei Jahren treffen.

Beispielhaft sind in Bild 15 die Ergebnisse eines Vorher-/ Nachher-Vergleichs über einen Zeitraum von 5 Jahren vor bzw. nach der Realisierung zusammengestellt. Deutlich wird hier der herausragende Beitrag des Unterfahrschutzes zur Verbesserung der Verkehrssicherheit.

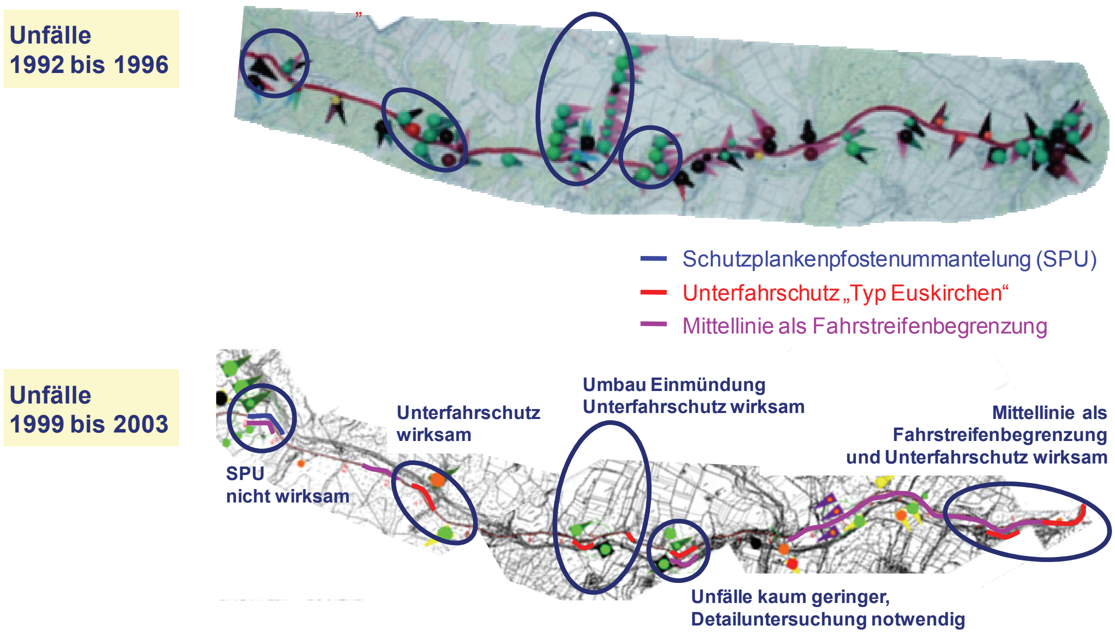


Bild 15: Wirksamkeit verschiedener Maßnahmen im Vorher-/Nachher-Vergleich der Unfalltypenkarten (7)

7. Fazit

Die Reduzierung der Anzahl der Motorradunfälle mit schweren Folgen ist ein hohes gesellschaftliches Ziel in Deutschland und leistet einen maßgeblichen Beitrag zur Erreichung der europäischen Vorgaben einer Halbierung der Anzahl der Getöteten im Straßenverkehr bis zum Jahre 2010.

Mit dem vorgelegten Regelwerk werden umfassende Möglichkeiten zur Verbesserung der Infrastruktursicherheit auf Motorradstrecken aufgezeigt. Für zahlreiche Maßnahmen liegen bereits gute Erfahrungen vor, einige müssen sich in den nächsten Jahren erst bewähren. Die realisierten Maßnahmen sollten begleitet werden, um die Wirkungszusammenhänge zu vertiefen.

Ohne einen wesentlichen Fortschritt bei der positiven Beeinflussung der Motorradfahrenden und der unterstützenden/ sichernden Fahrzeugtechnik wird es jedoch keine gravierende Verbesserung in der Motorradsicherheit geben können.

Es ist vorgesehen, in der FGSV in Zusammenarbeit mit anderen relevanten Institutionen diese Erfahrungen zu dokumentieren und übergreifend zur Verfügung zu stellen, um die verantwortlichen Baulastträger motivierend unterstützen zu können.

Eine englische Version des Regelwerks ist beabsichtigt, um den Zugang auch anderen europäischen Mitgliedsländern zu erleichtern.

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Bilder

Studying motorcycle learning in real context to improve rider's education

Beobachtungen des Lernprozesses von Motorrad-Fahrschülern im realen Straßenverkehr zur Verbesserung der Fahrerausbildung

Samuel Aupetit, PhD. Student
AMCO, University of Orléans – MSIS/INRETS,
Orléans/Paris, France

Jacques Riff, PhD.
AMCO, University of Orléans,
France

Olivier Buttelli, PhD.
Accredited to direct research AMCO, University of Orléans,
France

Stéphane Espié, Research Unit Director.
Accredited to direct research, MSIS/INRETS,
Paris, France

Abstract

The literature on motorcycle training and accident studies on riding shows the current inefficiency of initial training programs to reduce accident rate: motorcyclists' mortality, compared to the whole road fatalities, is increasing in Europe since 1996 (Baldi et al., 2005; IRT Project, 2007). The present research program defends that 1) an improvement of training can optimize motorcycle road safety, and 2) systematic studies of motorcycle learning dynamics in real context are relevant to improve training.

The research program presented here consists in a longitudinal and systematic study of ten riders' activity during initial training in motorcycle school, during licensing and after obtaining the license in traffic conditions. Theoretical and methodological frameworks of ergonomics analysis in real context are used (Saad, 1999): numerical data related to motorcycle dynamics, continuous audio-visual recordings of riders' behaviour and verbalisations data are collected during the whole learning process.

Results of the field study lead to several improvement proposals which concern: initial training, licensing and post-test training settings, according to the effective rider problems.

Key-words: riders' education, motorcycle learning, real activity, ergonomics, teaching aid.

Kurzfassung

Die Literatur über Motorradtrainings und Unfallstudien offenbaren die Defizite der Fahranfängerprogramme, zur Reduzierung der Unfallzahlen beizutragen. Die Anzahl der tödlich verunglückten Motorradfahrer in Relation zur Gesamtheit aller im Straßenverkehr tödlich Verunglückten steigt in Europa seit 1996 (Baldi et al., 2005; IRT Project, 2007).

Das derzeitige Forschungsprojekt zeigt auf, dass erstens eine Verbesserung der Trainings die allgemeine Sicherheit der Motorradfahrer erhöhen kann, und zweitens systematische Studien über die Lerndynamik beim Fahrten im realen Umfeld notwendig sind, um Motorradtrainings weiter zu verbessern.

Das Forschungsprogramm, welches hier präsentiert wird, besteht aus einer Untersuchung der Handlungsabläufe von zehn Motorradfahrern während der Fahrschulausbildung, der Fahrprüfung und anschließend unter realen Verkehrsbedingungen. Dabei bediente man sich des theoretischen und methodologischen Gerüsts der Ergonomieanalyse unter realen Bedingungen (Saad, 1999). Zahlenwerte in Bezug auf Fahrdynamiken, audio-viseuelle Aufzeichnungen des Fahrerverhaltens und der Kommunikation wurden während des gesammten Lernprozesses gesammelt.

Die Ergebnisse der Feldstudie führten zu mehreren Verbesserungsvorschlägen in den Bereichen Fahrausbildung, Fahrschulausbildung, Fahrsicherheitstrainings.

Studying motorcycle learning in real context

to improve rider's education

Introduction

The risks related to powered two wheelers riding constitute a current major stake of public health in Europe. The motorcyclists' mortality, compared to the whole road fatalities, is increasing in Europe since 1996 (CARE, 2007). Motorcyclists are twenty times more likely to die than passenger car in traffic crash in Europe, when travelled mileage is considered (MAIDS, 2003). Especially young riders are critically vulnerable users: 30% of all rider victims got their riding license for less than a year in France and for less than a month in Paris (ONISR, 2003).

These worrying data lead to three reports: (1) motorcyclists constitute particularly vulnerable road users who do not follow the general trends from road safety progress; (2) there is a specificity of powered two wheeler riding compared to other forms of driving; (3) the scientific efforts to a better understanding of the specific phenomena associated with riding and its learning are still limited. Research on motorcycle has not received the same investment and scope than driving research.

The aim of this paper is to present a research program focused on learning of riding a motorcycle. The main hypothesis is that improving rider's education can contribute to improve safety. Four parts in this article: (1) conceptual framework of the research program; (2) methods and procedures; (3) results; (4) discussion: rider's education improvement proposals.

1. Conceptual framework of the research program

1.1 Main trends of the motorcycle training and learning studies

Most of works on motorcycle training test the curriculum effectiveness from accidents data of motorcyclists who have or have not followed this curriculum (Billheimer, 1996). Results show that trained motorcyclists have the same risk level of being involved in an accident that untrained (Mortimer, 1982; Simpson and Mayhew, 1990). Some works attempt to demonstrate training effectiveness (McDavid et al., 1989; Billheimer, 1998). However, these results can be subtle at two levels: a) experimental conditions were not controlled enough (Simpson and Mayhew, 1990); b) training effectiveness is not calculated only by the number of accidents (Haworth and Mulvihill, 2005).

Several attempts to explain this ineffectiveness have been proposed: a) training focuses on driving skills and not enough on the cognitive mechanisms associated with these skills (Chesham et al., 1993); b) the psychological characteristics of learning is not sufficiently taken into account because most of accidents are not due to a driving skills control lack but to a deliberate behaviour (Haworth and Mulvihill, 2005); c) training would tend to increase motorcyclists self-confidence and not their assessment ability (Elliot et al., 2003).

In summary, these studies have contributed to test riding curriculum effectiveness and to propose some explanations of their ineffectiveness. However, there is a lack of scientific knowledge about the learning process characterization in real context: what exactly do motorcyclists? What are their effective problems during the curriculum and after obtaining the license? To what extent interactions between learners and trainer are convenient? No study has explored effective training programs whether in terms of learning process or training contents (Baldi et al., 2005). These questions can be taking into account by the conceptual framework presented next.

1.2 Conceptual framework: towards an alternative vision of situated riding

This research program refers to the “situated cognition” theory (Suchman, 1987; Lave, 1988), approach at the intersection of several disciplines: cognitive anthropology, psychology, micro sociology, which aims to explore relations between context, cognition and action in real context. « Situated cognition », positioned as an alternative to the computational approach, argues that a description of the human cognition, as computing, is not sufficient to reflect the emerging dynamics of activity (Winograd and Flores, 1989). This model fails to adequately understand the naturalistic mechanisms of driving (Ranney, 1994).

Our ambition is to follow motorcycle trainees in real context, i.e. in its social, cultural and technical dimensions. Instead of reducing learning to ride to a task made up a number of variables, the aim is to analyse it in its complexity. We prefer to use the term of “activity”, seeing as a totality, including emotions, attentions, perceptions, actions, communications and interpretations (Theureau, 2003). Table 1 identifies the main characteristics of human learning considering the situated action theory and its methodological consequences for the study of human learning and for the investigation of learning to ride a motorcycle.

Tab. 1: Methodological consequences of human learning characters for the study of learning to ride

Human learning characteristics	Methodological consequences for the human learning study	Methodological consequences for the study of learning to ride
Learning is **situated**, i.e. closely linked to the context in which it takes place. The action properties emerge with the setting.	The context of the study of human learning is necessarily **the real situation** itself and not an experimental and controlled situation.	The study must take place in a real motorcycle school with **genuine trainees** engaged in an actual training process.
Learning is **dynamic**, i.e. (1) a process in constant evolution due to experience gained and setting changes, (2) does not exclusively take place in training periods but before and after.	The data collection must be **a long time scale process**.	**Initial training** in motorcycle school, **licensing** and **riding after licensing has to be studied** (main experiences before training are taken into account).
Learning is **chaotic**, i.e. a non-linear process of periods of stability/instability, marked by bifurcations (micro-events).	The data collection has to be sufficiently **systematic** (we can not be satisfied by punctual data recordings) and sufficiently **detailed** (to considerer bifurcations).	**All riding sessions** performed during training and autonomous riding are studied/**Numerical data** are recorded for a detailed investigation

1.3 Design framework: the "course-of-action centered design"

This research program is driven by a primary objective of ergonomics design, considered as a situation design technology. The approach to which we refer is initiated by Pinsky and Theureau in the late seventies and developed in the future under the name of: "course-of-action centered design" (Theureau, 2003). The initial inspiration for the elaboration of this design framework came from the French Language Ergonomics tradition (ELF). The main ideas of "course-of-action centered design" are the followings:

- The necessity of analysing the actual operators' activities in real context for the design of new situations and new training devices;
- The necessity to consider actor's subjectivity in data collection, data analysis and design process. Each participant affected by the change plays a decisive role in our study: riders are by definition the most experienced people about their riding.

To sum up, the next figure (Fig. 1) shows the modelling of learning to ride a motorcycle according to the approach we use in this research program. In this figure, "significant experiences" represent the rider's experiences which can influence the way he learns to ride a motorcycle (i.e. driving experiences, moped/scooter riding experiences, bike experiences, illicit motorcycle riding experiences…).

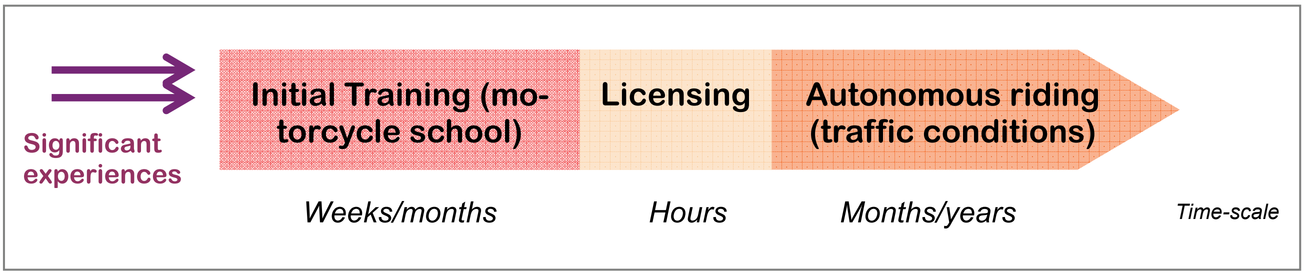

Fig. 1: Modelling of learning to ride a motorcycle in a situated approach

2. Methods and procedures

2.1 Approach

The set of studies consists in a *longitudinal* and *systematic* approach of learning to ride *in real context* (inspired by Saad, 1999):

- In real context: ten trainees engaged in a real training process in three French motorcycle schools (one rural/two urban) are studied. The data collection device was designed to be non-intrusive and to disturb the least possible riders and trainers;

- Longitudinal: riders are followed throughout the initial training process, during licensing situations and during several months after obtaining the license in traffic conditions;
- Systematic: all riding sessions are analysed.

2.2 Data collected/material

Five sets of data are collected: 1) continuous video recordings of motorcyclist behaviour, 2) continuous audio recordings of motorcyclist sound sources, 3) continuous heart rate recordings, 4) kinematic analysis of motorbike behaviour, 5) agents' verbalisations.

1) Continuous video recordings of rider behaviour (Motoki and Yamazaki, 1990):
   - Rider's trajectory (see Fig. 2) recorded by a camera carried by a researcher;
   - Gaze directions[1] (see Fig. 4 & 5) recorded by a helmet's camera (see Fig. 3);
   - Handlebar use (see Fig. 6) recorded by a second helmet's camera (see Fig. 3).

Fig. 2: Rider's trajectory

Fig. 3: The helmet's cameras

Fig. 4: Gaze directions/ training conditions

Fig. 5: Gaze directions/ traffic conditions

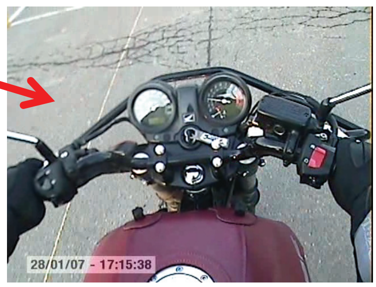

Fig.6: Handlebar use

[1] These data will be completed by eye tracking data during the study.

2) Continuous audio recordings of motorcyclist sound sources: communications with the trainer, interactions with other trainees, motorbike noises… (HF microphone);

3) Continuous heart rate recordings (heart rate monitor);

4) Kinematic analysis of motorbike behaviour: three axes acceleration and rotation, handlebar angle, wheels turns, accelerator positions and brake contact data are recorded by sensors embedded in a motorbike borrowed by a motorcycle school (see Fig. 7). Similar instrumentation to Larnaudie et al. (2006) is reproduced;

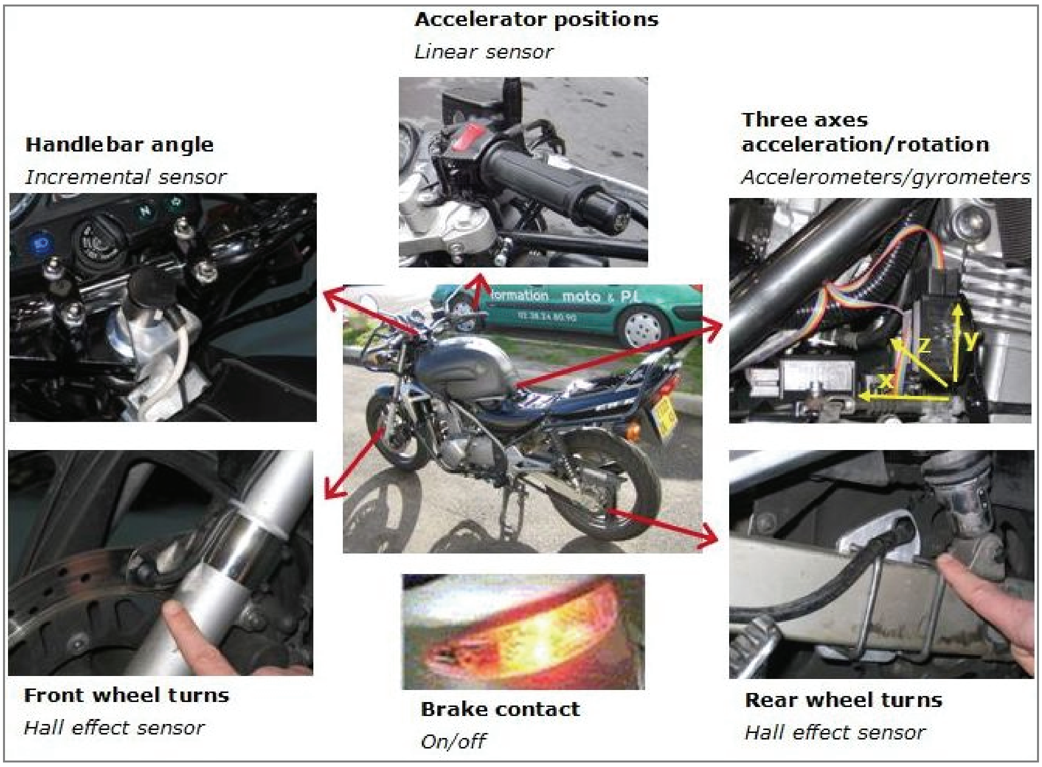

Fig. 7: The motorcycle sensors equipment

5) Agents' verbalisations collected by self-confrontation interviews (Theureau, 2003). This method can finely document the subjective actor's experience or immediate understanding of his activity at every moment. It consists in asking the rider to report any thoughts, emotions and sensations he had when he performed in real context, in front of the audiovisual recordings of his own activity (see Fig. 8).

Fig. 8: Self-confrontation interview situation

2.3 The two in-depth studies of the research program

Two successive studies are carried out:

1) A case study (November 2007 to April 2008) which consists in a continuous and systematic investigation of the training process performed by one trainee (the whole data was recorded except numerical data of motorbike dynamics);

2) A deeper study (in progress): ten trainees engaged in a real training process in three French motorcycle schools were volunteers to participate. The participants were selected from their representative profile by the trainers. After obtaining the motorcycle licence, they will be followed in traffic conditions with the experimental motorbike.

3. Results

French motorcycle initial training (i.e. pre-test training) is divided into five steps: 1) mastering the motorbike at low speed on track; 2) mastering the motorcycle at normal speed on track; 3) choosing its roadway position, crossing an intersection and changing directions on roads; 4) riding under normal conditions in traffic conditions and in urban areas; 5) knowing problematic situations. Steps 1 and 2 (at least 8 hours overall in theory) are held on “track”: a 130 meters long and 6 meters wide field. Steps 3, 4 and 5 (at least 12 hours overall) are performed in traffic conditions.

Two tests are included in motorcycle licensing. A first test happens at the end of track training: learners must perform handling exercises at low speed (1st gear) and normal speed (between 30 to 40 km/h) on track. If they succeed, they can begin training in traffic conditions. A second test takes place at the end of training on road: the examiner tests motorcyclist traffic skills during thirty minutes in traffic conditions (see Fig. 9)

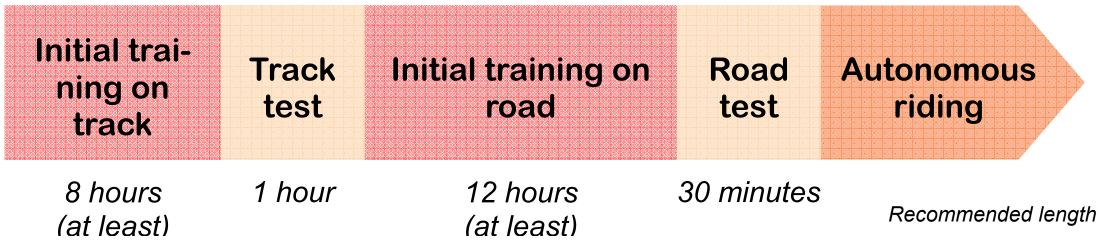

Fig. 9: Modelling of licensing and the recommended initial training process

3.1 Case study results: description of the real curriculum

3.1.1 Differences between the recommended curriculum and the real curriculum

The recommended curriculum is the initial training we can find in the official riding programme. The real curriculum is the curriculum performed by the trainee studied[2].

If the whole curriculum is considered, data argue that initial training is focused on track training (34 hours on 36 hours of training, i.e. 17 lessons on 18 lessons). The in-traffic-conditions part represents 2 hours and is however the most important part according to the number of hours and steps dedicated in the official programme (see Tab. 2).

Tab. 2: Length of recommended and real curriculum

	Training on tracks	**Training on road**
Recommended curriculum	8 hours (at least)	12 hours (at least)
Real curriculum	34 hours	2 hours

Trainers are aware of this phenomenon and try to link training situations to what happens in traffic conditions. The following verbalisation extract concerns the instructions given by the trainer (John) to the learners before the beginning of the obstacle avoidance setting:

> *John: « You can imagine that each obstacle of the slalom represents a curve on road, for the U-turn you will certainly have to make it in the traffic and for the avoidance manoeuvre, imagine that a door car opens. It must be said that every element of this track represent a component of autonomous riding in traffic » (John, 01.12.08)*

[2] The difference between recommended and real curriculum comes directly from the distinction between task and activity, which constitutes one of the main consideration of the French ergonomics (Leplat, 1997).

If track training is considered, data indicate that 1/3 of this training part consists in joining the track field and coming back to the motorcycle school (activity named “trip” in this document) (see Tab. 3). In France, track field does not traditionally belong to one motorcycle school but is shared among several driving schools.

Tab. 3: Length of track training

	Effective time spent on the track field	Effective time spent going to and fro between the motorcycle school and the track field
Length of entire track training (34h)	23 hours	11 hours

People can say that the course delivered during the “trip” is the same as the course which happens in traffic conditions after passing the track test. In this case, the 11 hours of trip could be considered as a traffic conditions course. But data collected show that these two sessions are different at several points:

- The road taken during the trip does not represent a high risk level. The usual road taken by the rider studied consists in secondary roads in order to avoid urban traffic conditions. Only two roundabouts are taken. As soon as the second lesson, the trainee is autonomous and joins the track field with the motorbike (followed of course by the trainer in a car). On the contrary, in traffic conditions course, trainer forces the learner to ride under various and complex conditions, in urban traffic, to confront him to confused intersections, priorities, turns…
- Trainer’s feedbacks are not the same during the trip and the traffic course: 43 feedbacks were given during the two-hours-lesson in traffic conditions and they concerned gaze direction (conspicuity, hazardous perception) and lateral position on road (in roundabout, in right and left intersections). During the eleven hours of trip, there were seven feedbacks on conspicuity and only three on road positioning. Very few feedbacks were given by the trainer. The most important for him is to safely join the track field, while no disturbing the other vehicles and develop autonomy of its trainees.

So even if the settings encountered during the trip can transform the rider, data prove that the course delivered during this trip and during the real traffic course are different.

To summarize, most of initial training of the rider studied is performed on track filed within controlled settings, although traffic situations encountered after obtaining the license are carried out in uncontrolled settings. These results are in line with the IRT Project considerations which indicate that the main problem of pre-test training is the concentration on machine control skills to the detriment of hazard awareness. We can say that the rider learns closed skills (Poulton, 1957) in the initial training in opposition to the open skills (Poulton, 1957) he has to perform on road. The closed skills take place in a stable, predictable environment like in the track field and the performer knows exactly what to do and when. Therefore, skills are not affected by the environment and tend to be habitual. Movements follow set patterns and have a clear beginning and end. However, traffic conditions involve open skills because this environment is constantly changing and so movements have to be continually adapted. Therefore, skills are predominantly perceptual. Knapp (1963) suggests that skills can fit on a continuum between open and closed.

3.1.2 Training settings as licensing settings reproduction

The study highlights that track training consists in about 520 exercises (see Tab. 4) which correspond, for the essential, to two different settings (at low and normal speeds), that are the reproduction of the settings proposed for the track test. The learning method consists for the trainers observed in repeating these situations.

Only few “new settings” (settings which are not test situations) were identified: the « 8 exercise » between two plots in order to improve the ability to make U-turn (lessons n°8 and 16) and a “modified slalom” performed at low speed to master cornering (lesson n°3). The first two lessons are dedicated to the motorbike and its command familiarisation and to the equilibrium seeking from the achievement of « waves ». These settings can not be considered also as test settings.

Tab. 4: Number and nature of exercises performed during track training

Lessons	Number of low speed exercises performed (= test settings)	Number of normal speed exercises performed (= test settings)	“New settings” performed
1	0	0	Motorbike familiarisation/ equilibrium seeking
2	0	0	Motorbike familiarisation/ equilibrium seeking
3	0	8	Modified slalom (repeated 8 times)
4	0	7	0
5	0	8	0
6	6	11	0
7	15	9	0

8	45	0	The « 8 » (10 minutes)
9	42	8	0
10	46	5	0
11	35	6	0
12	31	22	0
13	86	0	0
14	14	21	0
15	0	27	0
16	22	14	The « 8 » (5 minutes)
17	25	14	0
Total	**367**	**153**	

Finally, data indicate that the settings performed during track training are mainly the reproduction of the settings proposed at the motorcycle track test. Training situations are thus determined by the test settings. We can say that, as the track training constitutes the essential part of the initial training, the French curriculum prepares the trainees to pass the motorcycle track test and not to ride safely in traffic and hazardous conditions.

3.1.3 Obstacle avoidance skill: training settings v.s. autonomous riding

According to the 921 accidents analysed in MAIDS (2003) we can observe that the avoidance manoeuvre is often badly made (unsuccessful) and might aggravate the accident in several cases. For the MAIDS authors, initial training has to make improvements in teaching collision avoidance skill.

Data collected here point out two important things on the way that avoidance skill is trained during initial training:

1) Obstacle avoidance technique is taught on track: in controlled conditions, at 30 km/h, without surprise because the rider knows when and where he has to perform the manoeuvre (see Fig. 10). We can think that avoidance behaviour components in traffic conditions are different: emergency, hazardous conditions, higher speed… The skill acquired on track is most "circumvention behaviour" than real avoidance ability.
2) Very few avoidance training exercises are performed during initial training compared to the whole track training exercises:

Fig. 10: Avoidance training setting

the avoidance exercise was only achieved 38 times at the end of the training (18 right avoidances/20 left avoidances, see Tab. 5).

Tab. 5: Number of exercises performed during track training according to the four kinds of normal speed settings proposed

Lessons	Downshift braking	Emer-gency braking	Right Avoidance	Left Avoidance
1	0	0	0	0
2	0	0	0	0
3	8[3]	0	0	0
4	7	0	0	0
5	8	0	0	0
6	11	0	0	0
7	6	3	0	0
8	0	0	0	0
9	5	3	0	0
10	0	5	0	0
11	3	3	0	0
12	5	6	11	0
13	0	0	0	0
14	11	3	7	0
15	8	11	0	8
16	4	3	0	7
17	5	4	0	5
Total	**81**	**41**	**18**	**20**
Subtotal	**122**		**38**	

Table 5 indicates the progression of the proposed exercises. It begins with the downshift braking (without and after with braking), emergency braking at lesson seven, then right avoidance at lesson twelve and left avoidance technique is taught during the last three lessons before the test. The following discussion extract with a trainer (Mickael) can give some explanations:

[3] Downshift whitout braking.

Mickael: « I do not train avoidance skill because it is too dangerous for the motorbike and the rider. I have seen several falls. Anyway we expect the very end of the training on track to establish the avoidance course » (Mickael, 02.08.08)

At the end, obstacle avoidance technique at normal speed (> 50km/h) does not seem to be acquired during initial training but is involved in most motorcycle accidents. This skill is taught under controlled conditions which are too away from the actual traffic conditions encountered after licensing.

3.2 Expected results of the deeper study: detailing the real learning dynamics

The kinds of data collected in this deeper analysis in real context will generate results at two levels: (1) modelling the dynamics of learning to ride a motorcycle and the acquisition process of riding skills; (2) analysing learning settings v.s. describing the rider's activity in these settings and the difficulties he encountered.

(1) Modelling the dynamics of learning to ride a motorcycle and the acquisition process of riding skills

The systematic study of ten motorcyclists will allow to bring elements of modelling the dynamics of learning to ride, i.e.:

(a) Detailing the acquisition process of complex and motor coordination and high-level skills needed to ride a motorcycle;
(b) Identifying periods of stability and instability in the dynamics of learning;
(c) Identifying bifurcations that indicate the transitions between these different periods and characterizing the appearance conditions of these ruptures: what kinds of educational settings during training or autonomous riding settings can generate these failures? To what extent and how the system reorganizes itself? How can we describe the transition conditions (location in the learning dynamics, specific settings…) and are they typical?

(2) Analysing learning settings v.s. describing the rider's activity in these settings and the difficulties he encountered

On the one hand, the aim is to analyse training and licensing settings with an educational point of view. The study will focus on the trainer's activity:

- For the proposed training settings: identifying the learning structure, the progression envisaged, the actual educational contents, skills taught, the time spent to train each skill, learning contexts, types of feedbacks used…
- For the proposed licensing situations: determining the evaluated skills? Which are not? What are the proposed situations? What are the connections between these settings, training settings and autonomous riding settings?

On the other hand, the data collected allow to describe the trainees' activity (without neglecting interactions with the trainer, other riders…) during training, licensing and autonomous settings, and identifying their main difficulties. Practically, the questions are:

- What does the rider?
- What are the difficulties encountered by the trainee in existing situations?
- To what extent the interactions between learners and the trainer are effective?
- How can we note the constraints experienced by the rider during the learning process?

A specific effort will be carried out on riding settings after licensing through the characterization of skills learned in traffic: if it is a new skill or not, how long after licensing, what are the learning situations/conditions….

In conclusion, the expected results can lead to characterize the gap between training and autonomous riding settings in order to show how the current curriculum prepares effectively for safe riding.

4. Discussion: rider's education improvement proposals

The educational improvements we proposed here affect the whole learning process: 1) integrating the "new skills" in initial training, 2) improving the current educational settings knowing the dynamics of learning to ride in real context, 3) optimizing teaching devices by integrating in-depth data, 4) enriching the licensing settings, 5) designing post-test training based upon the identification of novice "vulnerable situations" on roads, and 6) designing a hybrid curriculum integrating simulation.

4.1 Integrating the "new skills" in initial training

Data seem to show that real avoidance behaviour, i.e. avoidance technique in traffic conditions, is acquired on road, after licensing, in critical and dangerous settings. Our hypothesis is that collision avoidance behaviour is not the only one skill which is acquired after licensing. So the aim is to successfully integrate this "hidden curriculum" in the training courses delivered by motorcycle schools, so that the riders make these experiences within safety conditions.

4.2 Improving the current educational settings

Because the trainers have few feedbacks on trainees' activity (only behavioural feedback), trainers are very interested in the description of the riders' activity and the identification of their real difficulties during training and after licensing. In-depth data on dynamics of learning can give them the opportunity to improve the educational settings they propose, towards greater correlation with riding in traffic, or to enrich their teaching methods according to the riders' profiles and problems. This improvement can take place in initial training or during post-test training.

4.3 Optimizing teaching devices by integrating in depth-data

The design objective of the research program is to develop new settings in terms of aid. A setting designed in terms of aid aims to help the agent to understand the situation and to take decisions himself. The human is seen as the central element in this case. The method here is to provide students tools for interpreting their own activity. This may be done through the viewing of audio-visual recordings made in real context highlighting significant learning dimensions. Discussion spaces can therefore be designed and raised by the integration in the conventional training of materials generated by the in-depth study. A number of works (Serres, Ria, Ade and Sève, 2006; Serres, 2006; Leblanc, 2007) tend to validate the assumption that the use of training settings which integrate audio-visual recordings promotes the immediate involvement of learners, who voluntarily compare what they perceive in the recorded situation and what they do. This improvement can take place in initial training or during post-test training.

4.4 Enriching the licensing settings

The results of the case study highlight a gap between licensing situations (which strongly determine training situations) and autonomous riding situations. The interest here is to improve the settings proposed at the track test in order to take greater account of the riding activity performed in real traffic conditions.

4.5 Developing post-test training based on the identification of novice "vulnerable situations" on roads

The study carried out after obtaining the license generates a number of knowledge on the characteristics of the riders' activity and on the "vulnerable situations[4]" they encounter on road (Aupetit and Riff, in progress). This knowledge could contribute to improve post-test course, knowing what young riders exactly do just after licensing and what kinds of situations are dangerous.

4.6 Designing a hybrid curriculum integrating simulation

The gains of using a riding simulator for initial training or post-test training are the followings:

- A green benefit (less fuel consumption);
- A financial gain for the motorcycle school (several simulators per room and one trainer: fuel/trainer work economy);
- A possibility to monitor the simulated environment in order to experiment critical situations with no risk for the rider/motorbike (to teach collision avoidance technique for example), to repeat the driving scenarios and to ride under various conditions (as weather conditions);
- An educational aid by directly confronting trainees to riding situations.

The kinds of simulator we expect to design:

- Are associated with specific educational settings developed with the help of the riders, trainers and experts in teaching;
- Are integrated in a hybrid curriculum: a curriculum which combines simulator course and traditional training in motorcycle school (unlike the current trend to do all the training on simulator);
- Are dedicated to learning, i.e. one simulator for one application (unlike the current trend to design one all purposes simulator);
- Integrate two characteristics: not only information processing (like the Honda Riding Trainer recently developed), but try to teach a complex and motor riding skill.

This project has a prototype simulator (see Fig. 11) with five degrees of freedom: two for the steering mechanism and three spatial rotations with more or less 15 degrees (pitch, roll, yaw). The frame of a real motorbike is set on the simulator platform. The visual and the audio rendering used come from the

[4] "Vulnerable situations" are typical road settings where different profiles of drivers encounter significant difficulties. For a more complete view on this point, see Aupetit and Riff (in progress).

MSIS/INRETS car driving simulators. It consists in up to height flat screens (approx. 4 m² each) and the 3D sound system for the best possible immersion of the rider (see Fig. 12).

Fig. 11: The MSIS/INRETS simulator

Fig. 12: The simulation room

Conclusion

To sum up, the following figure (Fig. 13) identifies all the improvement proposals (noted “P” in the figure) of the education process (during pre-test training, licensing and post-test training) offer by the real context study and proposed in this article. The whole learning process is affected by these proposals.

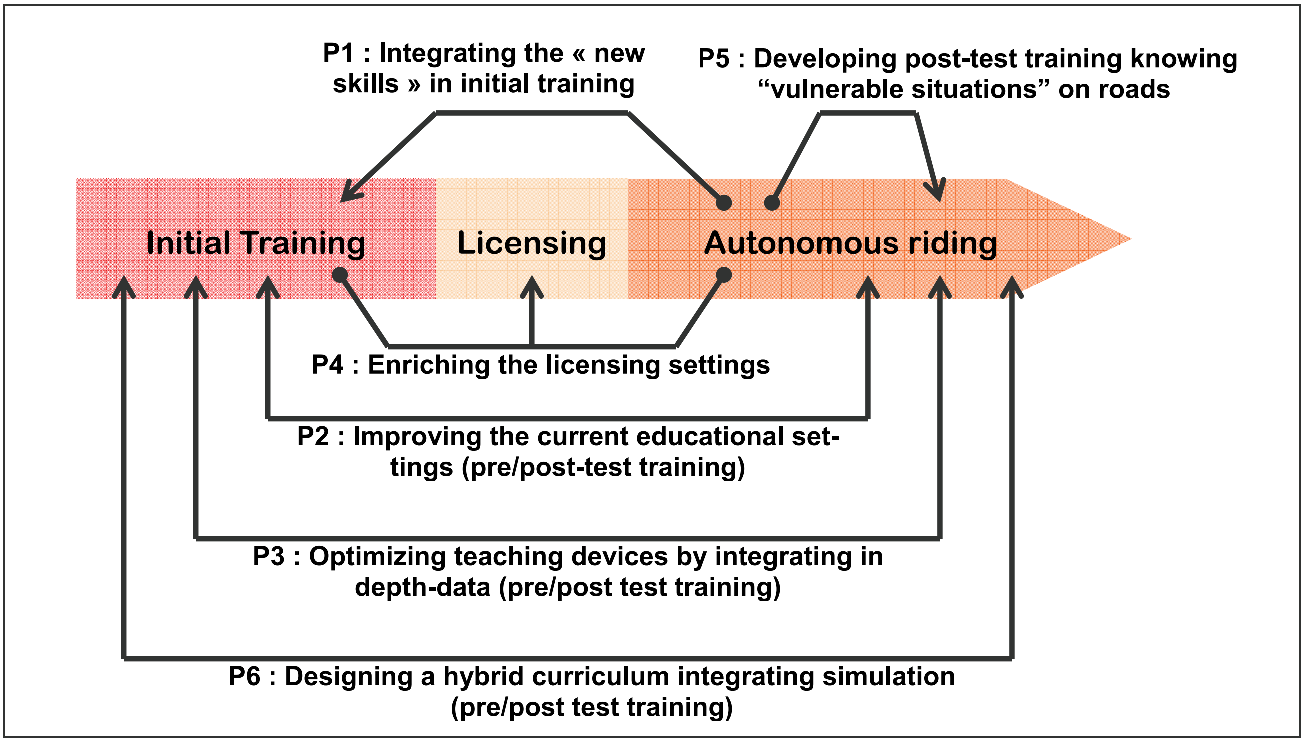

Fig. 13: The integrated approach to the improvement proposals of motorcycle riding education

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Testing the Safety Renewal Concept:
Preliminary Results from "The Discovery Project"

Test des neuen Sicherheitskonzeptes:
Erste Ergebnisse des „Discovery Projektes"

Dr. Ray Ochs, Sherry Williams

Motorcycle Safety Foundation (MSF), USA

Abstract

Building on recommendations from researchers that warned of pitfalls of evaluating the effectiveness of motorcycle rider training (Simpson & Mayhew, 1990) due to the difficulty of showing long-term effects from a single training program and the lack of comprehensive outcome measures, the Motorcycle Safety Foundation has entered into a cooperative agreement with NHTSA (National Highway Traffic Safety Administration) for a longitudinal study of training effectiveness.

The agreement supports a three to five year field study with two groups of matched subjects. One group will participate in a safety renewal condition utilizing the MSF's RETS (Rider Education and Training System) as the basis to deliver multiple courses and modules periodically. The second group is being trained in a MSF Basic RiderCourse only. This paper will report on the progress of the study including establishing a RETS training site, pilot testing procedures and validating instrumentation. Lessons learned from the pilot testing and study recruiting procedures will be shared.

Motorcycle Safety Foundation (MSF)
http://www.msf-usa.org

Kurzfassung

Aufbauend auf den Empfehlungen von Wissenschaftlern, die vor einer Evaluation der Wirksamkeit von Motorradsicherheitstrainings warnten, startete die Motorcycle Safety Foundation in Kooperation mit der NHTSA (National Highway Traffic Safety Administration) eine Langzeitstudie, um eine Trainingseffizienz nachzuweisen. Die Kritiker sahen die Schwierigkeit solcher Studien darin, die Langzeitwirkungen eines Trainigsprogramms aufzuzeigen sowie einen Mangel an objektiver Bewertung des Trainingserfolgs (Simpson & Mayhew, 1990).

Vorgesehen ist eine drei bis fünf Jahre lange Feldstudie von zwei Gruppen mit vergleichbaren Merkmalen. Die erste Gruppe wird dabei unter neuen Trainingsbedingungen periodisch an unterschiedlichen Kursen und Modulen, basierend auf dem MSF's RETS (Rider Education and Training System), teilnehmen. Die zweite Gruppe wird lediglich in MSF Basic RiderCourses trainiert. Dieser Beitrag berichtet über die Fortschritte der Studie, über die Einrichtung eines RETS-Trainigsplatzes, sowie über Prüfverfahren und Mess-/Beurteilugsmethoden. Die durch die Fahrertests und Studien-Rekrutierungs-Verfahren gewonnenen Erkenntnisse werden ebenfalls aufgezeigt.

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Situational hazard awareness of motorcyclists

Situationales Risikobewusstsein von Motorradfahrern

Ulrich Schulz, Universität Bielefeld

Andreas Seifert, Universität Paderborn

Abstract

Modern theories of driver behaviour emphasize the importance of cognitive representations of typical traffic situations and of the availability of appropriate behavioural plans. The traffic psychology group of Bielefeld University followed this research line for several years and developed among other instruments a video based questionnaire for recording several aspects of motorcycle riders' situational hazard awareness. The actual study is based on data of 138 motorcycle riders who rated 12 risk aspects for each of 13 motorcycling situations. These data are analysed in order to obtain an overview of the structural relations of risk aspects.

The relation of risk acceptance with other risk variables is of special interest. First we study by means of ordinal regression this relation for the entire sample. In a second step heterogeneity of the motorcyclists' population is shown by statistical means of segmentation (finite mixture modelling). One half of the motorcyclist population has a normal cognitive hazard awareness structure. The structure of the other half is similar to that of sensation-and thrill-seekers.

Kurzfassung

Moderne Theorien des Fahrerverhaltens stellen die Bedeutung der kognitiven Repräsentation typischer Verkehrssituationen und die Verfügbarkeit angemessener Verhaltenspläne heraus. Die Forschungsgruppe Verkehrspsychologie der Universität Bielefeld folgte diesem Forschungsstrang seit einigen Jahren und entwickelte unter anderen Instrumenten einen videogestützten Fragebogen, um verschiedene Aspekte des situationalen Risikobewusstseins von Motorradfahrern zu erfassen. Die aktuelle Studie beruht auf Daten von 138 Motorradfahrern, die 12 Risikoaspekte für jede von 13 Motorradsituationen beurteilten. Diese Daten werden analysiert, um einen Überblick über die strukturellen Beziehungen der Risikoaspekte zu erhalten.

Die Beziehung der Risikoakzeptanz zu anderen Risikovariablen ist von besonderem Interesse. Zunächst untersuchen wir mit Mitteln der ordinalen Regression diese Beziehung für die Gesamtstichprobe. In einem zweiten Schritt wird mit statistischen Mitteln der Segmentierung (endliche Mischmodelle) die Heterogenität der Motorradfahrerpopulation gezeigt. Die eine Hälfte der Motorradfahrerpopulation hat eine normale Struktur des Risikobewusstseins. Die Struktur der anderen Hälfte ist ähnlich der von Personen, die Erregung und Thrill suchen.

Situationales Risikobewusstsein von Motorradfahrern

Situationales Risikobewusstsein von Motorradfahrern

Moderne verkehrspsychologische Theorien des Fahrerverhaltens im komplexen, dynamischen System Verkehr stellen die Bedeutung der kognitiven Repräsentation typischer Verkehrssituationen heraus. So hat McKenna (McKenna & Crick (1994)) in den angelsächsischen Ländern umfangreiche Studien zur Gefahrenentdeckung in Verkehrssituationen vorgelegt und entsprechende videogestützte Testinstrumente entwickelt, die im Ausland auch bei der Fahrerlaubnisprüfung zum Einsatz kommen. Aus der Ausbildung von Flugzeugpiloten wurde in den angelsächsischen Ländern in jüngerer Zeit, zurückgehend auf Endsley (2000), das Konzept der Situation Awareness in die Fahrerausbildung übernommen. Hier werden drei Schritte herausgestellt:

1. Wahrnehmung der Situation mit ihren Schlüsselreizen
2. Verstehen und Bewerten der Informationen
3. Entwicklung eines Verhaltensplan und einer Projektion.

Andere Autoren setzten bei der Untersuchung komplexer Gefahrenerkennungsaufgaben und darauf basierender Entscheidungen für Wiedererkennungsprozesse spezielle Schlüsselszenarien ein, wie z.B. Klein (1998) mit seinem recognition primed decision model.

Einen ebenfalls situationalen Ansatz zur Risikoanalyse, der für die Verkehrsforschung aus der ökologischen Risikoforschung adaptiert wurde und auf psychometrischen Analysetechniken basierte, wurde in Bielefeld seit Mitte der 80er Jahre hauptsächlich für die Gruppe der Motorradfahrer von Schulz (1990) und Schulz & Kerwien (1990) verwendet und in einer Reihe von Studien (Kerwien 1994, Seifert 2007) fortgeführt und ausgebaut. Auch zur Analyse der Risikowahrnehmung und Risikoentscheidung von Autofahrern und Radfahrern erwies sich der Ansatz als brauchbar. Die Untersuchungen der Motorradfahrer brachten wegen des verwendeten psychometrischen Ansatzes umfangreiche Erkenntnisse über die Strukturierung des kognitiven Situationsbewusstseins, wenn man die verschiedenen Risikoaspekte durch geeignete Risikovariable erfasst.

Insbesondere konnte für das Motorradfahren nachgewiesen werden, dass hier alle aus der sportlichen Freizeitforschung bekannten Phänomene zum Tragen kommen. Vor allem die Risikobereitschaft wird nicht nur wie bei der alltäglichen Transporttätigkeit im Verkehr auf einer generellen Gefährlichkeitsabschätzung der anstehenden Verkehrshandlungen, sondern auf einer individuellen Wertabschätzung zwischen positiven und negativen Aspekten riskanter Verhaltensalternativen getroffen. Die Arbeiten von Schulz (1990), Schulz & Kerwien (1990), Kerwien (1994) haben solche Effekte für größere und kleinere Gruppen von Motorradfahrern nachgewiesen. Allerdings handelte es sich nach dem psychometrischen Ansatz immer um Analysen von Gruppendaten, bei denen für die Situation über die Personen zusammengefasste Daten verwendet wurden. Insofern konnten nur Aussagen über die

Durchschnittsperson gemacht, kaum aber individuelle oder differentielle Analysen durchgeführt werden.

Weiterreichende und tiefere Analysen der Strukturierung des situationalen Risikobewusstseins scheinen möglich, wenn man neuere multivariate Analyseverfahren einsetzt, wie sie mit gutem Erfolg in der Konsumforschung, insbesondere im Bereich der Marktsegmentierung, verwendet wurden (Vernunft & Magidson, 2005).

Datenerhebung

Zur Erhebung des situationalen Risikobewusstseins wurde ein Befragungsinstrument entwickelt, welches 13 Videoclips nutzte, die von Linnenbrügger (2000) auf der Grundlage der von Schulz (1990) verwendeten Videoszenen neu konzipiert, aufgenommen und geschnitten wurden. Die dargestellten Situationen lassen sich durch Kurztitel folgendermaßen charakterisieren:

- Möglichst schnelle Autobahnfahrt auf linker Spur
- Lichtausfall bei Nachtfahrt auf Autobahn
- Autobahnspurwechsel durch Lkw
- Fehlendes Ersatzteil bei Wartung ohne Schutzkleidung holen
- Aus Reihenfolge bei Gruppenfahrt ausbrechen
- Herausforderung durch einen anderen Motorradfahrer
- Vorfahrt an Kreuzung rücksichtslos wahrnehmen
- Probefahrt nach Wartung ohne Schutzkleidung
- Mitreißen lassen bei Regenfahrt durch zweiten Motorradfahrer
- Schaufahren am Motorradtreff
- Schlängeln im Stau
- Fahrt mit neuer Sozia
- Überholen langsamer Pkw-Kolonnen.

Jeder Videoclip zeigt eine Motorrad-Verkehrssituation, die auf einen Punkt zusteuert, an dem die Fahrerin oder der Fahrer sich entscheiden muss, eine als Vorschlag vorgegebene Verhaltensweise zu akzeptieren oder abzulehnen. Die Videoclips waren mit einem Sprechertext unterlegt, der zusätzliche Informationen über den technischen Zustand des Fahrzeugs sowie die physische und psychische Kondition der Fahrerin bzw. des Fahrers enthielt. Der Verhaltensvorschlag wurde verbal vom Sprecher und als Texttafel am Ende des Clips präsentiert.

Nach Präsentation der Videoszene sollte das situationale Bewusstsein durch die Einstufung des vorgeschlagenen Verhaltens auf den folgenden Variablen erfasst werden:

- Angst vor Gefahren
- Situationaler Anreiz zum vorgeschlagenen Verhalten
- Bekanntheit der Gefahren in der Situation
- Eigene Möglichkeiten der Gefahrenkontrolle
- Möglichkeiten der Gefahrenkontrolle anderer Verkehrsteilnehmer
- Freiwilligkeit des Einlassens auf Risiken beim vorgeschlagenen Verhalten
- Gewohntheit der Bedrohung durch Gefahren beim vorgeschlagenen Verhalten
- Ausmaß des Schadens bei einem Unfall beim vorgeschlagenen Verhalten
- Überraschung durch Gefahren beim vorgeschlagenen Verhalten
- Wahrscheinlichkeit eines Unfalls beim vorgeschlagenen Verhalten
- Akzeptanz der vorgeschlagenen Verhaltensweise.

Die Antworten der Personen wurden auf Antwortskalen erfasst, die Rohrmann (1978) hinsichtlich psychometrischer Eigenschaften, insbesondere der Äquidistanz, überprüft hatte.

Die Instruktion der zu befragenden Personen, die Präsentation der Videoclips und die Erfassung der Reaktionen der Befragten sowie Fragen zur Person, zur gefahrenen Maschine und zum Motorradfahren wurde. in ein HTML- Programm eingebunden und über das Internet den Personen präsentiert. Die Reihenfolge der Videoclips wurde in drei Zufallsreihenfolgen variiert. Die Anwerbung der Personen erfolgte über Motorradfahrerforen im Internet. An der Untersuchung nahmen 138 Personen teil. 123 (89%) waren männlich, 15 (11%) weiblich.

Ergebnisse

Zur Analyse wurden die gewonnen Daten in ein Format transformiert, in dem die 13 Situationen als 13 Faktorstufen eines Messwiederholungsdesigns für die 10 erhobenen Variablen aufgefasst wurden (Tabelle 1), die das situationale Bewusstsein der Personen beschreiben. Das situationale Risikobewusstsein kommt in der Variablen Akzeptanz zum Ausdruck. Eine Analyse der Abhängigkeit der Akzeptanz von den anderen 10 Variablen des situationalen Bewusstseins sollte einen vertieften Einblick in die kognitiven Strukturierungen des Risikobewusstseins geben.

Statistisch wurden hierzu Techniken der multiplen, ordinalen Regression verwendet, weil die Akzeptanz als ordinal skalierte Variable aufgefasst wurde. Desweiteren sollten endliche Mischmodelle solcher Regressionen zum Einsatz kommen, wie sie von McLachlan & Peel (2000) veröffentlicht und von Vernunft & Magidson (2005) im Programm Latent Gold dem statistischen Anwender zur Verfügung gestellt wurden.

Im ersten Schritt wurde die ordinale Regression für die Gesamtgruppe der 138 Motorradfahrer berechnet. Hierbei wurden alle verwendeten Prädiktoren über die Personen und wiederholten Situationen hinweg z-standardisiert, um die Regressionsgewichte zwischen den Prädiktoren im Sinne von Betagewichten vergleichbar zu machen. Die Ergebnisse dieser Analyse findet man in der zweiten Spalte von Tabelle 1.

Tabelle 1: Ordinale Regression der Akzeptanz

Gesamtstichprobe

Modell für Gruppe	Gesamtstichprobe
Pseudo-R-Quadrat	0,79
Anteil an Gesamtstichprobe	100%
Regressionsgewicht in Vorhersage der Risikoakzeptanz	
Angst vor Gefahren	-0,58
Anreiz	1,42
Bekanntheit der Gefahr	-0,12
Eigenkontrolle der Gefahren	0,11
Fremdkontrolle der Gefahren	0,20
Freiwilligkeit des Eingehens des Risikos	1,24
Gewohntheit der Bedrohung	0,25
Ausmaß des Schadens bei Unfall	-0,15
Überraschung durch Gefahr	0,11
Wahrscheinlichkeit eines Unfalls	-0,21

Die ordinale Regression der Akzeptanz auf die 10 Prädiktoren hat ein Pseudo-Rquadrat von 79%, der Einfluss des Prädiktorensets ist in der Gesamtgruppe signifikant (Chiquadrat-Test, 5%-Niveau) und hoch. Auch jeder einzelne Prädiktor weist ein signifikant von 0 verschiedenes Gewicht (Wald-Test, 5%-Niveau) in der Regressionsgleichung auf. Den stärksten Akzeptanz steigernden Einfluss hat der Anreiz mit 1,42, gefolgt von der Freiwilligkeit des Eingehens des Risikos mit 1,24. Weitere die Akzeptanz steigernde Prädiktoren sind die Gewohntheit der Bedrohung (0,25), die Fremdkontrolle der Gefahren (0,2), die Eigenkontrolle der Gefahr (0,11) und die Überraschung durch Gefahr (0,11). Als Akzeptanz senkende Prädiktoren erweisen sich die Angst vor Gefahren (-0,58), die Wahrscheinlichkeit eines Unfalls (-0,21) und das Ausmaß des Schadens bei einem Unfall (-0,15) sowie die Bekanntheit der Gefahr (-0,12).

Neben der Berechnung klassischer statistischer Verfahren bietet das Progamm Latent Gold die Möglichkeit, im Sinne einer Heterogenitätsannahme (Mischmodelle) verschiedene Teilpopulationen (Klassen) zu postulieren, in denen statistische Modelle verschiedene Parameter annehmen. Die Beurteilung der einzelnen für verschiedene Klassenanzahlen gefundenen statistischen Lösungen wird mit Hilfe des Bayesianischen Informations- Criteriums BIC vorgenommen.

Wird für ein statistische Modell eine maximale Logarithmierte Likelihood LL bei einem Stichprobenumfang von N und k geschätzten freien Parametern ermittelt, so berechnet sich das Informationskriterium zu BIC = -2 LL + log N *k. Bei Heterogenitätsüberprüfung wird empfohlen, die Anzahl der Klassen so zu bestimmen, dass BIC in Abhängigkeit von der Klassenzahl den geringsten Wert hat. Diese Beziehung zwischen Klassenzahl und BIC ist in Abbildung 1 für das behandelte Problem dargestellt.

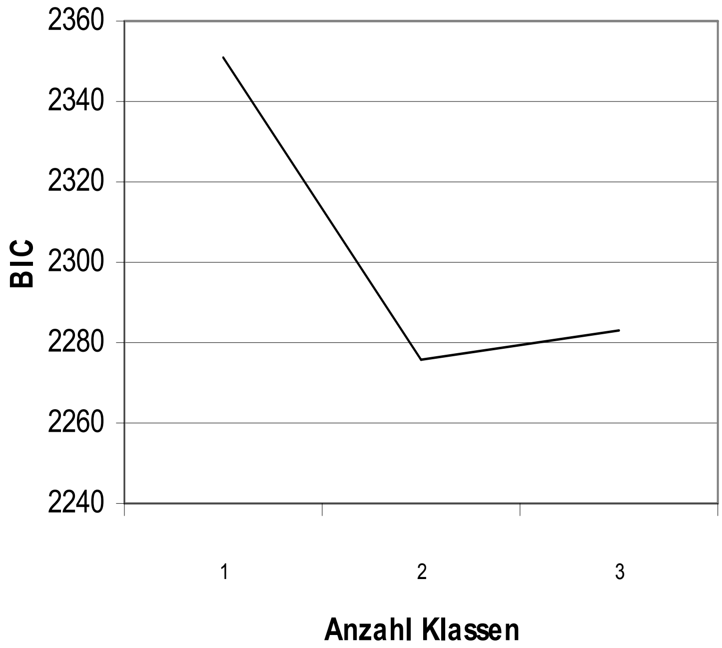

Abbildung 1: BIC in Abhängigkeit der Klassenzahl

Nach diesen Kriterien erweist sich die Gesamtpopulation als heterogen und setzt sich aus 2 Klassen (Teilpopulationen) zusammen. Die erste Teilpopulation macht 53% der Gesamtstichprobe aus, die zweite Klasse umfasst entsprechend 47%. Die Ergebnisse der ordinalen Regressionen sind für die beiden Klassen in der zweiten und dritten Spalte der Tabelle 2 berichtet. In beiden Klassen hat sich die Qualität der Regression noch einmal gegenüber der Tabelle 1 etwas verbessert und liegt bei einem Pseudo-R-Quadrat von 0,8 und 0,86.

Die Gewichte waren für alle Prädiktoren in beiden Klassen signifikant von 0 verschieden (Wald-Test 5%-Niveau). Ein Wald-Test auf Gleichheit der Gewichte eines Prädiktors in den beiden Klassen zeigte für Anreiz, Bekanntheit, Fremdkontrolle, Freiwilligkeit, Gewohntheit und Wahrscheinlichkeit auf dem 5%-Niveau signifikante Unterschiede. Für die restlichen Prädiktoren wurden die Gewichte in den beiden Klassen gleichgesetzt und entsprechende Werte geschätzt. Diese gleichen Gewichte sind jeweils in Tabelle 2 mit einem * gekennzeichnet.

In Klasse 1 hat der Prädiktor Anreiz das höchste Gewicht (1,76) weitere Prädiktoren mit positiven Gewichten sind Freiwilligkeit (0,71), Gewohntheit (0,49), Fremdkontrolle (0,13), Eigenkontrolle (0,11) und Überraschung (0,09). Diese Prädiktoren wirken also Akzeptanz steigernd. Akzeptanz verringernd wirken Angst (-0,64), Wahrscheinlichkeit (-0,32), Schaden (-0,15) und Bekanntheit (-0,04).

In Klasse 2 hat der Prädiktor Freiwilligkeit das höchste Akzeptanz steigernde Gewicht (3,72). Ebenfalls Akzeptanz steigernd wirken in dieser Klasse die Prädiktoren Anreiz (0,86), Fremdkontrolle (0,43), Wahrscheinlichkeit (0,17), Eigenkontrolle (0,11) und Überraschung (0,09). Akzeptanz mindernd wirken Angst (-0,64), Bekanntheit (-0,24), Gewohntheit (-0,23) und Schaden (-0,15).

Tabelle 2: Regressionsgewichte der Akzeptanz für jede Klasse

Modell für Gruppe	Klasse 1	Klasse 2
Pseudo Rquadrat	0,80	0,86
Anteil an Gesamtstichprobe	53%	47%
Regressionsgewicht Prädiktor in Vorhersage der Risikoakzeptanz		
Angst vor Unfall	-0,64 *	-0,64 *
Anreiz	1,76	0,86
Bekanntheit d. Gefahr	-0,04	-0,24
Eigenkontrolle der Gefahren	0,11 *	0,11 *
Fremdkontrolle der Gefahren	0,13	0,43
Freiwilligkeit des Eingehens des Risikos	0,71	3,72
Gewohntheit der Bedrohung	0,49	-0,23
Schaden bei Unfall	-0,15 *	-0,15 *
Überraschung durch Gefahr	0,09 *	0,09 *
Wahrscheinlichkeit eines Unfalls	-0,32	0,17

Signifikante Unterschiede (Wald-Test) zwischen den beiden Klassen wurden auf den Prädiktoren Freiwilligkeit, Anreiz, Bekanntheit, Fremdkontrolle, Gewohntheit und Wahrscheinlichkeit gefunden.

Diskussion

Die durchgeführte Studie zeigt, dass das situationale Risikobewusstsein von Motorradfahrern mit einem situationalen, multivariaten Untersuchungsansatz angemessen erforscht werden kann. Die zur Datenanalyse verwendeten Methoden der ordinalen Regression erlauben eine dem Skalenniveau der zentralen Variablen Akzeptanz angemessene statistische Untersuchung. Die geschlossene Analyse der Gesamtstichprobe der Motorradfahrer zeigte wie auch schon frühere Studien der Bielefelder Forschungsgruppe erneut, dass die Akzeptanz sich aus positiven Aspekten wie Anreiz, Kontrolle der Gefahren, Freiwilligkeit und Gewohntheit der Gefahren und aus negativen Aspekten wie Angst, Bekanntheit, Wahrscheinlichkeit und Schaden vorhersagen lässt. Die Verwendung von statistischen Segmentierungstechniken der Marktforschung zeigt aber auf, dass eine Heterogenität der Gesamtstichprobe hinsichtlich der Prognosestruktur der Akzeptanz gegeben ist.

Die Population teilt sich in fast zwei gleichgroße Hälften. Klasse 1 zeigt sich als Gruppe mit einer normalen Bewertungsstruktur; Anreize wirken sich besonders Akzeptanz steigernd aus, was bei Klasse 2 in wesentlich geringerem Maß der Fall ist. In Klasse 2 wirkt sich die Freiwilligkeit besonders Akzeptanz steigernd aus. Sie ist in Klasse 1 ebenfalls steigernd, aber wesentlich geringer. Die Gewohntheit wirkt in Klasse 1 steigernd und in Klasse 2 senkend auf die Akzeptanz. Die Bekanntheit spielt in Klasse 1 kaum eine Rolle, in Klasse 2 wirkt sie senkend. Die Fremdkontrolle hat in Klasse 2 ein deutlich steigerndes Gewicht, in Klasse 1 spielt sie eine geringe Rolle. Die Wahrscheinlichkeit wirkt schließlich in Klasse 1 wie zu erwarten Akzeptanz senkend, in Klasse 2 hingegen ist sie Akzeptanz steigernd. Aus diesen Gründen weist Klasse 2 eher eine etwas ungewöhnliche Bewertungsstruktur auf. In einigen Aspekten erweckt diese Struktur Erinnerungen an das Bild, das man in der Risikoforschung von einem Thrill & Sensation-Seeker hat.

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Potential of Active Suspension Systems for Vehicle Stabilization

Potenzial von vollaktiven Radaufhängungen zur Fahrzeugstabilisierung

Patrick Seiniger, Hermann Winner,
Technische Universität Darmstadt

Abstract

For four-wheelers, vehicle stability control systems, VSC (e.g. Bosch ESP) have proven their ability to lower fatal accidents by a significant number. For motorcycles, no comparable systems are available. This is due to the complex motorcycle driving dynamics. In a research project at TU Darmstadt, the feasibility of motorcycle VSCs beyond anti-lock and traction control systems has been evaluated. A method to detect relevant critical driving situations was developed and a yaw control system for the prevention of high-sider type accidents has been identified as feasible, and also potential for a system to stabilize the dangerous capsize mode of motorcycles on low-friction surfaces by means of active suspension has been identified. The results of that work have already been published in a project report and are summarized here.

This paper then goes beyond the published work and focuses on the potential of active suspension to control the roll and yaw motion of a motorcycle. With a simplified inverted pendulum model of a motorcycle, it is shown that no positive effect can be achieved in terms of roll stabilization. However, wheel load control by means of active suspension can be used to achieve yaw motion stabilization. The required force demands can be fulfilled by today's actuator systems.

Kurzfassung

Fahrdynamikregelsysteme wie das Bosch ESP haben nachweislich die Unfallzahlen vierrädriger Fahrzeuge deutlich gesenkt. Für Motorräder hingegen sind keine entsprechenden Systeme verfügbar. Hauptgrund hierfür ist die komplexe Fahrdynamik von Einspurfahrzeugen. In einem Forschungsprojekt an der TU Darmstadt wurden Möglichkeiten für über ABS und ASR hinausgehende Fahrdynamikregelungen für Motorräder untersucht. Es wurde eine Methode zur Erkennung kritischer Fahrsituationen und zur Vermeidung der gefährlichen „high-sider"-Unfälle entwickelt und darüber hinaus Potenzial zur Stabilisierung der Rollbewegung von Motorrädern durch aktive Fahrwerke identifiziert. Die Ergebnisse sind bereits veröffentlicht und werden hier zusammengefasst.

Darüber hinaus werden in dieser Veröffentlichung Abschätzungen bezüglich des Potenzials von aktiven Fahrwerken hinsichtlich der Fahrzeugstabilisierung vorgenommen. Mit einem analytischen Modell des Motorrads wird gezeigt, dass mit aktiven Fahrwerken keine Rollstabilisierung erreicht werden kann. Möglich ist jedoch die Stabilisierung der Gierbewegung eines Motorrades. Die notwendigen Kraftanforderungen werden durch heutige Aktoren bereits erfüllt.

Potential of Active Suspension Systems for Vehicle Stabilization

Introduction and Motivation

Despite all improvements on motorcycle safety technology that have been achieved in the last few years (e.g. antilock braking systems ABS, traction control systems TCS), motorcycles are still the most unsafe vehicles. The risk of being killed in traffic (as ratio traffic fatalities to distance travelled) is about 10 times higher for motorcycle riders than for passenger car drivers.

In Germany, the total amount of traffic fatalities decreased to an all-time low in 2006 (5,091), but the number of motorcycle fatalities stayed almost constant in the last decade (2006: 793). Accident research for four-wheelers has found vehicle stability control systems like the Electronic Stability Program ESP to be a major influence on the decrease of four-wheeler fatal accidents, refer to [1]. ABS and TCS for motorcycles exist since 1988 respectively 1992, but systems comparable to an ESP are not within the range of vision. Only an estimated 5% [2] of motorcycles is equipped with ABS or TCS (estimation from 2002; the percentage will have increased but is considered to be still under 10%, estimated for Germany).

A closer look to the reaction of motorcycle riders during accidents shows that two-third of them manage to react by activating the brake or trying to swerve around an obstacle, however obviously do not succeed. This leads to the question, if and how tomorrow's vehicle stability control systems could have helped those motorcycle rides.

This question has been partially answered in previous research work ([3] and [4]), the conclusions are summarized in chapter 1. A method for the detection of critical driving situations was developed and potential actuators to stabilize the capsize mode of motorcycles have been evaluated. Amongst all possibilities for roll angle stabilization, only the control of wheel load by means of active suspension has been identified as feasible actuator for future vehicle stability control systems. Focus of this paper is to answer the question if and how wheel load control can help stabilize motorcycles.

1 Future Vehicle Stability Control Systems for motorcycles

In order to assess the potential for future vehicle stability control systems, the accident types, vehicle dynamics properties and technical possibilities need to be taken into account:

A technical system intended to decrease the rate of fatal accidents should address accident types that occur often as well as have a high risk of being fatal. These accident types are identified by means of an accident analysis, for details, see [4]. The high risk accident types classified as preventable by future VSC systems are unbraked cornering accidents due to a step of friction (μ-step, accident type 1) and due to exceeding maximum lateral acceleration (e.g. trying to ride at a roll angle larger than the maximum roll angle determined by the road surface, type 2). Their share on Germany's high-risk motorcycle accidents is estimated to be 4 to 8%.

Any VSC has to fulfill two criteria: it has to be able to detect critical situations and it has to be able to prevent or mitigate them. Methods to detect the addressed critical situations are developed from the mathematical model. To check if these methods can distinguish critical from uncritical situations, they are validated with data from the experiments and simulations (critical) and with data from various uncritical test rides.

To gather information on the vehicle behavior during the accidents of both types, real-world experiments of simulated accidents using a test motorcycle and computer simulation studies with the simulation package VI/Motorcycle were conducted. A mathematical model for the vehicle behavior was derived from the experiments and computer simulations. The definition of critical and uncritical situations also derives from the analysis of experimental data.

The experimental setup is described in [3] and shown in Figure 1. A test motorcycle is equipped with safety bars that limit the roll angle to values of about 30°. It approaches an epoxy surface either while steady-state cornering (accident type 1) or when entering a turn, starting in upright position (accident type 2).

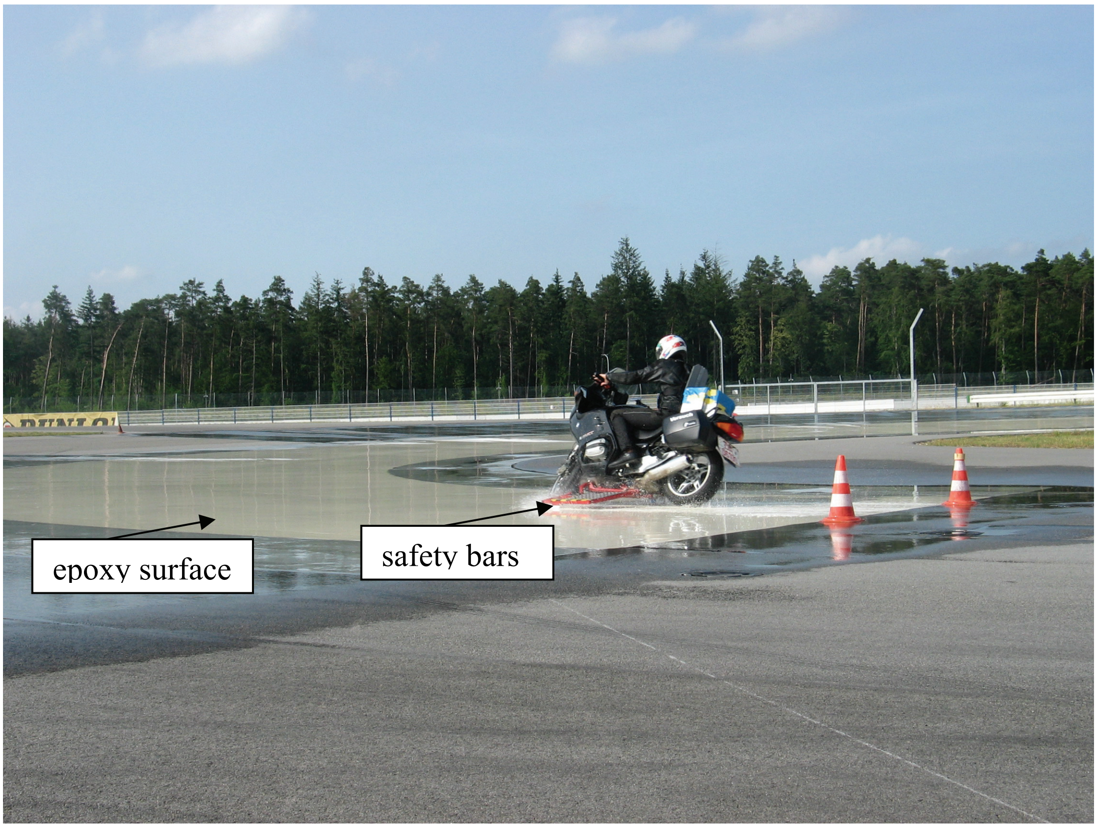

Figure 1: Real world experiments of simulated accidents, Motorcycle with safety bars on low-friction surface (wet epoxy)

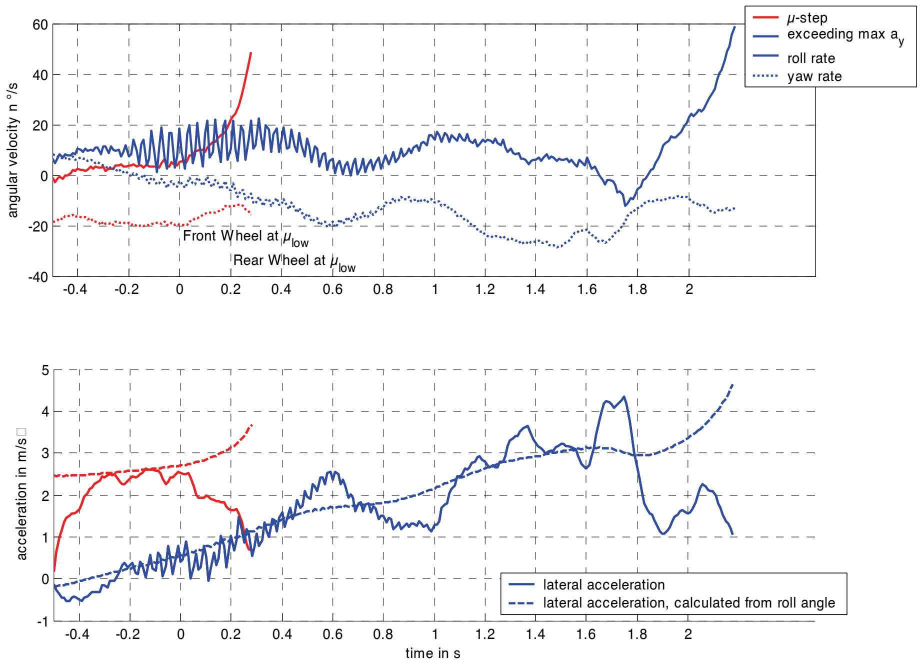

Figure 2: Vehicle Behavior during real world simulated accidents: roll and yaw rate, lateral acceleration, measured and calculated from the roll angle. The vibration in the roll rate signal for type 2 accident is generated by heavy engine vibration at that time but does not affect the data > t = 1s.

Results of the simulated accidents are shown in Figure 2. Type 1 accidents have a shorter duration compared to type 2 accidents. For accident type 1, the front wheel starts to slide as soon as it reaches the μ_{low}-surface. The front wheel side force decreases immediately to the value determined by the new friction coefficient, the vehicle starts to capsize, see roll velocity, time t=0s. The rear wheel arrives 0.2 seconds later at μ_{low}. At that time, the rear wheel side force also drops, the roll velocity increases. The unbalanced side forces of front and rear wheel lead to a yaw momentum and thus a yaw velocity between t = 0s and t = 0.2s. The vehicle turns to the outside of the bend. After approx. t=0.2s, the vehicle movement is inverted – it turns to the inside of the bend, until a short time later the vehicle impacts on the safety bars.

For accident type 2, the side forces drop to the sliding value both at the same time. The roll rate increases constantly. No yaw movement to the outside of the bend is observed; instead the vehicle turns to the inside just before the fall occurs (see the last 0.3 seconds of each plot). For both cases, pitch movement can be neglected.

The lateral acceleration drops to a level equal to g x μ when both wheels are sliding (after 0.2 seconds for type 1 respectively during the last 0.3 seconds for type 2). The "over-steering" yaw movement observed for the last few 0.1 seconds of both cases therefore cannot be explained by a turn. It can be explained by a slip angular velocity – the vehicle yaws but does not change its course in the same way.

Stabilization of the vehicle's yaw movement is possible with the methods used by passenger car stability control systems. However, no methods for stabilizing the capsize mode are known so far.

2 Capsize mode stabilization

The side force that can be generated by tires is limited by the maximum friction value μ which is a property of the actual road surface. In order to exceed these limits and achieve higher acceleration values, the wheel load has to be increased. One way to increase the wheel load is by applying a force between wheel and body. The force increases the wheel load but lifts the vehicle's body. The limit in suspension travel limits the time for a positive effect on wheel load. This concept is well known for passenger cars (see [5]), where the wheel travel is almost orthogonal with respect to the road plane.

As mentioned above in chapter 1 and [4], this concept can perhaps also be used for motorcycle stabilization. Focus of this chapter is to investigate the potential for a stabilizing effect on an analytical basis.

The defined accident types occur when the friction demand is not sufficient for the actual roll angle, either due to a drop in friction value or due to an increasing roll angle. The friction demand due to roll angle is

$$\mu_{demand} = \frac{\ddot{y}}{g} = \tan\lambda\,. \tag{3.1}$$

The friction difference $\Delta\mu$

$$\Delta\mu = \tan\lambda - \mu \tag{3.2}$$

which is always positive for the selected cases. If it would be negative, the motorcycle would not be instable.

For further investigation of the potential of active suspension, a simplified motorcycle model is used.

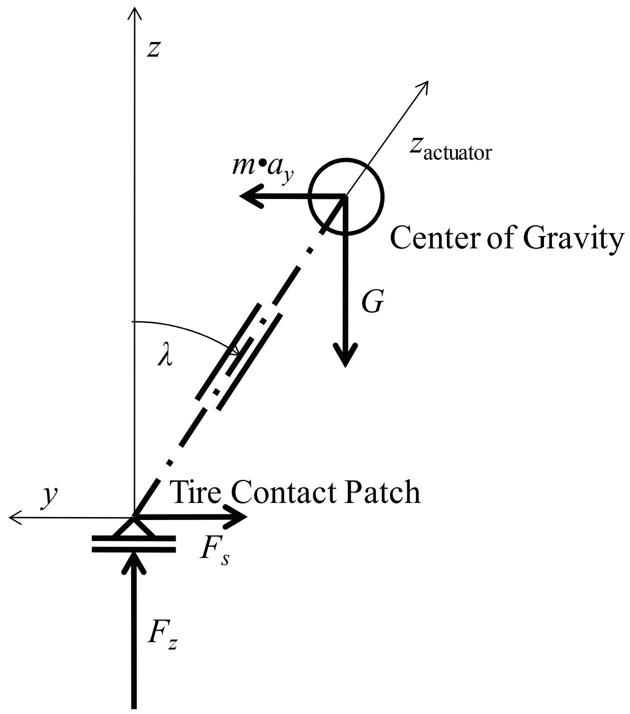

Figure 3: upside-down pendulum model for the motorcycle with additional degree of freedom $z_{actuator}$, view from rear while cornering to the right

In order to estimate the potential of this method, the upside-down pendulum model for the motorcycle is used, see Figure 3. An additional degree of freedom is introduced, the suspension travel z_{actuator}, measured in the vehicle coordinate system. Together with the roll angle λ, these two degrees of freedom form a polar coordinate system. In order to estimate the effect on the wheel load, the accelerations of the center of gravity in the Cartesian coordinate system (orthogonal and parallel to the road plane) have to be known. Centrifugal force due to cornering is treated as an external force, similar to the force of gravity. The sums of forces and moments are

$$\begin{aligned}
&\sum F_z \uparrow: F_z - m \cdot g = m \cdot \ddot{z} \\
&\sum F_y \leftarrow: m \cdot a_y - F_s = m \cdot \ddot{y} \\
&\sum M_x \otimes: m \cdot g \cdot z_{actuator} \cdot \sin\lambda - m \cdot a_y \cdot z_{actuator} \cdot \cos\lambda = \Theta_x \cdot \ddot{\lambda}
\end{aligned} \tag{3.3}$$

Eq. (3.3) shows the potential to achieve stability. In order to raise the motorcycle in a situation of danger, the centrifugal force acting on the center of gravity can be used to generate a counter-torque against the weight force torque. For sliding wheels, the centrifugal force is connected to the wheel load by the friction coefficient μ. Increasing the wheel load also increases the centrifugal force:

$$F_s = \mu \cdot F_z\,. \tag{3.4}$$

The wheel load can be increased by applying acceleration contrary to gravity. If the acceleration is not orthogonal to the road plane, it will also have an effect on side forces that weakens the benefits.

As shown in Figure 3, the Cartesian coordinates of the center of gravity are

$$\begin{aligned}
z &= \cos\lambda \cdot z_{actuator} \\
y &= -\sin\lambda \cdot z_{actuator}
\end{aligned}\,. \tag{3.5}$$

The actuator travel is not constant. The first and second derivates are

$$\begin{aligned}
\dot{z} &= \cos\lambda \cdot \dot{z}_{actuator} - \sin\lambda \cdot z_{actuator} \cdot \dot{\lambda} \\
\dot{y} &= -\sin\lambda \cdot \dot{z}_{actuator} - \cos\lambda \cdot z_{actuator} \cdot \dot{\lambda}
\end{aligned} \tag{3.6}$$

$$\begin{aligned}
\ddot{z} &= \cos\lambda \cdot \ddot{z}_{actuator} - 2\sin\lambda \cdot \dot{\lambda} \cdot \dot{z}_{actuator} - \cos\lambda \cdot \dot{\lambda}^2 \cdot z_{actuator} - \sin\lambda \cdot z_{actuator} \cdot \ddot{\lambda} \\
\ddot{y} &= -\sin\lambda \cdot \ddot{z}_{actuator} - 2\cos\lambda \cdot \dot{z}_{actuator} \cdot \dot{\lambda} + \sin\lambda \cdot \dot{\lambda}^2 \cdot z_{actuator} - \cos\lambda \cdot z_{actuator} \cdot \ddot{\lambda}
\end{aligned} \tag{3.7}$$

and the reaction forces form to

$$\begin{aligned}
F_z &= m \cdot g + m \cdot \cos\lambda \cdot \ddot{z}_{actuator} - m \cdot 2\sin\lambda \cdot \dot{\lambda} \cdot \dot{z}_{actuator} \\
&\quad - m \cdot \cos\lambda \cdot \dot{\lambda}^2 \cdot z_{actuator} - m \cdot \sin\lambda \cdot z_{actuator} \cdot \ddot{\lambda} \\
m \cdot a_y &= F_s - m \cdot \sin\lambda \cdot \ddot{z}_{actuator} - m \cdot 2 \cdot \cos\lambda \cdot \dot{z}_{actuator} \cdot \dot{\lambda} \\
&\quad + m \cdot \sin\lambda \cdot \dot{\lambda}^2 \cdot z_{actuator} - m \cdot \cos\lambda \cdot z_{actuator} \cdot \ddot{\lambda}
\end{aligned} \tag{3.8}$$

For the case of sliding wheels, tire side force is directly connected to wheel load by the friction coefficient μ. The effective lateral acceleration as a function of suspension actuator travel and roll dynamics forms to

$$\begin{aligned}
m \cdot a_y = {} & \mu \cdot m \cdot g - \mu \cdot m \cdot \cos\lambda \cdot \dot{\lambda}^2 \cdot z_{actuator} - \mu \cdot m \cdot \sin\lambda \cdot z_{actuator} \cdot \ddot{\lambda} + m \cdot \sin\lambda \cdot \dot{\lambda}^2 \cdot z_{actuator} \\
& - \mu \cdot m \cdot 2\sin\lambda \cdot \dot{\lambda} \cdot \dot{z}_{actuator} - m \cdot 2 \cdot \cos\lambda \cdot \dot{z}_{actuator} \cdot \dot{\lambda} - m \cdot \cos\lambda \cdot z_{actuator} \cdot \ddot{\lambda} \\
& + \mu \cdot m \cdot \cos\lambda \cdot \ddot{z}_{actuator} - m \cdot \sin\lambda \cdot \ddot{z}_{actuator}
\end{aligned} \tag{3.9}$$

Eq. (3.9) shows the influence of actuator travel to centrifugal force $m \cdot a_y$. This can be used to control the roll equilibrium Eq. (3.3)

$$\begin{aligned}\frac{\Theta_{Roll} \cdot \ddot{\lambda}}{m \cdot z_{actuator} \cdot \cos\lambda} = {} & g \cdot \tan\lambda - \mu \cdot g + \mu \cdot \cos\lambda \cdot \dot{\lambda}^2 \cdot z_{actuator} + \mu \cdot \sin\lambda \cdot z_{actuator} \cdot \ddot{\lambda} - \sin\lambda \cdot \dot{\lambda}^2 \cdot z_{actuator} \\ & + \mu \cdot 2\sin\lambda \cdot \dot{\lambda} \cdot \dot{z}_{actuator} + 2 \cdot \cos\lambda \cdot \dot{z}_{actuator} \cdot \dot{\lambda} + \cos\lambda \cdot z_{actuator} \cdot \ddot{\lambda} \\ & - \mu \cdot \cos\lambda \cdot \ddot{z}_{actuator} + \sin\lambda \cdot \ddot{z}_{actuator}\end{aligned} \quad . \quad (3.10)$$

In the selected accident cases, the roll angle is too high for the actual pavement friction value. The side forces cannot reach sufficient values to maintain roll equilibrium. To raise the motorcycle to a more upright position, the right-hand side of Eq. (3.10) needs to become negative. This holds true for

$$\ddot{\lambda} < 0 \, . \quad (3.11)$$

Assuming the motorcycle is travelling under steady-state conditions (all derivates of the roll angle are zero, the actuator velocity is also zero) the equation becomes

$$0 > (\tan\lambda - \mu)(g + \ddot{z}_{actuator} \cos\lambda) \, . \quad (3.12)$$

For the selected case $\tan\lambda > \mu$ the first bracket becomes positive. To obtain a positive effect on motorcycle stability, the actuator acceleration needs to be negative. This is a somewhat surprising effect, since this lowers the wheel load but also lowers the side force demand due to roll dynamics. To obtain a negative roll angular acceleration, the actuator acceleration is

$$\ddot{z}_{actuator} < \frac{-g}{\cos\lambda} \, . \quad (3.13)$$

Another condition derives from the wheel load. If the wheel load becomes negative, the wheel will be lifted from the road surface and cannot generate side force. The wheel load in the static case is

$$F_z = m \cdot g + m \cdot \cos\lambda \cdot \ddot{z}_{actuator} \geq 0 \quad (3.14)$$

and the actuator acceleration has to be

$$\ddot{z}_{actuator} \geq \frac{-g}{\cos\lambda} \, . \quad (3.15)$$

These conditions lead to a contradiction. Obviously, no stabilization (regarding a change of sign for roll angular acceleration) is possible. If roll angle velocity is > 0, the actuator acceleration to stop roll angular acceleration has to be

$$\ddot{z}_{actuator} < \frac{g}{-\cos\lambda} - \frac{(\mu \cdot \tan\lambda + 1)}{\Delta\mu} \cdot 2 \cdot \dot{z}_{actuator} \cdot \dot{\lambda} + \dot{\lambda}^2 \cdot z_{actuator} \, . \quad (3.16)$$

Of course, also in this case, the wheel load has to stay positive:

$$\begin{aligned}0 \le F_z &= m \cdot g + m \cdot \cos\lambda \cdot \ddot{z}_{actuator} - m \cdot 2\sin\lambda \cdot \dot{\lambda} \cdot \dot{z}_{actuator} \\ &\quad - m \cdot \cos\lambda \cdot \dot{\lambda}^2 \cdot z_{actuator} - m \cdot \sin\lambda \cdot z_{actuator} \cdot \ddot{\lambda} \\ \Leftrightarrow \ddot{z}_{actuator} &\ge -\frac{g}{\cos\lambda} + 2 \cdot \tan\lambda \cdot \dot{\lambda} \cdot \dot{z}_{actuator} + \dot{\lambda}^2 \cdot z_{actuator} + \tan\lambda \cdot z_{actuator} \cdot \ddot{\lambda}\end{aligned} \tag{3.17}$$

The actuator acceleration only fulfills both conditions for

$$-\underbrace{\frac{(\mu \cdot \tan\lambda + 1) + \tan\lambda \cdot \Delta\mu}{\Delta\mu}}_{>0} \cdot 2 \cdot \dot{z}_{actuator} \cdot \dot{\lambda} - \underbrace{\tan\lambda \cdot z_{actuator} \cdot \ddot{\lambda}}_{\ge 0} > 0\,. \tag{3.18}$$

$$\dot{z}_{actuator} \cdot \dot{\lambda} < -\frac{\Delta\mu}{4 \cdot \mu \cdot \tan\lambda + 2} \cdot \tan\lambda \cdot z_{actuator} \cdot \ddot{\lambda} \tag{3.19}$$

The right hand side of Eq. (3.19) is always negative. The actuator velocity is never positive. If the sign of the roll velocity changes without a change of sign for the acceleration, Eq. (3.19) cannot be fulfilled.

Concluding from these results, a full stabilization of a motorcycle's capsize mode is not possible. However, the wheel load of a motorcycle can be lowered by active suspension. An individual change of wheel loads leads to an individual change of tire side force. This can be used to control the yaw movement.

3 Yaw mode stabilization

For yaw mode stabilization, a single inverted pendulum model of the motorcycle is not appropriate. Yaw momentum derives from different side forces on both wheels. To estimate the potential, two separate inverted pendulum models for each wheel are used, see Figure 4.

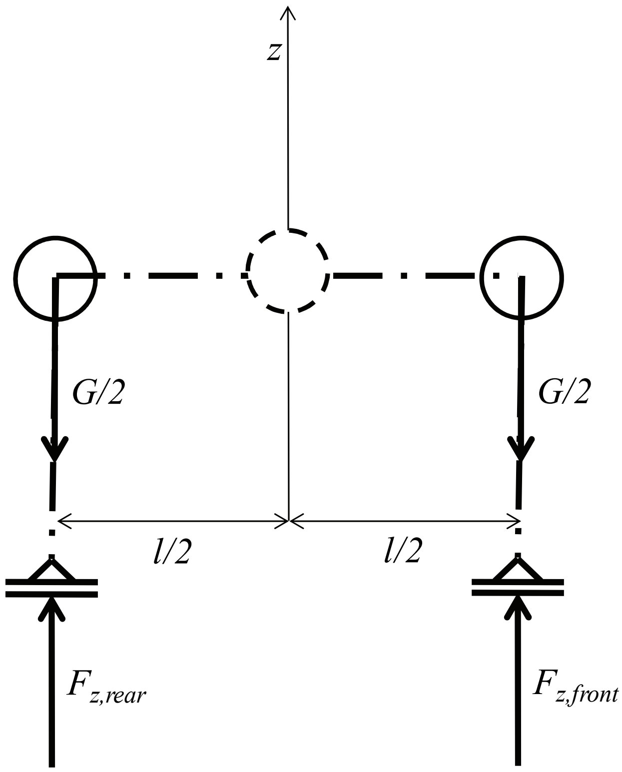

Figure 4: Motorcycle shown from right side as two coupled inverted-pendulum models

The equations of motion are

$$\begin{aligned}
&\sum F_z \uparrow: F_z - m \cdot g = m \cdot \ddot{z} \\
&\sum F_y \square : m \cdot a_y - F_s = m \cdot \ddot{y} \\
&\sum M_x \rightarrow: m \cdot g \cdot z_{actuator} \cdot \sin \lambda - m \cdot a_y \cdot z_{actuator} \cdot \cos \lambda = \Theta_x \cdot \ddot{\lambda} \\
&\sum M_z \uparrow: l/2 \cdot \left(F_{s,rear} - F_{s,front} \right) = \Theta_z \cdot \ddot{\psi}
\end{aligned} \tag{4.1}$$

For the case of sliding wheels, the side forces on each wheel are limited by the friction coefficient μ:

$$F_{s,i} = \mu \cdot F_{z,i} = \mu \cdot m \cdot g \cdot \frac{(l - l_i)}{l}. \tag{4.2}$$

With the substitution of the static part of Eq. (3.9) for the effective side force and using only half the mass, the yaw momentum is

$$\cos\lambda \cdot \frac{m}{2} \cdot \frac{l}{2} \cdot \Delta\mu \cdot \left(\ddot{z}_{actuator,front} - \ddot{z}_{actuator,rear} \right) = \Theta_z \cdot \ddot{\psi} \ . \tag{4.3}$$

This equation shows one of the advantages of yaw control over the previously proposed method of side force vectoring (see [3], the direction of force on a wheel can be changed by applying brake torque. This method is used in current ESP systems for four-wheelers): control of the yaw motion is possible without sacrificing side force, so the motorcycle capsize motion is not accelerated in comparison to the case without control system. Another advantage over side force vectoring is the much lower time delay between wheel load increase and side force increase. However, as in the previous case, with the change of each suspension acceleration's sign, the sign of the yaw acceleration also changes.

The necessary actuator accelerations for each actuator to stabilize the observed yaw accelerations of approx. 50 °/s² are

$$\ddot{z}_{actuator} = \frac{2 \cdot \Theta_z \cdot \ddot{\psi}}{\cos\lambda \cdot \Delta\mu \cdot l \cdot m} \approx \frac{100}{0.8 \cdot 0.15 \cdot 1.4 \cdot 300} \approx 2 \frac{\text{m}}{\text{s}^2} \ . \tag{4.4}$$

With a maximum suspension travel of 100 mm, the time until a change of sign occurs is 0.2 seconds, the maximum pitch angle of the vehicle is 8 °. The force demand is

$$F_{actuator} = \frac{m}{2} \cdot \ddot{z}_{actuator} \ . \tag{4.5}$$

For a motorcycle of 300 kg, the force demand is 300 N per actuator. This force can be provided by today's actuators. Actuator properties for suspension systems can be found in [6].

4 Conclusion and Outlook

The focus of this paper is to estimate the potential of active suspension systems to stabilize motorcycles. Wheel load control by means of active suspension has proved to increase the wheel load for passenger cars. This fact motivated deeper investigation whether this method is also applicable for motorcycles.

It was proven that stabilization of the capsize mode of a motorcycle is by no means possible with active suspension. This has been shown with an inverted pendulum model of a motorcycle incorporating an actuator to control wheel load. Applying a force between wheel and body increases the wheel load but this is overcompensated by the increasing friction demand.

However, wheel load control can be used to control the yaw instability of a sliding motorcycle. In advantage over side force vectoring (introduced in previous research work), with this method no side force has to be sacrificed. In addition, the time delay between wheel load change and side force change is supposed to be much lower.

5 References

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PISa – Powered two-wheeler Integrated Safety.
Project objectives, achievements and remaining activities

Ganzheitliche Schutzsysteme motorisierter Zweiräder.
Projektziele, Ergebnisse und ausstehende Aktivitäten.

Grant, R. & Frampton, R.,
Vehicle Safety Research Centre, Loughborough University, UK

Peldschus, S., and Schuller, E.
Institute of Legal Medicine, Ludwig-Maximilians University, Germany

StClair, V. & McCarthy, M.
Vehicle Safety and Engineering, TRL Limited, UK

Babu, R.
TVS Motor Company Limited, India

Pierini, M., & Savino, G,
Dipartimento di Meccanica e Tecnologie Industriali (DMTI), University of Firenze, Italy

Abstract

Starting point for investigation

The aim of this EC 6th Framework funded project is to identify, develop and test new technologies to provide integrated safety systems for a range of motorcycles which will greatly improve primary safety and link to secondary safety systems.

Methods

Seven priority accident scenarios were confirmed using existing analyses of PTW accident statistics. A case review of representative crashes was undertaken using existing in-depth data. A survey of PTW riders was carried out and existing survey data was re-analysed. Using this information, the functional requirements that would contribute to the avoidance of the crash and/or the reduction in the injury severity were determined and prioritised. Consideration was given to vehicle dynamics, rider/driver behaviour, protective equipment and HMI issues, environmental and road infrastructure factors, technological developments and vehicle communications.

Results

From a functions matrix system priorities across the spectrum of PTW accident scenarios have been determined. Important priorities for PTW crash reduction are warning the other vehicle of the PTW presence and automatically stopping that vehicle. Regarding PTW systems, priorities are warning the PTW of the presence of the other vehicle to improve crash avoidance and improvements to the PTW braking system including semi-autonomous braking to improve casualty reduction.

Impacts/effects/consequences

Those priorities which fall within the scope of PISa have been translated into a system specification and the relevant technologies are currently being developed and implemented on the PISa demonstration vehicles. The HMI (human-machine interface) issues are being considered and a test programme developed. Casualty reduction potential and cost benefit analysis is ongoing.

Kurzfassung

Ausgangspunkt der Untersuchungen

Das Ziel dieses im 6. Forschungsrahmenprogramm der EU geförderten Projektes ist es, neue Technologien zu identifizieren, zu entwickeln und zu testen, um damit ganzheitliche Schutzsysteme für eine Reihe motorisierter Zweiräder zur Verfügung zu stellen. Dadurch sollen in hohem Maße die aktive Sicherheit erhöht und gleichzeitig Systeme der passiven Sicherheit berücksichtigt werden.

Methoden

Unter Einbeziehung bestehender Auswertungen der Zweiradunfallstatistiken wurden sieben priorisierte Unfallszenarien bestätigt. Eine fallweise Untersuchung repräsentativer Unfälle wurde auf Basis bestehender In-Depth-Datenbanken durchgeführt, ebenso eine Befragung von Zweiradfahrern, die zusammen mit zuvor erhobenen Daten analysiert wurde. Auf Grundlage dieser Informationen wurden die funktionalen Anforderungen, die zur Unfallvermeidung und/oder zur Reduktion der Verletzungsschwere beitragen würden, bestimmt und priorisiert. Dabei wurden die Fahrzeugdynamik, das Fahrerverhalten, Schutzausrüstungen, MMI-Aspekte, Umgebungs- bzw. Straßenausstattungsfaktoren, technologische Entwicklungen und die Fahrzeug-Fahrzeug-Kommunikation berücksichtigt.

Ergebnisse

Ausgehend von einer Funktionsmatrix wurden Prioritäten im Spektrum der Zweiradunfallszenarien bestimmt. Wichtige Prioritäten zur Zweiradunfallvermeidung sind die Warnung des anderen Fahrzeugführers vor der Anwesenheit des motorisierten Zweirades und das notfalls automatische Stoppen dieses Fahrzeugs. In Bezug auf Systeme am Zweirad sind die Warnung des Aufsassen vor Anwesenheit eines anderen Fahrzeugs (zur Verbesserung der Unfallvermeidung) und weiterentwickelte Bremssysteme, inklusive semi-autonomen Bremsen, als Prioritäten zu betrachten.

Auswirkungen und Konsequenzen

Jene Prioritäten, die in das Entwicklungsfeld von PISa fallen, sind in Systemspezifikationen übersetzt worden. Die relevanten Technologien werden entwickelt und in den PISa-Demonstrationsfahrzeugen implementiert. Aspekte der Mensch-Maschine-Interaktion (MMI) werden dabei berücksichtigt und es wird ein Testprogramm entwickelt. Die Abschätzung des Potenzials zur Reduktion von Unfallopferzahlen und Kosten-Nutzen-Analysen sind andauernde Aktivitäten.

PISa – Powered two-wheeler Integrated Safety.

Project objectives, achievements and remaining activities

Introduction

PISa - Powered two-wheeler Integrated Safety - is an EC project funded under the 6th Framework Programme. The aim of this project is to identify, develop and test new technologies to provide integrated safety systems for a range of powered two-wheelers (PTWs) which will greatly improve primary safety and link to secondary safety systems.

This paper will first give an overview of the PISa project and describe the broad objectives of the project. A description of the contribution made by Workpackage 2: User Needs and Requirements will then be presented. Finally the achievements and remaining activities of the project (as at 30 July 2008) will be given.

Project overview

The PISa project started in June 2007 and, with a duration of 42 months, will conclude in November 2009. TNO is the project Co-ordinator and there are 12 participating organisations from 5 countries (4 European and 1 Asian) as shown in Table 1.

Table 1. Participants in PISa

	Participant organisation name	Short name	Country	Type of organisation
1	Netherlands Organisation for Applied Scientific Research	TNO	NL	RESEARCH
2	Università degli Studi di Firenze	UNIFI	IT	HIGHER EDUCATION
3	Loughborough University - Vehicle Safety Research Centre	LU-VSRC	UK	HIGHER EDUCATION
4	Ludwig-Maximilians-Universität	LMU	D	HIGHER EDUCATION
5	Transport Research Laboratory	TRL	UK	RESEARCH
6	IBEO	IBEO	D	INDUSTRY
7	Paioli Meccanica	PAI	IT	INDUSTRY
8	Malaguti Spa	MAL	IT	INDUSTRY
9	TVS Motor Company Ltd.	TVS	INDIA	INDUSTRY
11	Uniresearch bv	UNI	NL	IND/SME
12	Carver Engineering	CARVER	NL	IND/SME

The aim of the PISa project is to develop and use new technologies to provide integrated safety systems for a range of Powered Two Wheelers, which greatly improve primary safety and can link to secondary safety devices and will improve the performance and safety of the vehicles. PISa will contribute to the general EU target of 50% reduction in road accident fatalities. Also for PTW fatalities, a reduction of at least 50% should be the target. PISa will also contribute to India's automotive policy by enhancing the safety of PTW designs.

The general objective of the PISa project is to develop 'reliable and fail-safe' integrated safety systems for a powered-two-wheeler, to integrate these systems in two motorcycles and evaluate the benefit of these systems to motorcycle and traffic safety. In addition, the PISa project will be working towards quantified objectives for the integrated system, combining sensors and an advanced braking and suspension system to contribute to:

a) Avoiding 50% of accidents where a collision was not inevitable;
b) Reducing the impact speed, and hence reduce the injury severity by one MAIS integer for 50% of accidents where a collision was inevitable;
c) Preventing 50 % of the single vehicle loss of control accidents.

The PISa project will assess to what extent the objectives have been met in controlled tests to replicate the relevant accident mechanisms.

The scientific and technical objectives are:

a) Identify the most frequent causes – precipitating factors and contributory factors – of PTW accidents and determine how the rider interacted with the PTW during the pre-crash phase by analysing PTW accident data and video tapes recorded at dangerous junctions.
b) Examine rider and bike interaction when riding along known accident sites using an instrumented PTW.
c) Assess and measure rider behaviour in dangerous manoeuvres identified from the accident analysis and instrumented PTW using computer models, including human muscle activity, that replicate the interaction between a rider and a PTW.
d) Assess and measure the PTW behaviour and response in dangerous manoeuvres, identify potential areas for improvement by use of triggered control mechanisms on for instance suspension, brakes, steering.
e) Identify existing technologies and safety systems in passenger cars and assess their usability in PTWs.

f) Develop a PTW safety system that integrates sensors, warning devices – visual, acoustic, and/or mechanical – an intelligent braking system and automatically variable suspension that will reduce the incidence and severity of PTW accidents.

g) Assess the costs of the PTW safety system and the benefits in terms of reduction in accidents and injuries.

h) Fit the prototype integrated safety system to at least two PTWs and evaluate the PTWs on a test track and road using a range of subjects (riders).

i) Invite various dignitaries to observe the behaviour and hence the benefits of the integrated system during track and road tests.

In order to achieve these objectives the PISa work programme is divided into 7 Workpackages, each contributing specific activities and outcomes. These are illustrated in Figure 1.

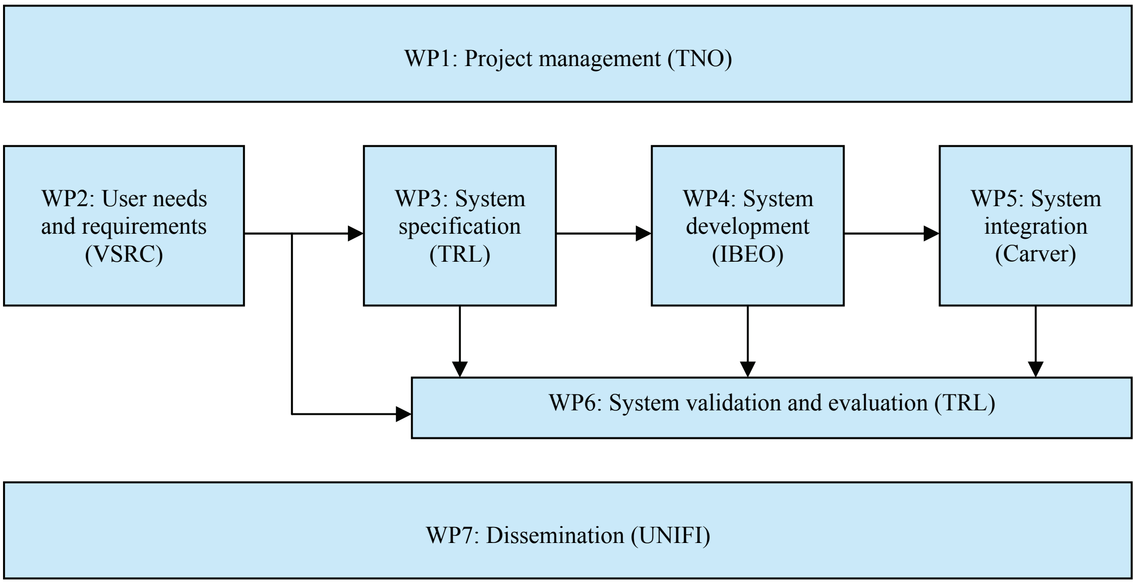

Figure 1. Plan of the PISa project structure and work package leaders

Having just passed the halfway point of the project (as at 30 July 2008) the activities of WP2 are finished, WP3 are nearing completion and WPs 4&5 are underway.

It must be recognised that, in the negotiation of the PISa project it was agreed that no new accident data collection or analysis would be conducted. Thus existing data bases and analyses were accessed and used. This presented some limitations to the PISa project. For example, the in-depth accident data available to the project was predominantly from Great Britain (GB) whilst the data analyses were from 4 European countries which did not include Great Britain. Some additional work was therefore necessary in order to establish whether the GB data was sufficiently representative.

A further limitation was that the analysis of junction video was not possible due to a change in the work plan at the start of the project.

A further issue for the PISa project was that whilst the early work identified all potential system developments it was recognised that some of these were either outside the scope of the PISa project or outside the capabilities of the PISa consortium. Some potential systems addressed the design and specification of other vehicles or infrastructure in the road system, such as vehicle to vehicle or vehicle to infrastructure communication systems. Other potential systems, whilst applying to PTWs, could not be developed or implemented by the PISa partners, such as traction control systems. Thus, the systems being developed within PISa do not address all of the potential safety improvements that were identified.

This paper will focus on the activities and results of WP2: User Needs and Requirements.

WP2: User Needs and Requirements

In developing the PISa PTW Integrated Safety System (ISS) it was considered important that the process was ‘needs-driven’ in terms of:

- What accident scenarios need to be addressed,
- What technologies best meet these needs and
- What rider/driver factors need to be considered in relation to the above two aspects to ensure an optimal solution.

The objectives of WP2 are given below, together with the tasks in which they were each carried out. These activities will then be described in more detail in the following sections.

❶ Identify and prioritise from existing statistical PTW accident data those accidents where integrated safety systems will make a positive contribution to accident/injury reduction (Task 2.1.1 Statistics).

❷ Identify knowledge, issues and techniques from existing motorcycle and integrated safety literature, which will assist in the definition and evaluation of integrated safety systems for motorcycles (Task 2.1.2 Literature).

❸ Review in-depth PTW accident data to identify relevant scenarios and to fully understand the issues of accident causation and outcome (Task 2.2.1 In-depth Accident Cases).

❹ Review video data of driver/rider behaviour at road junctions (of known accident sites) to further understand accident scenarios (Task 2.2.2 Junction Video Data).

❺ Identify the issues considered important to users (and experts) in relation to the performance of integrated safety systems (Task 2.2.3 User Information).

❻ Prioritise potential integrated safety systems in the context of accident reduction/user behaviour/technological possibilities (Task 2.3.1 and Task 2.3.2 Matrix and Scenario Intervention Priorities).

❼ Define the requirements of specific potential integrated safety system(s) in terms of the system performance and user needs and estimate the impact on fatalities and injuries (Task 2.3.3 Derived Driver Assistance Functions).

Accident Statistics (Task 2.1.1)

As previously mentioned the project brief precluded new data collection and analysis. As a consequence, a number of major European PTW accident studies were reviewed including: APROSYS (Advanced PROtection SYStems), MAIDS (Motorcycle Accident In Depth Study), SafetyNet, TRACE (Traffic Accident Causation in Europe), as well as various national studies. Each study was reviewed and data assimilated regarding the PTW market, accident data (trends, risk, scenarios and causation), injury data (distribution, type/outcome and causation), accident factors (time of day/year, weather/light conditions, speeding, engine size and hardware and traffic control methods), crash test scenarios and design implications. In addition, accident data from India was reviewed.

The findings were presented in the context of the future work packages of the PISa project to provide direction and guidance concerning the key factors to be considered. The output of this work is a public deliverable D2: Powered two-wheeler Integrated Safety (PISa): Review of current PTW accident data, which is available on the PISa website.

The most important information which was carried forward in WP2 was the summary of the most frequent and severe PTW accident configurations identified by the APROSYS project, represented by 7 crash scenarios as shown in Table 2. The data from India indicate that these scenarios are also relevant to Indian traffic conditions.

Table 2. The most frequent and severe PTW accident configurations identified by APROSYS

Importance	Location	PTW type	Struck object	Junction
1	Urban	Moped	Car	Intersection
2	Urban	Moped	Car	Straight
3	Urban	Motorcycle	Car	Intersection
4	Urban	Motorcycle	Car	Straight
5	Non-urban	Motorcycle	Single vehicle	Not stated
6	Non-urban	Motorcycle	Car	Straight
7	Non-urban	Motorcycle	Car	Intersection

Literature Review (Task 2.1.2)

A review was made of available literature relating to PTW technologies and safety. Information was reviewed regarding existing and near to market motorcycle technologies which may have a role to play within an ISS. In addition technologies from four-wheeled vehicles were considered which may be at least conceptually, if not technologically, transferable. Pertinent rider/driver issues were reviewed, such as age, gender, behaviour, vehicle usage, etc. Information on interface design was considered, in terms of cognitive psychology theories and Human-Machine Interface (HMI), including standards, best practice and guidance. Specific attention was given to gender issues associated with the project. Where available, information was identified regarding the involvement of females in PTW accidents and injury severity, but also their current PTW usage, trends and forecasts for the future. In the conclusion of the literature review the findings of the technologies and rider/driver issues are summarised in a table. This provides an overview of the information and illustrates how the information may be applied in the context of the PISa project.

The main findings of this review were that many technologies already exist on some high performance/ cost PTWs and others exist in the wider road fleet. Thus, if these various technologies can be integrated and applied to the wider range of PTWs, many of the objectives of PISa can be achieved.

The output of this work is a public deliverable D3**:** Powered two-wheeler Integrated Safety (PISa): Review of PTW safety technologies and literature.

In-depth Accident Cases (Task 2.2.1)

The objective of this task was to select appropriate in-depth PTW accident cases and to review them using a common methodology. The aim of the review process was to acquire an understanding of the issues of accident causation and to identify the functional requirements of intervention methods that would be effective for accident avoidance or mitigation.

Existing in-depth databases were used comprising a forensic accident database and the COST 327 database held by LMU, the UK On The Spot (OTS) database and the UK Fatals accident database held by TRL and the UK OTS database held by the VSRC.

The 7 accident scenarios previously defined by the APROSYS project formed the basis for the selection of relevant accidents. National data from Germany, Italy, Spain and The Netherlands were shown to fit well with the APROSYS scenarios. However, since the majority of in-depth cases available to the PISa project were from the UK, it was necessary to consider whether the accident scenarios identified in APROSYS were also relevant in the accident statistics for Great Britain and to confirm if, and to what extent, they differ. A review of the national statistics for Great Britain (STATS19) was undertaken, and although this analysis showed that the priority of the scenarios is different, largely due to the different kinds of PTW in the UK fleet compared to that in Europe, it was concluded that a vast majority of the STATS19 accident cases could be described using the APROSYS scenarios. Analysis was also carried out to ensure that the two regional OTS databases held by TRL and the VSRC were representative of the national GB statistics. As a result of the general applicability of the APROSYS scenarios and the representativeness of the OTS data, it was considered that the in-depth cases from Great Britain could be used and that the findings from these cases would be applicable to European accidents in general.

Each team reviewed their existing in-depth accident cases according to an outline of accident characteristics and selected, according to a developed set of selection criteria, a number of cases (+/- 20) which fell within the scenarios of relevance as identified by 2.1.1 and which contained sufficient in-depth information. The selected cases were analysed in detail to determine their characteristics (reciprocal vehicle positions, vehicle speeds, etc), which in turn could allow the detection of a dangerous situation (e.g. stability hazard) or a pre-crash condition. A series of inter-team workshops was held to establish a common understanding to the analysis of the in-depth accident cases. This analysis addressed the pre-crash, crash and post crash accident phases. Case summaries were produced to aid the inter-team case review and validation process. These included descriptions of the crash circumstances, vehicles involved and damage sustained, individuals involved and injuries received and on some occasions witness statements of those involved. Also included were photographs of the scene, vehicles and approach and where available, scene plans with measurements and key scene information. Drive through video data for each accident case (where available) was also used to obtain aspects of pre-crash information. The detailed case reviews considered accident characteristics including accident causation, vehicle (PTW and opponent) characteristics, environmental factors, human factors, PTW rider and opponent vehicle occupant characteristics. All the selected cases were reviewed by LMU, TRL, VSRC and UNIFI, to clarify and confirm the issues and employ a common understanding and approach to the case analysis process. The result of this analysis was the finalisation of a list containing 43 intervention functions taken from the in-depth case analyses and ordered according to the pre-crash, crash and post-crash phases.

Each of the 60 in-depth cases was assessed against the list of 43 functions to determine whether each function might have made a contribution to crash avoidance, crash severity or injury severity reduction. This list was taken forward into Tasks 2.3.1 and 2.3.2 in order to assign safety systems to each of the functions and then prioritise them as described later.

In-depth Video (Task 2.2.2)

Task 2.2.2 of the PISa project was originally intended to include an analysis of existing junction video and in-depth accident case ride/drive through footage. Due to a change in the partner contributions and project plan at the start of PISa the analysis of existing junction video was not possible. It was therefore only possible to review video footage from in-depth accident cases where video footage either already existed or where it was recorded specifically for the PISa project. This video was recorded post-crash by the investigating teams following the route taken by the crash partners (PTW and other vehicles where relevant). Thus the video gives a drive–through perspective of the approach, site and background of the crash but it does not provide a visual reconstruction of the crash as the crash partners and circumstances are not present or recreated. In the PISa analysis the video was used to clarify the circumstances of the crash as interpreted by the review group from the case summary and supporting information. It was also possible to use the video to verify some of the variables recorded in the case information and in some cases, make general estimates of distances and angles of approach. It was also possible to consider possible lines of sight of both the rider and driver. The video was also helpful in considering the alternative actions and outcomes that may have been possible in each crash situation. As a consequence the video analysis was used to enhance the understanding of each in-depth crash case. In total, 48 of the 60 in-depth cases had associated video footage which was included in the case review process. This video footage was either available with the original case material or collected retrospectively as part of the PISa project activity.

User Information (Task 2.2.3)

A survey of PTW users was undertaken in Germany (D), Italy (I) and The Netherlands (NL). Additional information from an existing extensive UK survey was also analysed. The data collected included background information about the rider, their PTW and their views on various safety features, to obtain insight in the present usage of PTWs and the demand and acceptance for new safety systems.

The survey data allowed the information to be related to existing data sources and to investigate the trends in PTW accidents. This analysis was used to relate rider characteristics to accident risk and to the user acceptance of systems. In total 261 PTW riders were included in the survey (D=68, I=100, NL=93) of who 85% were male and 15% female. The total number of correspondents cannot be regarded as being representative for all PTW riders in the EU because of the limited amount of countries involved in this study. However, it provides user information for a large group of different types of riders from Germany, Italy and the Netherlands.

A total of 253 PTWs were owned by the survey population. These were classified according to 7 categories: sports, touring, roadster/conventional street style, cruiser, off-road/enduro, scooter >250cc and scooter <250cc. The distribution is given in Figure 2.

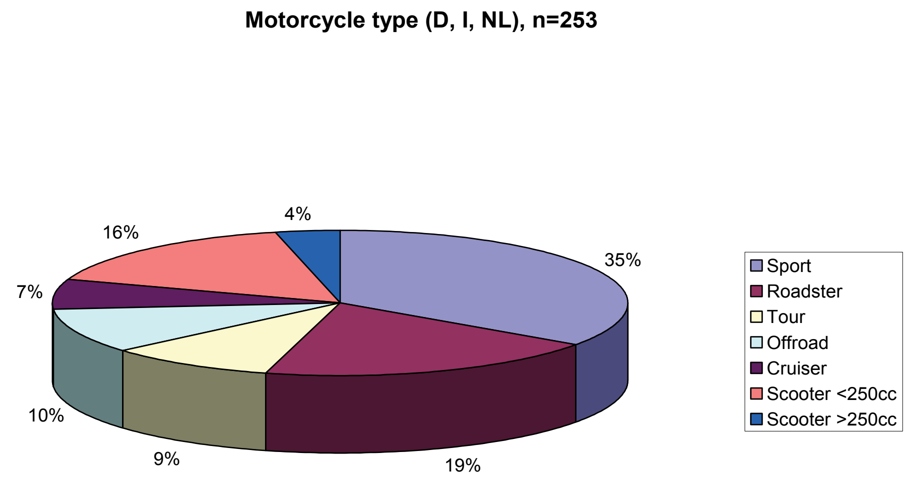

Figure 2. Motorcycle type (D, I, NL) n=253

The survey collected information including driving experience and licence held, types and circumstances of journey, reasons for riding a PTW, driving style and chosen protective equipment. Analyses of the data have been undertaken in order to establish the statistical relationships between variables of interest.

Of particular relevance to the PISa project were the views on safety systems. The outcome of the questionnaires referring to the desired systems showed that the PTW riders were in favour for direct driving support systems such as anti-lock brakes (ABS), electronic stability control (ESP/ESC), night vision displays, etc. Automatic support systems, taking away tasks from the PTW driver were disliked. It also seemed that the Italian drivers were more interested in the enhanced vision/night vision display than the other two countries. This could be related to the circumstances that the participants drove in, as Italian riders rode more during night and twilight than German and Dutch participants.

A disparity may exist between user acceptance and the potential benefit of safety systems due to the perception of systems, the motivation of PTW riding and the accident liability for rider groups. However, advanced handling and protection systems (AHPS systems) may be the most viable for implementation and could provide the most immediate safety benefits. Collision warning systems (CWS systems) should be prioritised towards inexperienced riders who have reduced hazard perception and observational skills and a high accident liability. This group may also have the least opposition to new safety systems. Although generally considered undesirable, automatic driving task support systems

(ADTS systems) should be focused towards particular user groups since the acceptance, functionality and therefore safety benefit is somewhat dependent on the purpose of riding.

The output of this work is a restricted deliverable D12**:** User Information, and an executive summary is available on the PISa website.

Matrix of Scenario Interventions and Priorities (Tasks 2.3.1 and 2.3.2)

The process of system selection and prioritisation was based on the accident data which was analysed in the in-depth case review. Having determined the functions which could serve as countermeasure interventions for each in-depth accident, it was necessary to consider the possible technical system solutions that would contribute either to accident avoidance and injury avoidance or mitigation. The first step was therefore to define systems which fulfilled the functional requirements. This list of systems was constructed initially at a global level and then at a specific technological level as illustrated in Table 3.

Table 3. An example of one of the 43 function/global system/specific system combinations.

Function	Global System	Specific System
Avoid locking of wheels	Braking	Anti-Lock Braking System (ABS)

It was then necessary to establish a priority list of these systems which would enable the PISa project to select those systems which would have most positive effect on accident prevention and/or mitigation.

Two different sets of analyses were completed to determine the priority list of functions. The first was carried out on the in-depth accident cases, where a system of scoring and weighting was developed. This scoring was allocated based on the expert team reviews, in which a common approach to the accident analysis and rating process was developed and validated in a series of inter-team workshops.

For the in-depth accident cases a matrix was constructed, consisting of the 43 functions/systems and the 60 accident cases in order to enable a score to be awarded to each system-case combination. A section of the matrix is shown in Table 4. A score of 0 (white) means that the system in question would not have had an effect on accident prevention, mitigation or injury severity reduction in that accident. A score of 1 or 2 (blue) was awarded if it was believed that the system would have a low level of influence on the accident. A score of 3 (orange) refers to a system which was felt would have a medium level of effectiveness in that accident situation whilst a score of 4 or 5 (red) was given if it was considered that the system being analysed would have had a significant impact on preventing the accident or on reducing the injury outcome. The colour coding produced a pictorial representation of the results that enabled a quick initial analysis of the 2580 system-case combinations to see which systems were affecting more accident cases.

Table 4. Illustration of the system-accident case matrix

Function	System	Accident Case Number		
		TRL0001	VSRC0002	LMU0003
Prevent PTW from starting if BAL > 0.5mg	Alco-lock key	1	0	4
Improve PTW con-spicuity	Active light-ing	0	2	3
Prevent PTW wheels from lock-ing	ABS	5	1	0

The second analysis was carried out on the UK Fatals Database. Due to nature of the coded data contained within this database, a rule-based system method of analysis was used to determine which systems would and would not have positively influenced the accident.

The ranking of functions based on the scores provided by the case by case analysis was used as the main input to prioritising the systems. The system list used as the basis of the proposed system selection was the "all scores" assessment of the in-depth cases for which any benefit was predicted. The most important priorities for PTW crash reduction were warning the other vehicle of the PTW presence and automatically stopping that vehicle. However, these and other functions that were deemed to be outside of the scope of the PISa project or not within the capability of the PISa consortium were then removed to give the priority list relevant to PISa. This proposed systems list is therefore the recommendation from WP2 to WP3 and an input for an initial benefit assessment which will assess the proposed list in terms of the monetary casualty benefit predicted for each system. The proposed system list was as follows:

- Stop PTW (autonomous braking)
- PTW to detect other vehicle and warn rider
- Special Fairings on PTW (improve PTW conspicuity with special fairings)

- ABS (anti-lock braking system)
- Brake Assist - EBS (enhanced braking system)
- Brake Assist - CBS (combined braking system/linked brakes)
- ACC (adaptive cruise control)

In addition, a review of the data and a small sample of cases from India confirmed that there was broad agreement with the proposed systems chosen with relevance to the traffic conditions in India.

Derived Driver Assistance Functions - Estimate of Impact (Task 2.3.3)

An initial benefit estimate was carried out on the proposed systems. This used the outputs from the prioritisation process to assess the 'target population' benefit attributable to each of the systems, where the target population is the number of annual casualties which may be influenced by the system.

The target population benefit assumes that the systems are 100% effective, and as such, this value provides the maximum potential benefit for each system. The potential benefit was calculated for European PTW casualties based on those systems that were predicted to have any level of influence on the accident, and those in which the system was predicted to have a significant influence on the accident. This analysis was also repeated for Great Britain, since it was known that the distribution of PTW bike styles is different to the general European picture.

Using values for the estimated number of annual PTW fatal, serious and slight casualties for Europe and Great Britain a series of calculations were made to derive estimates regarding the distribution of the severity classes by APROSYS accident scenario and the percentage of accident cases in each APROSYS scenario where the system was predicted to provide a benefit. Combining these values and scaling them up to annual casualty numbers resulted in the target population. Monetary values were then assigned to these numbers of casualties to provide an annual casualty benefit for each system. This analysis revealed that for Europe, the priority order of systems in terms of benefit was nearly identical to the priority order proposed by Task 2.3.2 Scenario Interventions and Priorities.

The analysis of data from Great Britain exhibited expected differences when compared with European accidents. This is due to the different bike type distribution and hence the difference in use and accident circumstances. For Great Britain, the systems selected fit well to the proposed systems, with the top five priorities covered. For those accidents which the system was predicted to make a significant difference, the selection of systems fits less well, although the two main priorities are addressed.

It should be noted that significant assumptions were made in the methodology that have not been validated. The largest of these assumptions is that the in-depth accidents taken as a sample of each APROSYS accident scenario were representative of European or national accidents. However, this and other assumptions were necessary to produce the best possible benefit assessment to validate the selection of systems for development within the PISa project. A more refined benefit estimate is planned for later in the PISa project in which realistic assessments of the effectiveness of the systems will also be incorporated.

The results of this benefit assessment confirm that the systems proposed to be taken forward by the PISa project are, in the light of the available information, appropriate in terms of the target population benefit. In conclusion, the systems proposed to be taken forward by the PISa project are:

- Slow/stop PTW (autonomous braking)
- PTW to detect other vehicle and provide warning (forward collision warning)
- Brake Assist - EBS (enhanced braking system)
- ABS (anti-lock braking system)
- Brake Assist - CBS (combined braking system/linked brakes)
- ACC (adaptive cruise control)
- Special fairings (improve PTW conspicuity with special fairings)

Status of PISa (as at July 2008)

In WP3: System Specification, computer tests and simulations have been carried out to analyse the rider kinematics in different accident mechanisms, taking into account the influence of muscle activity. The driver assistance functions and the parameters to be used in PISa have been chosen and are fixed in a system layout. The control logic for the integrated system is currently under development, and will be finalised in collaboration with WP4.

Work in WP4: System Development is progressing, various sensors have been selected and a state estimator in the form of a sensor is available. The total system layout including the desired functionality is defined and a controller is under development. The various human machine interfaces (HMI's) have been defined and the hardware is under development. The demonstrator PTWs are two Malaguti 500cc scooters and two TVS Apache 160cc motorbikes as shown in Figure 3. The layout charts of the ISS system for the Malaguti and TVS bikes have been prepared, as have layout charts of the interfaces and data protocols. A coordinated work plan between WP4 and WP5 has been prepared.

Figure 3. The Malaguti and TVS demonstrator PTWs

In WP5: System Integration the four PTWs will each undergo different developments, due to logistical reasons within the PISa project, including the limited timescale and budget and the varied expertise and geographical locations of the partners. The integration of the systems on the 4 PTWs has commenced and will continue during the coming months.

A laser scanner has been integrated into one of the Malaguti scooters, including all electrical and mechanical work necessary to accommodate the state estimating device, the power supply, and the decision logic in the baggage compartment of the bike. The first 5 live-test-rides with the laser-scanner integrated into the Malaguti have been conducted. The second Malaguti will be equipped with active forks, brakes and a haptic throttle. One of the TVS motorcycles will have the semi-active suspension system and the other will be equipped with a combined braking system.

The work of WP6: Evaluation and Validation has not begun but initial consideration is being given to the preparation of the test plan. This will include both track and road tests of the demonstrators and will involve skilled test riders and 'typical' riders, subject to ethical permissions. In addition, simulations will be performed using a simulator and video wall. These will be used to evaluate situations with extreme risk where specific controlled scenarios will be presented to the subjects. Information regarding initial reaction and physical response will be recorded.

The initial benefit estimate work will be extended into a thorough cost benefit analysis. This will enable the cost savings related to casualty reduction to be compared with the cost of fitting the devices/system to PTWs.

Finally a prototype demonstrator will be developed following consolidation of the results from the laboratory and track/road trials in the form of upgrades and optimisation of the systems.

The work of WP6 will be undertaken during 2009 with the final demonstrator available by the end of the project in November 2009.

Conclusion

Seven priority accident scenarios were confirmed using existing analyses of PTW accident statistics. A case review of representative crashes was undertaken using existing in-depth data. A survey of PTW riders was carried out and existing survey data was re-analysed. Using this information, the functional requirements which would contribute to the avoidance of the crash and/or the reduction in the injury severity were determined and prioritised. Consideration was given to vehicle dynamics, rider/driver behaviour, protective equipment and HMI issues, environmental and road infrastructure factors, technological developments and vehicle communications.

From a functions matrix system priorities across the spectrum of PTW accident scenarios have been determined. Important priorities for PTW crash reduction are warning the other vehicle of the PTW presence and automatically stopping that vehicle, but implementation of these systems is outside the scope of PISa. Regarding PTW systems, priorities are warning the PTW of the presence of the other vehicle to improve crash avoidance and improvements to the PTW braking system including semi-autonomous braking to improve casualty reduction.

Those priorities which fall within the scope of PISa have been translated into a system specification and the relevant technologies are currently being developed and implemented on the PISa demonstration vehicles. The HMI (human-machine interface) issues are being considered and a test programme will be developed and conducted in 2009. An initial casualty reduction potential and cost benefit analysis has been made which will be validated and consolidated in the final stages of the PISa project.

Acknowledgement

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Active Safety for Motorcycles based on Vehicle-to-Vehicle-Communication

Aktive Motorradsicherheit auf Basis von Fahrzeug-Fahrzeug-Kommunikation

Reiner Pfeifer, Peter Müller
BMW Motorrad, München

Felix Klanner, Arne Purschwitz, Timo Kosch
BMW Group Forschung und Technik, München

Abstract

With it's white paper: "European transport policy for 2010", the European Union sets the target to halve the number of fatal accidents in road traffic from more than 50,000 in 2001 until 2010. BMW Motorrad faces up to this challenge. BMW Motorrad has already introduced numerous safety technologies such as ABS (**Anti-Lock Brake System**) and ASC (**A**utomatic **S**tability **C**ontrol). Out of in-depth accident analyses, BMW Motorrad has developed a straightforward strategy for motorcycle safety. To further improve safety on motorcycles, we believe that foresighted active safety concepts will play an important and growing role in future. Accident data show that intersections are still accident-prone sites.

To improve safety at intersections, BMW develops assistance systems to avoid both accidents in turning and crossing situations within the scope of the nationally funded research project AKTIV (Adaptive and co-operative technologies for the intelligent traffic). This paper describes the underlying concepts of this assistance as well as a specific crossroad scenario. To receive information about surrounding traffic, direct vehicle-to-vehicle communication is used. In the scenario presented, a passenger car has to yield right-of-way. In case of a potential violation, the driver receives a warning while the motorcycle itself activates additional optic and acoustic measures to improve its perceptibility.

Kurzfassung

Ein wichtiges Ziel des EU-Weißbuches besteht in der Reduzierung der Unfalltoten im Straßenverkehr von mehr als 50.000 (2001) um 50% bis zum Jahr 2010. BMW Motorrad stellt sich dieser Herausforderung. Dem Schwerpunkt Verkehrssicherheit im EU-Weißbuch wird bei BMW Motorrad durch zahlreiche Entwicklungen und Aktivitäten, wie z.B. ABS (**A**nti-**B**lockier-**S**ystem) oder ASC (**A**utomatische **S**tabilitäts **C**ontrol), Rechnung getragen. Aus den Erkenntnissen der Unfallanalysen hat BMW Motorrad eine zielorientierte Strategie zur Motorradsicherheit entwickelt. Zur Erhöhung der Sicherheit wird ein besonderes Augenmerk auf vorausschauende aktive Sicherheitskonzepte gelegt. Aus der Unfallanalyse folgt, dass der Kreuzungsbereich einen Hauptunfallschwerpunkt darstellt.

Um die Sicherheit an Kreuzungen zu erhöhen, wird von der BMW Group im Rahmen des nationalen Förderprojekts AKTIV (**A**daptive und **K**ooperative **T**echnologien für den **I**ntelligenten **V**erkehr) ein Assistenzsystem zur Vermeidung von Unfällen beim Einbiegen/Kreuzen entwickelt. Der vorliegende Bericht zeigt das Grundkonzept dieser Assistenz sowie ein dargestelltes Kreuzungsszenario auf. Zur Erfassung der Daten anderer Fahrzeuge wird auf die Fahrzeug-Fahrzeug-Kommunikation zurückgegriffen. Im dargestellten Szenario ist das Motorrad vorfahrtsberechtigt. Im Falle einer potenziellen Vorfahrtsmissachtung durch einen Pkw erhält der Pkw-Fahrer eine Warnung und das Motorrad erhöht visuell und auditiv seine Wahrnehmbarkeit.

BMW Motorrad - Aktive Sicherheit auf Basis von Fahrzeug-Fahrzeug-Kommunikation

1 Die europäische Verkehrspolitik – das EU-Weißbuch

Die Europäische Charta für die Straßenverkehrssicherheit ist eine der Hauptinitiativen der Europäischen Kommission. Sie hat zum Ziel, bis zum Jahre 2010 die Zahl der Straßenverkehrstoten um 50% zu reduzieren (Basis ist das Jahr 2001), gemäß des Weißbuches „Die europäische Verkehrspolitik bis 2010: Weichenstellung für die Zukunft“.[1]

Das Weißbuch umfasst ein Programm von mehr als 60 Maßnahmen. Dazu gehört ein Aktionsprogramm, dessen Maßnahmen sich – mit Zwischenzielen – bis zum Jahr 2010 erstrecken. Bis zum Jahre 2005 konnte bereits die Zahl der Verkehrstoten um mehr als 16% reduziert werden.[2] Themen im Weißbuch, die den Leitlinien der EU gerecht werden, sind unter anderem die „Verbesserung des Straßenverkehrs“ und „Erhöhung der Straßenverkehrssicherheit“. Obwohl im EU-Weißbuch Motorräder bislang nur im Nebensatz erwähnt sind, zeigt sich anhand aktueller Statistiken, dass die prozentuale Auffälligkeit der verunglückten Motorradfahrer stetig mit der zunehmenden Wirkung von Sicherheitskonzepten bei anderen Verkehrsmitteln (Fahrdynamikregelsysteme, Nachtsichtassistenz, Spurhaltefunktionen) wachsen wird.

Die Verbesserung der Motorradsicherheit ist seit langem eines der Kernziele bei BMW. Dies wurde unter anderem nachdrücklich durch die konsequente Strategie zum Motorrad ABS aufgezeigt. Die Entwicklungen RDC (**R**eifen **D**ruck **C**ontrol), ASC und Xenon-Abblendlicht wurden detailliert in Foith[3] und Wagner[4] beschrieben.

2 BMW Motorradsicherheit

Freude am Fahren und die Erhöhung der Sicherheit sind bei BMW Motorrad wesentliche Triebfedern bei der Entwicklung von Motorrädern. BMW Motorrad hat sich als einer der ersten Motorradhersteller bereits in den 70er Jahren aktiv zur Motorradsicherheit bekannt. Der Einstieg wurde mit dem bei BMW Motorrad entwickelten Motorradhelm 1976, der Fahrerausstattung 1986 bis hin zum Motorrad ABS 1988 vollzogen.

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[1] Europäische Kommission (2001): Weißbuch.

[2] Europäische Kommission (2007): Weniger Verkehrstote auf Europas Straßen!

[3] Foith et al. (2006): Meilensteine der aktiven Sicherheit bei BMW Motorrad.

[4] Wagner et al. (2006): Entwicklungstendenzen von Fahrwerkregelsystemen bei BMW Motorrad.

Aus intensiven Untersuchungen im Bereich der passiven Schutzsysteme bei BMW Motorrad wurde jedoch erkannt, dass ein Sicherheitsniveau mittels passiver Systeme vergleichbar dem bei Pkw bei Motorrädern nicht erreichbar sein wird. Weiterhin sind den passiven fahrzeuggebundenen Systemen bei Motorrädern durch die generell vorhandene Trennung des Fahrers / Sozius vom Motorrad im Unfallverlauf physikalisch Grenzen gesetzt. In Folge dieser Randbedingungen besitzen die passiven Systeme nur einen begrenzten Wirkungsbereich im repräsentativen Unfallgeschehen.

Abgeleitet aus diesen Erkenntnissen ist bei BMW Motorrad das Augenmerk auf die Weiterentwicklung bzw. Einführung neuer Konzepte im Rahmen der aktiven Motorradsicherheit gelegt worden. Im Jahr 2005 mit der weltweiten Ersteinführung des Xenon-Abblendlichts, gefolgt von den Systemen ASC und RDC im Jahr 2006 / 2007, führte BMW Motorrad drei Systeme in Serie ein, welche die aktive Motorradsicherheit verbessern.

Um die Motorradsicherheit nachhaltig zu erhöhen werden bei der BMW Group weitere Konzepte zur Verbesserung der Motorradsicherheit geprüft. Dabei zeigt sich, dass als Grundlage für aktive Sicherheitssysteme der Umfelderfassung eine große Bedeutung zukommt. Im Pkw wird diese in der Regel auf Basis fahrzeuggebundener Sensorik (z.B. Radar) realisiert. Mit dieser ist jedoch die Erfassung der Positions- und Fahrdynamikdaten von Zweirädern nur eingeschränkt möglich. Zur Lösung dieser Problematik stellt die Nutzung von Fahrzeug-Fahrzeug-Kommunikation ein viel versprechendes Konzept dar.

Im Folgenden wird das Grundkonzept eines Assistenzsystems, basierend auf Fahrzeug-Fahrzeug-Kommunikation, dargestellt.

3 Grundkonzept eines Assistenzsystems basierend auf Fahrzeug-Fahrzeug-Kommunikation

Wie aus Abb. 1 ersichtlich, basiert das Grundkonzept auf drei Teilsystemen:

1. System zur Generierung der Positions- und Fahrdynamikdaten jedes Fahrzeugs
2. Kommunikationssystem
3. Assistenzsystem

Die Eingangsgrößen in das Assistenzsystem im Eigenfahrzeug sind die Positions- und Fahrdynamikdaten des Eigenfahrzeugs und der Fremdfahrzeuge. Die Informationen der Fahrzeuge werden über ein

Kommunikationssystem übertragen. Die Funktion des Assistenzsystems im Eigenfahrzeug ist unabhängig davon, ob in den Fremdfahrzeugen Assistenzsysteme integriert sind oder nicht.

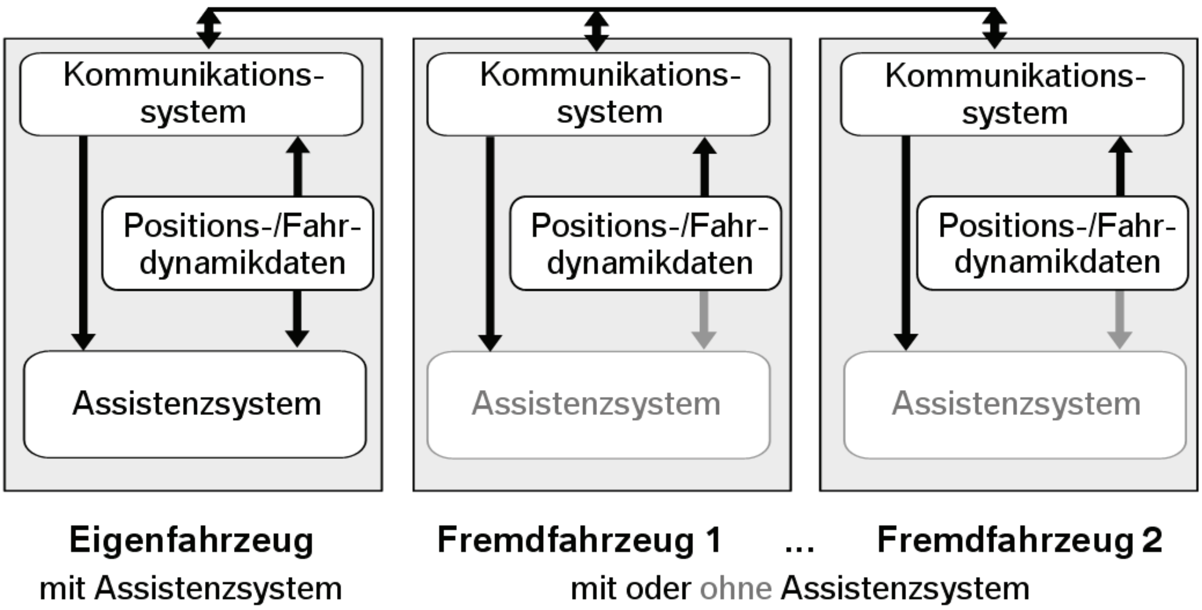

Abb. 1: Grundkonzept für das Gesamtsystem

Fig. 1: Basic concept of the complete system

In den folgenden Kapiteln wird detailliert auf die Teilsysteme eingegangen.

3.1 Positionsbestimmung

Für die absolute Positionsbestimmung bietet sich das Satellitennavigationssystem GPS (**G**lobal **P**ositioning **S**ystem) an. Diese Positionsbestimmung wird durch verschiedene Fehlerquellen verfälscht. Im Rahmen von Klanner[5] wurden Stillstandsmessungen über einen Zeitraum von 30 Minuten durchgeführt. Dabei zeigte sich eine maximale Positionsabweichung gegenüber dem Mittelwert aller GPS-Punkte von +14m bis -11m. Eine Verringerung der Positionsabweichung kann durch die Verwendung eines Korrektursignals erreicht werden, dem so genannten DGPS (**D**ifferential **GPS**). So lagen die maximalen Positionsabweichungen unter gleichen Randbedingungen zwischen ±3m. Messfahrten in der Stadt haben jedoch gezeigt, dass diese Positionsabweichungen auch teilweise über ±10m liegen. Ursache hierfür ist insbesondere eine Mehrwegeausbreitung des GPS-Signals durch Reflektion an Objekten, wie Gebäuden (Multipath-Effekt). Eine Positionsbestimmung nur auf Basis von GPS weist daher nur eine geringe Zuverlässigkeit auf.

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[5] Klanner (2004): Analyse des Potentials von Satellitennavigation bei der Kreuzungsassistenz.

Um die Zuverlässigkeit zu erhöhen, wird eine Kopplung von DGPS und Fahrdynamikdaten vorgeschlagen. Der Vorteil dieser Kopplung besteht im gegenläufigen Fehlerverhalten der beiden Datenquellen. So kann auf kurze Strecken die Fahrzeugposition sehr gut durch eine Integration der Fahrdynamikdaten fortgeführt werden. Über den Weg summiert sich jedoch auch der Messfehler der einzelnen Sensoren, was zu einer Zunahme der Positionsabweichung führt. Dem gegenüber steht auf langen Strecken eine gute Positionsfortschreibung mit DGPS-Koordinaten. Die Koppelung wird in einem Kalman-Filter durchgeführt. Der Kalman-Filter zählt zu den Verfahren die der optimalen Schätzung des Zustandes dynamischer Systeme dienen, trotz mancher Störeinflüsse und Unsicherheiten, wie sie die Praxis mit sich bringt.[6]

Im Kalman-Filter wird von stochastisch verteilten Messfehlern ausgegangen. Treten jedoch wie beim Multipath-Effekt systematisch verfälschte Messdaten auf, so führt dies zu einem inkonsistenten Filterergebnis. Dies zeigt die Notwendigkeit einer dem Kalman-Filter vorgelagerten Signalplausibilisierung auf. Durch diese werden systematisch verfälschte DGPS-Messdaten erkannt und verworfen. Damit erfolgt die Positionsfortschreibung zeitweise nur noch mit Fahrdynamikdaten.

3.2 Kommunikationssystem

Seit mehreren Jahren wird im Rahmen verschiedner nationaler und internationaler Projekte an der Entwicklung eines herstellerübergreifenden Kommunikationssystems gearbeitet. Ein Beispiel ist das vom BMBF (**B**undes**m**inisterium für **B**ildung und **F**orschung) geförderten Projekte NoW (**N**etwork **o**n **W**heels). Um einerseits eine erhöhte Wirksamkeit und andererseits eine größere Wirtschaftlichkeit des Kommunikationssystems zu erreichen, ist eine möglichst weite Verbreitung der Technologie wichtig. Zur Beschleunigung der Einführung hat sich das C2C CC (**CAR 2 CAR C**ommunication **C**onsortium) gebildet, welches auf Betreiben europäischer Automobilhersteller zustande gekommen ist. Aufgabe dieses Konsortiums ist die Definition von Standards für die eingesetzte Kommunikation als Voraussetzung für eine schnelle und effektive Markteinführung. Aktuell wird an einem WLAN-basierten Standard im Frequenzband von 5,9 GHz gearbeitet. Grundlage hierfür ist das in den USA bereits in Referenzimplementierung verfügbare Konzept des geplanten WLAN-Standard IEEE802.11p. Dieser WLAN-Standard wird eigens für die Kommunikation zwischen Fahrzeugen sowie Fahrzeugen und der Infrastruktur entwickelt.

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[6] Brammer/Siefling (1994): Kalman-Bucy-Filter.

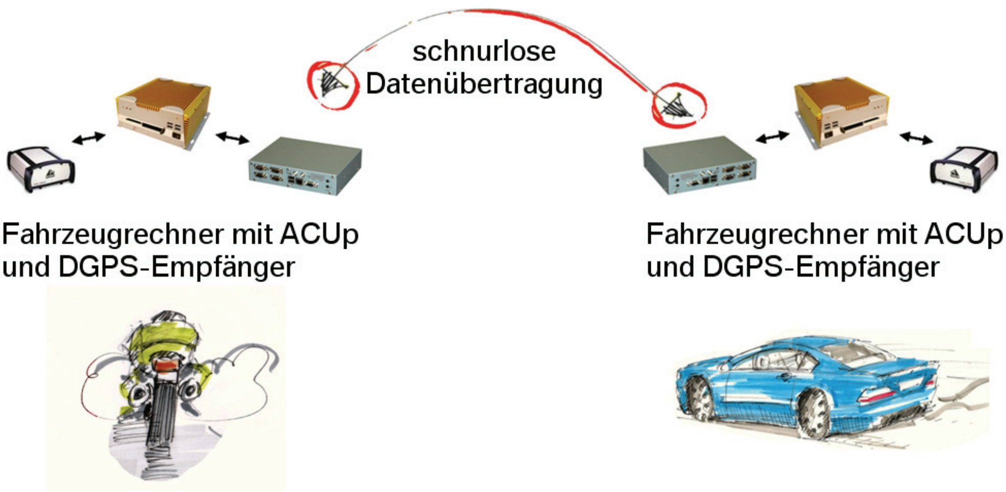

Abb. 2: Fahrzeug-Fahrzeug-Kommunikationskonzept basierend auf dem Kommunikations-Framework ACUp

Fig. 2: Vehicle-to-Vehicle-Communication based on the ACUp-Communication-Framework

Auf Basis der Arbeiten von NoW und dem C2C-CC wurde im Rahmen von AKTIV das Kommunikationssystem ACUp (**A**KTIV **C**ommunication **U**nit based on 802.11**p**) entwickelt.[7] Ein Ziel bestand dabei darin, auch die hohen Anforderungen von Sicherheitsapplikationen an das Kommunikationssystem, wie eine Latenzzeit von kleiner 100 ms und Updaterate von bis zu 10 Hz, zu erfüllen.[8] Dieses Kommunikationssystem wird für den Datenaustausch zwischen den Fahrzeugen verwendet. Die benötigten Hardware-Komponenten werden in Abb. 2 dargestellt.

3.3 Assistenz

Die Ausprägung der Assistenz wird aus der Unfallanalyse abgeleitet. Dabei werden die Unfallsituationen ausgewählt, bei denen der Einsatz eines aktiven Sicherheitssystems einen großen Nutzen verspricht. Dies sind Situationen, bei denen so viele Unfälle entstehen, dass ein relevantes Reduktionspotential vorhanden ist. Zudem muss die Möglichkeit einer Unfallvermeidung durch ein aktives Sicherheitssystem überhaupt aus technischer Sicht gegeben sein.

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[7] Zahn/Kosch (2008): AKTIV Communication Unit based on 802.11p.

[8] Klanner/Ehmanns/Winner (2006): ConnectedDrive: Vorausschauende Kreuzungsassistenz.

Die Auswertung der GIDAS (**G**erman **I**n-**D**epth **A**ccident **S**tudy)[9] Unfalldatenbank mit Unfällen aus den Jahren 1999 bis 2006 zeigt, dass 39% aller getöteten Motorradfahrer dem Fahrunfall sowie 26% dem Kreuzungsunfall (Abbiegen, Einbiegen/Kreuzen) zuzuordnen sind. Dieser Auswertung liegen gewichtete Fälle zu Grunde, so dass die Aussagen als repräsentativ für ganz Deutschland gelten können. Um die Zahl der Getöteten und verletzten Motorradfahrer zu reduzieren, sind bereits aktive Sicherheitssysteme wie ABS, RDC und ASC bei BMW Motorrad in Serie eingeführt. Diese unterstützen den Motorradfahrer aktiv bei der sicheren Führung des Motorrads.

Das Ziel aktueller Forschungsarbeiten besteht nun in der Erhöhung der Sicherheit an Kreuzungen. Als Grundlage wird hierfür eine Klassifizierung der Kreuzungsunfälle durchgeführt. Hiefür bieten sich die Datenbanken MAIDS (**M**otorcycle **A**ccidents **I**n-**D**epth **S**tudy)[10] und GIDAS an. Diese Datenbanken zeichnen sich durch einen umfassenden Informationsgehalt zum Unfallablauf und den Unfallfolgen aus.

Als Klassifizierungskriterien werden das Unfallszenario und die Unfallursache betrachtet. Die zusammen häufigsten Unfallszenarien bei Unfällen mit getöteten und verletzten Motorradfahrern an Kreuzungen werden in Abb. 3 dargestellt.

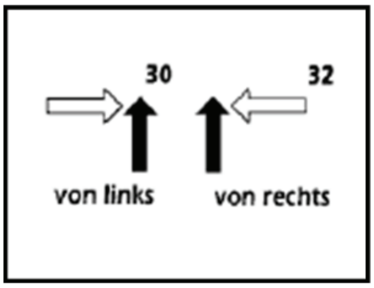

Abb. 3: Häufigste Unfallszenarien beim Einbiegen oder Kreuzen mit getöteten und verletzten Motorradfahrern

Fig. 3: Most frequent accident scenarios when turning or crossing with fatalities and injured motorcycle riders

Im Rahmen durchgeführter Einzelanalysen zeigt sich, dass die häufigsten Unfallursachen bei Kreuzungsunfällen Unaufmerksamkeit und Fehleinschätzung des wartepflichtigen Pkw-Fahrers sind. Dies zeigt die Notwendigkeit, den Pkw-Fahrer möglichst schon bei der Kreuzungsannäherung bei der

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[9] Hannawald (2005): Unfallanalyse zur Entwicklung und Bewertung von Fahrerassistenzsystemen.

[10] MAIDS (2008): Motorcycle Accidents In-Depth Study.

Erkennung potenziell kritischer Verkehrssituationen zu unterstützen. Um dies zu erreichen, wird bei der BMW Group ein kommunikationsbasierter Querverkehrsassistent entwickelt.

4 Kommunikationsbasierte Querverkehrsassistenz

Im kommunikationsbasierten Querverkehrsassistenten wird zunächst auf Grundlage der Eigen- und Fremdfahrzeugdaten eine Beurteilung des Kreuzungsgeschehens durchgeführt. Eine hierauf aufbauende Assistenz unterscheidet sich danach, ob sie im Pkw oder auf dem Motorrad erfolgt. Hierauf wird im Folgenden genauer eingegangen.

4.1 Grundlage für eine Assistenz

Im Assistenzsystem werden grundsätzlich drei Informationen ermittelt:

- Kollisionswahrscheinlichkeit
- Vorfahrtsituation
- Beurteilung des Verhaltens vom Pkw-Fahrer

Zur Bestimmung der Kollisionswahrscheinlichkeit muss jedes Fahrzeug, das in die Wahrscheinlichkeitsberechnung einbezogen wird, über eine Positionsbestimmung verfügen. Für die Berechnung der Kollisionswahrscheinlichkeit werden aus den Positionsdaten aller erfassten Fahrzeuge, einschließlich des eigenen Fahrzeuges, die Trajektorien prädiziert. Aus Unfallanalysen ist bekannt, dass bei den meisten Kreuzungsunfällen mit Querverkehr die Fahrbahnen keine oder nur eine schwache Krümmung aufweisen. Daher wird für die Trajektorienprädiktion zunächst eine Gerade angenommen. Grundsätzlich ist es aber auch denkbar, die Fahrbahnkrümmung aus einer digitalen Karte zu entnehmen und bei der Trajektorienprädiktion zu berücksichtigen.

Für die Beurteilung der Vorfahrtssituation wird auf eine erweiterte digitale Karte zurückgegriffen, denn aktuell ist diese Information noch nicht in den verfügbaren digitalen Karten enthalten.

Der Beurteilung des Verhaltens vom Pkw-Fahrer kommt eine große Bedeutung zu. Denn die Akzeptanz eines Assistenzsystems wäre problematisch, wenn eine Warnung erfolgt, obwohl der Pkw-Fahrer die Verkehrssituation richtig interpretiert. Daher muss der Querverkehrsassistent vor einer Warnung erkennen, ob der Fahrer richtig reagiert. Dies wird beispielsweise anhand des Geschwindigkeitsverlaufes entschieden.

4.2 Assistenz im wartepflichtigen Pkw

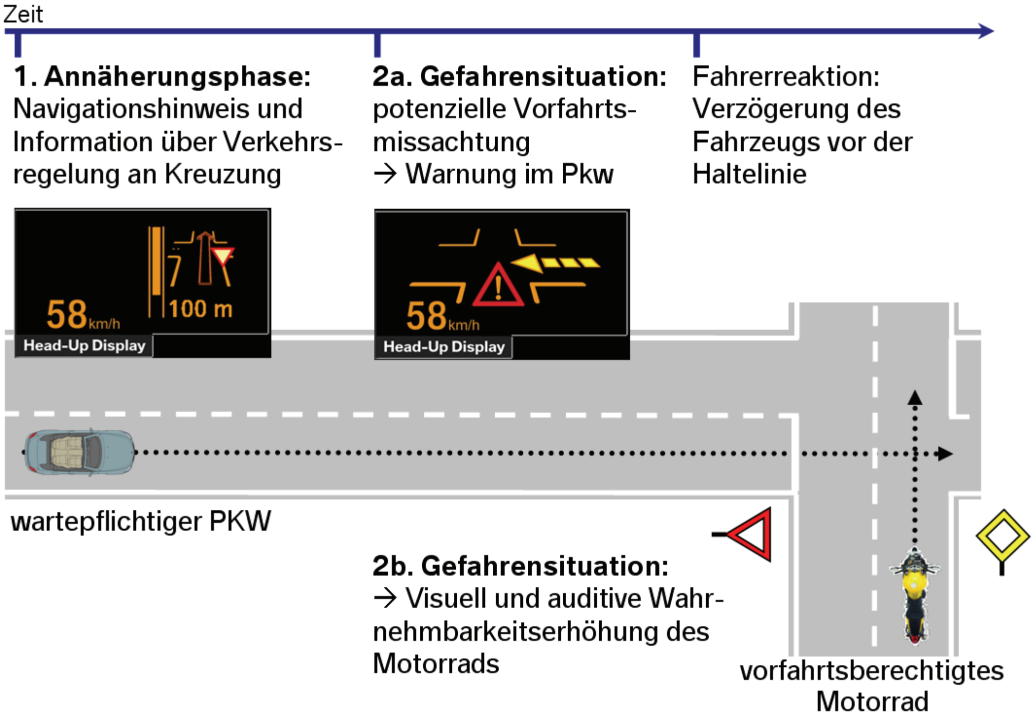

Abb. 4: Assistenzmaßnahmen des Querverkehrsassistenten im Pkw und Motorrad

Fig. 4: Assistant measures of the cross traffic assistant within the car and motorcycle

Eine Assistenz im Pkw erfolgt nur, wenn sich dieser auf einer nicht vorfahrtsberechtigten Straße befindet. Die Assistenzstufen im Pkw werden in Abb. 4 dargestellt.

Bereits während der frühen Phase der Kreuzungsannäherung erhält der Pkw-Fahrer eine Information über die Verkehrsregelung an der Kreuzung. Diese wird zusammen mit dem Navigationshinweis ausgegeben.

Eine zweite Assistenzstufe erfolgt nur, wenn eine hohe Kollisionswahrscheinlichkeit vorliegt und der Pkw bereits den letztmöglichen Warnzeitpunkt erreicht hat. In diesem Fall erfolgt die Ausgabe einer visuell-auditiv-haptischen Warnung.

- Visuelle Warnung: Warnung erfolgt durch Einblenden des Warnsymbols (siehe Abb. 5) im Head-Up-Display
- Auditive Warnung: Warnung erfolgt durch Warnton im PKW
- Haptische Warnung: Verzögerung des Pkw während der Reaktionszeit mit einer ACC-Bremsung

Abb. 5: Warnsymbol des kommunikationsbasierten Querverkehrsassistenten im Instrumenten-Kombi und dem Head-Up Display

Fig. 5: Warning icon of the communication based cross traffic assistant in the Instrument cluster and Head-Up Display

Das Ziel dieser Warnung besteht darin, die Aufmerksamkeit des Pkw-Fahrers auf die potenziell kritische Kreuzungssituation zu lenken. Die Warnung erfolgt auf der einen Seite so rechtzeitig, dass der Fahrer das Fahrzeug noch vor der Haltelinie zum Stehen bringen kann. Andererseits liegt die Warnung so spät, dass der Pkw-Fahrer nur in einer voraussichtlich sehr kritischen Kreuzungssituation eine Warnung erhält. Es wird davon ausgegangen, dass durch eine Vollverzögerung des Fahrers die kritische Kreuzungssituation entschärft wird.

4.3 Assistenz auf dem vorfahrtsberechtigten Motorrad

Die Unfallstatistiken zeigen, dass Gefahrensituationen für Motorradfahrer an Kreuzungen im wesentlichen dadurch entstehen, dass der Motorradfahrer von anderen Verkehrsteilnehmern nicht wahrgenommen, oder die Situation falsch eingeschätzt wird. Die im Vergleich zum Pkw generell erschwerte Wahrnehmbarkeit des Motorrades spielt hier eine große Rolle. Durch die deutlich schmalere Silhouette sind das Erkennen und die Einschätzung der Geschwindigkeit beim Motorrad schwieriger. Mit diesen Randbedingungen ist das Ziel die Wahrnehmbarkeit des Motorrades an Kreuzungen zu erhöhen.

Die Wahrnehmbarkeitserhöhung beim Motorrad wird situationsabhängig in Form folgender vier Stufen realisiert.

- **Modulation** des Fahrlichts
- **Erhöhung** der Fahrlicht**intensität**
- **Zusätzliche** Aktivierung von weiteren **Lichtquellen** (LED) an der Fahrzeugfront und Fahrzeugseite, zur Verbreiterung der beleuchtet Silhouette
- Aktivierung der **Hupe**

Nähert sich das vorfahrtsberechtigte Motorrad einer Kreuzung, in deren nahem Umfeld sich bereits andere Verkehrsteilnehmer befinden, so wertet der Querverkehrsassistent die Situation aus und bewertet die Kollisionswahrscheinlichkeit. Werden die Kriterien für eine Wahrnehmbarkeitserhöhung am Motorrad im Querverkehrsassistent erfüllt, werden abstandsabhängig obige vier Stufen zur Wahrnehmbarkeitserhöhung durchlaufen.

Diese Funktion ist bei der BMW Group in einem Prototyp umgesetzt und wird in Realsituationen getestet.

5 Ausblick

Die Zukunft des Motorrads wird wesentlich durch Entwicklungen im Bereich der Motorradsicherheit beeinflusst. Daher ist es wichtig, dass sich Systeme der passiven Sicherheit (z.B. Neck-Brace-System) sowie der aktiven Sicherheit (z.B. ASC) weiter etablieren. Neben diesen individuellen Maßnahmen zur Sicherheitserhöhung sind auf Grund der Erkenntnisse aus Unfallanalysen auch kooperative Systeme notwendig. So zeigt sich, dass bei Motorrad-Pkw-Kollisionen ein hoher Anteil durch Unachtsamkeit oder falsche Einschätzung des Pkw-Fahrers verursacht wird. Der vorgestellte kommunikationsbasierte Querverkehrsassistent ist hierfür ein Lösungsansatz, der auch für weitere Kreuzungssituationen Potenzial zur Unfallvermeidung bietet.

6 Zusammenfassung

Ausgehend von den Zielen des Europäischen Weißbuches über einen Abriss der BMW Motorradsicherheit wurde in der vorliegenden Abhandlung das Konzept einer Querverkehrsassistenz auf der Basis der Fahrzeug-Fahrzeug-Kommunikation dargestellt. Die Motivation für das konkrete Szenario wurde aus der Unfallanalyse gewonnen. Anschließend wurden Konzepte für die Assistenzmaßnahmen auf der Seite des Pkw und des Motorrades dargestellt. Ein Ausblick über die Motorradsicherheit bildet den Abschluss.

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Changes in blood pressure (RR), heart rate (HR) and energy profile (EP) depending on age (years), body mass index (BMI), general physical level (h/week) and job-related and time spent motor cycling during long-time motor cycling for average male test person

Blutdruck- (RR), Herzfrequenz- (HF) und Energieprofil- (EP) Veränderungen korreliert zum Alter (Jahre), zum Body Mass Index (BMI), zur körperlichen Fitness (h/Woche) und zum Motorradfahren – beruflich und in der Freizeit – beim Langzeitmotorradfahren männlicher Normalpersonen

Rainer Nietschke, Dr. med. Georg Huber, Prof. Dr. med. Aloys Berg
Medizinsche Universitätsklinik Freiburg,
Rehabilitative, Präventive Sportmedizin

Hartmut Marquardt, Rüdiger Müller
PK BAB Braunschweig

Dipl.-Päd. Matthias Haasper
ifz, Institut für Zweiradsicherheit e.V.

Dr. med. Thomas Rebe
Medizinische Hochschule Hannover, Abteilung Arbeitsmedizin

Abstract

Motor-cyclists (n = 39) at the age-group under and over 48 years (A1 = 43 years, A2 = 52 years) were surveyed. The anamnestic defined training level was 2,5 h/week (T1 = 0,74 h/week, T2 = 4,73 h/week). Concerning the BMI the groups were separated at 26,5 kg/m² (bmi1 = 24,2 kg/m², bmi2 = 30,4 kg/m²). Motor cycling was defined for a job-related mileage of 2000 km/year (ber1 = 858 km/year, ber2 = 3050 km/year) and a free-timed mileage of 8500 km/year (priv1 = 5340 km/year, priv2 = 12100 km/year) and conducted – regardless of weather conditions - on a 114 kW highly productive motor bike (Kawasaki 1400GTR).
During the 100000 km motor bike ride (n = 83 days, Ø = 1133 km/day) long-time ECGs with heart rate and long-time blood pressure (Tonoport V®, GE Healthcare) recordings as well as an energy transformation measuring (Bodymedia® SenseWear® PRO2 bracelet) were conducted. The test persons were surveyed in terms of physical fitness and motor-bike training performance. The test persons had to undergo a standard ergometric bicycle test with ECG and heart rate recordings as well as lactate and blood pressure tests and with permanent energy transformation measuring which was calculated into complete energy conversion (kcal/h), metabolic unit (MET, kcal/h/kg), the active energy conversion (kcal/h) and the period of physical activity. It was also divided into first and last hour as well as complete operational profile.

Positive significances arise from training concerning average speed (T1 = 79,6 km/h, T2 = 89,8 km/h) and from free-time kilometre performance concerning average speed (priv1 = 81,2 km/h, priv2 = 90,6 km/h), negative significances from BMI concerning average speed (bmi1 = 87,7 km/h, bmi2 = 81,3 km/h) and route (bmi1 = 1249 km, bmi2 = 1090 km) and from job-related mileage in regard of journey time (ber1 = 15,45 h, ber2 = 12,49 h) and route (ber1 = 1314 km, ber2 = 1068 km) by test persons with better practical experiences. Depending on age there is a positive visible trend but not a significant difference concerning journey time (A1 = 13,25 h, A2 = 14,37 h).
The heart rate profile shows a negative significant difference depending on the age structure; depending on the BMI it shows a positive trend but not a significant difference.
Long-term blood pressure measurements showed no significance for systolic and diastolic blood pressure in the comparative groups in terms of age, BMI and physical fitness in all examination sections.
Depending on age there was a visible trend concerning complete energy conversion and MET; concerning active energy conversion there was a significant decrease between first and last driving section.
At physical fitness and BMI there was a positive significant difference for the better trained persons or for overweight ones in all driving sections as well as a significant decrease concerning complete and active energy conversion and MET between first and last driving section.

Negative significances arise from job-related and free-time motor-cycling between first and last driving section concerning MET and complete and active energy conversion, positive significances from job-related mileage during the first driving section concerning MET and complete and active energy conversion and negative significances from free-time motor-cycling during first and last driving sections concerning MET and complete and active energy conversion by each with higher practical annual mileage.

Blood pressure is not different in consideration of a health risk. Demands on the cardiovascular system during motor cycling are not limited concerning a health risk of here-used testing variables.

Physical fitness as well as job-related and free-time motor-cycling has an influence on motor-bike driving performances.

Energetic rates show positive significance referring to overweight as well as a direct connection to training level and motor bike performances in job and free-time.

Heart rate and blood pressure attitude produce no correlation to energetic conversion.

A precise assessment of energy conversion during motor-cycling should be linked with standardized pressure associated with specific driving determination of metabolic parameters.

A motor bike simulator examination should be recommended.

Kurzfassung

Untersucht wurden Motorradfahrer (n = 39) der Altersgruppe unter und über 48 Jahren (A1 = 43 Jahre, A2 = 52 Jahre). Der anamnestisch definierte Trainingszustand betrug 2,5 h/Woche (T1 = 0,74 h/Woche, T2 = 4,73 h/Woche). Beim BMI wurde eine Gruppeneinteilung für einen Wert von 26,5 kg/m^2 (bmi1 = 24,2 kg/m^2, bmi2 = 30,4 kg/m^2) vorgenommen. Das Motorradfahren wurde auf eine Kilometerleistung von 2000 km/Jahr beruflich (ber1 = 858 km/Jahr, ber2 = 3050 km/Jahr) und 8500 km/Jahr privat (priv1 = 5340 km/Jahr, priv2 = 12100 km/Jahr) definiert und witterungsunabhängig auf einem 114 kW leistungsstarken Motorrad durchgeführt (Kawasaki 1400GTR). Während der 100000 km-Motorradfahrt (n = 83 Tage, Ø = 1133 km/Tag) wurde eine Langzeit-EKG Aufzeichnung mit Herzfrequenzbestimmung und eine Langzeitblutdruckmessung (Tonoport V®, GE Healthcare), sowie eine Energieumsatzmessung (Bodymedia® SenseWear® PRO2 Armband) vorgenommen. Die Probanden wurden bezüglich körperlicher Fitness und Motorradtrainingsleistung anamnestisch befragt und einer standardisierten Fahrradsitzend-Ergometrie mit EKG-, Herzfrequenzaufzeichnung, Laktat- und Blutdruckbestimmung, sowie permanenter Energiemessung unterzogen. Die Energiemessung wurde für den Gesamtenergieumsatz (kcal/h), die Metabolischen Einheiten (MET, kcal/h/kg), den aktiven Energieumsatz (kcal/h) und die Dauer der körperlichen Aktivität berechnet und in erste und letzte Stunde, sowie ein Gesamtfahrprofil, eingeteilt.

Positive Signifikanzen ergeben sich beim Training bezüglich Durchschnittsgeschwindigkeit (T1 = 79,6 km/h, T2 = 89,8 km/h) und bei privater Kilometerleistung bezüglich Durchschnittsgeschwindigkeit (priv1 = 81,2 km/h, priv2 = 90,6 km/h), negative Signifikanzen beim BMI bezüglich Durchschnittsgeschwindigkeit (bmi1 = 87,7 km/h, bmi2 = 81,3 km/h) und Fahrtstrecke (bmi1 = 1249 km, bmi2 = 1090 km) und bei beruflicher Kilometerleistung bezüglich Fahrtzeit (ber1 = 15,45 h, ber2 = 12,49 h) und Fahrtstrecke (ber1 = 1314 km, ber2 = 1068 km) für die jeweils Erfahreneren. Ein tendenziell positiver aber nicht signifikanter Unterschied ergibt sich beim Alter bezüglich Fahrtzeit (A1 = 13,25 h, A2 = 14,37 h).

Das Herzfrequenzprofil weist bezogen auf die Altersstruktur einen negativ signifikanten, bezogen auf den BMI einen tendenziell positiven aber nicht signifikanten Unterschied auf.

Die Langzeitblutdruckmessung ist für systolischen und diastolischen Blutdruck in allen Untersuchungsabschnitten und für die Vergleichsgruppen Alter, BMI und körperliche Fitness ohne Signifikanz.

Bezogen auf das Alter wurde bezüglich Gesamtenergieumsatz und MET eine tendenzielle, bezüglich aktiver Energiemessung eine signifikante Verminderung zwischen erstem und letztem Fahrtabschnitt gemessen.

Bei körperlicher Fitness und BMI hat sich sowohl in allen Fahrtabschnitten ein positiv signifikanter Unterschied für die besser Trainierten beziehungsweise Übergewichtigen als auch bezogen auf gesam-

te und aktive Energiemessung und auf MET zwischen erstem und letztem Fahrtabschnitt ein signifikanter Rückgang ergeben.
Negative Signifikanzen ergeben sich bei beruflicher und freizeitlicher Fahrleistung zwischen erstem und letztem Fahrtabschnitt bezüglich MET sowie gesamter und aktiver Energiemessung, positive Signifikanzen bei beruflicher Fahrleistung im ersten Fahrtabschnitt bezüglich MET und gesamtem und aktivem Energieumsatz und negative Signifikanzen bei freizeitlicher Fahrtleistung im ersten und letzten Fahrtabschnitt bezüglich MET sowie gesamter und aktiver Energiemessung für die jeweils höhere jährliche Kilometerleistung.

Der Blutdruck ist nicht unterschiedlich unter Berücksichtigung bzw. bezogen auf ein gesundheitliches Risiko. Die Herz-Kreislauf-Belastung ist bezogen auf ein gesundheitliches Risiko über die hier genutzten Prüfvariablen nicht eingeschränkt.
Die körperliche Fitness und Motorradfahren als Freizeit-Belastung nehmen jedoch signifikanten Einfluss auf die Motorradfahrleistung.
Die energetischen Umsätze zeigen eine positive Signifikanz bezogen auf Übergewicht und auch eine direkte Beziehung zum Trainingszustand und zu Motorradfahrleistungen in Beruf und Freizeit.
Herzfrequenz und Blutdruckverhalten erbringen keine Korrelation zum Energieumsatz. Sichere Bewertungen des Energieumsatzes beim Motorradfahren sollten durch standardisierte Belastungen in Verbindung mit der fahr- und belastungsspezifischen Bestimmung von metabolischen Parametern verbunden werden.
Eine Simulator-Untersuchung ist hier zu empfehlen.

Changes in blood pressure (RR), heart rate (HR) and energy profile (EP) depending on age (years), body mass index (BMI), general physical level (h/week) and job-related and time spent motor cycling during long-time motor cycling for average male test person

Introduction

The history of motorbikes is a success story. At the beginning of the 19th Century the trailing wheel by Baron von Drais is thought of as an alternative to the horse carriage. With the invention of the motor at the turn of the century at the beginning of the 20th Century the motorbike also became a practical means of transportation. Subsequently, the areas of application of the motorised two wheeler kept being expanded. The motorbike was predominantly seen as a piece of leisure equipment. Driving motorbikes was also done occupationally. But the sporty aspect could not be ignored. Motor sport and especially motorbike sport enjoyed great popularity.

The motor-cyclist himself is far more than an ordinary motor vehicle driver when exposed to the environment and the conditions in the road traffic. The seat of the motorbike has become a work station [5].

Medical aspects will be discussed, especially by patients with cardiovascular diseases (hypertonia), the age of the biker, as well as diseases of endocrinologically genesis [1,7,8,14]. Environmental factors, influences on the biorhythm related to times of day and climatic conditions were included in the study of the different work groups [2,12]. By new construction the motorbike industry has taken into account the influence of clothing, the motorbike helmet, the field of vision and the influences of noise in reaction to the improvement of safety aspects [3,4,6,9,10,11,13].

The influence of energy conversion on the capability of the human organism has not been tested in long term studies on drivers.

It has not yet been documented in how far physical training influences long-time capability with respect to the risk factors of heightened blood pressure, overweight and age.

A consistent cause for motorbike accidents could not be found in the overall accident statistic. It can be assumed, that cardio cyclical and metabolic changes in the human organism can lead to the impairment of the physical and psychological capabilities of recreational and occupational motor cycling.

Given this initial situation, it was the goal of this study to find out, in how far, long term biking influences the blood pressure, the heart frequency and the energy conversion by normal persons.

Method

The parameter was a motorbike endurance test of over 100000 km. The compleate distance should be accomplished in 100 days. This represented a great challenge both for the human organism and the motorbike.
The record drive was of scientific importance both from the view of transport policy as well as from work and social medicine views.

– Research vehicle

The motorbike drives were carried out, regardless of the weather conditions, as day trips with a motorbike with 114(155) kW(PS) (Kawasaki 1400 GTR).

– Proband collective

The participant's consisted of 39 male test persons. The average age was 46.9 Years (+/- 6.108 Years), the youngest participant was 29 Years old, the oldest participant was 57 Years old.
The average BMI was 28.5 kg/m² (+/- 4,061 kg/m² ; fluctuation range: 21,2 kg/m² until 40,9 kg/m²).

The individual training condition of the participants was asked in the case history and ergonomically defined. This was on average 3.0 h/Week (+/- 2.915 h/Week), whereas the best trainer test stated 14 h/Week. Some individuals did not carry out any extra training measures per week.

By none of the test persons a restrictive illnesses was known which could have affected the drive at the time the tests were carried out.

- Research Parameters

To verify the differences comparison collectives were formed for the following parameters:

- Body Mass Index (BMI) (kg/m²): Group B1 (< 25 kg/m²), Group B2 (25 kg/m² < x < 30 kg/m²) and Group B3 (≥ 30 kg/m²)
- Bodily fitness (given in Training (h/Week)): Group T1 (< 4 h/Week) and Group T2 (≥ 4 h/Week)
- Bodily fitness (measured according to bicycle dynamometer dater (mmol/l)): Group L1 (< 2 mmol/l) and Group L2 (≥ 2 mmol/l)
- Age (Years): Group A1 (<48 Years) and Group A2 (≥ 48 Years)
- Kilometres travelled yearly on the motorbike, expressed in the yearly total mileage (KLges): Group KLges1 (< 10500 km/Year) and Group KLges2 (≥ 10500 km/Year)

There were no excluding criteria with reference to the above mentioned parameter and risk factors. The test persons were defined by their occupational group (Highway Police), so that all persons who were available for the study could be included into the evaluation without restrictions.

The individual drives were subdivided into three sections for the statistical collection. The first section is equivalent to the 1st hour, the third section to the last hour of each drive. The second section, which represents the midsection of the drives, was constricted for all drives to form comparable sections so that longer drive times could be compared to shorter drive times in the evaluation.

– *Evaluation technique*

During the drives a long term ECG recording was done to define the heart frequency and to analyse the cardiac arrhythmia (CardioMem®, GE Germany), a long term blood pressure measurement (Tonoport V®, GE Germany) and a energy conversion determination (Bodymedia® SenseWear® PRO_2 Armband). The test persons were subjected to a standardised ergometric bicycle test (Ergometer eBike®, GE Germany) with ECG-, heart rate recording, Lactate and blood pressure determination. The health documentation was generated by a physical check and a comprehensive lab chemistry.

– *Driving performance*

Using a questionnaire the test persons were asked to give information on the kilometres travelled per year on a motorbike, split into the overall value as well as those travelled for business and those travelled for leisure. The result was a mean for the total yearly travelled kilometres of 7860 km/Year (+/- 5838.6 km/Year ; degree of fluctuation: 800 km/Year – 28000 km/Year). The job related kilometres travelled per year by the participants was on average 1869 km /Year (+/- 1981.7 km/Year ; degree of fluctuation: 100 km/Year – 10000 km/Year), for leisure 6570 km/Year (+/- 4914.9 km/Year ; degree of fluctuation: 100 km/Year – 25000 km/Year).

The average journey time was 14.04 hours (+/- 3.6 hours) per day, daily hours of work between 4.00 hours – 24.00 hours. The respective sample groups are described in more detail.

With reference to the body weight (BMI) it shows, that persons of normal weight have a longer drive time (B1 = 15.10 hours), persons who are slightly over weight (B2 = 14.12 hours) and persons who are over weight (B3 = 11,92 hours) have a shorter drive time.
The collective with an intensive weekly body training (T1) showed a longer drive time (14.40 hours) compared to those who did not train (T2 = 12.20 hours). This difference must be related to the average driving speed (Fig.9).

– *Driving speed*

The 39 participants handled the on average 1133km (+/- 294.8 km) with an average speed of 81.7 km/h (+/- 13.3 km/h). The highest average speed lay by 120.4 km/h, the lowest average speed laid by 56.2 km/h.

With reference to the body weight (BMI) the highest average speed (85.9 km/h) was measured by the slightly over weight persons (B2) and by the over weight persons (B3) the lowest average speed of (83.0 km/h).
The distribution according to the aerobic ergometric competitiveness rendered a higher average speed by the high performance participants (L1) than for the lower performance participants (L2) (L1 = 86.9 km/h, L2 = 79.4 km/h). With reference to the training it showed a difference for the fitter candidates (T2) of 14.1 km/h (T1 = 80.3 km/h, T2 = 94.4 km/h).
The biological age does not show any differences with respect to the average speed (A1 = 84.7 km/h, A2 = 84.0 km/h) (Fig.9).

– *Driving route*

The 39 probands have a daily mileage of 1133 km (+/- 294.8 km) (Fig.9).

– *Statistical evaluation*

All data relevant for the evaluation were captured with a statistic program (SPSS) and statistically analysed. The mean value was determined from the statistically analysable data and then compared with each other. For the evaluation of the level of significance the following tests were done for all data: three or more paired samples as non parametric using the Friedman-Test, the Kendall‘S-W Test as a non parametric method for the quantification of the compliance between multiple judges, the Mann-Whitney-U-Test was used as a parameter free test for the evaluation of the compliance of two independent distributions and the Wilcoxon-Test was used for the non parametric test of two independent probes. After the checking of the data it can be assumed, that they are normal variables.

Results

– *Blood pressure*

The systolic blood pressure shows no significant fluctuations during the duration of the drive by the comparative collectives (Fig.8).

Under consideration of the weekly body training there were no differences between the three drive segments.

With reference to the aerobic ergometric tested performance a difference of 11.6 mmHg for the better trained persons (L1) in comparison to the lesser trained persons (L2) in the 1st exposure hour was determined (insignificant). For the mid section of the drive no differences could be found (L1 = 156.6 mmHg (+/- = 9.6 mmHg), L2 = 155.8 mmHg (+/- = 14.1 mmHg)). In the last hour of the drive the difference was 6.3 mmHg (L1 = 153.3 mmHg (+/- = 12.8 mmHg), L2 = 159.9 mmHg (+/- = 17.1 mmHg)).

The average blood pressure values in relation to the body weight (BMI) showed no significant differences based on the specific driving stages (1.stage: B1 = 152.3 mmHg (+/- 20.7 mmHg), B2 = 156.8 mmHg (+/- = 14.6 mmHg), B3 = 162.6 mmHg (+/- = 28.4 mmHg); mid stage: B1 = 153.6 mmHg (+/- = 8.4 mmHg), B2 = 154.5 mmHg (+/- = 14.0 mmHg), B3 = 157.7 mmHg (+/- = 15.0 mmHg); last stage: B1 = 155.9 mmHg (+/- = 12.7 mmHg), B2 = 155.6 mmHg (+/- = 16.3 mmHg), B3 = 153.9 mmHg (+/- = 17.3 mmHg)). The first hour yielded a non significant difference between B1 and B3 of 10.3 mmHg.

No differences could be depicted for the motorbike specific yearly mileage (1.section: KLges1 = 158.8 mmHg (+/- = 25.4 mmHg), KLges2 = 155.6 mmHg (+/- = 19.7 mmHg); mid section: KLges1 = 154.0 mmHg (+/- = 8.1 mmHg), KLges2 = 155.4 mmHg (+/- = 12.7 mmHg); last section: KLges1 = 155.3 mmHg (+/- = 10.0 mmHg), KLges2 = 154.2 mmHg (+/- = 16.8 mmHg)).

In view of the average age of both age groups no significant changes in all three drive sections could be measured (1.section: A1 = 157.1 mmHg (+/- = 24.2 mmHg), A2 = 157.2 mmHg (+/- = 16.5 mmHg); mid section: A1 = 153.2 mmHg (+/- = 12.9 mmHg), A2 = 157.4 mmHg (+/- = 12.4 mmHg); last section: A1 = 149.9 mmHg (+/- = 15.4 mmHg), A2 = 161.3 mmHg (+/- = 12.7 mmHg)), whereas the oldest collective showed a systolic insignificant difference of 11.4 mmHg in the last hour of exposure.

– Heart rate

The average heart rate for the whole collective and for the whole examination time lies by 102.3/min (+/- 19.3/min),whereas an accumulation of a heart rate of 86.6/min and 113.2/min ensue. At the Minimum 73.2/min and at the Maximum 153.7/min are described (Fig.7).
By the splitting into the individual driving sections no significant differences were recorded for the whole collective (1.section: 101.2/min (+/- 30.9/min) ; middle section: 108.1/min (+/- 20.6/min) ; last section: 97.5/min (+/- 25.7/min)) (Fig.10).

The mean heart rate for the BMI showed no significant differences (B1 = 96.9/min, B2 = 102.7/min, B3 = 106.9/min) (Fig.8).
In comparison, the BMI allocation for the individual collectives showed a slightly significant difference in the average heart frequency during the evaluation in the mid section as well as in the last hour. (middle section: B1 = 99.7/min, (+/- = 25.7/min), B3 = 117.4/min (+/- = 21.0/min) ; last section: B1 = 93.3/min (+/- = 31.3/min), B3 = 106.1/min (+/- = 19.9/min)).

The ergometrically determined aerobic performance shows an insignificant difference for the total exposure and for the whole collective (L1 = 95.2/min, L2 = 107.7/min) (Fig.8).
For the first section a weak significance and for the middle section a tendency difference for the aerobic high performance was depicted during the split-up into the individual driving sections (1.section: L1 = 89.6/min (+/- = 20.3/min), L2 = 109.8/min (+/- = 29.1/min) ; middle section: L1 = 102.4/min (+/- = 18.8/min), L2 = 113.8/min (+/- = 21.1/min)) (Fig.2).

The differentiation according to the bodily fitness shows in consideration of the whole collective (T1 = 101.5/min, T2 = 104.1/min) (Fig.8), as well as in the individual observation of the driving sections no significant differences. (1.section: T1 = 99.1/min (+/- = 26.7/min), T2 = 106.5/min (+/- = 41.5/min) ; middle section: T1 = 109.3/min (+/- = 22.8/min), T2 = 105.0/min (+/- = 14.2/min) ; last section: T1 = 96.1/min (+/- = 25.3/min), T2 = 101.0/min (+/- = 28.2/min)).
The split-up into trainings per week shows a significant difference between the persons doing no fitness training per week and those doing one hour training per week.

The yearly mileage shows no significant difference with respect to the chosen allocation for the whole recording (KLges1 = 98.8/min, KLges2 = 102.2/min) (Fig.8).
For the individual driving sections a sometimes higher heart rate in the first section and in the middle section was shown for the collective, which yearly renders a higher driving performance. (1.section: KLges1 = 93.8/min (+/- = 23.2/min), KLges2 = 107.6/min (+/- = 37.3/min) ; middle section: KLges1 = 96.3/min (+/- = 11.7/min), KLges2 = 110.5/min (+/- = 20.3/min)). In the last driving section the

heart rate for the group with the greatest yearly mileage was slightly significantly lower (KLges1 = 106.3/min (+/- = 26.6/min), KLges2 = 88.4/min (+/- = 23.7/min)).

According to age, group A1 achieves a value of 105.1/min and group A2 a value of 99.0/min (Fig.8). This difference between the two comparable groups is significant.

The comparison for the chosen age classification shows no significant differences for all test sections (1.section: A1 = 105.2/min (+/- = 33.0/min), A2 = 96.6/min (+/- = 29.1/min) ; middle section: A1 = 112.0/min (+/- = 14.3/min), A2 = 103.6/min (+/- = 25.9/min) ; last section: A1 = 98.0/min (+/- = 26.2/min), A2 = 96.9/min (+/- = 26.1/min)).

– Cardiac output product

The cardiac output product for the three driving sections for the BMI-collective showed for the first section no significant differences, in the middle section a significance from the normal weight persons to the over weight persons. This was also depicted in the last section (1.section: B1 = 14863 mmHg x 1/min, B2 = 16645 mmHg x 1/min, B3 = 15825 mmHg x 1/min ; middle section: B1 = 15329 mmHg x 1/min, B2 = 16596 mmHg x 1/min, B3 = 18522 mmHg x 1/min ; last section: B1 = 14545 mmHg x 1/min, B2 = 14716 mmHg x 1/min, B3 = 16318 mmHg x 1/min) (Fig.5).

The ergometrically tested aerobic performance shows no significant differences for the middle section and the last section (mid section: L1 = 16038 mmHg x 1/min, L2 = 17725 mmHg x 1/min ; last section: L1 = 14337 mmHg x 1/min, L2 = 15899 mmHg x 1/min). In the first section a medial significance is recognizable (L1 = 13698 mmHg x 1/min, L2 = 18053 mmHg x 1/min).

With reference to the weekly bodily training no significant differences arose in all three driving sections. In the middle section an increase tendency was recorded (1.section: T1 = 15626 mmHg x 1/min, T2 = 16587 mmHg x 1/min ; mid section: T1 = 17160 mmHg x 1/min, T2 = 15820 mmHg x 1/min ; last section: T1 = 15101 mmHg x 1/min, T2 = 15176 mmHg x 1/min) (Fig.1).

With reference to the driving experience a weakly significant change was detected in the first section and in the middle section related to the heightened driving experience. In the last section a significant difference is noticeable with reference to the lesser driving experience. (1.section: KLges1 = 14891 mmHg x 1/min, KLges2 = 16749 mmHg x 1/min ; middle section: KLges1 = 14823 mmHg x 1/min, KLges2 = 17180 mmHg x 1/min ; last section: KLges1 = 16506 mmHg x 1/min, KLges2 = 13633 mmHg x 1/min) (Fig.6).

In comparison to the age no significant changes could be found between the two groups A1 and A2 and the individual driving sections (1.section: A1 = 16526 mmHg x 1/min, A2 = 15185 mmHg x 1/min ; middle section: A1 = 17157 mmHg x 1/min, A2 = 16307 mmHg x 1/min ; last section: A1 = 14692 mmHg x 1/min, A2 = 15627 mmHg x 1/min).

– Active energy conversion

In comparison, the BMI of the three groups shows a difference by trend for the normal weight individuals to the over weight individuals. No significance is noticeable (B1 = 886 kJ, B2 = 1154 kJ, B3 = 1213 kJ) (Fig.8). Only in the first section a significance between the normal weight individuals as well as the slightly over weight individuals and the over weight individuals in the individual driving sections is noticeable. In the middle section and in the last section no significant differences are depicted (1.section: B1 = 1052 kJ (+/- = 328.2 kJ), B2 = 1089 kJ (+/- = 605.3 kJ), B3 = 1729 kJ (+/- = 618.5 kJ) ; middle section: B1 = 965 kJ (+/- = 164.3 kJ), B2 = 1136 kJ (+/- = 363.4 kJ), B3 = 1232 kJ (+/- = 93.8 kJ) ; last section: B1 = 641 kJ (+/- = 354.1 kJ), B2 = 1236 kJ (+/- = 530.8 kJ), B3 = 678 kJ (+/- = 406.2 kJ)).

With reference to the ergometrically tested performance no significant differences are apparent in the individual driving sections (1.section: L1 = 1450 kJ (+/- = 680.0 kJ), L2 = 1110 kJ (+/- = 480.3 kJ) ; middle section: L1 = 1208 kJ (+/- = 271.4 kJ), L2 = 976 kJ (+/- = 206.2 kJ) ; last section: L1 = 1039 kJ (+/- = 537.7 kJ), L2 = 597 kJ (+/- = 376.8 kJ)) (Fig.3).

Comparably for the bodily training no significance is noticeable for the first and the middle section. In the last section a significant difference is depicted for the individuals who train intensively (1.section: T1 = 1151 kJ (+/- = 562.7 kJ), T2 = 1578 kJ (+/- = 662.0 kJ) ; middle section: T1 = 1010 kJ (+/- = 232.7 kJ), T2 = 1356 kJ (+/- = 159.5 kJ) ; last section: T1 = 578 kJ (+/- = 350.2 kJ), T2 = 1312 kJ (+/- = 482.8 kJ)).

The active energy conversion based on the yearly driving performance shows a clearly significant change in the first section as in the last section. (1.section: KLges1 = 1705 kJ (+/- = 540.3 kJ), KLges2 = 1016 kJ (+/- = 552.5 kJ) ; last section: KLges1 = 1215 kJ (+/- = 527.5 kJ), KLges2 = 668 kJ (+/- = 315.2 kJ)). In the middle section no significant changes were noted (Klges1 = 1276 kJ (+/- = 259.8 kJ), KLges2 = 1005 kJ (+/- = 253.6 kJ)).

A relation between the active energy conversion and age does not exist.

Discussion

The risk profile in the general and in the special cardiac medicine is based on the pathological behaviour of the blood pressure in the calm state and under pressure. In the health check the heart rate behaviour is adducted in the calm and under pressure state. The ergometrically tested performance with respect to the aerobic and anaerobic energy supply as well as the weekly trained fitness in hours documents the degree of regeneration after physical effort.

Similarly the performance of an active person is determined by the BMI (Body Mass Index) and the resulting energy conversion.
Decisive by long term motorbike driving are additionally the driving routine through the number of kilometres driven each year on the motorbike and the age of the driver.

The heart rate profile by motor bike exposure during racing and leisure has been described in many cases. A respective continuous recording for the systolic and diastolic blood pressure is not known. The relationship between the physical performance, tested on the bicycle ergometer, as well as the weekly conducted fitness training measures and the cardiac output product are of importance as the influence on the driving capacity of long term motorbike drivers can not be excluded. The risk factors overweight and age additionally influence the performance of long term bikers under normal road conditions.

The requirement to drive 100000 km in 3 months on a commercial motorbike in the upper horse power class demands that 1000 km are driven per day. To achieve a trip with normal traffic and weather conditions daily trips were driven over 83 days.

The collective of 39 drivers with an average age of 47 years drove under the road traffic regulations the given trip time on driving routs with different road profiles.
The driving breaks were given by the normal refuelling stops after two hours respectively.

The heart rate profile shows an average of 102.3/min over the whole driving time. The heart rate distribution shows an accumulation of 86.6/min and 113.2/min. In the normal distribution the lowest heart rate was calculated by 73.2/min, the highest by 153.2/min (Fig.7).

Under consideration of the physical training it shows that the test persons with 1- up to 7 hours of fitness training per week have a better adaptation of the organism to the required long term driving burden. It is significantly proven, that already one hour of training per week has a positive influence on the heart rate condition. In a comparison of the fitness training hours, a training of more then 4 hours per week as an additional beneficial factor for the heart rate behaviour has significantly been depicted.

The significance between the comparison groups of the physical training with reference to the heart rate during driving a motorbike shows, that the better trained persons on average drove with a lower heart rate then those lesser trained individuals. The physical fitness has a positive effect of the endurance ability during long term motorbike driving.

The better trained individuals outclassed the lesser trained individuals at the beginning and at the end of the trips. (Fig.2). This means that the physically able drove faster, which can been seen in the comparison of the groups average speed (Fig.9).

Analog to the results of the physical fitness a significance also results out of the motorbike specific yearly driving experience in all three sections of the trips. The lower heart rates by the lesser trained individuals in the first hour and in the middle section of the tests are indications therefore, that those test persons drove slower in the start section as well as during the middle section of the tests. Only after acquiring the necessary security for the motorbike after increasing duration of the tests the training weak collective became familiar with the task, so that these test persons showed a better adapted or equal heart rate to the posed task in the last section of the test drives.

As the test persons had an average age of 47 years a comparison to younger rasher motorbike drivers was not possible.

The long term blood pressure recordings are not different in their systolic and diastolic absolute values weather in reference to body weight, training, age or driving practice.

Under default of the core values for the systolic and diastolic blood pressure in rest state of 130/80 mmHg, the average blood pressure determined for the collective during ergonomically carried out stress tests on the bicycle ergometer can be related to a performance of 60-75 Watt. Therefore an average performance blood pressure of RR 155.8/97 mmHg is achieved over an average drive time of 14 hours.

The blood pressure behaviour during the test drives shows no significant relationship to the risk relevant BMI-allocation with reference to the systolic blood pressure. This applies for the whole collective for the duration of the driving time and for the individually defined driving sections. The physical training of more than one hour per week shows a reduction of the initial blood pressure RRsys from 156 mmHg to 150 mmHg for the duration of the drives. These changes are just as insignificant as the relationship to the ergometrically tested aerobic performance. According to the improved aerobic performance a difference can be seen in the RRsys of 12 mmHg in the first driving section for the aerobic better group.

The RR- behaviour relating to the group over the age of 50 Years shows a difference of RRsys 11.4 mmHg in the last driving section to the ones under the age of 48 Years. These changes are not to be related to the driving performance as it is age specific.

The balance of the test collective shows no usable relationship for the motorbike driver for the yearly driven kilometres done professionally and for leisure.

The blood pressure behaviour therefore can not be used as an age specific risk factor.

A risk constellation was not documented for the complete collective with reference to the risk factor blood pressure. The influence of physical training and the resulting aerobic performance as well as the indirect relationship to the BMI are still recognizable. Whereby, a benefit is given through the duration of the strain in the long term driving tests when looking at the last driving sections.

Long term motorbike driving is not a classification for blood pressure by healthy male persons.

A first degree risk factor is overweight. The Body-Mass-Index (BMI) is classified into three valuations of risk. In the analysis an adjustment was made corresponding to the generally valid health risk specifications for the different additional research parameters.

The average heart rate profile shows, that there is no significant difference between the three BMI-risk groups in the first section of the stress test. In the middle section and in the last section there are significant differences between the normal weighted group and the clearly overweight group (BMI>30kg/m²) of HR 17/min. This means, that the normal weighted collective adduced the whole driving performance with a heart rate of 100/min, the over weighted collective with a heart rate of 117/min. In the last section there is also a difference of HR 13/min noticeable. Therefore, one must keep in mind the long term stress by the overweight persons in correlation to the BMI.

With the cardiac output product (RRsys x HR) the meaning of the BMI as a risk factor is clarified (Fig.5). In the middle distance and in the end distance there are significant differences with respect to the overweight and normal weighted persons. These differences do not correlate with the aerobic performance, which were measured with the bicycle ergometer test and with the physical fitness training.

With reference to the age of the collective no significance was found to the risk factor overweight.

The risk factor overweight is so far of importance by long term motorbike drivers because the increased stress is a negative burden on the cardiac output. Weight reduction is also recommended for long term motorbike drivers.

The active energy conversion (kJ) during biking has no significant correlation to the BMI. Only for the over weight persons there is a significantly heightened turnover apparent in the first section.

In view of the aerobic energy preparation the active energy conversion shows no significance, but it is better by trend for the probands with better aerobic competitiveness in all three driving sections (Fig.3). This energy change can be explained by the heightened average speed (Fig.9). It can be assumed, that the energy turnover is evoked by the better energy recovery of the nutrients. Under consideration of the weekly physical training in all driving sections it can be seen, that also by better physically trained individuals an economical energy turnover over time is utilised by motorbike stress.

The benefits to the metabolism through the training guidelines are observable through the correlation of the general driving experience to the energy turnover. By improved driving experience over time there is a clear improvement of the active energy turnover by motorbike stress. The difference in the first and last section is 700 kJ.
With reference to the active energy turnover there is an increased heart rate for the heightened average speed and accordingly a changed positive energy turnover for the abler aerometric aerobic performers and the intensive trainers (Fig.8).

Under consideration of the risk parameters blood pressure, overweight and physical fitness the respective improvements of the aerobic performance can be shown clearly with the analysis, that the ability of the human organism can be improved for long term motorbike stress. The recommendations from the WHO and the DEG as well as from the hypertension and heart circulation association must urgently be considered by long term motorbike driving. Training and nutritional programmes are generally useful by long term motorbike driving. Physical fitness is also recommended for precautionary measures in the heavy traffic conditions.

In preparation of the motorbike season training and nutritional recommendations should be observed as with the recommendations for the skiing season.

In how far the accident statistic can be changed can not be shown by these results. These problems need further investigation with measurements of the stress profiles and the blood gas parameters under long term motorbike stress.

Summary

The cardiovascular risk factor hypertension is only of significance in combination with other risk factors and untrained individuals for long term motorbike driving. Under consideration of the requirements placed on cardiac performance an optimal medicinal blood pressure adjustment for hypertension patients is urgently recommended for long term motorbike drives.

A weight reduction in the area of the BMI-standard is recommended as a positive influence on the physical performance by long-time motor cycling.

The revised training performance referring to aerobic competitiveness has a favourable influence on the active energy conversion.

Weekly fitness training of more than 4 hours supports not only the cardiovascular performance but also the conduct in regeneration during strains of several hours.

Driving experience is not only in conjunction with healthy risk factors but also referring to seasonal motor cycling of necessary importance.

The test persons included in the study were on average over 40 years old, so on the one hand a connection can not be established to juvenile age-group (18-35 years) and on the other hand it showed, that the older motor cyclist can make a motorbike journey without risk amongst handicap of accepted health and fitness judgement.

The accident rate in motorbike accidents should be surveyed in further studies with determination of stress profile and blood gas parameters.

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Figures

Fig. 1

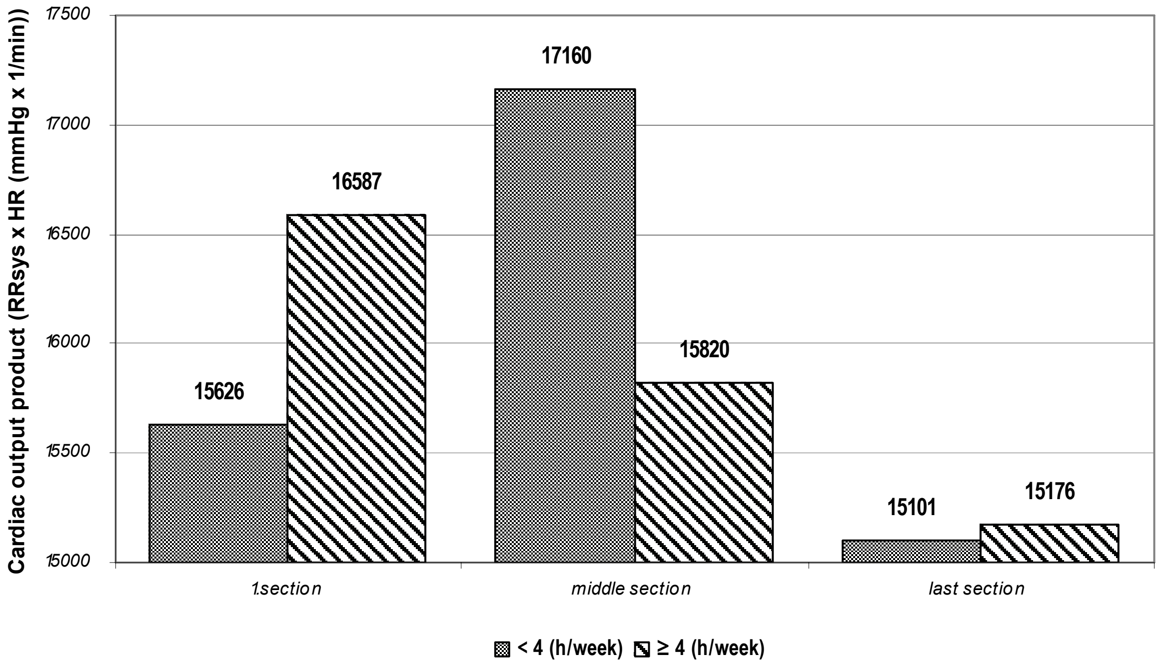


Fig. 2

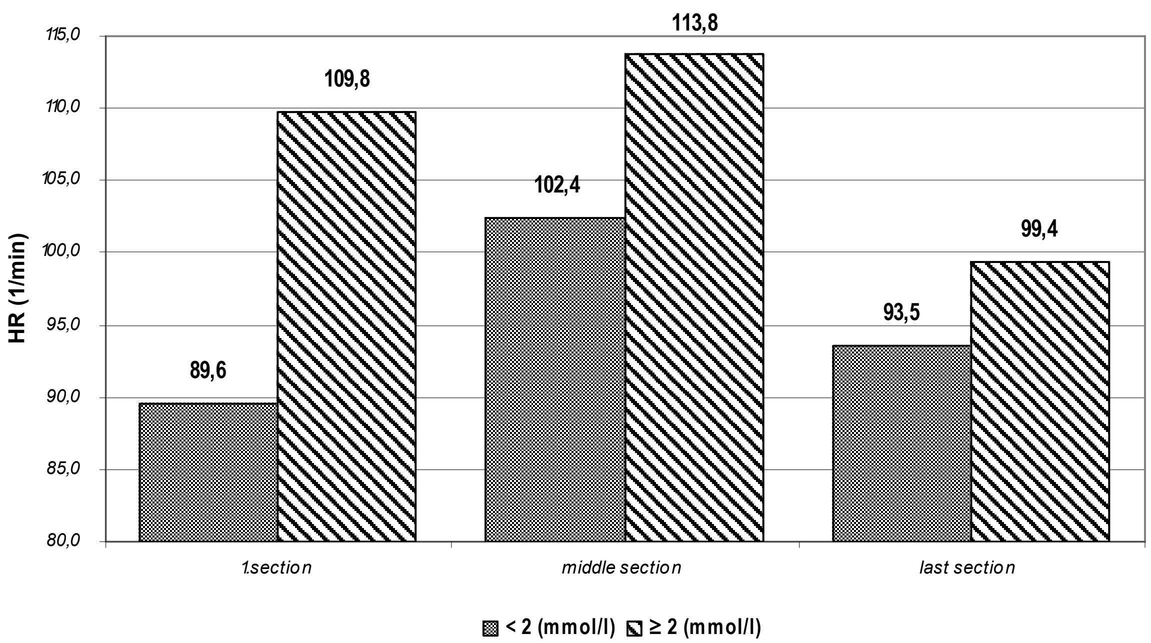
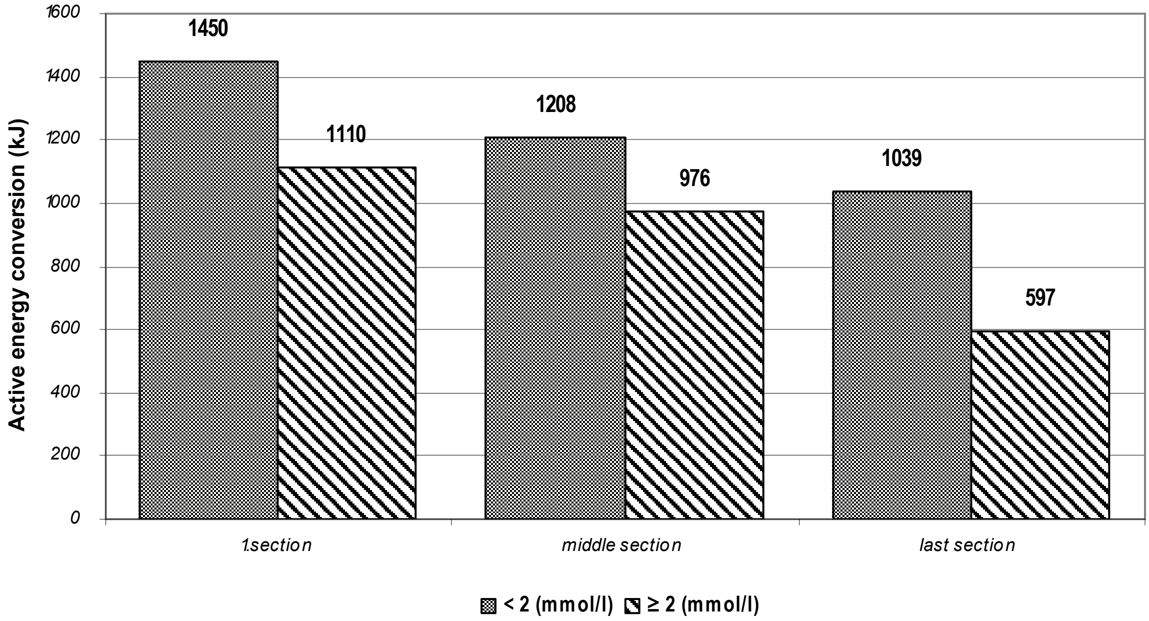
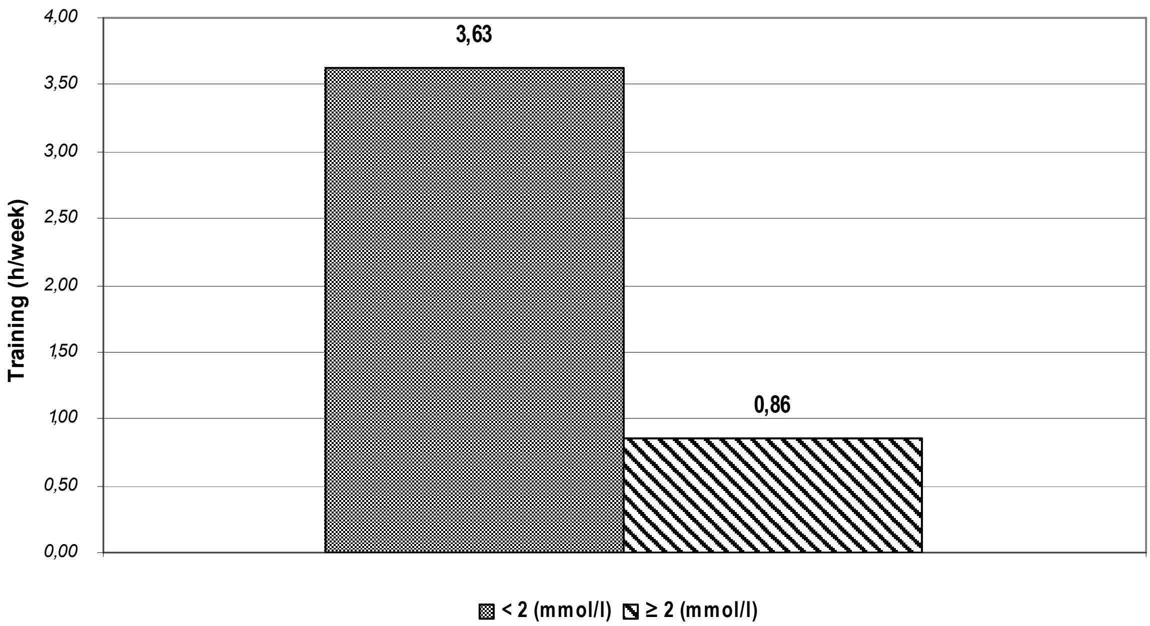


Fig. 3



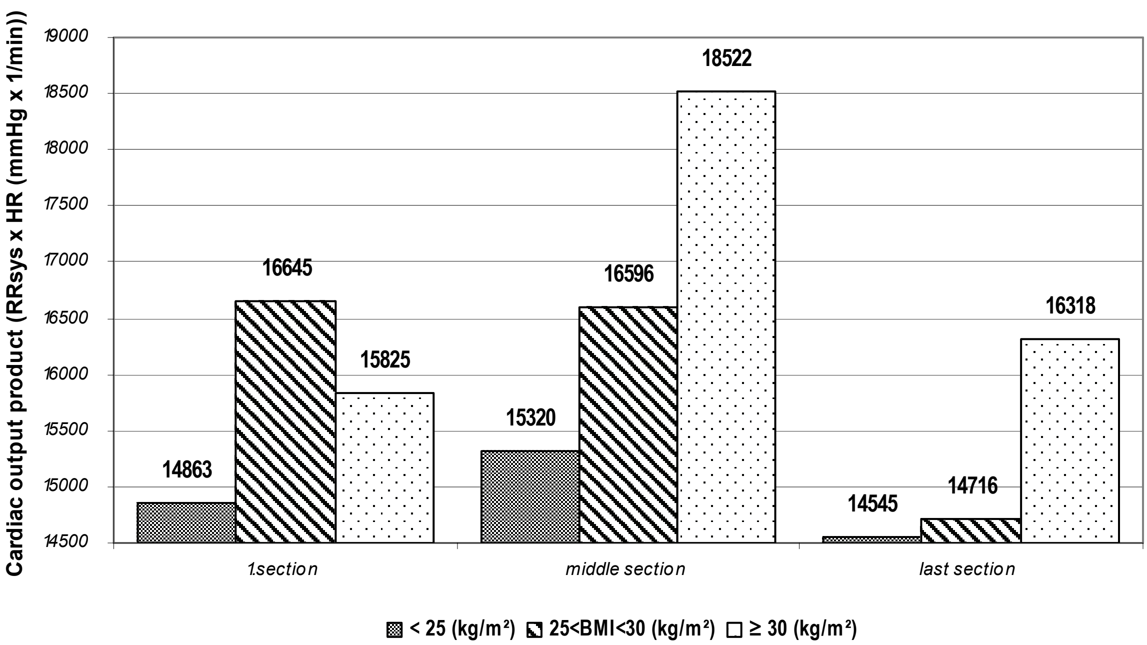
1600
1400
1200
1000
800
600
400
200
0
Active energy conversion (kJ)
1450
1110
1208
976
1039
597
1.section
middle section
last section
< 2 (mmol/l)
≥ 2 (mmol/l)

Fig. 4



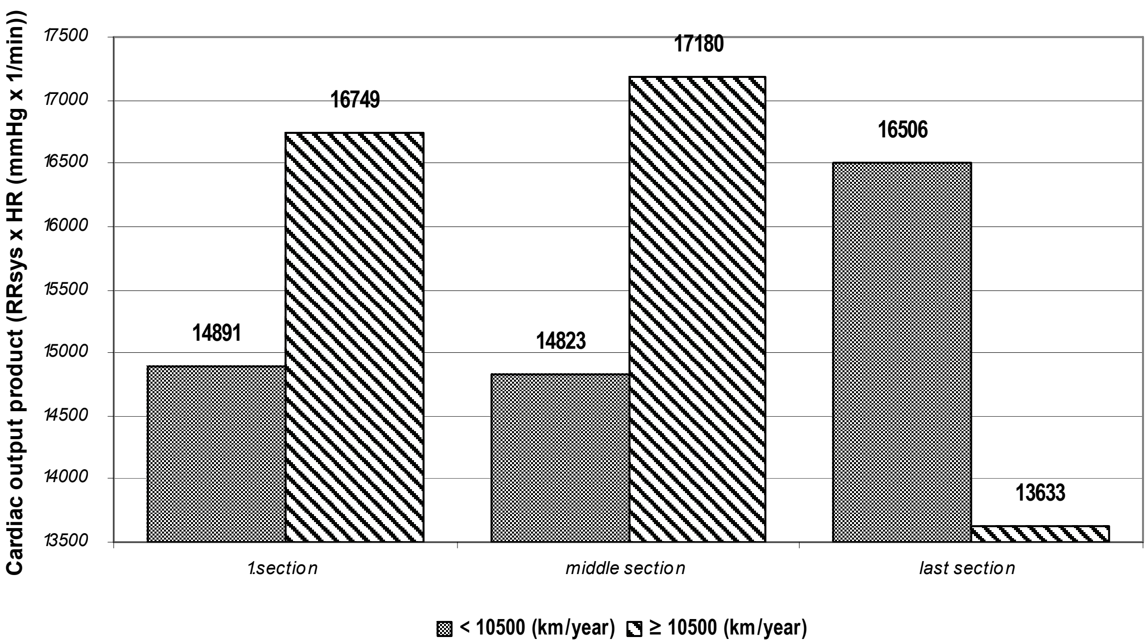
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Training (h/week)
3,63
0,86
< 2 (mmol/l)
≥ 2 (mmol/l)

Fig. 5



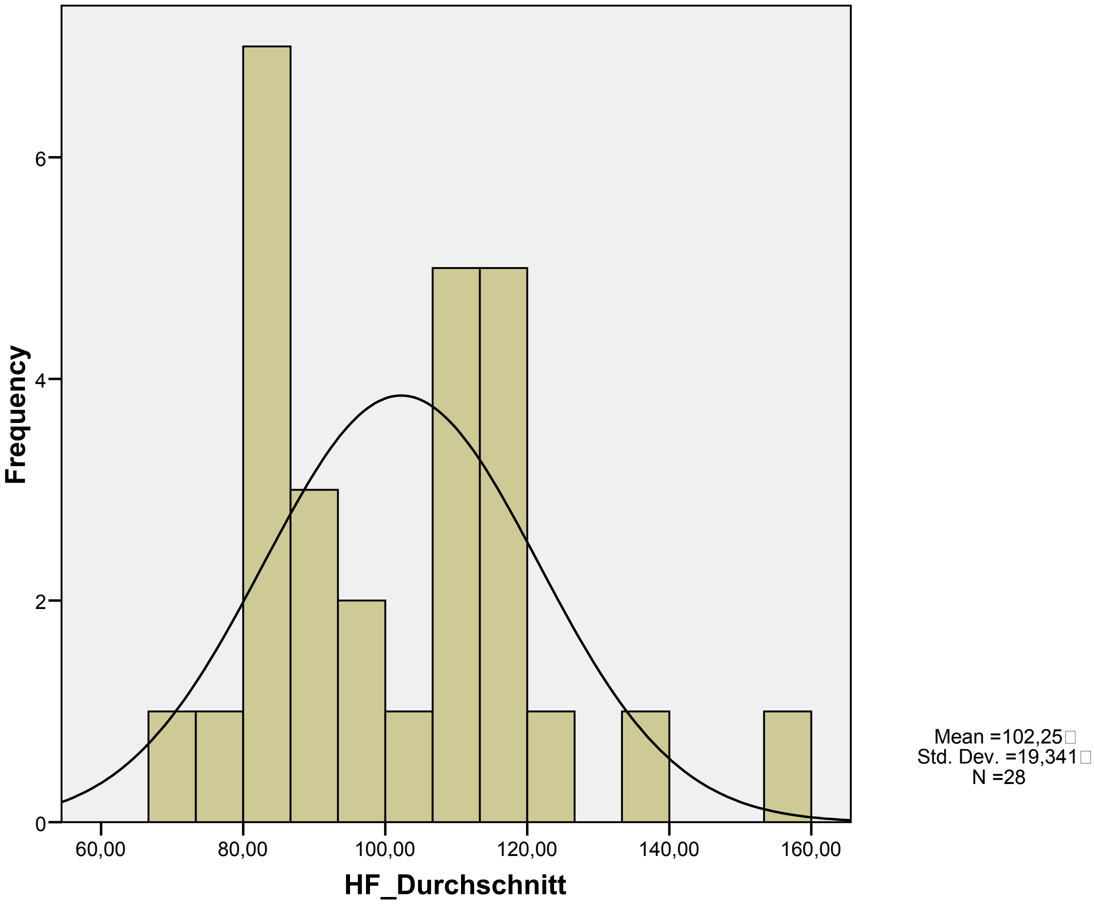
Cardiac output product (RRsys x HR (mmHg x 1/min))
19000
18500
18000
17500
17000
16500
16000
15500
15000
14500
14863
16645
15825
15320
16596
18522
14545
14716
16318
1.section
middle section
last section
< 25 (kg/m²)
25<BMI<30 (kg/m²)
≥ 30 (kg/m²)

Fig. 6



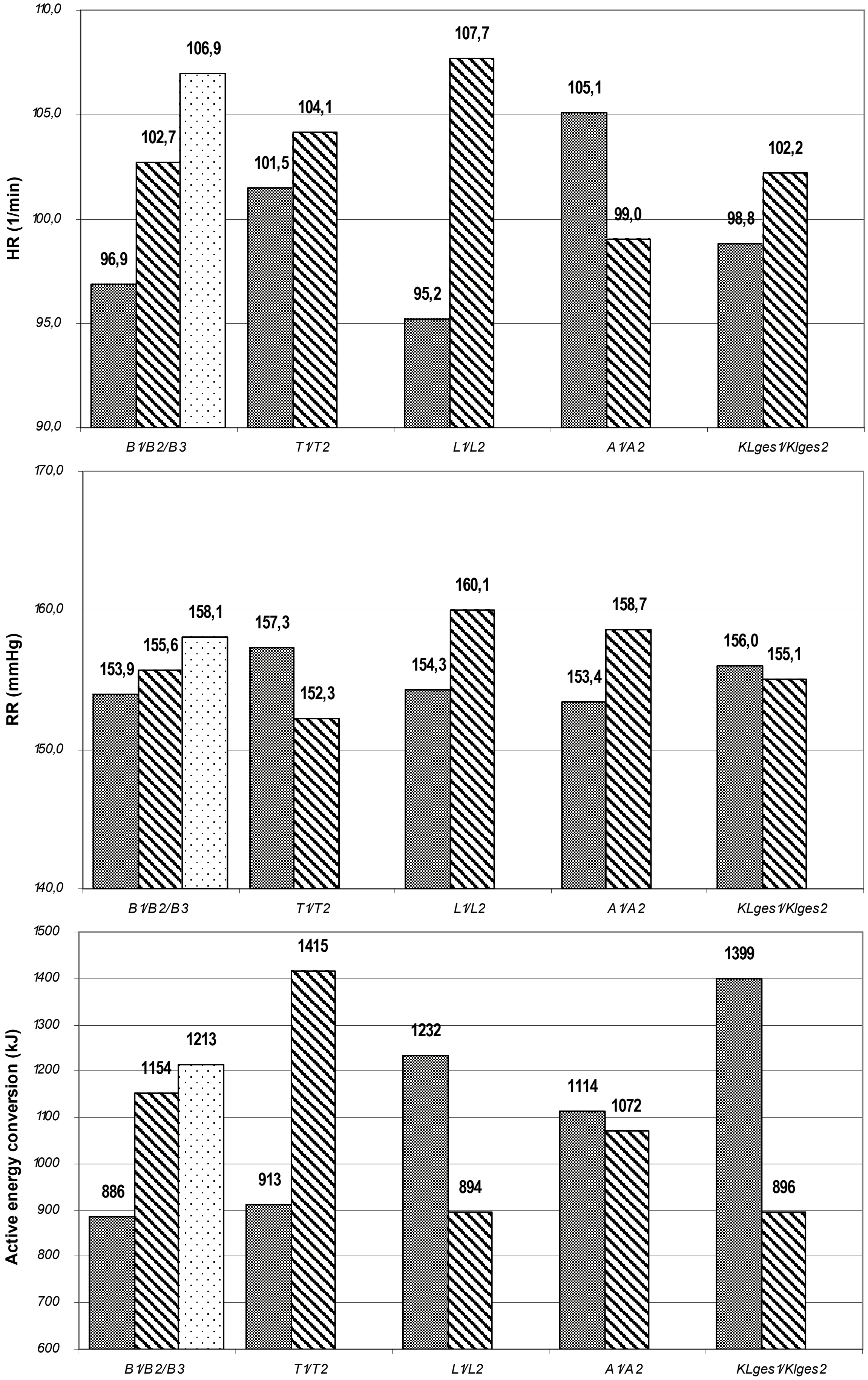
Cardiac output product (RRsys x HR (mmHg x 1/min))
17500
17000
16500
16000
15500
15000
14500
14000
13500
14891
16749
14823
17180
16506
13633
1.section
middle section
last section
< 10500 (km/year)
≥ 10500 (km/year)

Fig. 7



Frequency
0
2
4
6
60,00
80,00
100,00
120,00
140,00
160,00
HF_Durchschnitt
Mean =102,25
Std. Dev. =19,341
N =28

Fig. 8



HR (1/min)
110,0
105,0
100,0
95,0
90,0
96,9
102,7
106,9
101,5
104,1
95,2
107,7
105,1
99,0
98,8
102,2
B1/B2/B3
T1/T2
L1/L2
A1/A2
KLges1/Klges2
RR (mmHg)
170,0
160,0
150,0
140,0
153,9
155,6
158,1
157,3
152,3
154,3
160,1
153,4
158,7
156,0
155,1
B1/B2/B3
T1/T2
L1/L2
A1/A2
KLges1/Klges2
Active energy conversion (kJ)
1500
1400
1300
1200
1100
1000
900
800
700
600
886
1154
1213
913
1415
1232
894
1114
1072
1399
896
B1/B2/B3
T1/T2
L1/L2
A1/A2
KLges1/Klges2

Fig. 9

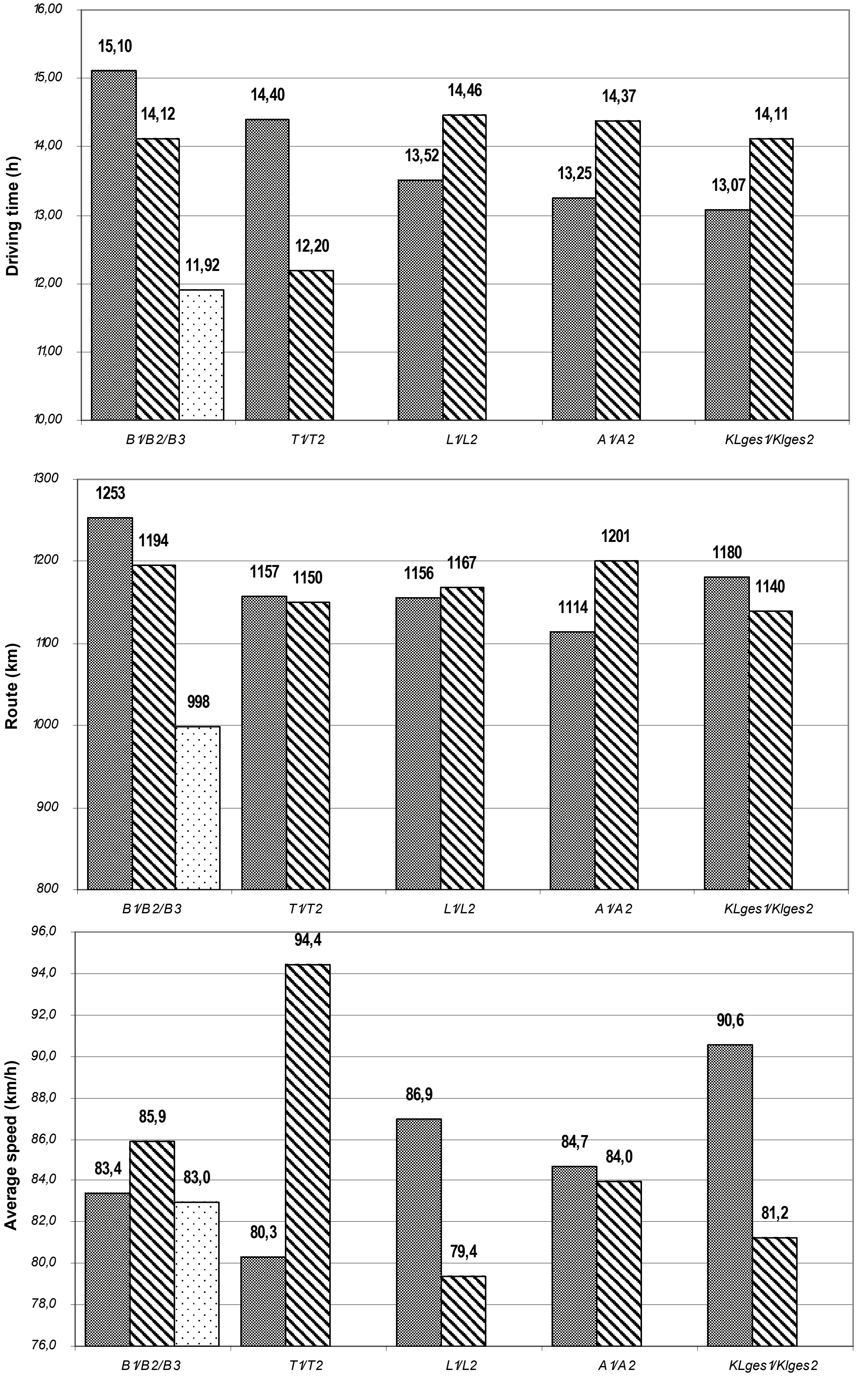
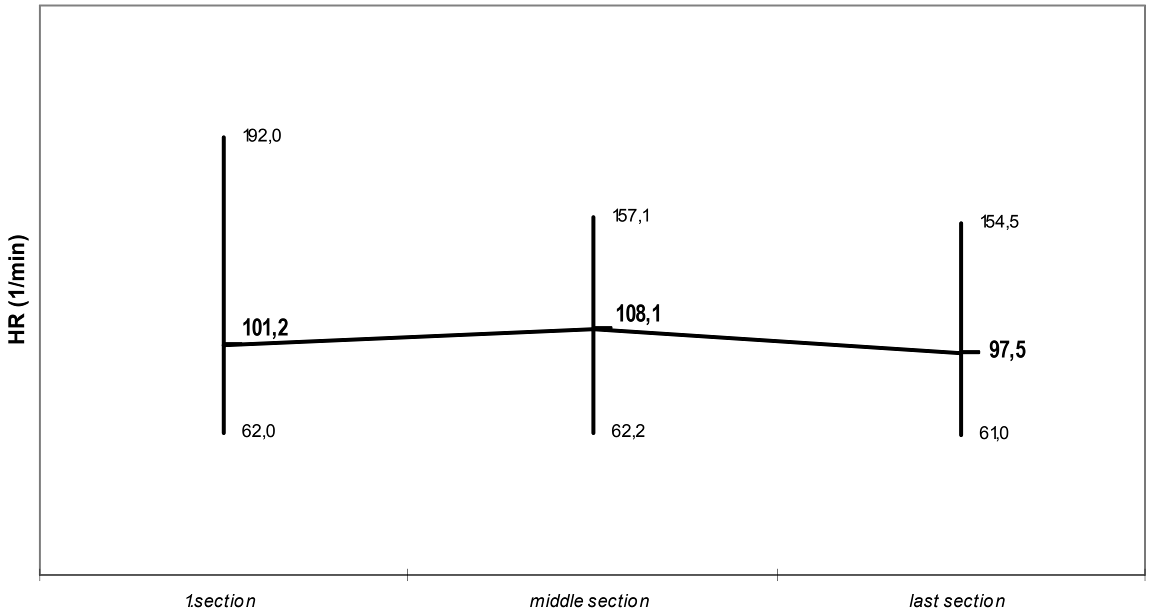

Driving time (h)
16,00
15,00
14,00
13,00
12,00
11,00
10,00
15,10
14,12
11,92
14,40
12,20
13,52
14,46
13,25
14,37
13,07
14,11
B 1/B 2/B 3
T 1/T 2
L 1/L 2
A 1/A 2
KLges 1/Klges 2
Route (km)
1300
1200
1100
1000
900
800
1253
1194
998
1157
1150
1156
1167
1114
1201
1180
1140
B 1/B 2/B 3
T 1/T 2
L 1/L 2
A 1/A 2
KLges 1/Klges 2
Average speed (km/h)
96,0
94,0
92,0
90,0
88,0
86,0
84,0
82,0
80,0
78,0
76,0
83,4
85,9
83,0
80,3
94,4
86,9
79,4
84,7
84,0
90,6
81,2
B 1/B 2/B 3
T 1/T 2
L 1/L 2
A 1/A 2
KLges 1/Klges 2

Fig. 10



HR (1/min)
192,0
101,2
62,0
157,1
108,1
62,2
154,5
97,5
61,0
1.section
middle section
last section

Blutdruck- (RR), Herzfrequenz- (HF) und Energieprofil- (EP) Veränderungen korreliert zum Alter (Jahre), zum Body Mass Index (BMI), zur körperlichen Fitness (h/Woche) und zum Motorradfahren – beruflich und in der Freizeit – beim Langzeitmotorradfahren männlicher Normalpersonen

Einleitung

Die Geschichte des Motorrads ist eine Erfolgsgeschichte. Zu Beginn des 19. Jahrhunderts ist das Laufrad nach Freiherr von Drais noch als menschenbetriebene Alternative zu den Pferdekutschen gedacht. Mit der Erfindung von Motoren um die Jahrhundertwende zu Beginn des 20. Jahrhunderts wurde auch das Motorrad zu einem zweckmäßigen Fortbewegungsmittel. In der Folge erweiterten sich stetig die Einsatzgebiete des motorisierten Zweirades. Das Motorrad wurde zum überwiegenden Teil als Freizeitgerät verstanden. Das Motorradfahren wurde auch beruflich betrieben. Aber der sportliche Aspekt blieb nicht außen vor. Der Motorsport, und im Speziellen der Motorradsport, erfreut sich großer Beliebtheit.

Der Motorradfahrer selbst ist dabei weitaus mehr als ein gewöhnlicher Pkw-Fahrer dem Umfeld und den Bedingungen des Straßenverkehrs ausgesetzt. Der Motorradsitz ist auch zum Arbeitsplatz geworden [5].

Diskutiert werden medizinische Aspekte, besonders bei Patienten mit Herz-Kreislauf-Erkrankungen (Hypertonie), das Alter der Motorradfahrer sowie Erkrankungen endokrinologischer Genese [1,7,8,14]. Auch Umweltfaktoren, Einflüsse des Biorhythmus bezogen auf tageszeitliche und klimatische Bedingungen wurden bei verschiedenen Arbeitsgruppen in die Forschung einbezogen [2,12]. Die Motorradindustrie hat auf die Einflüsse der Kleidung, des Motorradhelms, der Sichtfelder und des Lärms in entsprechenden Neukonstruktionen, bezogen auf Verbesserung der Sicherheitsaspekte, reagiert [3,4,6,9,10,11,13].

Die Einflüsse auf das Leistungsvermögen des menschlichen Organismus, bezogen auf den Energieumsatz, sind noch nicht in Langzeitstudien bei Fahrzeugführern untersucht worden.

Inwieweit das körperliche Training das Dauerfahrtleistungsvermögen beeinflusst, ist, bezogen auf die Risikofaktoren erhöhter Blutdruck, Übergewicht und Alter, nicht dokumentiert.

Eine einheitliche Ursache für Motorradunfälle in der Gesamtunfallstatistik konnte nicht gefunden werden. Es ist davon auszugehen, dass kardiozirkulatorische und metabolische Veränderungen im menschlichen Organismus zur Beeinträchtigung der physischen und psychischen Leistungsfähigkeit beim freizeitlichen und beruflichen Motorradfahren führen.

Angesichts dieser Ausgangsposition galt es mit dieser Studie herauszufinden, inwiefern Langzeitmotorradfahren einen Einfluss auf den Blutdruck, die Herzfrequenz und den energetischen Umsatz bei Normalpersonen hat.

Methode

Die Vorgabe war ein Motorraddauertest über 100.000 km. Die Gesamtstrecke sollte in 100 Tagen bewältigt werden. Dies stellt sowohl für den menschlichen Organismus als auch für das Motorrad eine große Herausforderung dar.
Die Rekordfahrt war sowohl aus verkehrspolitischer Sicht wie auch unter arbeits- und sozialmedizinischen Gesichtspunkten von wissenschaftlicher Bedeutung.

– Untersuchungsfahrzeug

Die Motorradfahrt war witterungsunabhängig als Tagesfahrt auf einem Motorrad mit 114 (155) kW (PS) durchgeführt worden (Kawasaki 1400 GTR).

– Probandenkollektiv

Das Teilnehmergut bestand aus 39 männlichen Probanden. Das Durchschnittsalter lag bei 46,9 Jahren (+/- 6,108 Jahre), der jüngste Teilnehmer war 29 Jahre, der älteste 57 Jahre.
Der durchschnittliche BMI betrug 28,5 kg/m² (+/- 4,061 kg/m² ; Schwankungsbreite: 21,2 kg/m² bis 40,9 kg/m²).

Anamnestisch erfragt und ergometrisch definiert wurde außerdem der individuelle Trainingszustand der Teilnehmer. Dieser betrug im Durchschnitt 3,0 h/Woche (+/- 2,915 h/Woche), wobei der Besttrainierteste 14 h/Woche angegeben hat. Einzelne haben keine zusätzliche Trainingsmaßnahme pro Woche durchgeführt.

Bei keinem der Probanden war zum Zeitpunkt der Untersuchung eine für die Fahrt einschränkende Erkrankung bekannt.

– Untersuchungsparameter

Zur Verifizierung der Unterschiede wurden jeweils Vergleichskollektive für folgende Parameter gebildet:

- Body Mass Index (BMI) (kg/m²): Gruppe B1 (< 25 kg/m²), die Gruppe B2 (25 kg/m² < x < 30 kg/m²) und die Gruppe B3 (≥ 30 kg/m²)
- Körperliche Fitness (angegeben in Training (h/Woche)): Gruppe T1 (< 4 h/Woche) und die Gruppe T2 (≥ 4 h/Woche)

- Körperliche Fitness (gemessen anhand der Fahrradergometerdaten (mmol/l)): Gruppe L1 (< 2 mmol/l) und die Gruppe L2 (≥ 2 mmol/l)
- Alter (Jahre): Gruppe A1 (<48 Jahre) und die Gruppe A2 (≥ 48 Jahre)
- Jährliche Kilometerfahrleistung auf dem Motorrad, ausgedrückt durch die jährliche Gesamtfahrleistung (KLges): Gruppe KLges1 (< 10500 km/Jahr) und die Gruppe KLges2 (≥ 10500 km/Jahr

Es bestanden keinerlei Ausschlusskriterien in Bezug auf die oben aufgeführten Parameter und Risikofaktoren. Der Probandenkreis war durch die Berufsgruppe definiert (Autobahnpolizei), so dass alle für die Untersuchung zur Verfügung stehenden Personen ohne Einschränkung in die Auswertung mit einbezogen wurden.

Die einzelnen Motorradfahrten wurden für die statistische Erfassung jeweils in drei Teilsegmente unterteilt. Der erste Abschnitt entspricht zeitlich der ersten, der dritte Abschnitt der letzten Stunde jeder Motorradfahrt. Der zweite Abschnitt, der den Mittelteil der Motorradfahrt repräsentiert, wurde für alle Fahrten auf vergleichbare Abschnitte zusammengezogen, so dass in der Auswertung längere mit kürzeren Fahrtzeiten miteinander verglichen werden konnten.

– Untersuchungstechnik

Während der Motorradfahrt wurden eine Langzeit-EKG-Aufzeichnung mit Bestimmung der Herzfrequenz und der Analyse von Herzrhythmusstörungen (CardioMem®, GE Deutschland), eine Langzeit-Blutdruckmessung (Tonoport V®, GE Deutschland) und eine Energieumsatzbestimmung (Bodymedia® SenseWear® PRO_2 Armband) vorgenommen. Die Probanden wurden einer standardisierten Fahrradsitzend-Ergometrie (Ergometer eBike®, GE Deutschland) mit EKG-, Herzfrequenzaufzeichnung, Laktat- und Blutdruckbestimmung unterzogen.
Die Gesundheitsdokumentation wurde durch eine körperliche Untersuchung und eine umfassende Laborchemie erbracht.

– Fahrleistung

In einem Fragebogen waren die Probanden aufgefordert worden, Angaben zu ihrer jährlichen Motorradkilometerleistung, unterteilt in einen Gesamtbereich, einen beruflichen und einen privaten, zu machen. Dabei ergaben sich für die jährliche Gesamtkilometerleistung im Mittel ein Wert von 7860 km/Jahr (+/- 5838,6 km/Jahr; Schwankungsbreite: 800 km/Jahr – 28000 km/Jahr). Beruflich sind die Teilnehmer im Durchschnitt 1869 km /Jahr (+/- 1981,7 km/Jahr; Schwankungsbreite: 100 km/Jahr – 10000 km/Jahr) gefahren, privat 6570 km/Jahr (+/- 4914,9 km/Jahr ; Schwankungsbreite: 100 km/Jahr – 25000 km/Jahr).

Die durchschnittliche Fahrtzeit betrug 14,04 Stunden (+/- 3,6 Stunden) pro Tag, die Tagesarbeitszeit lag bei 4,00 Stunden bis 24,00 Stunden. Die jeweiligen Untersuchungsgruppen werden genauer dargestellt.

Bei der Beziehung zum Körpergewicht (BMI) zeigt sich, dass die Normgewichtigen eine längere (B1 = 15,10 Stunden), die geringgradig Übergewichtigen (B2 = 14,12 Stunden) und die Übergewichtigen (B3 = 11,92 Stunden) eine kürzere Fahrtzeit aufwiesen.
Das Kollektiv mit einem intensiveren wöchentlichen körperlichen Training (T1) hatte eine längere Fahrtzeit (14,40 Stunden) verglichen mit den nicht Trainierenden (T2 = 12,20 Stunden). Diese Differenz muss auf die durchschnittliche Fahrgeschwindigkeit bezogen werden (Abb.9).

– *Fahrgeschwindigkeit*

Die 39 Teilnehmer bewältigten die durchschnittlich 1133 km (+/- 294,8 km) mit einer Durchschnittsgeschwindigkeit von 81,7 km/h (+/- 13,3 km/h) Die höchste durchschnittliche Geschwindigkeit lag bei 120,4 km/h, die niedrigste Durchschnittsgeschwindigkeit bei 56,2 km/h.

Unter Bezugnahme auf das Körpergewicht (BMI) war für die leicht Übergewichtigen (B2) die höchste Durchschnittsgeschwindigkeit (85,9 km/h), für die Übergewichtigen (B3) die niedrigste Durchschnittsgeschwindigkeit (83,0 km/h) gemessen worden.
Die Aufteilung der Kollektive nach der aeroben ergometrischen Leistungsfähigkeit erbringt für die Leistungsbesseren (L1) eine höhere Durchschnittsgeschwindigkeit als für die Leistungsschwächeren (L2) (L1 = 86,9 km/h, L2 = 79,4 km/h). Bezogen auf das körperliche Training ergab sich ein Unterschied für die besser Trainierten (T2) von 14,1 km/h (T1 = 80,3 km/h, T2 = 94,4 km/h).
Das biologische Alter erbringt keine Unterschiede bezogen auf die Durchschnittsgeschwindigkeit (A1 = 84,7 km/h, A2 = 84,0 km/h) (Abb.9).

– *Fahrtstrecke*

Die 39 Probanden hatten eine tägliche Fahrleistung von 1133 km (+/- 294,8 km) (Abb.9).

– *Statistische Auswertung*

Alle für die Auswertung relevanten Daten wurden durch das Statistik-Programm SPSS erfasst und statistisch ausgewertet. Von den statistisch auswertbaren Daten wurden jeweils die Mittelwerte gebildet und diese miteinander verglichen. Zur Beurteilung des Signifikanzniveaus wurden für alle Daten als nicht-parametrischer Test für drei oder mehr gepaarte Stichproben der Friedman-Test, als nicht-parametrisches Verfahren zur Quantifizierung der Übereinstimmung zwischen mehreren Beurteilern der Kendall´S-W-Test, als parameterfreier Test zur Überprüfung der Übereinstimmung zweier unabhängiger Verteilungen der Mann-Whitney-U-Test und als nicht-parametrischer Test für zwei unabhängige Stichproben der Wilcoxon-Test angewendet. Es konnte nach der Überprüfung der Daten davon ausgegangen werden, dass diese normal verteilt sind.

Ergebnisse

– Blutdruck

Der systolische Blutdruck während der gesamten Motorradfahrt zeigt bei den Vergleichskollektiven keine signifikanten Schwankungen (Abb.8).

Unter Berücksichtigung des wöchentlichen körperlichen Trainings ergaben sich in allen drei Fahrsegmenten keine Unterschiede.

Bezogen auf die aerobe fahrradergometrisch getestete Leistungsfähigkeit wurden nur in der 1. Belastungsstunde für die besser Trainierten (L1) eine Differenz von 11,6 mmHg gegenüber den weniger Trainierten (L2) gemessen (nicht signifikant). Für den Mittelabschnitt der Motorradfahrt ergaben sich keine Unterschiede (L1 = 156,6 mmHg (+/- = 9,6 mmHg), L2 = 155,8 mmHg (+/- = 14,1 mmHg)). In der letzten Stunde der Motorradfahrt betrug der Unterschied 6,3 mmHg (L1 = 153,3 mmHg (+/- = 12,8 mmHg), L2 = 159,9 mmHg (+/- = 17,1 mmHg)).

Die durchschnittlichen Blutdruckwerte für die Beziehung zum Körpergewicht (BMI) waren nicht signifikant unterschiedlich, bezogen auf die einzelnen Fahrtabschnitte (1.Abschnitt: B1 = 152,3 mmHg (+/- 20,7 mmHg), B2 = 156,8 mmHg (+/- = 14,6 mmHg), B3 = 162,6 mmHg (+/- = 28,4 mmHg); Mittelteil: B1 = 153,6 mmHg (+/- = 8,4 mmHg), B2 = 154,5 mmHg (+/- = 14,0 mmHg), B3 = 157,7 mmHg (+/- = 15,0 mmHg); letzter Abschnitt: B1 = 155,9 mmHg (+/- = 12,7 mmHg), B2 = 155,6 mmHg (+/- = 16,3 mmHg), B3 = 153,9 mmHg (+/- = 17,3 mmHg)). In der 1. Stunde ergibt sich ein nicht signifikanter Unterschied zwischen B1 und B3 von 10,3 mmHg.

Für die motorradspezifische jährliche Fahrleistung können keine Unterschiede dargestellt werden (1.Abschnitt: KLges1 = 158,8 mmHg (+/- = 25,4 mmHg), KLges2 = 155,6 mmHg (+/- = 19,7 mmHg); Mittelteil: KLges1 = 154,0 mmHg (+/- = 8,1 mmHg), KLges2 = 155,4 mmHg (+/- = 12,7 mmHg); letzter Abschnitt: KLges1 = 155,3 mmHg (+/- = 10,0 mmHg), KLges2 = 154,2 mmHg (+/- = 16,8 mmHg)).

Bei der Betrachtung des Durchschnittsalters ist für beide Altersgruppen in allen drei Fahrtabschnitten keine signifikante Veränderung gemessen worden (1.Abschnitt: A1 = 157,1 mmHg (+/- = 24,2 mmHg), A2 = 157,2 mmHg (+/- = 16,5 mmHg) ; Mittelteil: A1 = 153,2 mmHg (+/- = 12,9 mmHg), A2 = 157,4 mmHg (+/- = 12,4 mmHg) ; letzter Abschnitt: A1 = 149,9 mmHg (+/- = 15,4 mmHg), A2 = 161,3 mmHg (+/- = 12,7 mmHg)), wobei das ältere Kollektiv in der letzten Belastungsstunde einen systolisch nicht signifikanten Unterschied von 11,4 mmHg aufwies.

– Herzfrequenz

Die Durchschnittsherzfrequenz liegt für das gesamte Kollektiv und die gesamte Untersuchungszeit bei 102,3/min (+/- 19,3/min), wobei sich eine Kumulierung bei einer Herzfrequenz von 86,6/min und 113,2/min ergibt. Im Minimum werden 73,2/min, im Maximum 153,7/min beschrieben (Abb.7).
Bei der Aufteilung in die einzelnen Fahrtabschnitte wurden für das Gesamtkollektiv keine signifikanten Unterschiede aufgezeichnet (1.Abschnitt: 101,2/min (+/- 30,9/min); Mittelteil: 108,1/min (+/- 20,6/min) ; letzter Abschnitt: 97,5/min (+/- 25,7/min)) (Abb.10).

Die mittlere Herzfrequenz für den BMI ergibt keine signifikanten Unterschiede (B1 = 96,9/min, B2 = 102,7/min, B3 = 106,9/min) (Abb.8).
Im Vergleich der BMI-Einteilung für die einzelnen Kollektive ist sowohl im Mittelteil als auch in der letzten Stunde ein schwach signifikanter Unterschied, bezogen auf die Durchschnittsherzfrequenz während der Untersuchung, aufgetreten. (Mittelteil: B1 = 99,7/min, (+/- = 25,7/min), B3 = 117,4/min (+/- = 21,0/min) ; letzter Abschnitt: B1 = 93,3/min (+/- = 31,3/min), B3 = 106,1/min (+/- = 19,9/min)).

Die ergometrisch ermittelte aerobe Leistungsfähigkeit zeigt für die Gesamtbelastung und das Gesamtkollektiv einen nicht signifikanten Unterschied (L1 = 95,2/min, L2 = 107,7/min) (Abb.8).
Bei der Aufteilung in die einzelnen Fahrtabschnitte sind für den ersten Abschnitt eine schwache Signifikanz und im Mittelteil eine tendenzielle Unterschiedlichkeit für die aerob Leistungsbesseren dargestellt worden (1.Abschnitt: L1 = 89,6/min (+/- = 20,3/min), L2 = 109,8/min (+/- = 29,1/min) ; Mittelteil: L1 = 102,4/min (+/- = 18,8/min), L2 = 113,8/min (+/- = 21,1/min)) (Abb.2).

Die Differenzierung nach der körperlichen Fitness erbringt sowohl in der Betrachtung des Gesamtkollektivs (T1 = 101,5/min, T2 = 104,1/min) (Abb.8), als auch in der Einzelbetrachtung der Fahrabschnitte keinen wesentlichen Unterschied. (1.Abschnitt: T1 = 99,1/min (+/- = 26,7/min), T2 = 106,5/min (+/- = 41,5/min) ; Mittelteil: T1 = 109,3/min (+/- = 22,8/min), T2 = 105,0/min (+/- = 14,2/min) ; letzter Abschnitt: T1 = 96,1/min (+/- = 25,3/min), T2 = 101,0/min(+/- = 28,2/min)).
Die Aufteilung in Trainingsstunden pro Woche erbringt zwischen keinem Fitnesstraining und einer Trainingsstunde pro Woche einen signifikanten Unterschied.

Die jährliche Fahrleistung ergibt bezogen auf die gewählte Einteilung keinen signifikanten Unterschied für die gesamte Aufzeichnung (KLges1 = 98,8/min, KLges2 = 102,2/min) (Abb.8).
Für die einzelnen Fahrtabschnitte zeigt sich für das Kollektiv, welches eine größere Fahrleistung jährlich erbringt, eine tendenziell höhere Herzfrequenz im ersten Abschnitt und im Mittelteil (1.Abschnitt: KLges1 = 93,8/min (+/- = 23,2/min), KLges2 = 107,6/min (+/- = 37,3/min) ; Mittelteil: KLges1 = 96,3/min (+/- = 11,7/min), KLges2 = 110,5/min (+/- = 20,3/min)). Im letzten Fahrtabschnitt ist die Herzfrequenz für die Gruppierung mit der größeren jährlichen Kilometerleistung schwach signifikant niedriger (KLges1 = 106,3/min (+/- = 26,6/min), KLges2 = 88,4/min (+/- = 23,7/min)).

Für das Alter ergibt sich für die Gruppe A1 ein Wert von 105,1/min, für die Gruppe A2 einer von 99,0/min (Abb.8). Die Differenz zwischen den beiden Werten der Vergleichsgruppen ist signifikant.

Der Vergleich für die gewählte Alterseinteilung ergibt in allen Untersuchungsabschnitten keine signifikante Differenz (1.Abschnitt: A1 = 105,2/min (+/- = 33,0/min), A2 = 96,6/min (+/- = 29,1/min) ; Mittelteil: A1 = 112,0/min (+/- = 14,3/min), A2 = 103,6/min (+/- = 25,9/min) ; letzter Abschnitt: A1 = 98,0/min (+/- = 26,2/min), A2 = 96,9/min (+/- = 26,1/min)).

– Herzleistungsprodukt

Das Herzleistungsprodukt erbrachte für die BMI-Kollektive, bezogen auf die drei Fahrtabschnitte, im ersten Abschnitt keine signifikanten Unterschiede, im Mittelteil eine Signifikanz von den Normgewichtigen zu den Übergewichtigen. Dies ist auch im letzten Abschnitt dargestellt worden (1.Abschnitt: B1 = 14863 mmHg x 1/min, B2 = 16645 mmHg x 1/min, B3 = 15825 mmHg x 1/min ; Mittelteil: B1 = 15329 mmHg x 1/min, B2 = 16596 mmHg x 1/min, B3 = 18522 mmHg x 1/min ; letzter Abschnitt: B1 = 14545 mmHg x 1/min, B2 = 14716 mmHg x 1/min, B3 = 16318 mmHg x 1/min) (Abb.5).

Die ergometrisch getestete aerobe Leitungsfähigkeit erbringt für den Mittelteil und den letzten Abschnitt keine signifikanten Unterschiede (Mittelteil: L1 = 16038 mmHg x 1/min, L2 = 17725 mmHg x 1/min ; letzter Abschnitt: L1 = 14337 mmHg x 1/min, L2 = 15899 mmHg x 1/min). Im ersten Abschnitt ist eine mittlere Signifikanz erkennbar (L1 = 13698 mmHg x 1/min, L2 = 18053 mmHg x 1/min).

Bezogen auf das wöchentliche körperliche Training sind in allen drei Fahrtabschnitten keine signifikanten Unterschiede eingetreten. Im Mittelteil ist eine in der Tendenz eingetretene Erhöhung aufgezeichnet (1.Abschnitt: T1 = 15626 mmHg x 1/min, T2 = 16587 mmHg x 1/min ; Mittelteil: T1 = 17160 mmHg x 1/min, T2 = 15820 mmHg x 1/min ; letzter Abschnitt: T1 = 15101 mmHg x 1/min, T2 = 15176 mmHg x 1/min) (Abb.1).

Unter Bezugnahme auf die Fahrpraxis sind im ersten Abschnitt und im Mittelabschnitt schwach signifikante Veränderungen, bezogen auf die höhere Fahrpraxis, dokumentiert. Im Endabschnitt ist ein signifikanter Unterschied, bezogen auf die geringere Fahrpraxis, erkennbar (1.Abschnitt: KLges1 = 14891 mmHg x 1/min, KLges2 = 16749 mmHg x 1/min ; Mittelteil: KLges1 = 14823 mmHg x 1/min, KLges2 = 17180 mmHg x 1/min ; letzter Abschnitt: KLges1 = 16506 mmHg x 1/min, KLges2 = 13633 mmHg x 1/min) (Abb.6).

Für den Vergleich beim Alter zwischen den beiden Gruppen A1 und A2 und den einzelnen Fahrtabschnitten lassen sich keine signifikanten Unterschiede aufzeigen (1.Abschnitt: A1 = 16526 mmHg x 1/min, A2 = 15185 mmHg x 1/min ; Mittelteil: A1 = 17157 mmHg x 1/min, A2 = 16307 mmHg x 1/min ; letzter Abschnitt: A1 = 14692 mmHg x 1/min, A2 = 15627 mmHg x 1/min).

– aktiver Energieumsatz

Im Vergleich der drei Gruppen beim BMI ergibt sich ein tendenzieller Unterschied für die Normgewichtigen zu den Übergewichtigen. Eine Signifikanz ist nicht erkennbar (B1 = 886 kJ, B2 = 1154 kJ, B3 = 1213 kJ) (Abb.8). In den einzelnen Fahrtabschnitten ist nur im ersten Abschnitt eine Signifikanz zwischen den Normgewichtigen sowie leicht Übergewichtigen und den Übergewichtigen zu erkennen. Im Mittelabschnitt und im Endabschnitt sind keine signifikanten Unterschiede dargestellt (1.Abschnitt: B1 = 1052 kJ (+/- = 328,2 kJ), B2 = 1089 kJ (+/- = 605,3 kJ), B3 = 1729 kJ (+/- = 618,5 kJ) ; Mittelteil: B1 = 965 kJ (+/- = 164,3 kJ), B2 = 1136 kJ (+/- = 363,4 kJ), B3 = 1232 kJ (+/- = 93,8 kJ) ; letzter Abschnitt: B1 = 641 kJ (+/- = 354,1 kJ), B2 = 1236 kJ (+/- = 530,8 kJ), B3 = 678 kJ (+/- = 406,2 kJ)).

In den einzelnen Fahrtabschnitten ist kein signifikanter Unterschied, bezogen auf die ergometrisch getestete Leistungsfähigkeit, erkennbar (1.Abschnitt: L1 = 1450 kJ (+/- = 680,0 kJ), L2 = 1110 kJ (+/- = 480,3 kJ) ; Mittelteil: L1 = 1208 kJ (+/- = 271,4 kJ), L2 = 976 kJ (+/- = 206,2 kJ) ; letzter Abschnitt: L1 = 1039 kJ (+/- = 537,7 kJ), L2 = 597 kJ (+/- = 376,8 kJ)) (Abb.3).

Für das körperliche Training ist im Vergleich und für den ersten Abschnitt und den Mittelabschnitt keine Signifikanz erkennbar. Im letzten Abschnitt ist ein signifikanter Unterschied für die intensiver Trainierenden dargestellt (1.Abschnitt: T1 = 1151 kJ (+/- = 562,7 kJ), T2 = 1578 kJ (+/- = 662,0 kJ) ; Mittelteil: T1 = 1010 kJ (+/- = 232,7 kJ), T2 = 1356 kJ (+/- = 159,5 kJ) ; letzter Abschnitt: T1 = 578 kJ (+/- = 350,2 kJ), T2 = 1312 kJ (+/- = 482,8 kJ)).

Der aktive Energieumsatz, bezogen auf die jährliche Fahrleitung, zeigt sowohl im ersten als auch im letzten Abschnitt eine deutlich signifikante Veränderung (1.Abschnitt: KLges1 = 1705 kJ (+/- = 540,3 kJ), KLges2 = 1016 kJ (+/- = 552,5 kJ) ; letzter Abschnitt: KLges1 = 1215 kJ (+/- = 527,5 kJ), KLges2 = 668 kJ (+/- = 315,2 kJ)). Im Mittelteil sind keine signifikanten Veränderungen aufgezeigt (Klges1 = 1276 kJ (+/- = 259,8 kJ), KLges2 = 1005 kJ (+/- = 253,6 kJ)).

Eine Beziehung des aktiven Energieumsatzes zum Alter der Probanden besteht nicht.

Diskussion

Das Risikoprofil in der allgemeinen und speziellen kardiologischen Medizin ist auf das pathologische Verhalten des Blutdrucks in Ruhe und unter Belastung bezogen. In der Gesundheitsbeurteilung wird das Herzfrequenzverhalten in Ruhe und unter Belastung herangezogen. Sowohl die ergometrisch getestete Leistungsfähigkeit, bezogen auf die aerobe und anaerobe Energiebereitstellung, als auch die wöchentlich trainierte Fitness in Stunden, dokumentieren den Regenerationsgrad nach körperlicher Anstrengung.

In gleicher Weise werden die Leistungsfähigkeit eines aktiven Menschen durch das Körpergewicht (Body-Mass-Index = BMI) und den sich ergebenden Energieumsatz bestimmt. Bei einer Langzeitmotorradfahrt sind zusätzlich die Fahrroutine durch die Menge der jährlich zurückgelegten Fahrkilometer auf dem Motorrad und das Alter des Motorradfahrers bestimmend.

Das Herzfrequenzprofil bei Motorradbelastungen im Rennsport als auch in der Freizeit ist vielfach beschrieben. Eine entsprechende Daueraufzeichnung für den systolischen und diastolischen Blutdruck ist nicht bekannt. Die Beziehung zwischen körperlicher Leistungsfähigkeit, getestet auf dem Fahrradergometer, sowie der wöchentlich durchgeführten Fitness-Trainingsmaßnahmen und dem Herzleistungsprodukt sind insofern von Bedeutung, als eine Beeinflussung des Fahrleistungsvermögens beim Langzeitmotorradfahren nicht ausgeschlossen werden kann. Der Risikofaktor Übergewicht und Alter beeinflussen das Leistungsvermögen beim Langzeitmotorradfahren unter normalen Straßenverkehrsverhältnissen zusätzlich.

Die Vorgabe in 3 Monaten 100000 km auf einem handelsüblichen Motorrad der oberen PS-Klasse zu erreichen, verlangt, dass eine tägliche Fahrstrecke von mehr als 1000 km gefahren werden mussten. Um eine den üblichen Verkehrs- und Witterungsverhältnissen angepasste Fahrt zu erreichen wurde täglich über 83 Tage gefahren.

Das Kollektiv von 39 Fahrern mit einem Durchschnittsalter von 47 Jahren ist gemäß der Straßenverkehrsordnung die vorgegebene Fahrtzeit auf Fahrstrecken mit verschiedenem Straßenprofil gefahren.

Die Fahrpausen waren durch die für das Motorrad notwendigen Tankstopps nach jeweils zwei Stunden gegeben.

Das Herzfrequenzprofil zeigt über die Gesamtfahrzeit einen Durchschnitt von 102,3/min. Die Herzfrequenzverteilung weist eine Kumulierung bei 86,6/min und 113,2/min auf. In der Normalverteilung sind die niedrigsten Herzfrequenzwerte bei 73,2/min, die höchsten bei 153,2/min berechnet (Abb.7).

Unter Berücksichtigung des körperlichen Trainings zeigen die Probanden mit einem 1- bis 7-stündigem Fitnesstraining pro Woche eine bessere Anpassung des Organismus an die geforderte Langzeitmotorradbelastung. Es ist signifikant nachgewiesen, dass schon das Training von einer Stunde pro Woche auf das Herzfrequenzverhalten einen positiven Einfluss hat. Im Vergleich der Fitness-Trainingsstunden ist ein Training von mehr als 4 Stunden pro Woche als zusätzlich begünstigender Faktor auf das Herzfrequenzverhalten unter Belastung signifikant dargestellt worden.

Die Signifikanzen zwischen den Vergleichsgruppen des körperlichen Trainings, bezogen auf die Herzfrequenz während der Motorradfahrt, zeigen, dass die besser Trainierten im Durchschnitt mit einer niedrigeren Herzfrequenz gegenüber den weniger Trainierten gefahren waren. Die körperliche Fitness wirkt sich positiv auf das Ausdauervermögen während einer Langzeitmotorradfahrt aus.
Die besser Trainierten sind zu Beginn und während der Motorradfahrt den weniger Trainierten überlegen gewesen (Abb.2). Dies bedeutet, dass die körperlich Leistungsfähigeren schneller gefahren waren, was sich besonders im Vergleich der Gruppen bei der Durchschnittsgeschwindigkeit darstellte (Abb.9).

Analog zu den Ergebnissen bei der körperlichen Fitness ergibt sich auch für die motorradspezifische jährliche Fahrpraxis eine Signifikanz in allen drei Abschnitten der Motorradfahrt. Die bei den weniger gut Trainierten niedrigeren Herzfrequenzen in der 1. Stunde und im Mittelteil des Tests sind Hinweis darauf, dass diese Probanden sowohl langsamer im Startabschnitt als auch im Mittelteil des Tests gefahren sind. Erst in der erworbenen Sicherheit für das Motorrad bei zunehmender Dauer des Tests wurde das trainingsschwächere Kollektiv vertrauter mit der Aufgabe, so dass bei diesen Probanden im letzten Abschnitt der Testfahrt eine gleichwertige bzw. bessere Anpassung der Herzfrequenz an die gestellte Aufgabe erfolgte.

Da die Probanden durchschnittlich 47 Jahre alt waren, ist ein Vergleich zu jüngeren, unbesonneneren Motorradfahrern, nicht möglich.
Die Langzeitblutdruckaufzeichnung ist in ihren systolischen und diastolischen Absolutwerten weder körpergewichtsbezogen noch trainings-, alters- und fahrpraxisbezogen unterschiedlich.

Unter Vorgabe der Grundwerte für den systolischen und diastolischen Blutdruck in Ruhe von 130/80 mmHg ist der Durchschnittsblutdruck unter der bei dem Kollektiv ergometrisch sitzend durchgeführten Belastung auf dem Fahrradergometer einer Leistung von 60-75 Watt zuzuordnen. Somit ergibt sich ein Leitungsblutdruck über die durchschnittliche Fahrzeit von 14 Stunden von durchschnittlich RR 155,8/97 mmHg.

Das Blutdruckverhalten bei der Motorradtestfahrt zeigt, bezogen auf den systolischen Blutdruck, keine unterschiedlich signifikante Beziehung zu der risikorelevanten BMI-Einteilung. Dies gilt sowohl für das Kollektiv während der Gesamtfahrtzeit, als auch für die einzelnen definierten Fahrtabschnitte. Das Fitnesstraining von mehr als einer Stunde pro Woche zeigt zwar tendenziell über die Dauer der Fahrt eine Reduktion des Ausgangsblutdrucks RRsys von 156 mmHg auf 150 mmHg. Diese Veränderungen sind ebenso wenig signifikant wie die Beziehung zu der ergometrisch getesteten aeroben Leitungsfähigkeit. Entsprechend der verbesserten aeroben Leistungsfähigkeit ist im ersten Fahrtabschnitt ein Unterschied von RRsys 12 mmHg für die aerob-bessere Gruppe zu sehen.

Das RR-Verhalten, bezogen auf die Gruppierung mit dem Alter über 50 Jahre, zeigt im letzten Fahrabschnitt einen Unterschied zu den unter 48-Jährigen von RRsys 11,4 mmHg. Diese Veränderung ist nicht auf die Fahrleistung zu beziehen, sondern alterspezifisch zu werten.

Die Ausgeglichenheit des Testkollektivs ergibt keine verwertbare Beziehung für die jährliche berufliche und private Kilometerleistung als Motorradfahrer.

Das Blutdruckverhalten ist somit altersspezifisch nicht als Risikofaktor zu werten.

Eine Risikokonstellation ist für das Gesamtkollektiv, bezogen auf den Risikofaktor Blutdruck, nicht dokumentiert worden. Die Einflüsse von körperlichem Training und daraus folgender aerober Leistungsfähigkeit sowie eine indirekte Beziehung zum BMI sind dennoch erkennbar, wobei gerade auf die Dauer der Belastung im Langzeitmotorradtest eine Begünstigung jeweils aus der Betrachtung der letzten Fahrabschnitte gegeben ist.

Das Langzeitmotorradfahren ist somit nicht für gesunde männliche Personen, bezogen auf den Blutdruck, einzustufen.

Ein Risikofaktor erster Kategorie ist das Übergewicht. Der Body-Mass-Index (BMI) wird in drei Bewertungen des Risikos eingestuft. In der Untersuchung wurde eine Einteilung gemäß der allgemein gültigen Gesundheitsrisikovorgaben zu den verschiedenen zusätzlichen Untersuchungsparametern vorgenommen.

Das Durchschnittsherzfrequenzprofil zeigt, dass im ersten Abschnitt der Belastung kein signifikanter Unterschied zwischen den drei BMI-Risikogruppen besteht. Im Mittelteil und im letzten Abschnitt ergeben sich von der Gruppe mit Normgewichtigen zu der Gruppe der deutlich Übergewichtigen (BMI>30kg/m²) ein Unterschied von HF 17/min. Dies bedeutet, dass das Kollektiv der Normgewichtigen mit einer Herzfrequenz von 100/min, das der Übergewichtigen mit 117/min die gesamte Fahrleistung erbracht hat. Im letzten Abschnitt ist ebenfalls ein Unterschied von HF 13/min erkennbar. Somit ist beim Übergewichtigen die Korrelation zum BMI insbesondere für die Langzeitbelastung zu beachten.

Im Herzleistungsprodukt (RRsys x HF) wird die Bedeutung des BMI als Risikofaktor noch verdeutlicht (Abb.5). Im Mittelabschnitt und im Endabschnitt sind, bezogen auf Übergewicht zu Normgewicht, signifikante Unterschiede aufgetreten. Diese Unterschiede korrelieren nicht mit der aeroben Leistungsfähigkeit, die im Fahrradergometertest gemessen wurde, und auch nicht mit dem körperlichen Fitnesstraining.

Bezogen auf das Alter des Kollektivs war keine Signifikanz zum Risikofaktor Übergewicht zu erheben.

Der Risikofaktor Übergewicht ist beim Langzeitmotorradfahren insofern von Bedeutung, weil bei zunehmender Belastung eine negative Beeinflussung der Herzleistung eintritt. Die Gewichtsreduktion wird auch für das Langzeitmotorradfahren wie allgemein gesundheitlich empfohlen.

Der aktive Energieumsatz (kJ) während der Motorradfahrt ist ohne signifikante Korrelation zum BMI. Nur für die Übergewichtigen ist im ersten Abschnitt ein signifikant erhöhter Umsatz erkennbar.

Unter Berücksichtigung der aeroben Energiebereitstellung ist der aktive Energieumsatz nicht signifikant, aber tendenziell in allen Abschnitten für die Probanden mit der höheren aeroben Leistungsfähigkeit besser (Abb.3). Diese Energieveränderung erklärt sich aus der höheren Durchschnittsgeschwindigkeit (Abb.9). Es ist zu vermuten, dass der Energieumsatz durch die bessere energetische Verwertung der Nährstoffe hervorgerufen wird. Unter Einbeziehung des wöchentlichen körperlichen Trainings ist in allen Fahrabschnitten zu erkennen, dass auch beim körperlich besser Trainierten ein ökonomischerer Energieumsatz über die Zeit der Motorradbelastung genutzt wird.

Die Begünstigung des Stoffwechsels durch die Trainingsvorgaben ist in der Korrelation der allgemeinen Fahrpraxis zum Energieumsatz erkennbar. Bei besserer Fahrpraxis ergibt sich über den Zeitraum der Motorradbelastung, bezogen auf die aktive Energie, ein deutlich besserer Umsatz. Der Unterschied beträgt im ersten und letzten Abschnitt 700 kJ.

Bezogen auf den aktiven Energieumsatz ergeben sich für die schnellere Durchschnittsgeschwindigkeit eine höhere Herzfrequenz und daraus entsprechend ein geändert günstigerer Energieumsatz für die ergometrisch aerob Leistungsfähigeren und die intensiver Trainierenden (Abb.8).

Unter Berücksichtigung der Risikoparameter Blutdruck, Übergewicht und körperlicher Fitness und der dadurch entsprechenden Verbesserung der aeroben Leistungsfähigkeit kann mit der Untersuchung verdeutlicht werden, dass für eine Langzeitmotorradbelastung die Leistungsfähigkeit des menschlichen Organismus verbessert werden kann. Die Empfehlung der WHO und der DEG sowie der Hypertonie- und Herzkreislaufgesellschaft müssen auch beim Langzeitmotorradfahren zwingend beachtet werden. Trainings- und Ernährungsprogramme nützen gesundheitlich beim Langzeitmotorradfahren. Die körperliche Fitness kann auch vorbeugend für die immer dichter werdenden Verkehrsverhältnisse als sinnvoll empfohlen werden.

In der Vorbereitung der Motorradsaison sollten die Trainings- und Ernährungsempfehlungen ebenso Beachtung finden wie die Empfehlungen zur Vorbereitung etwa der Skisaison.

Inwieweit die Unfallstatistik geändert werden wird, kann durch die Ergebnisse der vorgelegten Studie nicht angegangen werden. Diese Probleme bedürfen einer weitergehenden Untersuchung mit Messung der Stressprofile und der Blutgasparameter unter Langzeitmotorradbelastung.

Zusammenfassung

Der Risikofaktor Hypertonie ist beim Langzeitmotorradfahren nur für Untrainierte und in Kombination mit anderen Risikofaktoren von Bedeutung. Unter Berücksichtigung der Anforderungen an die kardiale Leistung ist für den Hypertoniepatienten eine optimale medikamentöse Blutdruckeinstellung vor einer Langzeitmotorradfahrt dringend zu empfehlen.

Eine Gewichtsreduktion in den Bereich der BMI-Normwerte ist auch für die positive Beeinflussung der körperlichen Leistungsfähigkeit beim Langzeitmotorradfahren zu empfehlen.

Der aktive Energieumsatz wird durch die verbesserte Trainingsleistung, bezogen auf die aerobe Leistungsfähigkeit, günstig beeinflusst.

Ein wöchentliches Fitness-Training von mehr als 4 Stunden unterstützt nicht nur die Herz-Kreislaufleistung, sondern auch das Regenerationsverhalten bei mehrstündigen Belastungen.

Die Fahrpraxis ist nicht nur in Verbindung zu gesundheitlichen Risikofaktoren, sondern auch bezogen auf das saisonale Motorradfahren von großer Bedeutung.

Die in die Untersuchung einbezogenen Probanden waren in ihrer Altersstruktur durchschnittlich über 40 Jahre, was einerseits die Beziehung zur jugendlichen Altersgruppe (18 – 35 Jahre) nicht herstellt, andererseits gezeigt hat, dass der ältere Motorradfahrer unter der Vorgabe der üblichen Gesundheits- und Fitnessbewertung ohne Risiko auch eine Langzeitmotorradfahrt machen kann.

Die Unfallstatistik bei Motorradunfällen muss durch weiterführende Studien zur Bestimmung der Stressprofile und der Blutgasparameter untersucht werden.

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Abbildungen

Abb. 1

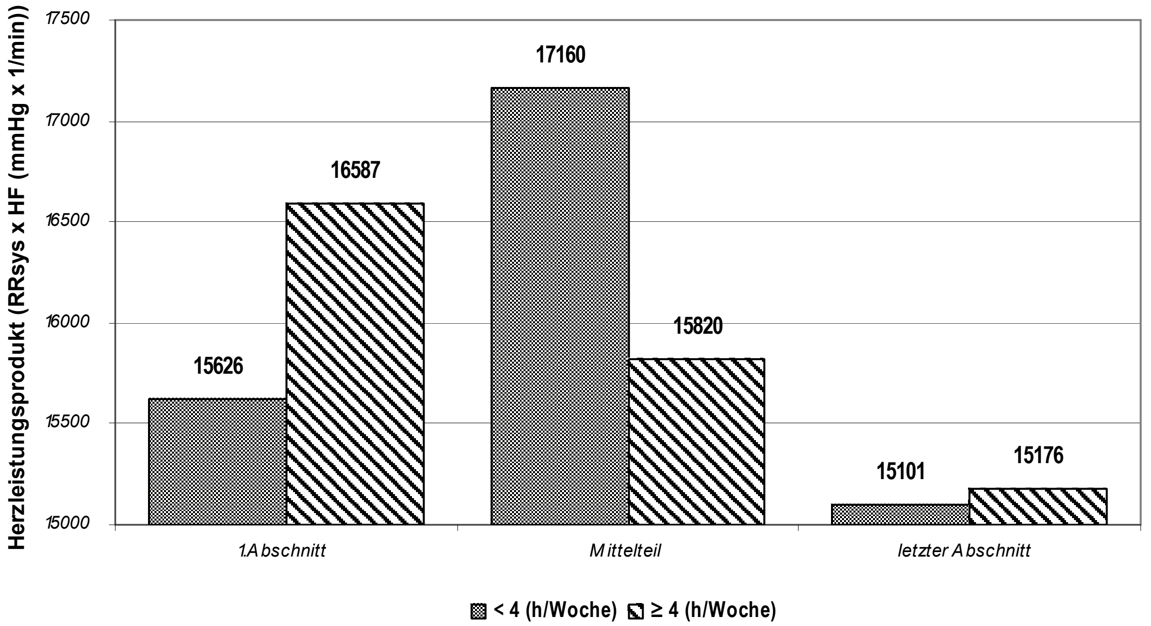
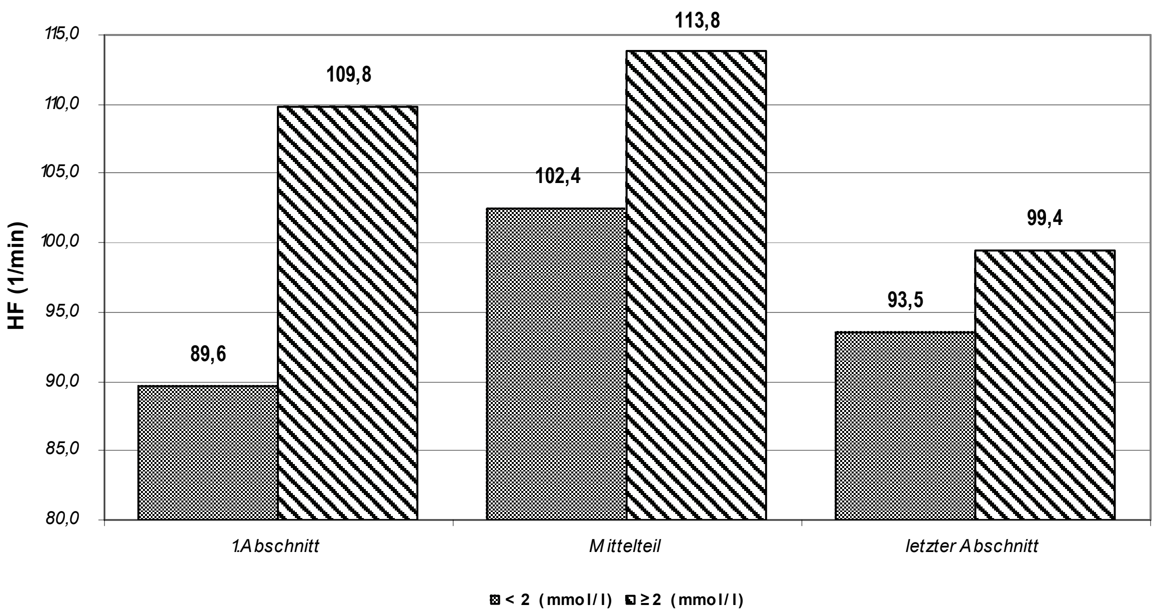


Abb. 2



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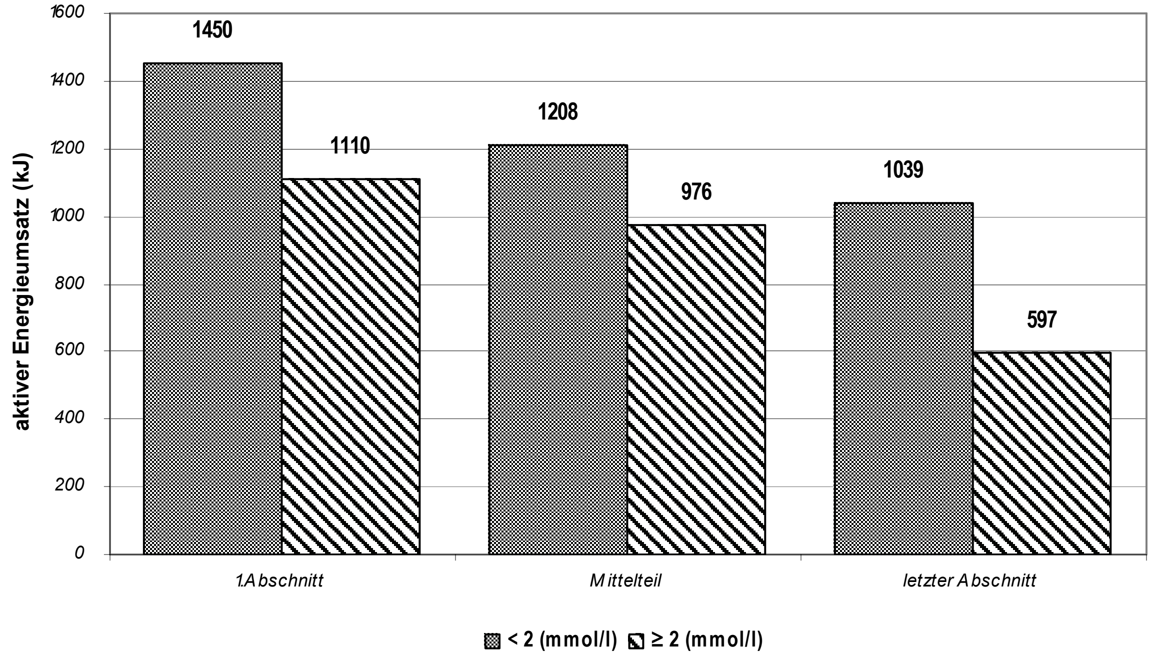

1600
1400
1200
1000
800
600
400
200
0
aktiver Energieumsatz (kJ)
1450
1110
1208
976
1039
597
1.Abschnitt
Mittelteil
letzter Abschnitt
< 2 (mmol/l)
≥ 2 (mmol/l)

Abb. 4

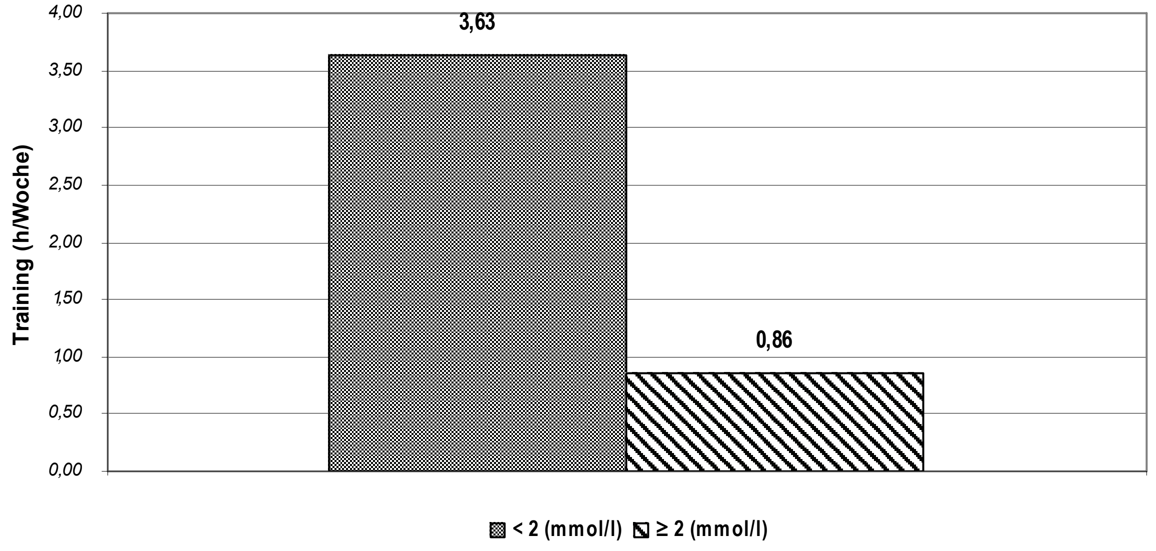
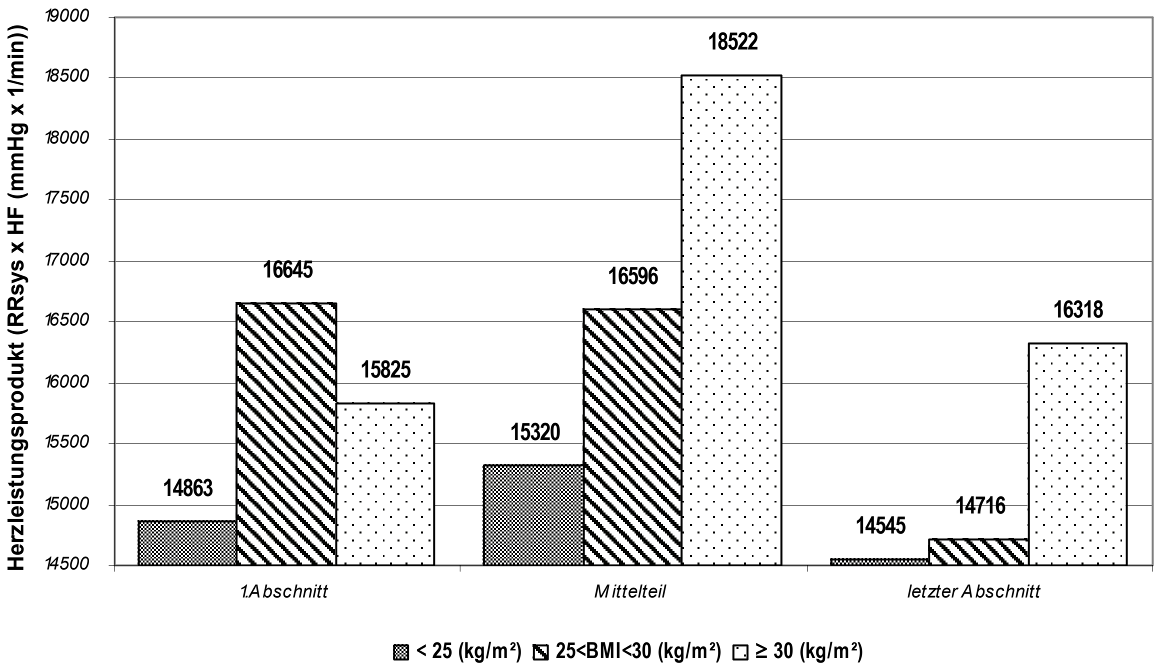
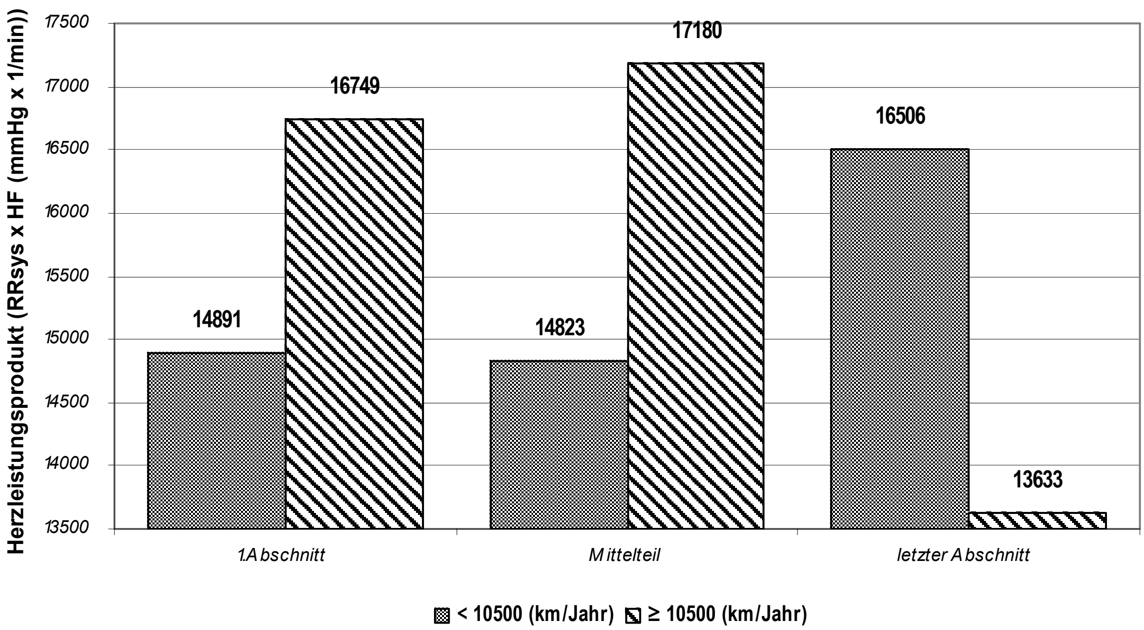

4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Training (h/Woche)
3,63
0,86
< 2 (mmol/l)
≥ 2 (mmol/l)

Abb. 5



Herzleistungsprodukt (RRsys x HF (mmHg x 1/min))
19000
18500
18000
17500
17000
16500
16000
15500
15000
14500
14863
16645
15825
15320
16596
18522
14545
14716
16318
1.Abschnitt
Mittelteil
letzter Abschnitt
< 25 (kg/m²)
25<BMI<30 (kg/m²)
≥ 30 (kg/m²)

Abb. 6



Herzleistungsprodukt (RRsys x HF (mmHg x 1/min))
17500
17000
16500
16000
15500
15000
14500
14000
13500
14891
16749
14823
17180
16506
13633
1.Abschnitt
Mittelteil
letzter Abschnitt
< 10500 (km/Jahr)
≥ 10500 (km/Jahr)

Abb. 7

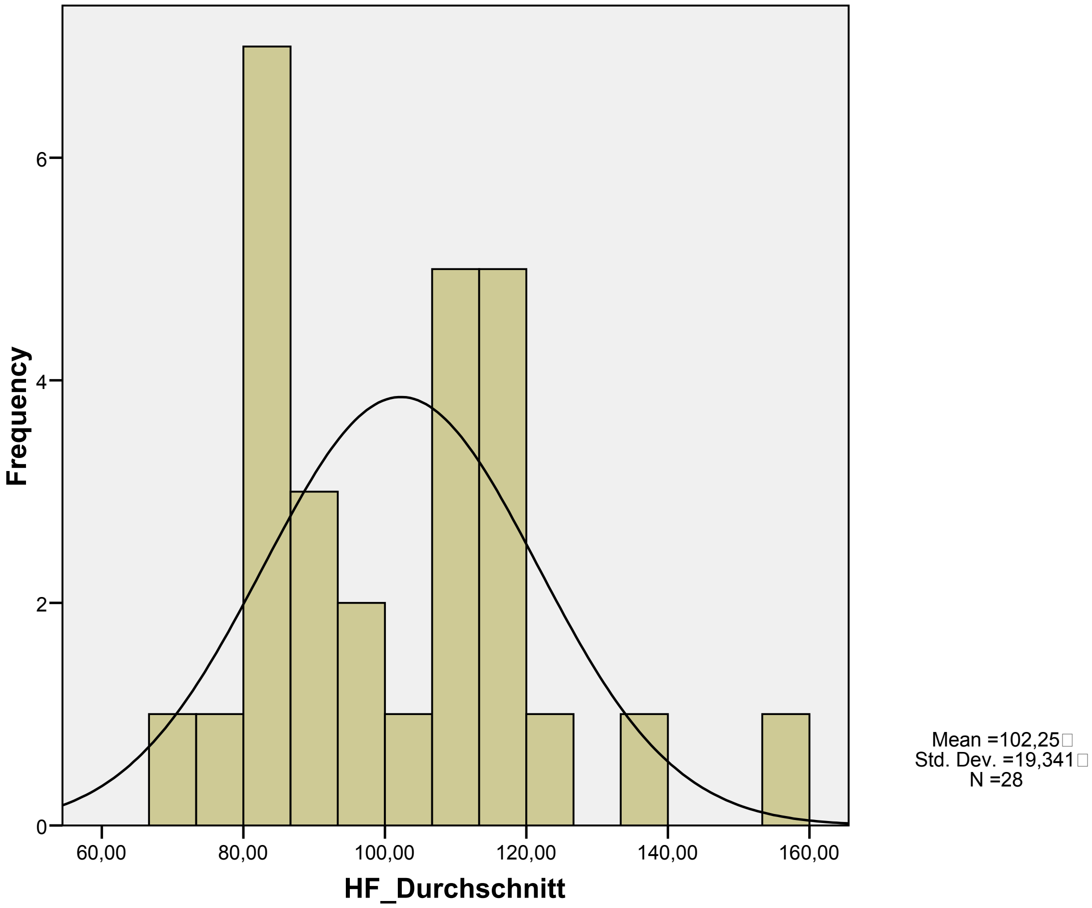
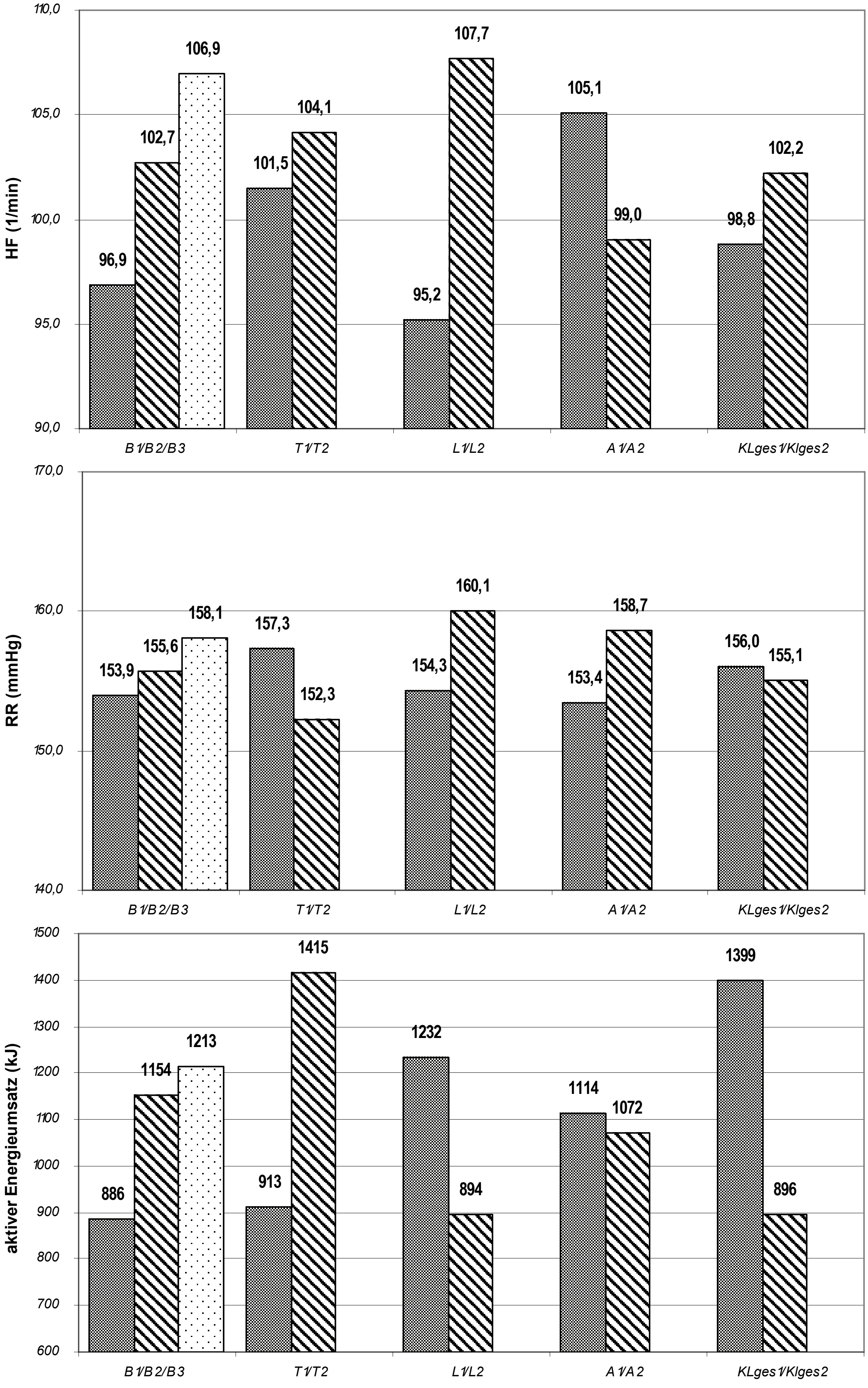
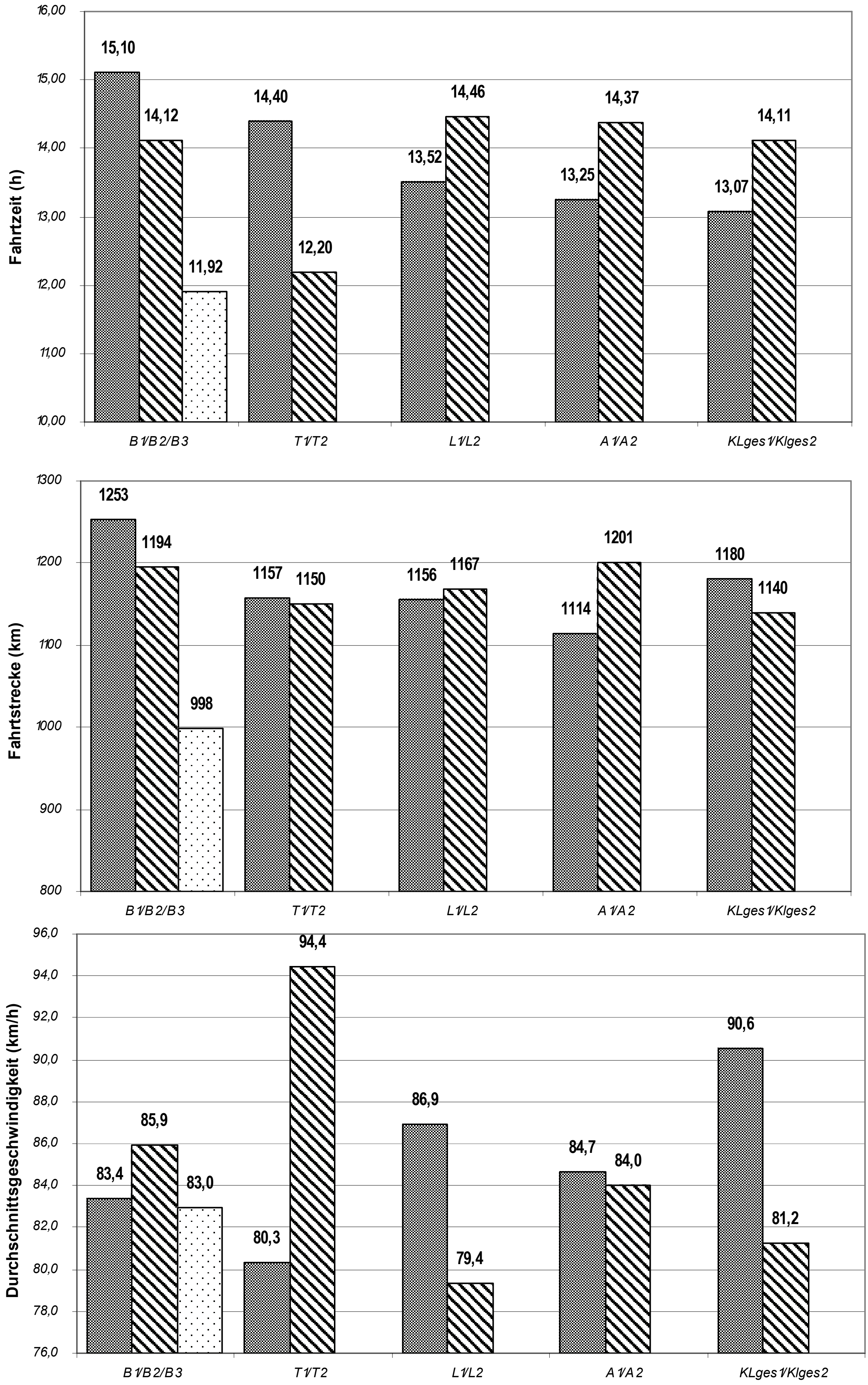

Frequency
0
2
4
6
60,00
80,00
100,00
120,00
140,00
160,00
HF_Durchschnitt
Mean =102,25
Std. Dev. =19,341
N =28

Abb. 8



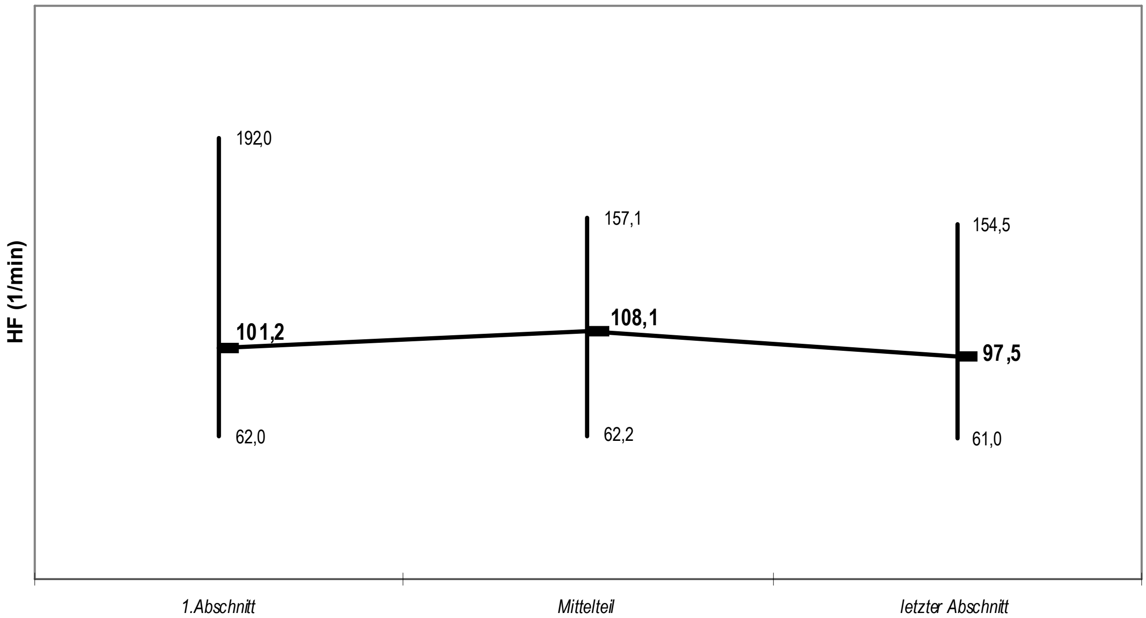
HF (1/min)
110,0
105,0
100,0
95,0
90,0
96,9
102,7
106,9
101,5
104,1
95,2
107,7
105,1
99,0
98,8
102,2
B1/B2/B3
T1/T2
L1/L2
A1/A2
KLges1/Klges2
RR (mmHg)
170,0
160,0
150,0
140,0
153,9
155,6
158,1
157,3
152,3
154,3
160,1
153,4
158,7
156,0
155,1
B1/B2/B3
T1/T2
L1/L2
A1/A2
KLges1/Klges2
aktiver Energieumsatz (kJ)
1500
1400
1300
1200
1100
1000
900
800
700
600
886
1154
1213
913
1415
1232
894
1114
1072
1399
896
B1/B2/B3
T1/T2
L1/L2
A1/A2
KLges1/Klges2

Abb. 9



16,00
15,00
14,00
13,00
12,00
11,00
10,00
Fahrtzeit (h)
15,10
14,12
11,92
14,40
12,20
13,52
14,46
13,25
14,37
13,07
14,11
B1/B2/B3
T1/T2
L1/L2
A1/A2
KLges1/Klges2
1300
1200
1100
1000
900
800
Fahrtstrecke (km)
1253
1194
998
1157
1150
1156
1167
1114
1201
1180
1140
B1/B2/B3
T1/T2
L1/L2
A1/A2
KLges1/Klges2
96,0
94,0
92,0
90,0
88,0
86,0
84,0
82,0
80,0
78,0
76,0
Durchschnittsgeschwindigkeit (km/h)
83,4
85,9
83,0
80,3
94,4
86,9
79,4
84,7
84,0
90,6
81,2
B1/B2/B3
T1/T2
L1/L2
A1/A2
KLges1/Klges2

Abb. 10



HF (1/min)
192,0
101,2
62,0
157,1
108,1
62,2
154,5
97,5
61,0
1.Abschnitt
Mittelteil
letzter Abschnitt

Research issues in Motorcycle Ergonomics & Rider Human Factors

Forschungsaufgaben zur Motorradergonomie und zu Fahrerfaktoren

Dr Alex W. Stedmon
Centre for Motorcycle Ergonomics & Rider Human Factors
University of Nottingham, UK

Abstract

Motorcycles are complex high performance machines and riding them is a very skilled task. The motorcycle and rider combine to make an interactive system operating within a very demanding safety critical environment. Understanding this system interaction is what underpins motorcycle ergonomics and rider human factors. In many ways motorcycle ergonomics is still synonymous with rider comfort and ease of use for control systems. However, apart from the physical design of the motorcycle, thermal comfort, or why some motorcycles are more suited to particular riders based on their anthropometrics, motorcycle ergonomics also encompasses aspects such as:

- workload – how much physical and mental effort does it take to ride in different conditions?
- situation awareness – how aware is the motorcyclist of what's going on around them?
- vigilance – how quickly can the motorcyclist process information from the motorcycle or from other traffic and the general environment?
- perception of danger and risk taking behaviour – how and when does a rider make decisions about their riding style?

Motorcycle ergonomics and rider human factors is an exciting new research area which is being developed in the UK at the University of Nottingham. This paper will explore key research questions in the domain and also provide a practical overview of conducting research with the arguments for and against the feasibility of real road research and simulations, and the importance of publishing more research findings, gaining industry support from manufacturers, road safety organisations, motorcycle media and more fundamentally, the riders themselves.

Kurzfassung

Motorräder sind komplexe Maschinen mit hoher Leistung, deren Beherrschung eine sehr anspruchsvolle Aufgabe ist. Motorrad und der Fahrer funktionieren zusammen als ein interaktives System, welches unter dem Sicherheitsaspekt in einem kritischen Umfeld genutzt wird. Dieses interaktive System zu verstehen, setzt ein Verständnis für die Motorradergonomie und den „Faktor Fahrer" voraus. In vielen Bereichen wird die Ergonomie des Motorrades immer noch mit Komfort und guter Bedienbarkeit der Instrumente gleichgesetzt. Neben dem Design des Motorrades spielen jedoch auch thermischer Komfort und die Frage, warum einige Fahrer aufgrund ihrer körperlichen Beschaffenheit auf bestimmte Motorräder passen, eine Rolle.

Die Ergonomie von Motorrädern umfasst Aspekte wie:

- Beanspruchung – welche körperliche und mentale Anstrengung ist erforderlich, um unter verschiedenen Bedingungen Motorrad zu fahren
- Situationsbewusstsein – wie aufmerksam ist ein Motorradfahrer
- Aufmerksamkeit – wie schnell kann der Motorradfahrer Informationen des Motorrads, des Verkehrsgeschehens oder des Umfeldes verarbeiten
- Risikowahrnehmung und Risikoverhalten – wann trifft der Fahrer welche Entscheidungen bezüglich seines Fahrverhaltens/Fahrmanövers?

Die Ergonomie von Motorrädern und der „Faktort Fahrer" stellen ein spannendes neues Forschungsgebiet dar, welches an der Universität zu Nottingham (University of Nottingham, UK) erschlossen wird. Dieser Beitrag behandelt Schlüsselfragen dieses Forschungsgebiets und gibt darüber hinaus einen Überblick der weiterführenden Forschung mit Argumenten für und wider die Realisierbarkeit solcher Forschung und Simulationen im realen Verkehr. Zusätzlich geht es um die Bedeutung der Veröffentlichungen von Forschungsergebnissen, die Unterstützung durch Industrie, Verkehrssicherheitsorganisationen und Motorradmedien – und grundlegender um den Fahrer selbst.

Research issues in Motorcycle Ergonomics
& Rider Human Factors

Motorcycling as a user-centred interactive system

Motorcycle ergonomics and rider human factors is a new research area which is being developed by the Centre for Motorcycle Ergonomics and Rider Human Factors in the UK. Whilst research has been conducted in many areas of transportation there has been one notable exception: motorcycles. One of the reasons for this could be that motorcyclists represent a niche road user group in many countries and so resources are focussed on other higher profile initiatives. However, with the expanding economies of India and China who rely more on motorcycle transport than the West, things could well change in the future (Stedmon, et al, 2008a). A sad fact remains that motorcycles still account for a disproportionate number of road traffic accidents and rider safety is a major concern on increasingly congested road systems.

Riding motorcycles is a relatively complex and risky activity (McInally, 2003). Motorcycles are unique in the way they operate as the rider sits on the motorcycle and controls it motorcycle through their body position and physical activity, putting force onto the handlebars, balancing their weight on their legs and controlling the engine through the throttle, gears and brakes. Many motorcycles offer a compact, agile and fuel efficient means of transport but they are open to the weather and wind, both of which can affect the stability of the motorcycle, the safety and enjoyment of the motorcyclist, and the effort it takes to control the motorcycle (McInally, 2003). In addition, a rider will also be looking around for potential hazards that can cause a motorcycle to lose its grip on the road or make the task of riding it more physically and mentally demanding.

The motorcycle and rider can be understood in terms of an interactive system operating within a very demanding safety critical environment. This interplay of the rider, motorcycle and environment means that research should focus on many aspects such as how the rider processes the vast array of information around them (directly or indirectly from the motorcycle and environment), what impact experience and training has on the rider's ability to control the motorcycle and interact with the ever-changing environment, what factors affect a rider's ability to ride safely or push their limits (and what happens when things go wrong). A lot of research has concentrated on the causes of road traffic accidents and although motorcycle manufacturers are beginning to take the physical design of motorbikes more seriously with some, albeit limited, adjustability in their models, virtually no human factors research has been conducted on motorcyclists. Ergonomics takes a user-centred approach to understand the needs, requirements and limitations of riders. Understanding the complexities within this interactive system and developing a human factors research agenda is crucial to understanding capturing user needs and requirements with any degree of accuracy.

Motorcycle ergonomics

Motorcycle ergonomics is often synonymous with rider comfort and ease of use for control systems. Motorcycles, by their design, tend not to 'fit the user' and riders are expected to 'fit the motorcycle' (Robertson 1987; Stedmon, 2007a). This goes very much against user-centred design principles and often dictates the market for different types of motorcycle based on the physical size of the rider. Standard motorcycles are often very limited in their adjustability and design features such as controls, displays, seating and wind protection all depend on the relative size and location of the rider to be effective (Roberston & Minter, 1996). It is important to understand the physical characteristics of the user population if design solutions are to fully support them, otherwise there is a danger that if inaccurate data are used as a basis for designing motorcycles or clothing, they will not fully support the needs of the rider. Just as there is a danger of manufacturers using the wrong data, there is also the possibility that some riders may not be riding the 'right bike' or should be able to make adjustments in terms of their comfort, enjoyment and ultimately their safety.

Previous measurements of samples from the population of UK motorcycle riders have shown that they are consistently taller than the normal UK population (Robertson 1987; Robertson & Porter, 1987; Roberston & Minter, 1996). The distributions of the stature data from both these studies were remarkably similar and illustrated that the motorcyclists were proportionally taller by approximately 35 mm than the general UK population. More recent research (Stedmon, et al, 2008b) has reported similar findings with evidence that the male motorcycle rider population is still taller than the general UK population and car driver population. This supports the notion that motorcyclists are a unique user group that requires further investigation and systematic measurement to build a larger data set in the future.

Rider comfort has also been investigated in relation to the short term impact and distraction that can occur as well as the potential for longer term riding related disorders. In a recent comfort survey there was a high degree of consistency in the body areas that were reported with symptoms of discomfort (e.g. forearms, knees, neck and bum) and that the highest level and range of discomfort was reported in the right wrist (Stedmon, 2007a). The design of many motorcycles means that the rider's wrist can be under intense and continuous physical loading throughout a ride with no opportunity to rest. It may also be flexed as the throttle rotates beyond a comfortable level and maintained at that level for as long as the rider wishes to maintain a particular speed.

Further research explored the relationship of rider comfort and motorcycle design in a quasi-experimental trial where a number of riders with different anthropometric characteristics rode different styles of motorbikes and provided comfort ratings across a number of dimensions (Stedmon, et al, 2008c). The findings illustrated that ‘one size does not fit all’ and different sized riders have very different experiences of the same motorcycle. It was also apparent that motorcycle riders experience various degrees of discomfort when riding. The discomfort ratings supported the general trend as reported by Stedmon (2007a) where the lower arms, neck and bum and particularly the wrists were affected by riding.

Rider human factors

Expanding the concept of motorcycle ergonomics and rider human factors based on the user-centred interactive system, a research agenda emerges which takes a wider focus on the issues affecting riders:

- **motorcycle design & rider equipment** – research into engineering solutions, advanced systems and motorcycle controls including new and emerging technologies (such as rider Sat-Nav systems, intercoms, bike-to-bike communications, GPS and geospatial information, advanced head up and helmet mounted display systems) as well as more traditional aspects such as rider clothing and protection with a greater focus on the rider-motorcycle interaction (RMI) that takes place in different environments.

- **rider behaviour** – investigating issues such as workload (the amount of physical and mental effort it takes to ride in different conditions), situation awareness (the motorcyclist’s awareness of what is happening around them and how this is affected by training and experience), vigilance and spare mental capacity (how quickly the motorcyclist processes information from the motorcycle, other traffic and the general environment), as well as decision making, risk-taking and perceptions of danger (how and when do riders make decisions about their riding style).

- **road safety** – examining the interplay of roadside furniture, signage and natural features on riding behaviour as well as the specific circumstances that might cause riders to lose control of their motorcycles.

- **driver education, rider training and competence** – investigating how other road users often see motorcyclists as unnecessary risk takers without appreciating that it is often safe to overtake on a motorcycle when it is not possible to conduct the same manoeuvre in a car. Examining how riders might learn/train their responses to unlikely events (developing new training methods across a range of experience levels).

Many of these areas have been explored in other domains (e.g. military and civilian aviation and even other road user groups) and some work has been conducted into the potential use and transfer of established methods and tools into the motorcycle domain. There has been success with modified Body Part Discomfort ratings (Stedmon, 2007a; Stedmon, et al, 2008c), the Rapid Upper Limb Assessment tool (Stedmon, 2007b), NASA-TLX workload analysis and heart-rate monitoring.

Developing a simulator for research

Whilst collecting data from the real world is a valuable way of doing research especially when the riding conditions, road surfaces, and traffic make every ride different, there are serious issues concerned with public safety and practicality of research which have led to the development of a bespoke motorcycle simulator 'MotorcycleSim'.

Simulators are common technologies in many transport applications. Within aviation, they have been used as a cost effective way of supporting pilot training in both military and civilian situations for both fixed-wing and rotary-wing aircraft. Train simulators have also been used for driver training and refresher sessions. At the University of Nottingham a train simulator has been built and used to test rail infrastructure problems and changes in signal design and the impact on drivers regarding driveability and route safety (Yates, et al, 2007). With road transport, simulators have been used for research into driver behaviour using advanced speech recognition interfaces (Stedmon & Bayer, 2001; Stedmon, et al, 2002) or satellite navigation and driver information systems (Pettitt, et al, 2007; Burnett, 2008). Just as there has been little human factors research into motorcycling, motorcycle simulation technology is virtually non-existent with possibly less than 5 different types around the world in the public domain (Stedmon, et al, 2008a).

With the growth of motorcycle ergonomics and rider human factors as a specific research area which is generating interest and support from manufacturers, road safety organisations, motorcycle media and the riders themselves, simulators offer a means of investigating many of the issues surrounding motorcycle riding without subjecting riders to the dangers of real riding. Within the Centre for Motorcycle Ergonomics and Rider Human Factors a simulator has been developed specifically for pioneering research. 'MotorcycleSim' has been designed as the world's first full size, interactive leaning motorcycle simulator that is linked to dedicated 'STI-Sim' simulation software which provides realistic riding scenarios. The simulator is illustrated in Figure 1 below.

Figure 1: MotorcycleSim with a rider leaning into a corner

Using MotorcycleSim it is possible to put riders through identical scenarios which are not possible on the road (where even lighting, traffic, weather conditions can vary on the same route between different rides). This means it is possible to control many of the variables in the interactive system and rigorously investigate factors independently. Simulators also allow riders to experience demanding road conditions where they can make mistakes and test the limits of their riding ability in the safety of the lab (e.g. riding under normal conditions or to test endurance, alcohol effects, rider distraction, etc). Furthermore, simulators provide an opportunity to model riding hazards that are not easy to recreate or capture on real road trials due to their infrequency and unpredictability (for more information on MotorcycleSim please refer to Stedmon, et al, 2008a).

Developing future research and disseminating findings

The potential of motorcycle ergonomics and rider human factors research is vast and both real world and simulated research will feature high on emerging research agendas. To support real world research 'instrumented motorcycles' will become more common. These are dedicated research motorcycles that collect data on rider behaviour and motorcycle performance. Novel methods will emerge (and are already in development) for capturing real world data in real time and in a non-intrusive manner. Simulated trials will provide a valuable research and training tool for riders. However, this is only one part of the process and it is important that the findings and information emerging from research are disseminated to the widest audience. Whilst there is a tendency to publish academic papers in prominent journals, the author has also published extensively in leading motorcycle media publications around the world in order to communicate information directly to riders in a more accessible form.

It is also important to canvass the support of leading road safety organisations,, Government agencies and policy makers, police forces, motorcycle action groups and manufacturers as well as rider themselves. Furthermore, engaging with mainstream media (TV, radio and mainstream newspapers) also helps to raise the profile of research. This has been particularly successful with MotorcycleSim due to its unique status. With support from the motorcycle industry and satellite agencies it is easier to pick up on key research issues as well as feed the results back to make a direct impact on safer riding for the future.

Conclusion

The University of Nottingham is leading research into various aspects of motorcycle ergonomics and rider human factors. This is a relatively new area that is gaining prominence within the academic community, motorcycle industry and road user organisations across the UK, Europe and USA. By taking a user-centred perspective the aim is to better understand the highly complex interactive system which characterises the rider, motorcycle and safety critical environment in which riders (and other road users) operate. It is necessary to develop research that focuses on many of the areas detailed in this paper, develop methods, tools and technologies to support research, disseminate the results and engage with the media for the greatest impact.

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The University of Nottingham is leading research into various aspects of motorcycle ergonomics and rider human factors. This is a relatively new and exciting research area that is gaining prominence within the academic community, motorcycle industry and road user organisations across the UK, Europe and USA. Motorcycle human factors takes a user-centred approach to defining motorcycling as an interactive system comprising of the rider, motorcycle and environment. Whilst attention has traditionally focussed on rider comfort issues and rider anthropometry, motorcycle ergonomics also includes aspects of motorcycle design, rider equipment, rider behaviour, road safety and training/competence. This paper explores key research areas in the domain and also provides an overview of a unique simulator that has been developed, along with the importance of publishing research findings, gaining industry support from manufacturers, road safety organisations, motorcycle media and more fundamentally, the riders themselves.

Safety Belt for Motorcyclists

Sicherheitsgurt für Motorradfahrer

Raphael Murri, Dipl.-Ing FH, Bereichsleiter passive Sicherheit

Roberto Martinbianco, Dipl.-Ing FH

Bernhard Gerster, Dipl.-Ing. FH Dozent FH / Geschäftsführer DTC

DTC, Dynamic Test Center, CH-2537 Vauffelin
in Partnerschaft mit der Berner Fachhochschule

Abstract

There is good reason why the motorcycle has so many friends: it is fast, unrivalled in handling and there are hardly any parking problems, therefore it is best suited to being ahead of the masses of motorists at all times. The price of having this advantage of mobility is the substantial reduction in passive safety. The possibility of securing a motorcyclist during a collision, by means of a restraining system, has not been used up to the present time.

At the Dynamic Test Center, in an in-house initiative, different technical options were analysed, which could transform throwing the motorcyclist into a retarded movement, and could thereby reduce the risk of injury to the motorcyclist in an accident. In the evaluation of the restraining system, value was placed on a mechanical, simple and reversible system, as well as on passive operation (better acceptance). With this, possible injury in the event of a release failure does not deter the user. In the event of a fall or similar situation, in which no restraining force can be built up, the motorcyclist removes himself from his motorcycle in the usual way.

In a test series of motorcycle skidding trials and motorcycle impact trials with light and also heavy motorcycles into the side of stationary motor cars, the effectiveness of the belt system could be proved. This was not only under standard conditions (ISO 13232), but also in a collision with double energy at 70 km/h.

In the next stages of development the body harness must, on the one hand, be optimised for use on the motorcyclist and the bio-mechanical load on the body in a collision must be further determined. On the other hand, the belt fastener needs to be developed together with the appropriate loocking strategy and construction. By far the greatest requirement, however, lies in gaining sufficiently high acceptance of the restraining system on the market. The thought of a motorcycle accident is usually ruled out by the rider, this is why motorcycle manufacturers do not introduce passive safety as a marketing instrument. The awareness of the dangers of motorcycling can have a negative effect on the turnover figures. This could quickly change, if at the legislative level appropriate measures were called for.

Zusammenfassung

Nicht umsonst hat das Motorrad so viele Freunde: Es ist schnell, konkurrenzlos handlich und es gibt kaum Parkplatzprobleme. Es ist also bestens geeignet, der Masse der Automobilisten stets eine Nasenlänge voraus zu sein. Preis dieses Mobilitätsvorteils ist die wesentlich geringere passive Sicherheit. Die Möglichkeit, den Motorradfahrer bei einer Kollision durch Rückhaltesysteme zu sichern, wird bis heute nicht genutzt.

Am Dynamic Test Center wurden in Eigeninitiative verschiedene technische Möglichkeiten analysiert, wie der Freiflug in eine verzögerte Bewegung umgewandelt werden und damit das Verletzungsrisiko für den Motorradfahrer bei einem Unfall reduziert werden könnte. Bei der Wahl des Rückhaltesystems wurde Wert auf ein mechanisch einfaches und reversibles System, sowie wegen einer besseren Akzeptanz auf ein passives Wirken gesetzt. Damit wird der mögliche Schaden bei einer allfälligen Fehlauslösung für den Benutzer nicht zur Abschreckung. Im Falle eines Sturzes oder ähnlicher Situationen, bei denen keine Rückhaltekraft aufgebaut werden kann, trennt sich der Motorradfahrer wie gewohnt von seinem Motorrad.

In einer Versuchsreihe von Motorrad-Schlittenversuchen und -Anprallversuchen mit leichten und schweren Motorrädern in die Seite von stehenden Personenwagen konnte die Wirksamkeit des Gurtsystems erwiesen werden. Dies nicht nur unter Normbedingungen (ISO 13232), sondern auch bei einer Kollision auf doppeltem Energieniveau mit 70 km/h.

In den nächsten Entwicklungsschritten müssen das Gurtzeug für den Einsatz am Motorradfahrer optimiert und die biomechanischen Belastungen auf den Körper bei einer Kollision weiter ermittelt werden. Andererseits ist das Gurtschloss mit der entsprechenden Verriegelungsstrategie und der Konstruktion zu entwickeln. Die weitaus größere Herausforderung wird aber darin liegen, auf dem Markt eine genügend große Akzeptanz für ein Rückhaltesystem zu erreichen. Der Gedanke an einen Motorradunfall wird durch die Fahrer üblicherweise verdrängt, weshalb Motorradhersteller die passive Sicherheit nicht als Marketinginstrument einsetzen wollen. Das Bewusstsein über die Gefahren des Motorradfahrens könnte sich negativ auf die Umsatzzahlen auswirken. Dies könnte sich sehr schnell ändern, wenn auf gesetzlicher Ebene entsprechende Maßnahmen gefordert würden.

Sicherheitsgurt für Motorradfahrer

Passive Sicherheit für Motorräder

In den vergangenen zehn Jahren hat sich die Zahl der Motorräder auf unseren Straßen fast verdoppelt. Während in der Vergangenheit die Zahl der im Straßenverkehr getöteten Personenwageninsassen rückläufig war, ist die Zahl der tödlich verunglückten Motorradfahrer angestiegen oder im besten Fall stagniert. Heute ist jeder fünfte Verkehrstote ein Motorradfahrer (Quelle: bfu – Beratungsstelle für Unfallverhütung, Bern, Schweiz). Dies ist unter Berücksichtigung der geringen jährlichen Fahrleistung im Vergleich zum Automobil um so dramatischer. Der Stand der passiven Sicherheit heutiger Motorräder ist mit derjenigen von Automobilen der 60er Jahre vergleichbar. Der Motorradfahrer kann bei einer Kollision, außer bei einem Motorrad-Luxusmodell, nicht von einem Rückhaltesystem profitieren.

Aufgrund der immer gewichtigeren Anzahl an verletzten oder getöteten Motorradfahrern sind Entwicklungen im Bereich der passiven Sicherheit bei Motorrädern künftig unumgänglich. Ein abwarten gesetzlicher Vorgaben ist sicher nicht ratsam.

Systemevaluation

Die physikalischen Rahmenbedingungen für ein wirkungsvolles Rückhaltesystem sind bei einer Motorradkollision aus 50 km/h, Bild 2, mit denjenigen im Automobil vergleichbar:

- ca. 1 m verfügbarer Verzögerungsweg
- ca. 10 g mittlere Verzögerung
- ca. 11 kN mittlere Rückhaltekraft erforderlich

Bild 1: Motorrad in Kollisionspunkt

Eine Rückhaltekraft (Zugrichtung) birgt ein geringeres Verletzungspotenzial als eine Stützkraft (Druck), welche im ungünstigsten Fall partiell am Kopf wirken könnte.

Im Vergleich zum Airbag hat der Sicherheitsgurt für Motorräder folgende Vorteile:

- wirkt, wenn die Abstützung möglich ist und eine Rückhaltekraft aufgebaut werden kann
- einfaches und kostengünstiges System
- im Falle einer „Fehlaktivierung“ reversible

Bild 2: Motorrad 70 km/h mit Gurt

- für die Sensierung einer allfälligen Trennung des Motorradfahrers vom Motorrad steht deutlich mehr Zeit zur Verfügung, als dies für den Zündentscheid eines Airbags der Fall ist.

Ein Nachteil ist: Um das Gurtsystem in der Bekleidung zu integrieren, ist eine Zusammenarbeit zwischen Motorrad-, Gurtsystem- und Bekleidungsherstellern unumgänglich.

Gurtsystem

Ziel des Rückhaltesystems ist es, die ersten 100 ms nach Crashbeginn möglichst effizient für die Verzögerung des Motorradfahrers zu nutzen. Wenn möglich, sollte der Kopfanprall an der Fahrzeugseitenwand oder der Dachkante verhindert werden. In jedem Fall muss die Geschwindigkeit des Motorradfahrers bis zum Anprall deutlich reduziert werden, damit die Kopf-, Halswirbelsäulen-, Brust- und Beckenverletzungen massiv vermindert werden können.
Um eine günstige Krafteinleitung in den Körper zu realisieren, besteht das entwickelte Gurtsystem aus zwei Schulter-, Becken- und Schrittgurten, Bild 4.

Aufgrund der auf Motorrädern realisierbaren Gurtverankerungspunkte wurde primär mit Schlittenversuchen getestet, ob sich für Motorradfahrer durch die Gurtverankerungspunkte in Höhe des H-Punktes eine vernünftige Verzögerungskinematik realisieren lässt und ob die Rückenwirbelsäule dadurch nicht zu stark belastet würde.
Die Schlittenversuche aus 50 km/h haben gezeigt, dass das entwickelte Gurtsystem für die Rückhaltung von Motorradfahrern im Prinzip funktioniert und dabei keine biomechanischen Belastungsgrenzwerte überschritten werden.

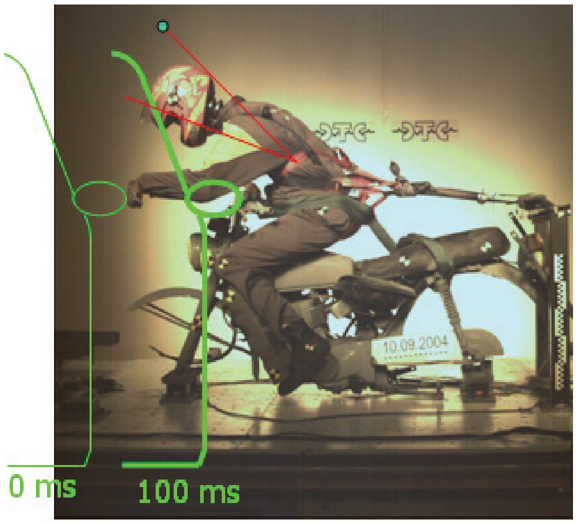


Bild 3: Schlittenversuch 50 km/h mit Motorrad-Sicherheitsgurt

Damit die Gurtkräfte im Realfall über den Motorradrahmen auf den Kollisionspartner abgestützt werden können, ohne dass das Motorradheck übermäßig angehoben wird, muss das Motorrad eine zusätzliche Crashbox aufweisen. Für die Crashversuche wurde diese Crashbox aus Styrofoam teilweise in der Motorradverschalung integriert. Im Wesentlichen besteht das Rückhaltesystem für Motorräder aus folgenden Komponenten, Bild 4:

- eine Crashbox in der Frontverkleidung des Motorrades
- seitliche Schutzvorrichtungen in der Verschalung des Motorrades für die Beinabstützung beim Frontalaufprall oder im Falle einer Seitenkollision als Beinschutz
- optimierte Tankform zur Abstützung des Beckens mit geringem Beckenverletzungsrisiko
- Sicherheitsgurt

Für einen möglichst hohen Tragkomfort sollte der Sicherheitsgurt in der Motorradbekleidung integriert werden können. Der Sicherheitsgurt besteht aus folgenden Hauptkomponenten:

- für den Motorradfahrer entwickelter Sicherheitsgurt, bestehend aus
- zwei Schulter-, einem Becken- und zwei Schrittgurten
- zwei Gurtroller für die gewohnte Bewegungsfreiheit in Fahrt
- zwei Gurtschlösser mit entsprechender Öffnungsstrategie und -konstruktion

Bild 4: Sicherheitsgurt und Komponenten des Motorrad-Rückhaltesystems

Mit diesen Komponenten erfolgte nach den positiven Ergebnissen der Schlittenversuche ein erster realer Crashtest mit gesichertem Motorradfahrer.

Crashversuch mit leichtem Motorrad

Zu Beginn wurde ein leichtes Motorrad mit einer Geschwindigkeit von 50 km/h gegen die Seite eines Leichttransporters mit Blechseitenwand gefahren. Bei diesem Crashversuch wurde das Zusammenwirken von Sicherheitsgurt, Krafteinleitung in den Motorradrahmen und Abstützung der Rückhaltekräfte über eine Crashbox am Kollisionspartner untersucht.
Das Motorrad war mit einer improvisierten Crashbox vor dem Gabelkopf sowie zwei seitlichen Beinschutzvorrichtungen bestückt, welche in Längsrichtung ein hohes Energieaufnahmevermögen haben, aber in Querrichtung steif sind. Beide Komponenten könnten künftig ohne wesentliche Gewichtserhöhung und sehr kostengünstig durch Schäumung der Front- und Seitenverschalung realisiert werden. Am verstärkten Motorradheck war ein Sechspunktsicherheitsgurt verankert.
Die ersten Ergebnisse vermochten zu überzeugen. Immerhin hat der Dummykopf die Seitenwand des Leichttransporters trotz einer Aufprallgeschwindigkeit von 50,1 km/h nicht touchiert.

Die Crashbox im Frontbereich stützte das Motorrad an der Seitenwand des Leichttransporters ab und verhinderte ein starkes Anheben des Motorradhecks. Der angeschnallte Fahrer blieb während der Verzögerungsphase nahezu aufrecht. Am Dummykopf wurde eine 3-ms-Spitzenbeschleunigung von 44,0 g (biomechanischer Grenzwert = 80 g) und ein 87 % unter dem biomechanischen Grenzwert liegender Kopfverletzungsschwereindex (HIC) gemessen.

Bild 5: Crash nach 100 ms, die Geschwindigkeit ist nahezu abgebaut

Realisierbarkeit von Gurtverankerungspunkten an Motorrädern

Touren- und Straßenmotorräder sind für die Einführung eines Gurtsystems und einer entsprechenden Umrüstung am besten geeignet. Der Rahmen im Heckbereich ist für die Gurtverankerungspunkte genügend stabil und die Verschalung eignet sich sehr gut zur Realisierung der Crashbox, welche die Rückhaltekräfte am Kollisionspartner abstützt. Zudem ist davon auszugehen, dass die Motorradfahrer dieser Motorradkategorien am einfachsten von der positiven Wirkung passiver Sicherheitseinrichtungen überzeugt werden könnten.
In der Folge wurde eine Honda CBR 600 am Rahmenheck mit Gurtverankerungspunkten nachgerüstet. Die Crashbox aus Styrofoam wurde in der Verschalung integriert. Das Motorrad kollidierte mit 50 km/h einmal ohne und einmal mit Rückhaltesystem mit der Seite eines hohen Personenwagens.

Bild 6: Schweres Motorrad mit 50 km/h mit/ohne Gurt

Ohne Gurtsystem prallt der Motorradfahrer mit dem Kopf an die Dachkante des Personenwagens. Nebst hohen Kopfbeschleunigungen, bei welchen die biomechanischen Grenzwerte überschritten wurden, lagen auch die Belastungen der Halswirbelsäule über den zulässigen Grenzwerten. Aufgrund der Tankform des verwendeten Motorrades ist zudem mit Verletzungen im Becken- und Genitalbereich zu rechnen. Mit Hilfe des Rückhaltesystems konnte der Kopfanprall am Fahrzeug komplett verhindert werden. Die Kopf- und Halswirbelsäulenbelastungen lagen deutlich unterhalb der biomechanischen Grenzwerte. Im Vergleich zum leichten Motorrad war die Crashbox sehr knapp ausgelegt, weshalb das Motorradheck durch die Einleitung der Gurtkräfte angehoben wird.

Hochgeschwindigkeitscrash mit schwerem Motorrad

Gurtsysteme haben den Vorteil, dass sie über einen großen Energiebereich gut abgestimmt werden können, ohne dass, wie bei einem Airbag, unterschiedliche Stufen gezündet werden müssen. Um dies unter Beweis zu stellen und um die Wirksamkeit des Gurtsystems auch bei deutlich höheren Geschwindigkeiten zu untersuchen, wurde nochmals eine Honda CBR 600 mit Gurtsystem mit 70 km/h in die Seite eines stehenden hohen Personenwagens (SUV) gefahren, Bild 7.

Die Ergebnisse waren beeindruckend:

Mit Hilfe der Crashbox in der Motorradfrontverkleidung konnte die Kraftabstützung der Gurtkräfte über das Motorrad wirkungsvoll auf dem Personenwagen realisiert werden. Gurt, Gurtzeug und Verankerungspunkte haben den extrem hohen Belastungen standgehalten.

Außer geringen Streifspuren konnte ein massiver Kopfanprall an der Dachkante/B-Säule des Personenwagens verhindert werden, Bild 7. Die Kopf- und Halsbelastungen lagen im überlebbaren Bereich.

Bild 7: Sicherheitsgurt und Komponenten des Motorrad-Rückhaltesystems

Gestützt auf diesen Versuch kann davon ausgegangen werden, dass sich ein Sozius bei einer Kollision mit 50 km/h auf dem Motorradfahrer abstützen ließe. Wenn möglich sollte aber auch für den Sozius ein Gurtsystem vorgesehen werden.

Biomechanische Belastungen auf den Fahrer

Damit die Belastungen auf den Fahrer umfassend beurteilt werden konnten, wurde mit einem vollinstrumentierten 50% Dummy auf einem kleinen Motorrad mit 50 km/h gegen die Seite eines VW T5 durchgeführt. Der Motorradfahrer wurde wiederum wirkungsvoll auf dem Motorrad zurückgehalten, so dass kein Kopfanprall an der Seitenwand des Fahrzeugs stattfinden konnte.

Bild 8: M=BUS Dummy auf Motorrad

Die biomechanischen Grenzwerte wurden grundsätzlich eingehalten, wobei, bedingt durch die zusätzliche Helmmasse am Hals, durch Zug dort die höchsten relativen Belastungen gemessen wurden. Die Belastungen vom Thorax an nach unten liegen teilweise weit unterhalb 50% der zulässigen Grenzwerte.

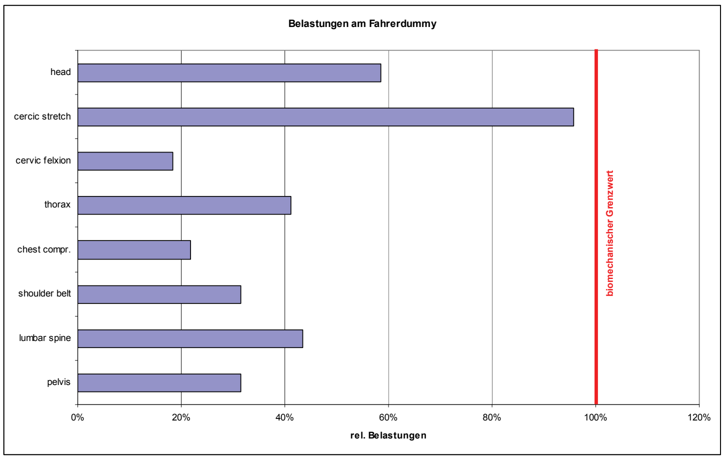


Bild 9: Relative Belastungen am Fahrerdummy

Herausfordernde Motorradkategorien

Für Motorräder, auf welchen in der natürlichen Sitzposition der Fahrerkopf horizontal betrachtet einen zu geringen Abstand zum vordersten Punkt des Vorderrades aufweist, würde der Nutzen eines Sicherheitsgurtes nur noch gering ausfallen. Weiter könnten Sicherheitsgurte nur an Motorrädern vorgesehen werden, welche eine genügend stabile Struktur aufweisen.

Wie ein Crashversuch mit einem Roller gezeigt hat, müsste die Rahmenstruktur von Rollern mit Sicherheitsgurten verstärkt werden. Der Rahmen des Rollers kollabierte im Bereich der Fussstützen. Zudem wurde der Personenwagen unterfahren. Die Knie stützten sich direkt am VW Bus T5 ab. Die deutlichsten Grenzwertüberschreitungen wurden am Kopf infolge des heftigen Anpralls gemessen.

Bild 10: Roller mit 50 km/h und Sicherheitsgurt

Entsprechende Verstärkungen für den Rahmen von Rollern könnten aus dem Rennbereich übernommen werden.

Im weiteren stellen sehr leichte Motorräder ebenfalls für die Integration eines Sicherheitsgurts eine große Herausforderung dar. In Folge der geringen Massenträgheit extrem leichter Zweiräder müsste die Crashbox exakt auf die abzustützenden Kräfte abgestimmt sein. Zudem müsste die Höhe mit den einzuleitenden Gurtkräften abgestimmt sein.

Dies wurde mit Hilfe eines Crashtests mit einem Zweirad mit angegurtetem Fahrer verdeutlicht, welches mit 40 km/h in die Seite eines hohen Personenwagens gefahren wurde. Die Deformationen am Fahrradrahmen zeigen, dass der Fahrer über den Sicherheitsgurt etwas zurückgehalten worden ist. Dadurch wurde das Heck des Zweirades sehr schnell angehoben. Beim Anprall des Fahrers in die Seite des Personenwagens wurden die Belastungsgrenzwerte teilweise massiv überschritten.

Bild 11: Zweirad mit 40 km/h und Sicherheitsgurt

Schutzpotenzial bewiesen

Die Entwicklungen und Versuche haben die technische Möglichkeit gezeigt, einen Motorradfahrer mit einem Sicherheitsgurtsystem bei einer Frontalkollision wirkungsvoll zu schützen. Die Rückhaltekräfte können bei Verwendung einer Crashbox über den Motorradrahmen abgestützt werden. Dabei können die biomechanischen Belastungen weit unter den Grenzwerten gehalten werden. Das Gurtsystem kann seine Schutzwirkung entwickeln, wenn die Rückhaltekräfte am Kollisionspartner genügend abgestützt werden können. Zudem müssen die Zweiräder über einen genügend stabilen Rahmen verfügen. Bei

Kollisionen ohne genügende Stützmöglichkeit oder in unkontrollierten Lagen (z.B. Sturz) werden die beiden Gurtschlösser freigegeben und der Motorradfahrer kann sich wie heute üblich vom Motorrad trennen.
Im Rahmen einer Diplomarbeit an der Berner Fachhochschule wurden etwa 100 Motorradunfälle mit schwer verletzten oder getöteten Motorradfahrern in der Schweiz bezüglich einer möglichen Wirksamkeit eines Rückhaltesystems analysiert. Die Ergebnisse decken sich mit ähnlichen Untersuchungen aus Deutschland zur Schutzwirkung von Airbags, wobei die Schutzwirkung eines Sicherheitsgurtes nicht von einer Auslösung abhängt. Mit einem Gurtsystem für Motorradfahrer hätten 30 % der untersuchten Motorradunfälle zu geringeren Verletzungen geführt.

Markteinführung

Die große Herausforderung besteht darin, auf dem Markt eine genügende Akzeptanz für Motorräder mit Rückhaltesystemen zu erreichen. Der Gedanke an einen Motorradunfall wird durch die Fahrer üblicherweise verdrängt, weshalb Motorradhersteller die passive Sicherheit nicht als Marketinginstrument einsetzen können. Die bewusste Wahrnehmung der Gefahren des Motorradfahrers könnte sich negativ auf die Umsatzzahlen auswirken. Trotzdem sollte der Markt mit positiven Meldungen bearbeitet werden, bevor auf gesetzlicher Ebene zur Erreichung der Halbierung der Verkehrstoten entsprechende Maßnahmen von der Motorradindustrie gefordert werden.

Bild 12: Trike mit Sicherheitsgurt

Am konkretesten steht derzeit die Homologation des Gurtsystems an einem Trike zur Diskussion. Weil in der Schweiz auf solchen Fahrzeugen beim Tragen von Sicherheitsgurten auf den Helm verzichtet werden könnte, ist bei etlichen Fahrern mit großem Interesse zu rechnen. Zudem ist auf diesen Fahrzeugen noch keine Weiterentwicklung des Gurtschlosses erforderlich. Kombiniert mit einem Überrollbügel würden diese Fahrzeuge über eine recht hohe passive Sicherheit verfügen.

Experimental Study of Pitching Control of Large Motorcycles with Short Wheelbases using a Brake-by-Wire System

Untersuchung zur Kontrolle des Nickverhaltens eines großvolumigen Motorrades mit kurzem Radstand durch Applikation eines Brake-by-Wire Systems

Yutaka Nishikawa, Takehiko Nanri, Kazuya Takenouchi
Shinji Takayanagi, Kazuhiko Tani, Syuichi Fukaya

Honda R&D Co., Ltd. Motorcycle R&D Center
Japan

Abstract

The authors constructed a brake-by-wire system which generates the optimum brake force according to the detected input pressure with the feeling of a normal braking operation. This system operates as a conventional brake when the motorcycle runs at very low speeds. However, while the motorcycle is in operation, the hydraulic connection to the brake is replaced by an electronic one, activating the brake-by-wire system. This system can control the brake force with a quicker response time than the rider can achieve. In this study, the optimal braking characteristics for a motorcycle in the sports category were examined by using the constructed brake-by-wire system. During strong braking, larger pitching that lifts up the rear wheel might occur in short wheelbase motorcycles in the sports category. To reduce this phenomenon, authors thought that it would be effective to operate ABS before the pitching increased, momentarily decreasing the pitching moment. However, such a control was challenging with conventional ABS, which controls the braking force by detecting only the slip ratio of the tire. This newly constructed system was able to reduce the occurrence of larger pitching by controlling braking force according to increasing rate of input force.

Kurzfassung

Die Autoren haben ein Brake-by-Wire-System konstruiert, das die optimale Bremskraft entsprechend des ermittelten Eingangsdrucks mit dem Gefühl einer normalen Bremsbetätigung erzeugt. Bei sehr niedrigen Geschwindigkeiten arbeitet das System wie eine konventionelle Bremse. Sobald das Motorrad aber in Betrieb ist, wird die hydraulische Verbindung zur Bremse durch eine elektronische ersetzt und das Brake-by-Wire-System aktiviert. Mit dem System kann die Bremskraft schneller kontrolliert werden als es dem Fahrer möglich ist.

In der vorliegenden Studie wurde die optimale Bremscharakteristik für ein Motorrad der Sportkategorie unter Einsatz des Brake-by-Wire Systems untersucht. Bei Sportmotorrädern mit kurzem Radstand kann es bei starken Bremsungen zu größeren Nickbewegungen mit abhebendem Hinterrad kommen. Um dieses Phänomen zu verringern, hielten es die Autoren für wirkungsvoll, das ABS einzusetzen bevor die Nickbewegung zunimmt, um das Nickmoment kurzzeitig zu vermindern. Es war jedoch schwierig, dies mit einem herkömmlichen ABS zu steuern, das die Bremskraft nur basierend auf der Schlupfrate des Reifens kontrolliert. Mit dem neu konstruierten System konnte das Auftreten größerer Nickbewegungen verringert werden, indem die Bremskraft entsprechend der Anstiegsrate der Eingangskraft gesteuert wird.

Experimental Study of Pitching Control of Large Motorcycles with Short Wheelbases using a Brake-by-Wire System

1. Introduction

In general, the center of gravity on motorcycles is relatively high because their wheelbases are shorter than those of passenger cars. Therefore, the load transfer during braking is large, and pitching occurs easily. Especially in the sports category, motorcycles that demand higher maneuverability performance have shorter wheelbases, compared with cruiser or touring category motorcycles. Consequently, during strong braking, the load transfer from the rear wheel to the front wheel is larger and stronger pitching that the rear wheel is lifted up can occur before the front wheel locks. Up to now, this has made it challenging to install Anti-lock Brake Systems (ABS) in large motorcycles with short wheelbases. However, we recognized the possibility that a system which could freely control the brake force would be able to address this issue (1). There is a time lag between the brake input and the start of the pitching. If the braking force is momentarily decreased (i.e., ABS is operated) during this time lag, larger pitching can be reduced. To address this issue, the authors constructed a brake-by-wire system (i.e., one in which a hydraulically connected brake system is replaced by an electronically connected system) in which the optimal braking force was controlled by an electronic control unit (hereafter referred to as "ECU").

This paper describes the main features of this system and explains the ABS control method, based on experimental results obtained on sports category motorcycles.

2. Brake-by-Wire System

2.1. Design Objective

The following objectives were established for the brake-by-wire system.

1. Brake operation should feel like a conventional system.
2. The mass of the system should not influence maneuverability of the motorcycle.
3. There should be flexibility for installing the system in the motorcycle.

2.2. Features of the System

A conventional hydraulic brake system for motorcycles is composed of a master cylinder which generates hydraulic pressure from the rider's input force on the hand (or foot) lever, brake calipers that convert the hydraulic pressure to a brake force, and the brake hoses that hydraulically connect those parts. In the newly constructed brake-by-wire system, a modulator that generates pressure through an electric actuator (hereafter referred to as the "power unit"), a valve unit, an ECU, and wheel-speed sensors are added to an ordinary hydraulic brake system. The power unit and the valve unit are incorporated between the master cylinder and the brake calipers, and the two wheel-speed sensors are incorporated in the front and rear wheels. These are electronically connected to the ECU. The space between parts is smaller in large sports-type motorcycles with short wheelbases because of the need to concentrate the mass. This system is divided into small units that can be easily mounted in sports-type motorcycles. As the system can separately control the brakes of the front wheel and the rear wheel, a combined brake system can be achieved without using a special caliper like the 2-channel caliper found in conventional combined brake systems (2). Therefore, there is no increase in the unsprung mass from wheel speed sensors.

2.3. System Operations

2.3.1. System under operational conditions

Figure 1 is a diagram of the brake-by-wire system used in this study, while Table 1 defines the symbols used in Fig. 1. When the motorcycle runs at very lower speeds and the input pressure from the rider is smaller, the pressure from the master cylinder is transmitted directly to the caliper through the solenoid valve SNOM that is normally open. When the input from the rider exceeds the prescribed level, the system is shifted from conventional operation to by-wire operation. The solenoid valve SNOM shuts off the passage from the master cylinder to the brake calipers, and brake pressure from the rider is transmitted to the piston in the stroke simulator SymF through the solenoid valve SNCS. As the load-deformation characteristics of the rubber spring located on the end of this piston are the same as those of the conventional brake lever, the rider has the same braking feeling as in an ordinary braking operation. At the same time, the brake pressure generated by the power unit is transmitted to the brake caliper through the solenoid valve SNCP. The ECU controls the pressure of the brake caliper, detecting the pressure and the rate of pressure increase from the input side.

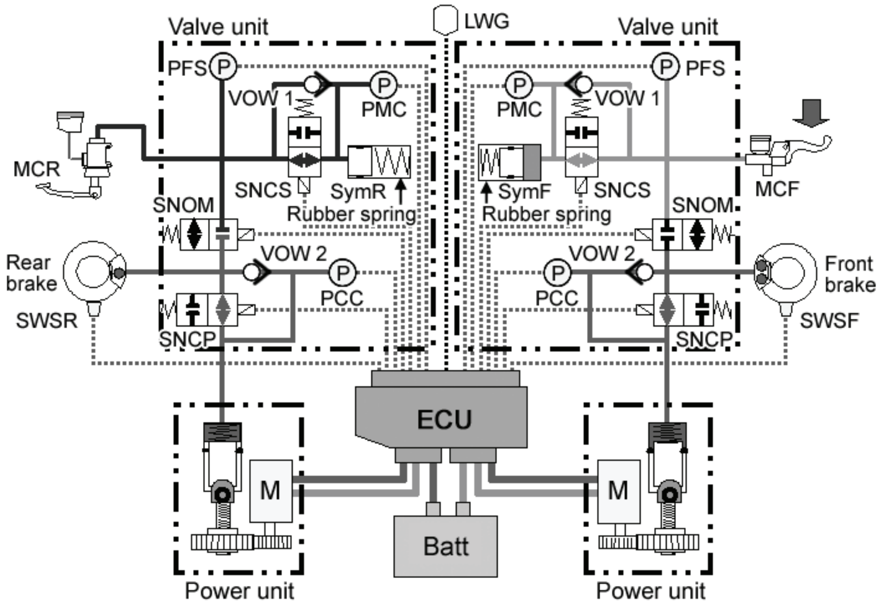


Figure 1: Brake-by-wire system (System under operational condition)

Table 1: Diagram code of brake-by-wire system

Codes	Meanings
SNOM	Solenoid Valve, Normal Open, Master cylinder
SNCS	Solenoid Valve, Normal Close, Simulator
SNCP	Solenoid Valve, Normal Close, Power Unit
PMC	Pressure Sensor of Master Cylinder
PFS	Pressure Sensor of Fail Safe
PCC	Pressure Sensor of Brake Caliper Cylinder
VOW 1	One-way Valve
VOW 2	One-way Valve
SWSF	Front Wheel Speed Sensor
SWSR	Rear Wheel Speed Sensor
SymF	Front Brake Stroke Simulator
SymR	Rear Brake Stroke Simulator
MCF	Front Brake Master Cylinder
MCR	Rear Brake Master Cylinder
LWG	Warning Lamp
Batt	Battery
ECU	Electric Control Unit
M	Motor

As the motor rotates and the ball screw moves the piston up, brake pressure is generated. Finally, the hydraulic pressure works on the brake calipers, causing braking force to be applied to the wheel. When the brake force is excessive and the slip ratio increases, the ABS is activated. When the motor is reversed, the piston moves downward and the brake pressure decreases. Consequently, the slip ratio also decreases, thus helping prevent wheel lock.

This system also shifts simultaneously from conventional to by-wire operation in the rear braking system. The ECU controls the power unit of the rear braking system to harmonize with the front brake. Therefore, the system functions as a combined brake. Although the above explanation is for a hand operated brake, the same operation applies in a foot operated brake.

2.3.2. System under non-operational conditions

Figure 2 shows the conditions when the ignition switch is turned off. The front master cylinder MCF and the rear master cylinder MCR are connected to each brake caliper through the normal-open solenoid valve SNOM. The solenoid valve SNCS that connects the master cylinder with the stroke simulator SymF (SymR) and the solenoid valve SNCP that connects the brake caliper with the power unit are closed under these conditions. When the rider operates the hand lever or the foot lever with the ignition turned off, the induced brake pressure directly works on the brake caliper, which means that the rider can apply the brake even when the brake-by-wire system is not functioning. Though system malfunction rarely occurs, in such an event the ECU shuts down the power supply to each solenoid valve. When the power is turned off, the spring in the solenoid valve restores the conditions that existed before the power application. Since these conditions are the same as when the ignition switch is turned off, conventional braking is maintained.

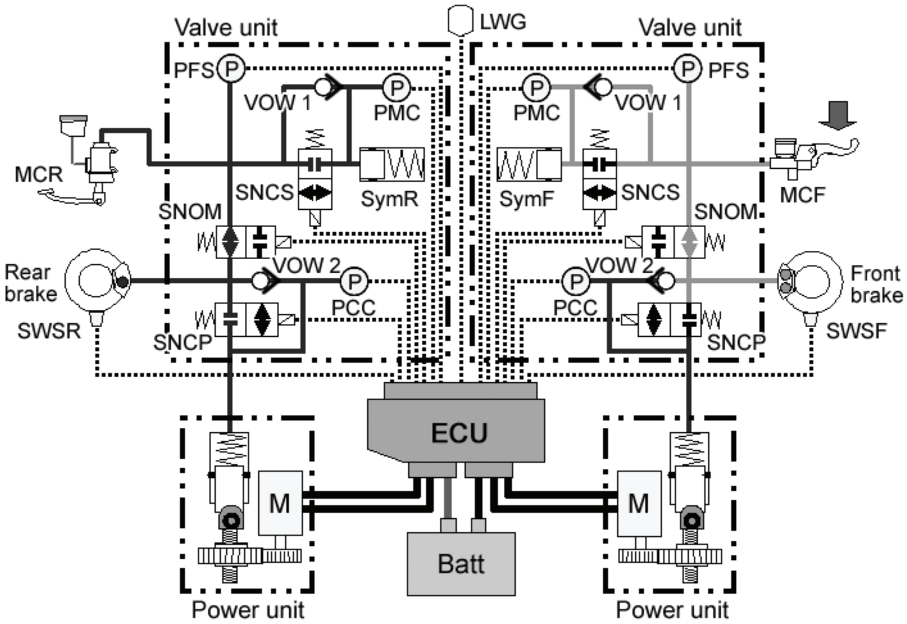
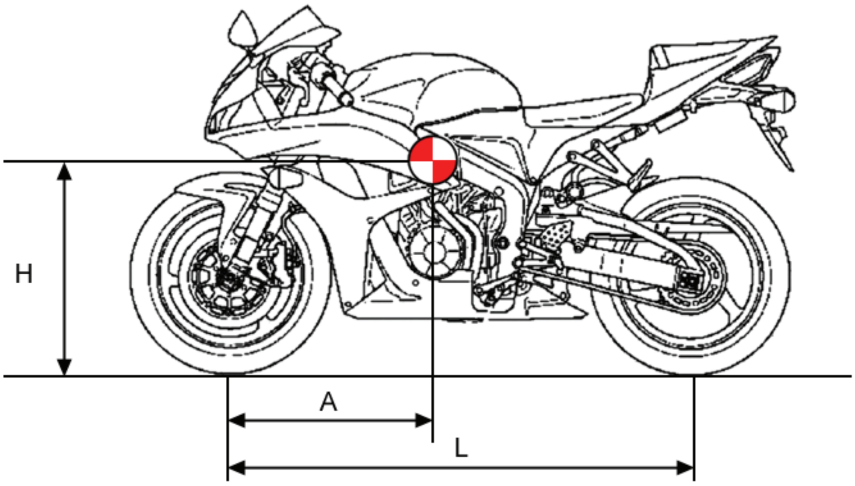


Figure 2: Brake-by-wire system (System under non-operational condition)

3. Pitching control by the "Brake-by-Wire" system

Pitching occurs on a motorcycle as a result of inertia when the rider applies the brakes. The authors defined the pitching tendency index as the "pitching factor" (Figure.3), using the height of the center of gravity and the horizontal distance from the center of gravity to the front wheel axle (3). The distribution of pitching factor of each motorcycle is shown in Figure 4. It shows that pitching occurs easily in large motorcycles with short wheelbases compared to other motorcycles. Stronger pitching does not occur in motorcycles with a larger pitching factor, but might occur in motorcycles with a smaller pitching factor. The pitching moment generated by the deceleration greatly compresses the front suspension. There is a time lag between the rider's application of the brake and the depression of the front suspension and the occurrence of pitching. If the suspension does not bottom out during the time lag, the pitching moment that lifts up the rear wheel does not occur. If the slip ratio of the front wheel increases at that time, the pitching moment that lifts up the rear wheel does not occur. In other words, if the ABS can be activated at this time, it is possible to achieve pitching control. However, the necessary braking pressure could not be generated in that short time lag with a conventional ABS because the rider could not exert higher pressure quickly enough, and as a result, conventional ABS was not able to control pitching appropriately.

On the other hand, the brake-by-wire system can freely control the output pressure in response to the input pressure by lever operations. That is, the activation of ABS can be controlled at will. The following control methods were designed based on the idea described above. The ECU judges that stronger pitching will occur when the input pressure and the rate of pressure increase exceed the thresholds set by the experiments. At the same time, the caliper pressure is instantaneously increased by the power unit without any relationship to the rider's input pressure. As a result, the front wheel begins to slip, and ABS begins to operate sooner.



Pitching facter = $\frac{A}{H}$

H: Height of center of gravity
A: Horizontal distance from center gravity to font wheel axle
L: Wheelbase

Figure 3: Definition of "Pitching factor"

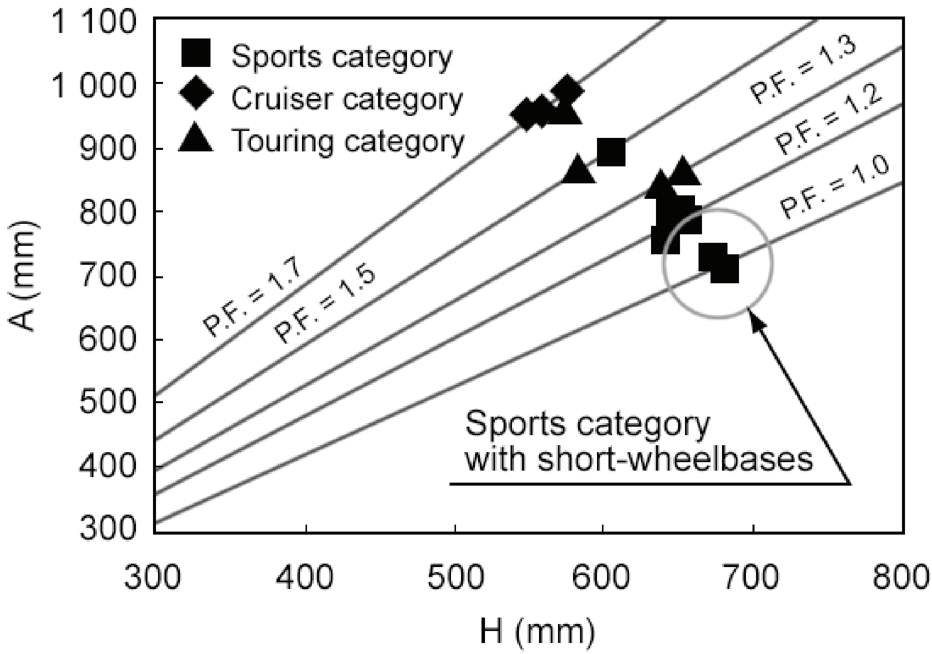


Figure 4: Pitching factor of large sized motorcycle

4. Tests

4.1. Specifications of the Test Motorcycle

Table 2 presents the specifications of the test motorcycle. The items that were measured are shown in Table 3.

4.2. Test Conditions

In order to verify the effectiveness of the control method, riding tests were conducted using experienced riders. The test conditions are shown in Table 4. In the tests, straight-traveling conditions were maintained on a dry asphalt surface, the throttle was controlled to attain an initial speed of 50-80 km/h and then maintain a constant motorcycle speed, the brakes were applied, and the pitching motions were measured. The measured pitch rate was integrated and converted to an angle for the pitch angle calculation. The engine brake worked on the rear wheel. The rider was directed to brake as strongly as possible.

Table 2: Major specifications of test motorcycles

Items		Test motorcycle
Brake system	—	Brake-by-wire
Wheelbase	L (m)	1.371
Curb mass	M (kg)	197.0
Height of C.G.	H (m)	0.531
Distance between C.G. and rear axle	X (m)	0.698
Distributed load of motorcycle with one rider	Front (N)	1 246
	Rear (N)	1 352
Pitching factor		1.04
Engine displacement	V (cm^3)	599

Table 3: Recorded variables and sensors

#	Variables	Sensors
1	Front wheel angular speed	Hall element magnetic sensor
2	Rear wheel angular speed	Hall element magnetic sensor
3	Front brake master cylinder pressure	Pressure transducer
4	Rear brake master cylinder pressure	Pressure transducer
5	Front brake caliper pressure	Pressure transducer
6	Rear brake caliper pressure	Pressure transducer
7	Pitch rate	Pitch rate sensor

Table 4: Test conditions

Items	Brake-by-wire System	Brake Operation	Brake Control Program		
			ABS	Combined Brake	Pitching Control
Test 1	Deactivated	Conventional brake (hand and foot)	Deactivated	Deactivated	Deactivated
Test 2	Activated	Hand operated combined brake	Activated	Activated	Deactivated
Test 3	Activated	Hand operated combined brake	Activated	Activated	Activated

4.3. Test Results

4.3.1 Example of the result

Figure 5 is an example of the measurement results of Test 1. This example is with a conventional brake system, so the input pressure when the rider operates the brake lever and the output pressure from the brake caliper are equal. When the front and rear brakes were applied simultaneously at an initial speed of 50 km/h, the motorcycle decelerated due to the increased brake pressure. It can be noted that the pitch angle of the motorcycle also increased at that time. The brake pressure then decreased rapidly because the rider tried to avoid severe pitching by releasing the brake levers, but even after the brake had been released the inertia force further increased the pitch angle of the vehicle, which finally reached 15 degrees. The deceleration of the rear wheel was greater than that of the front wheel because larger pitching occurred, causing the rear wheel to lift up. The maximum potential deceleration on the tested road surface is 0.9 G. However, the deceleration when the pitching was generated in Test 1 was only 0.5 G. This corresponds to 55% of the potential deceleration.

Figure 6 is an example of the measurement results of Test 2. The brake system was the hand operated combined brake with the pitching control deactivated. Although the rider was not operating the foot lever, the rear caliper pressure was increased by the power unit for the rear caliper. The deceleration generated immediately after braking was 0.8 G. The rider canceled braking because pitching immediately occurred. The maximum pitch angle of the vehicle was 26.8 degrees, which means that the combined brake was unable to effectively control pitching.

Figure 7 is an example of the measurement results of Test 3. The brake system was a hand operated combined brake with the pitching control activated. The rate of brake pressure increase of the master cylinder and the calipers was the same, 8.8 MPa/sec, when the rider applied the brake. The ECU judged that larger pitching had initiated and sent a command to the power unit for a higher rate of pressure increase. Then, the rate of pressure increase was 18.2 MPa/sec. As a result, ABS was activated and an appropriate slip ratio was maintained. The deceleration at that time was 0.8-0.9 G during the stop time, and the maximum pitch angle of the vehicle was 4.6 degrees.

Figure 8 shows the test results summarized by the relationship between the average deceleration speed just after the beginning of braking and the maximum pitch angle that occurred during the braking. Without pitching control the rider has to cope with the pitching alone, so neither the deceleration nor the pitch angle is stable (as in Test 1 and Test 2). However, when the pitching control is activated the deceleration is 0.8 G and the pitch angle is stable at 3.8 - 6.0 degrees. Normally the nosedive caused by braking is at a pitch angle of approximately 6 degrees. Therefore, this result means that the pitching control is effective.

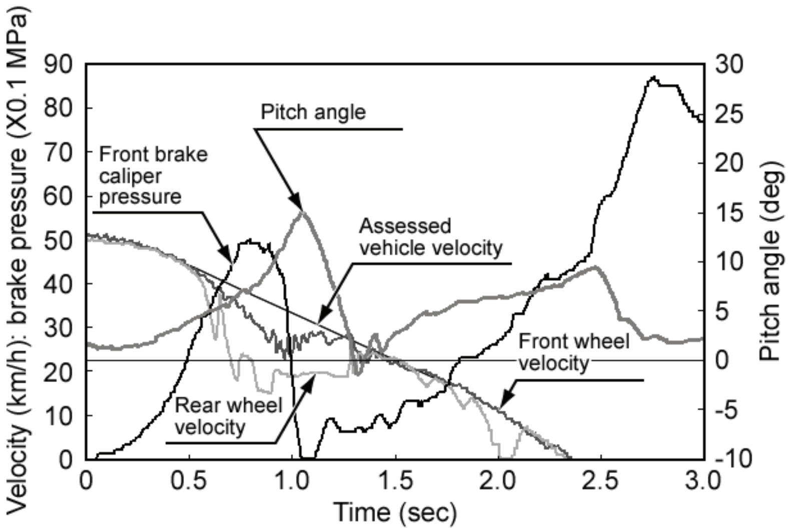


Figure 5: Example of time history data (Conventional brake)

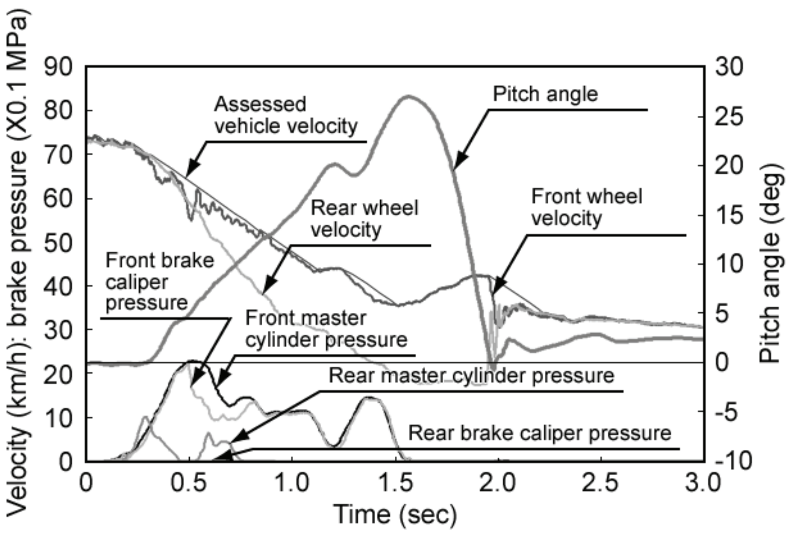


Figure 6: Example of time history data (Brake-by-wire system without pitching control)

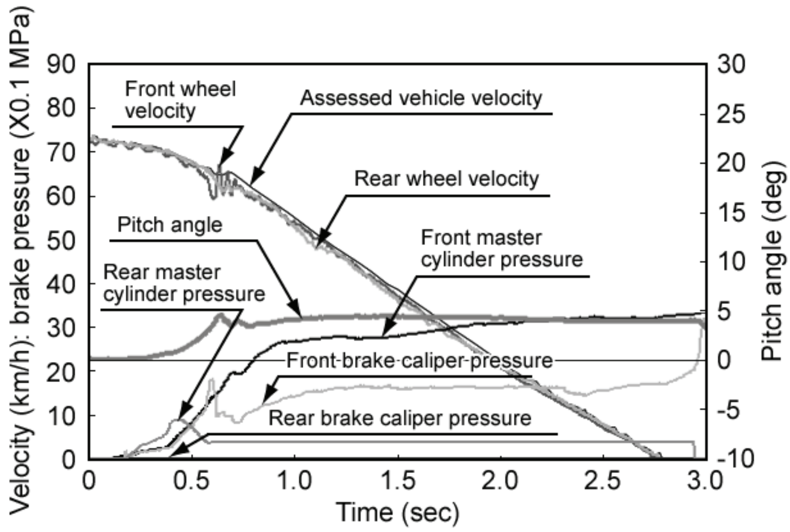


Figure 7: Example of time history data (Brake-by-wire system with pitching control)

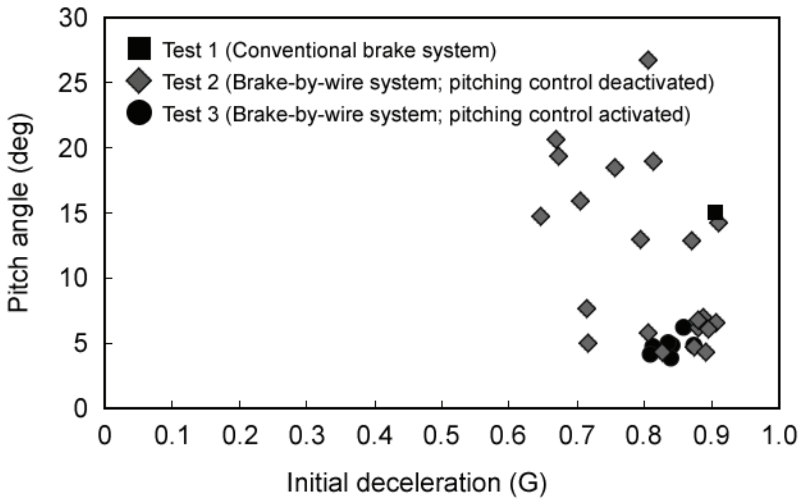


Figure 8: Effect of pitching control in the brake-by-wire system

4.3.2 Analysis of effect

As Figure 8 shows, even without the pitching control it is possible to attain a high deceleration close to the friction limit of the road surface just after braking begins. However, it is a challenge for a rider to retain that deceleration, because of the pitching that results. The authors defined an index that shows "how much time an initial deceleration is maintained" (Figure 9). The time from the start of braking to the stop of the vehicle, assuming that the initial deceleration is maintained, is defined as "T1." The time during which the brakes are actually applied is defined as "T2." "T2/T1" was defined as the "brake continuation rate".

Figure 10 compares the test results using the brake continuation rate. In the case of Tests 1 and 2, the variation in the brake continuation rate was 30-90%, even though the initial deceleration of braking was 0.65-0.9 G. From that fact, it can be seen that the deceleration could not be maintained due to the occurrence of pitching in the vehicles without the pitching control system. Meanwhile, in Test 3, the brake continuation rate was 100%, which means that the initial deceleration of 0.9 G was maintained until the test motorcycle was completely stopped.

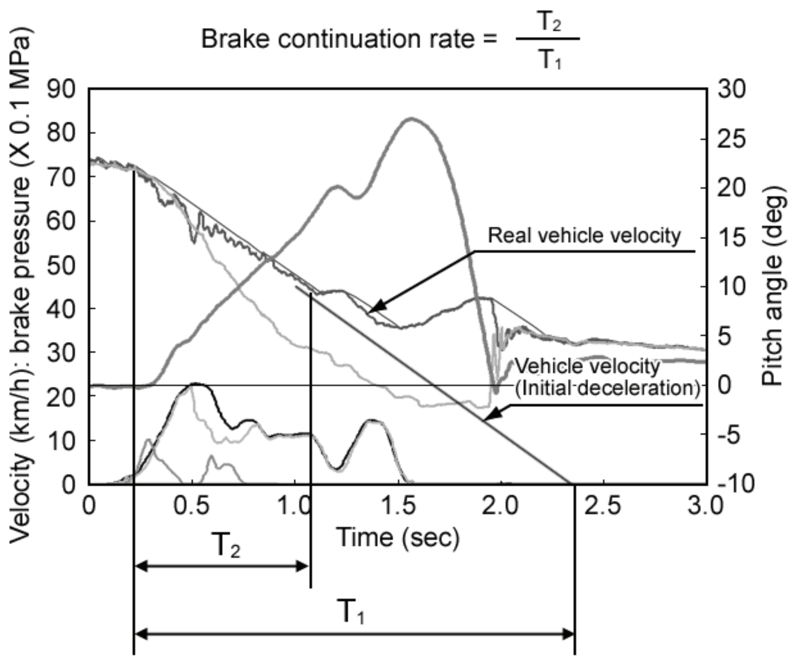


Figure 9: Definition of "Brake continuation rate"

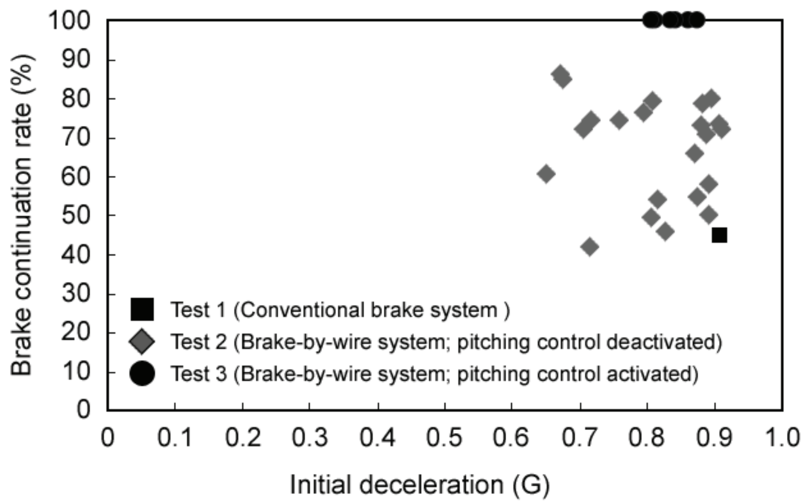


Figure 10: Comparison of "Brake continuation rate"

5. Conclusions

1. A brake-by-wire system which generates the optimum brake force according to the detected input pressure with the feel of a conventional braking operation was constructed.
2. It was realized that this system could control pitching by forecasting the occurrence of the pitching from the rate of pressure increase and activating the ABS at an earlier time.
3. The system appears most beneficial to sports-type motorcycles with short wheelbases which demand high maneuverability performance.

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Basis and Development for the Snell M2010 Motorcycle Helmet Standard

Grundlagen und Entwicklung des Motorradhelm-Prüfstandards Snell M2010

Edward B. Becker
Snell Memorial Foundation, Inc., USA

Abstract

The Snell Memorial Foundation’s first standard for vehicular helmets was published in 1959. Since then, the standard has been revised many times to demand all the crash protection consistent with advances in helmet materials and technology and with increased public acceptance and use of protective helmets. The current Snell motorcycle helmet standard, M2005, will soon be superseded by M2010.

The new M2010 standard allows compliance with current European impact test requirements. Furthermore, M2010 certification demonstrates a premium of protective capability for impact severities well beyond those applied in current ECE 22-05 testing.

This report demonstrates the factors currently preventing cross-certification of helmets to both Snell and European requirements and concludes that it is not feasible to build useful motorcycle helmet lines which will satisfy both M2005 and ECE 22-05. It identifies the impact mass specification as the single test aspect most responsible for the incompatibility and the basis for the revision to eliminate the incompatibility. It then describes all the necessary revisions secondary to the mass specification change. The resulting M2010 standard still differs strongly from ECE 22-05 in the scope and severity of its impact test requirements.

M2010 certified helmets must still be submitted to proper European authorities for ECE 22-05 evaluation. However, helmets cross-certified to both standards will equip European motorcyclists with head protection for reasonably foreseeable crash impacts much more severe than those anticipated in current ECE 22-05 testing.

Kurzfassung

Der erste Standard für Fahrzeug-Helme der Snell Memorial Foundation wurde 1959 veröffentlicht und seitdem regelmäßig überarbeitet. Im Interesse eines ständig optimierten Unfallschutzes wurden alle Veränderungen der Helmmaterialien und -technologien sowie die zunehmende Akzeptanz und Nutzung von Helmen mit einbezogen. Der aktuelle Motorradhelm-Standard Snell M2005 wird bald durch den neuen Standard M2010 ersetzt.

Dieser erlaubt den Vergleich mit den derzeitigen europäischen Testanforderungen. Darüber hinaus verlangt die M2010-Zertifizierung bessere Eigenschaften für die Aufprallschwere als der derzeitige ECE 22-05-Standard.

Dieser Beitrag zeigt die Faktoren auf, die eine Kreuz-Zertifizierung von Helmen im Rahmen beider Standards (Snell und europäischen Anforderungen) verhindern und folgert, dass es nicht machbar ist, Motorradhelme zu bauen, die beiden Standards entsprechen. Exemplarisch werden die Aufprall-Spezifikation sowie der Aspekt des „Einmaltests“ (Prüfmethode Schlagfestigkeitstest ECE 22-05: Helm wird am Aufschlagspunkt nur ein Mal getestet) dargestellt, welche am deutlichsten die Inkompatibilität beider Standards herausstellen. Ebenso wird eine Basis der Veränderungen, die diese Inkompatibilität beseitigen könnten, aufgezeigt.

Basis and Development for the Snell M2010 Motorcycle Helmet Standard

Introduction

The Snell Memorial Foundation was incorporated in California in 1957 in order to promote the development, production and use of superior protective crash headgear and published the first Snell standard in 1959. Although the initial interest was in helmets for automobile racing, Snell certification was also sought by manufacturers and users of motorcycle helmets. There were no US consumer standards for either at the time. The British Standards Institute had begun promulgating the world's first consumer standards for vehicular helmets only a few years earlier.

Back then the Sports Car Club of America (SCCA) required drivers to wear Snell certified helmets in some auto racing events. But, even so, the Foundation had no real regulatory authority. In particular, motorcycle helmets were not obliged to meet Snell requirements and motorcyclists were not required to wear those helmets which did. Fortunately, many motorcyclists needed no coercion to buy and wear motorcycle helmets and many of these opted for the additional assurance implicit in Snell certification. Given a demand for Snell certified helmets, enough manufacturers chose to join Snell programs voluntarily to allow Snell to continue. The most recent Snell motorcycle helmet standards are M2000[1] superseded by M2005[2] which, in turn will be superseded by M2010[3].

In 1974, the US Federal Government promulgated Federal Motor Vehicle Safety Standard 218[4,5], the "DOT" standard. FMVSS 218 was very similar to the 1968 Snell requirements but was federally mandatory; motorcycle helmets distributed for sale in the United States were required to meet it. The Snell standard had evolved since 1968 so manufacturers who wished to participate in Snell programs had to contend with two standards. Unless manufacturers could satisfy both DOT and Snell with the same helmet, they would have to drop Snell certification. For that reason, Snell revisions were also constrained to seek FMVSS 218 compatibility.

Surprisingly, the imposition of a mandatory, government standard did not obviate the Snell motorcycle helmet program altogether. Its survival may be due to the following:

1. The Snell Memorial Foundation, Inc. is widely known and respected. It is classified by the U.S. Federal government as a 501c(3) organization; that is, a not-for-profit corporation performing testing for public benefit.

2. Snell programs identify a subset of FMVSS 218 qualified helmets capable of withstanding much more severe levels of impact.

3. The fact of Snell certification compensates for necessary helmet features such as increased weight and silhouette.

4. Snell certification offers a more plausible assurance of helmet effectiveness than the "self-certification" helmet manufacturers perform to meet the US Federal government's mandatory FMVSS 218 requirements. The government performs no pre-marketing testing of helmet samples and only limited spot checking of helmets in the market.

In Europe, however, Snell certification is generally considered for use in competition only. Street use motorcycle helmets must meet ECE 22-05[6]. There is sufficient incompatibility between ECE 22-05 and current Snell requirements that there are no ECE 22-05 model lines which also satisfy Snell throughout their full range of sizes.

Aside from the UK Department for Transport's Safety Helmet Assessment and Rating Programme (SHARP), there is no agency in Europe promoting the development, production and use of motorcycle helmets whose capabilities exceed those demanded in ECE 22-05. Furthermore, SHARP may have no strong influence on increased impact severity management; the kerbstone anvil, even at the highest SHARP impact velocity, is not particularly severe.

Studies such as COST 327 indicate that helmets which manage more severe impacts would reduce the incidence of death and serious injury. But there is no reliable way for European riders to identify such helmets. Although increased impact management implies increased helmet weight and silhouette, the converse is not true; a lightweight, close-fitting helmet cannot exceed mandatory requirements by much but a heavier, bigger helmet may not either. Absent some device to identify superior impact management capability, rider preferences effectively mean that mandatory minimums must also be maximums which no helmet manufacturer may exceed for very long.

Snell M2005 - ECE 22-05 Incompatibility

At some point in the early 1980's two different opinions on helmet test head forms emerged: one had it that head form mass should not vary with size and the other that head form mass should be set proportional to the cube of the head form circumference. The former opinion was accepted for the ISO DIS 6880-1982 standard for impact test head forms and also for the BSI 6658-1985[7] standard for vehicular helmets. The latter was accepted for the March 1982 revision of the United Nations Regulation 22 Uniform Provisions Concerning the Approval of Protective Helmets for Drivers and Passengers of Motor

Cycles and Mopeds, and for the 1988 revision of the United States Federal Motor Vehicle Standard 218 Motorcycle Helmets (FMVSS 218). The Snell Memorial Foundation did not actually specify head form mass precisely until the late 1990's. However, Snell impact testing prescribed uniform levels for the kinetic energies of the falling head form regardless of head form circumference which suggests strongly that Snell's directors agreed with the ISO DIS and with BSI 6658 that there should be no correlation between head form mass and circumference.

These differences in test head form masses can be substantial. A helmet that might reasonably be impact tested on a 3.1 kg head form in the latest revision of Regulation 22, ECE 22-05, would be tested on a 5.0 kg head form for Snell M2005 or BSI 6658-1985. These head form differences imply substantially different demands on helmet construction across these various standards. Helmets which do well on lighter head forms might score even better against impact test criteria when tested on heavier head forms, unless the higher impact energies overwhelmed them altogether. Helmets which do well on heavier head forms would likely not be overwhelmed when tested on lighter head forms but they could conceivably exceed peak acceleration criteria and HIC limits anyway.

Comparison Tests

The Foundation studied this incompatibility in 2005 by selecting comparable Snell certified and EC 22-05 homologated models for comparison testing. The two models were made by the same manufacturer. They were full face helmets with similar styling and features and both would be considered well appointed and relatively expensive in comparison to the rest of the market. The test matrix called for pairs of helmets to be tested identically to impacts as specified in Snell M2000 or in ECE 22-05. Snell M2000 preceded M2005 and differed only in the range of impact sites at which the helmet might be tested. The comparison included two different size configurations: one for the "M" head form and the other for the "J". Only two test conditions were considered: hot and cold. The permutations called for a total of 16 helmets: four of each model and size configuration. Although these models are available in other size configurations; the tests on the "M" and J head forms are sufficient. The "M" head form testing indicates that for helmets in sizes 60 cm and greater, Snell-ECE compatibility may be feasible. However, the "J" head form results suggests that, for helmets sized smaller than 60 cm, Snell-ECE compatibility is very difficult at best. And, for sizes smaller than 57 cm, Snell-ECE compatibility may be all but impossible.

All the tests were performed on twin-wire, guided fall impact test devices. Otherwise, care was taken to perform all the ECE type impacts with appropriate drop masses, impact sites and impact surfaces. Had the facility been available to us, it would have been interesting to perform comparisons on free drop, full head form devices as set forth in ECE 22-05 requirements. However, tests on the guided fall device have been found to be more severe generally than comparable tests on an ECE device. Furthermore, the precise alignment of the head form with respect to the impact surface allows better duplication of tests as well as more reliably "worst case" impacts against the kerbstone surface.

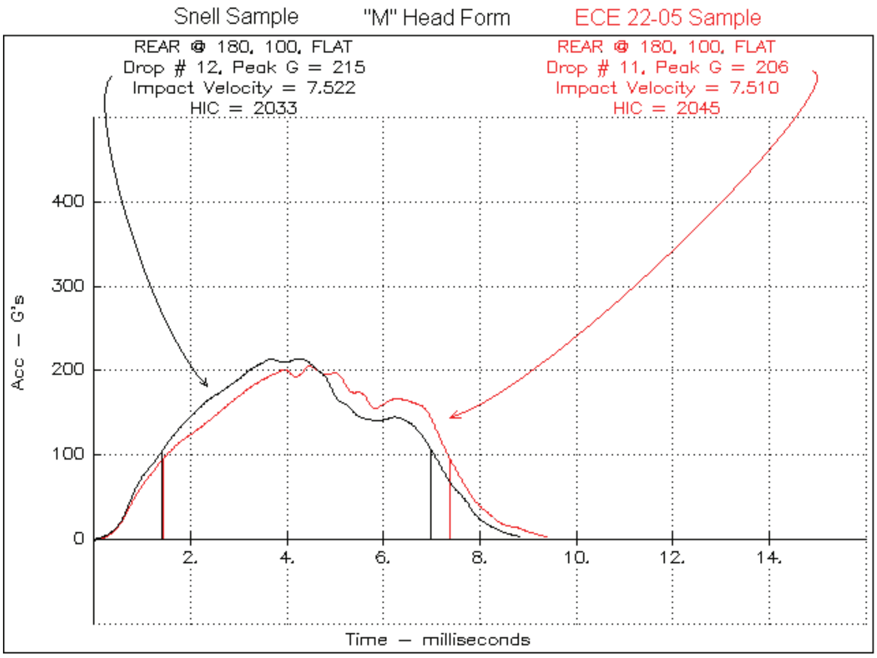

Figure 1: ECE 22-05 Flat Impact Performance - Time Domain

The ECE type testing obtained comparable results for the ECE and Snell helmets tested on the "M" head form. For these tests, impacts against flat surfaces are the most interesting. The heavier "M" drop mass required the Snell configuration to manage 5% more impact energy than demanded in the first of the two Snell impacts. The twin-wire test device was also expected to deliver impacts as much as 20% more severe than standard ECE testing to the ECE helmet configuration. In fact, both helmet configurations obtained similar results comfortably within ECE test criteria. The first figure compares acceleration versus time for both configurations and the second cross-plots acceleration versus the calculated deformation of the helmet wall. Both M sized helmet configurations met all ECE test criteria in all the impacts on both flat and kerbstone anvil surfaces throughout all the test conditions and did so with very similar numbers.

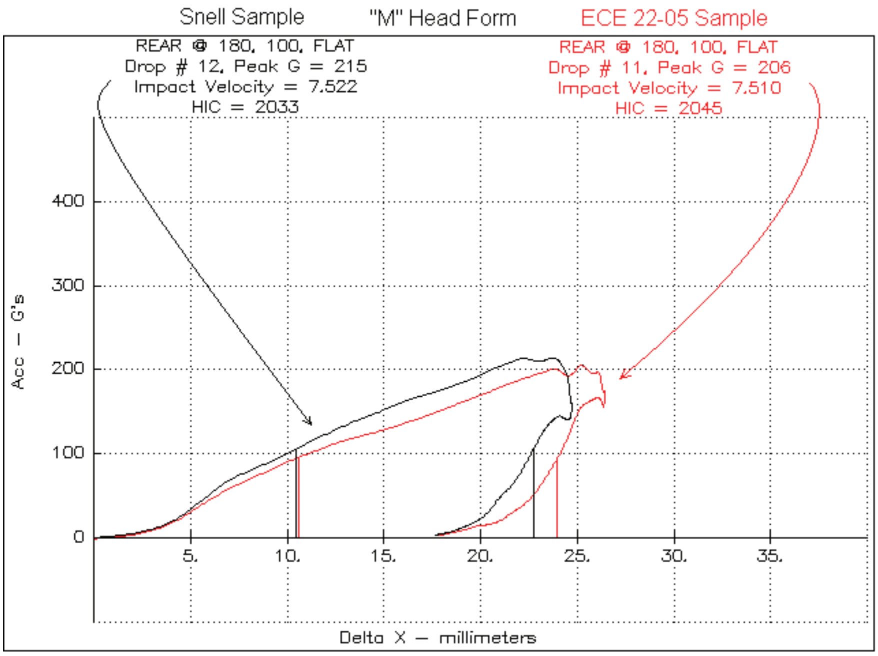

Figure 2: ECE 22-05 Flat Impact Performance - Cross Plot

Samples of these same "M" sized helmets were also tested in Snell type impacts. For these tests, the most interesting results were expected to be those for impacts against the hemispherical anvil. In fact, though, the results for both flat and hemispherical anvil surfaces were very similar. The technician was able to obtain failing results for rear impacts against the hemispherical anvil but only because he tested at the M2005 test line. Both the Snell and the ECE 22-05 configurations obtained results exceeding the Snell 300 G criterion. However, neither helmet should have been demanded to withstand that impact. The Snell helmet had been certified to M2000 requirements for which the rear test line is one centimeter higher while the ECE 22-05 rear impact site is well above even that.

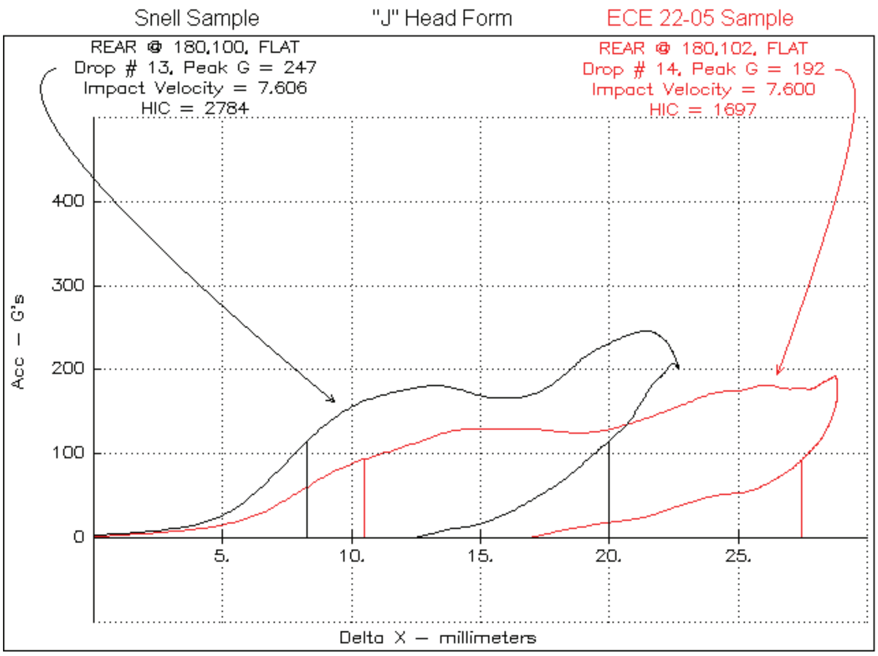

Figure 3: ECE 22-05 Flat Impact Performance - Cross Plot

The results for the “J” size configurations were considerably more dramatic. In ECE 22-05 impacts, the Snell model failed to meet the HIC 2400 criterion for all the flat impacts and also exceeded the peak acceleration criterion with a 279 G peak for one of these impacts. Conversely, in Snell type testing, the ECE model failed in hemispherical impact at two of four test sites and also failed in one of two edge impacts.

The slopes of the cross plots of the flat impacts shown in Figure 3 indicate that the Snell J configuration is considerably stiffer in flat impact than the ECE “J” helmet. This difference in stiffness is directly responsible for the higher accelerations of the Snell “J” sized configuration’s responses and also for the greater peak helmet wall deformations observed for the ECE “J” configuration. Figure 4 compares the results for Snell type flat impacts for both the J and M sizes of the Snell and ECE helmet configurations. The cross plots for the ECE “M” size configuration and the Snell “M” and “J” configurations have similar slopes while slope for the ECE “J” configuration is appreciably less steep. Since all the Snell testing shown was performed with 5.0 kg drop masses, these slopes should correspond to the relative densities, or stiffness, of the shock managing liners within the four helmet configurations. The comparison suggests that the ECE “M” configuration might have had difficulties meeting ECE 22-05 requirements if it had been tested on the lighter J head form. There is also the suggestion that helmet liner density depends strongly on the head form drop mass and on the shock test criteria in the helmet standard. Since the Snell “M” and “J” configurations are tested with the same drop mass and to the same criterion, the liner densities are similar. The slightly steeper slope for the Snell "M" configuration suggests a denser liner, maybe to offset the slight decrease in shell bending stiffness arising from the difference in helmet dimensions. The ECE "M" configuration is tested on a heavier head form which suggests increased density but the criteria demand reduced peak acceleration which suggests lower density. In this case, the requirements come close to canceling each other out.

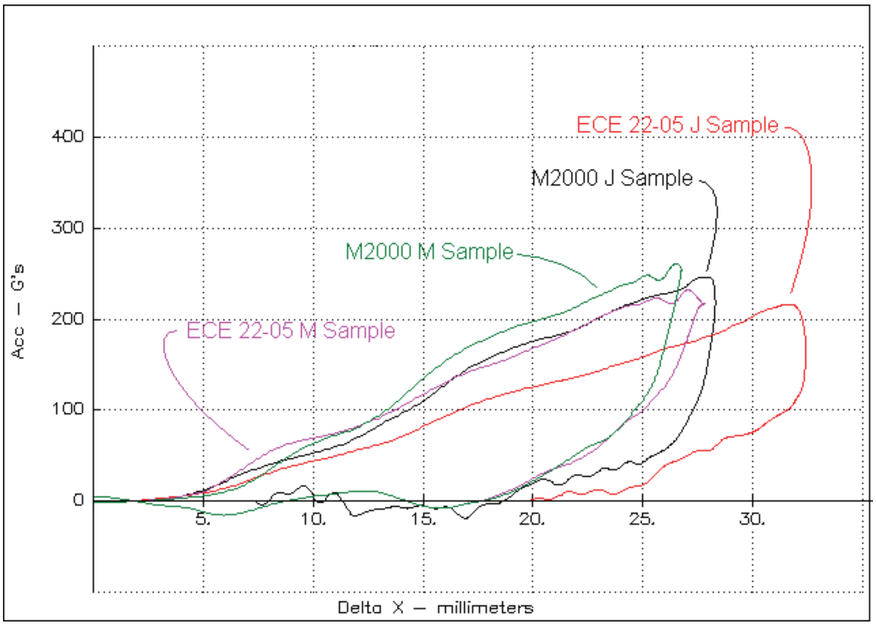

Figure 4: Snell Type Flat Impact to the Brow - Cross Plot

For flat surfaces, there is plenty of helmet wall thickness in the ECE "J" configuration to manage even the Snell impact severities. However, these wall deformations are much greater for impacts against load concentrating surfaces such as the edge and hemispherical anvils. At Snell impact severities, the ECE "J" configuration failed in front hemispherical and top edge impact because the helmet wall reached its crush limit before all the impact energy was managed. Figure 5 compares cross plots for the first and second impacts for both the Snell and ECE "J" configurations. Data collection began just as the samples passed through the velocity gate almost 20 mm before contact with the impact surface. The gate was not readjusted before the second impact so as to make the second response, as much as possible, a continuation of the first. Both samples appear to have almost 15 mm of residual deformation after the first impact. The Snell configuration appears to have undergone a maximum deformation of just over 40 mm as a result of both impacts while the ECE configuration saw about 5 mm less than that. The shape of the ECE configuration's response indicates that the second impact collapsed the helmet wall completely. At that point, the remaining head form momentum had to be managed nearly instantaneously with the only attenuation enabled by deformation of the head form. As a result, the acceleration response spiked suddenly to levels well beyond the test criteria and the capabilities of the test instrumentation. In order to have passed this test and still have met ECE 22-05 flat impact requirements, the ECE configuration would have needed a considerably greater wall thickness than even the Snell configuration.

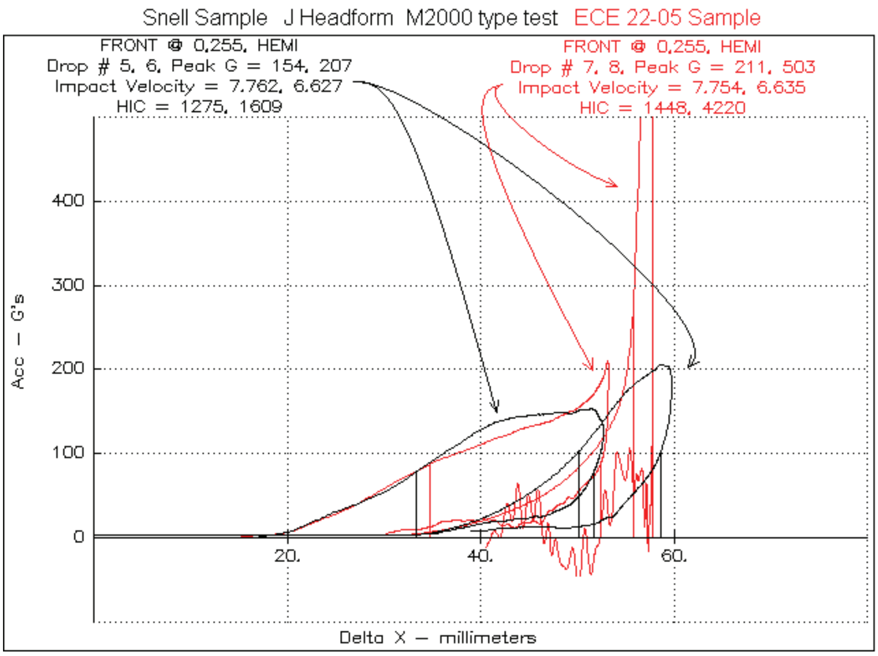

Figure 5: Snell Type Hemi Impact to the Brow - Cross Plot

Reasonably, the divergence between Snell and ECE 22-05 head form masses for the smaller "E" and "A" head forms would worsen the Snell flat response in ECE type testing and the ECE hemispherical and edge responses in Snell type testing. A sense of the magnitude of the problem can be obtained by some calculations based on the impact response data collected for the Snell "M" and "J" helmet configurations. If the acceleration values collected during testing are scaled by the drop mass and then cross plotted against calculated helmet wall deformation, they correspond to force versus deformation curves. These can be split into loading and unloading segments at the point of maximum deformation and then these segments can be manipulated to approximate the helmet response to slightly modified test configurations. Presumably, if the helmet's material properties are not velocity dependent, this method might yield some useful insights into impacts at the same site and same impact surface but with different drop masses and impact velocities. The essence of the method is first: calculate the kinetic energy of the impact to be simulated. Then find the point along the loading segment of the base data such that the area beneath the curve and to the left of the point is equal to the simulation drop energy. Then shift the unloading curve from the base data to the left until it intersects the loading curve at that point. The basic assumption is that the simulated drop will start at the plot's origin, follow the loading curve moving left out to the energy point and then follow the unloading curve downward and to the right. A simulated time response can be calculated directly from the manipulated force response curve.

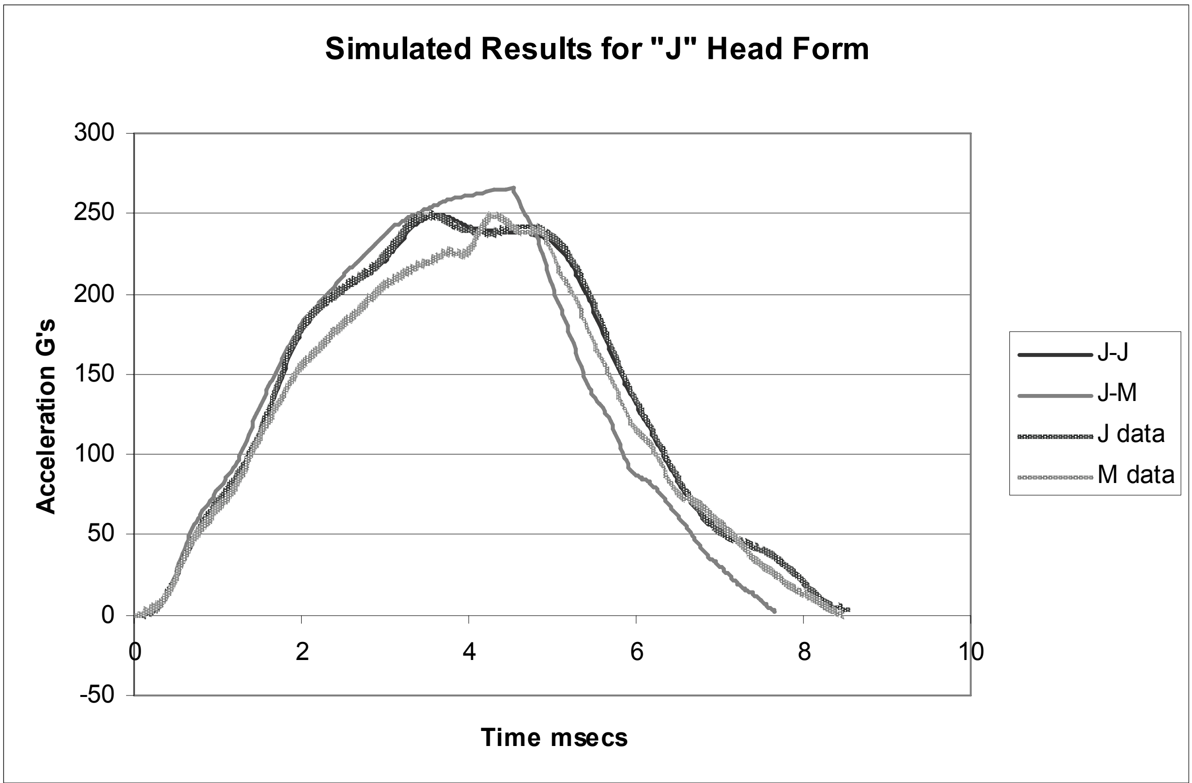

Figure 6: Simulated Flat Impact - J Head Form

Simulation Results for Smaller Head Forms					
		Base Data Set			
		J		M	
		Peak G	HIC	Peak G	HIC
Simulation	A	328	4418	343	4352
	E	286	3498	290	3307
	J	250	2838	267	2845

There are caveats to this simulation though. The shell response and even the shock managing liner response are both velocity dependent to some degree. Although, in the simulation, the rate of deformation at the calculated energy point is precisely zero, the simulation assumes the force generated by the helmet is the same as that in the actual test when the rate of deformation may have been substantial. That is, the peak head form acceleration yielded by this method is likely to be the most suspicious. Also, the unloading response depends greatly on the damage sustained during loading. Since a lower energy drop will do less damage, the entire stretch of simulated unloading should also be viewed with suspicion. Finally, the method breaks down if the energy of the simulated drop exceeds that of the actual drop.

However, even considering these caveats, tinkering with the results of the Snell type J and M sized helmets yields some useful insights. Figure 6 shows actual results for the for the M and J head forms as well as simulated results for a test at precisely 7.5 meters per second on a J head form massing precisely 4.7 kg. Trace “J-J” represents the simulation based on the actual J results shown here as “J data”. They are practically the same curve; no surprise as the actual head form mass and impact velocity were quite close to the ideal values. Trace “J-M” is the simulation based on the M data. The simulation is at least plausible. The table following the figure shows peak G and HIC values from the J and M simulations of ideal drops with each of the A, E and J head forms. Peak G and HIC are reasonably the same for each of the two simulations for each head form. The next two figures show the graphical results of the simulations.

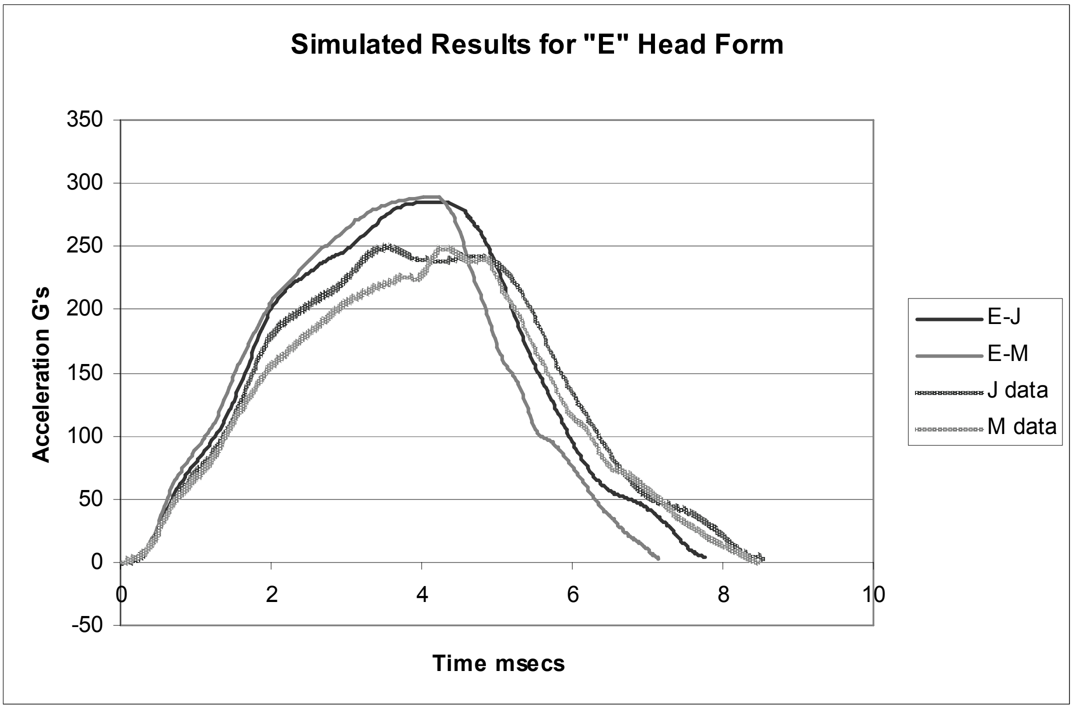

Figure 7: Simulated Flat Impact - E Head Form

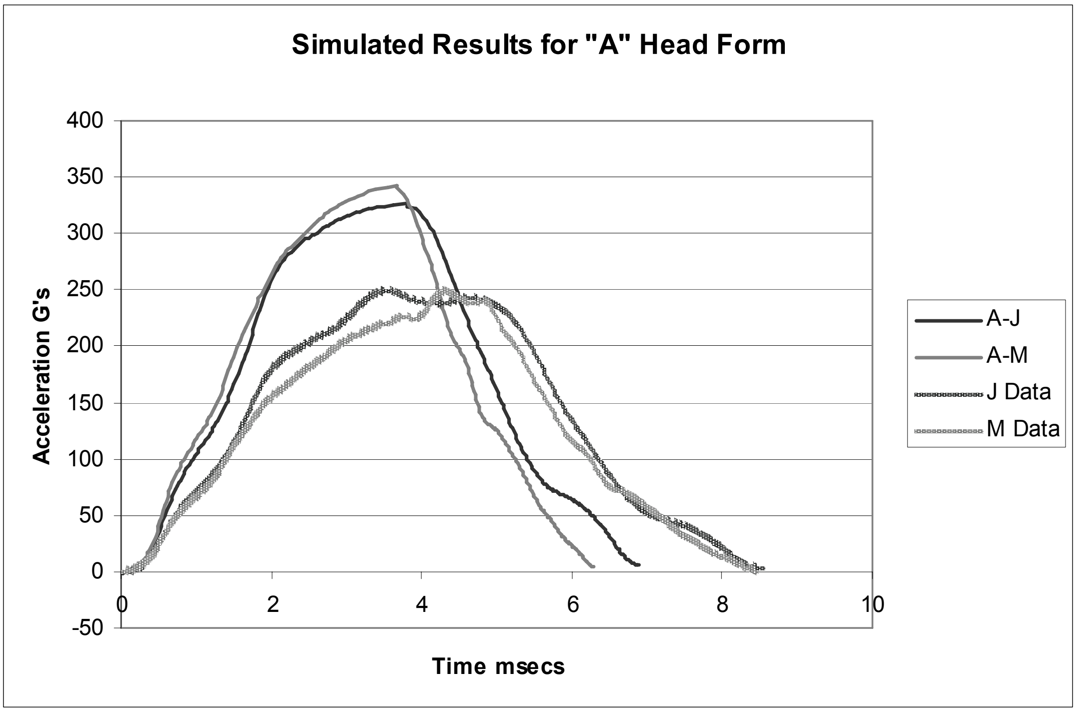

Figure 8: Simulated Flat Impact - A Head Form

The results provide a plausible indication that Snell type helmets will fail to meet ECE 22-05 peak G and HIC requirements for the E and then the A head forms. The results are not as dire as scaling the actual results according to the ratio of the simulated versus test head form weights might imply. The lower drop energies effectively end the simulated loading well before the levels reached in the original tests. But the results are a pretty conclusive indication that there won't be any viable head gear fitting the A or E head form and cross certified to both Snell M2005 and ECE 22-05.

Implications

The data collected for the M sized Snell M2000 certified helmet suggests that Snell/ECE 22-05 compatibility is possible for helmets sized 60 cm and larger. The performance of the M sized ECE 22-05 helmet shows that such helmets may already be available for sale in Europe. It should be remembered, though, that from the outset, this study sought helmets which would do as well as possible against either standard. Snell requirements are not expected to allow much latitude to designers to meet differing demands but ECE 22-05 may permit a much broader range of capabilities among qualifying models. Therefore, it may be reasonable to conclude that most Snell M and O sized helmets will do well in ECE 22-05 impacts but the converse may not be true for M and O sized ECE 22-05 helmets tested in Snell impacts.

The data collected for the J sized Snell M2000 certified helmet suggests that Snell/ECE 22-05 compatibility may not be possible for helmets sized smaller than 60 cm and this conclusion is supported by simulated responses for E and A sizes drawn from the results for the M and J sized Snell M2000 certified samples. The results for the J sized ECE 22-05 helmet, which had been considered the likeliest on the European market to perform up to Snell requirements, confirm this conclusion.

The incompatibility found for the medium and smaller sizes of helmets means that there can be no viable model line sized for a reasonably broad range of riders which could be certified to both Snell and ECE motorcycle helmet requirements. Furthermore, the source of the incompatibility is the differing head form mass specifications in Snell and ECE 22-05.

Head and Head Form Mass

Until recently, there had been no impetus at Snell to move away from the 5.0 kg mass specification for all impact testing regardless of head form size. Clauser's data[8] indicated a correlation between head size and mass but not particularly strong and definitely not a cubic. Walker's data[9] from a study at Tulane University in New Orleans showed no correlation between head mass and any other anatomical parameter except total body weight. It seemed that hat size did not imply head weight. However, in 2006, Dr. Ching at the University of Washington showed the Foundation's directors results of a study[10] he had performed a few years earlier. The study was limited, only fifteen subjects, but the procedures were carefully controlled. Dr. Ching found a strong correlation between head mass and head circumference and this correlation was remarkably close to a cubic.

The following figure shows the head form masses for the DOT and ECE 22-05 impact testing plus best fit cubics through them. The Snell masses are also shown. The line segment for the correlation found by Dr. Ching is shown with a reasonably well fitted cubic approximation.

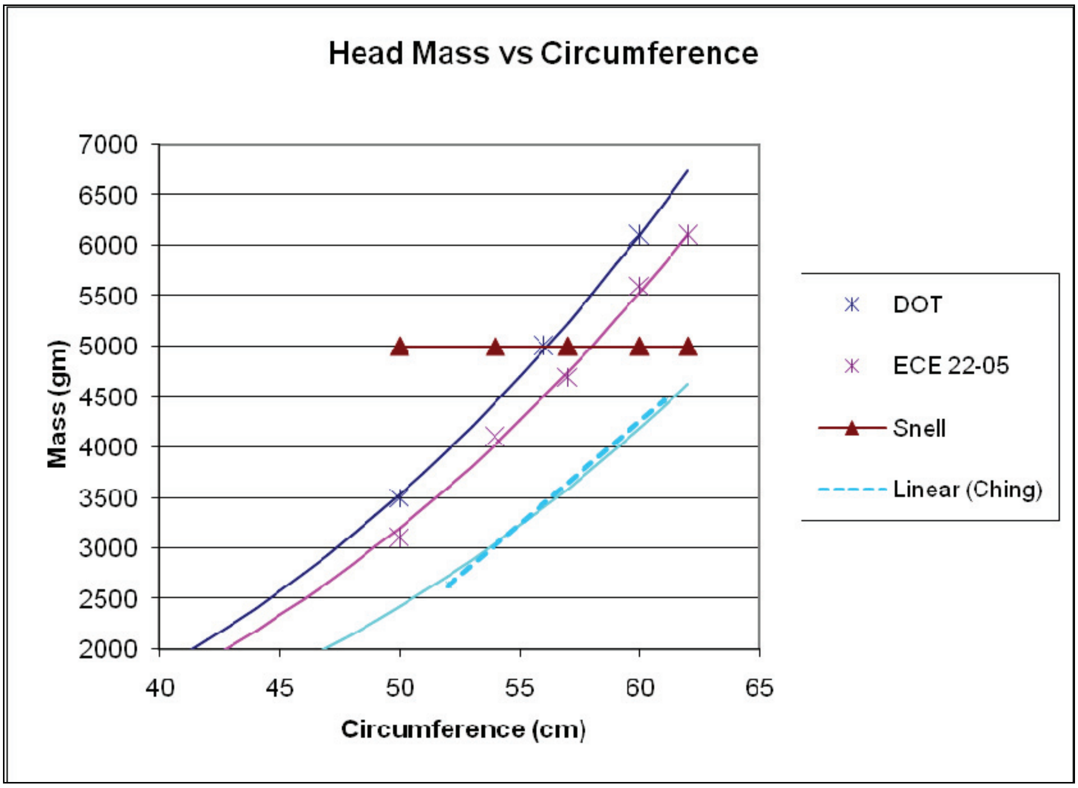

Figure 9: Head and Head Form Mass vs Circumference

Although Dr. Ching's head mass findings are well below those used by DOT or ECE 22-05, this difference can be attributed to the manner in which Dr. Ching's samples were dissected. In Dr. Ching's study, the entire neck was removed before the head samples were weighed. Other studies have used different dissection protocols. The critical issue, though, is the shape of the regression. Dr. Ching's data suggest that impact tests with masses selected according to the cube of the head form circumference will select helmets according to uniform limits of head acceleration stress regardless of helmet size.

Of course, Dr. Ching's data set was too small to be conclusive. However, there is no strong support for uniform head mass either. At best, the findings allowed the Foundation's directors to consider a fundamental change to Snell standards. There was no indication that the change would lead to helmets with better, more protective impact performance. But the helmets might reasonably be as protective as before and the change might simplify compatibility with DOT and allow complete compatibility, at last, with ECE 22-05.

Consequences

The switch from 5.0 kg impact test masses to the ECE 22-05 masses requires a host of changes to current Snell test policies. Rather than go through the entire process, it is probably more useful to list the changes and some of the thinking behind them.

Peak G Criteria

Formerly, the Snell peak G criterion had been a uniform 290 G for certification testing and 300 G for enforcement testing. The difference was there to assure that no helmet became certified through measurement uncertainties and that no helmet might later be decertified for similar reasons. In the new Snell standard, helmets smaller than 60 cm are held to 275 G and 285 G for certification and enforcement respectively. These lower criteria match the ECE 22-05 values. But for helmets sized 60 cm and larger, the new Snell criteria are even lower than that. The reason is that a 275 G criterion for helmets tested on an M or O head form would allow helmets which would transmit more shock than is currently permitted in M2005. The peak G criteria developed for the new standard correspond to the more stringent of either M2005 or ECE 22-05.

Test Head Forms

ECE 22-05 calls out five standard head forms with geometries approximately the same as those in the ISO 6220-1982 DIS currently demanded in Snell standards. However, there is a large gap in circumference and mass between the smallest of these, the A head form, and the next larger E head form. Since previous Snell standards had set all head form drop masses to 5.0 kg, the gap between the 50 cm A head form and the 54 cm E head form posed no real problems. But for ECE 22-05, the masses jump by almost 33% from 3.1 kg for the A to 4.1 kg for the E. Another helmet standard, jointly issued by FIA and Snell, fills this gap with a C head form with a 52 cm circumference and a 3.6 kg drop mass. This C head form has also been added to the head form set in M2010.

Impact Severity

Traditionally, Snell had expressed impact severity in terms of the kinetic energy of the falling head form. This kinetic energy formulation equated directly to impact velocities and enabled a concise statement of the impact requirements. For a 5.0 kg head form, the Snell first impact energy of 150 joules implies a first impact velocity of 7.75 m/s and the second impact energy of 110 joules equates to an impact velocity of 6.63 m/s. These impact demands have been reached in careful increments since the first Snell helmet standard in 1959. The Foundation considers that, in terms of previous Snell standards, these impact demands are very close to the limits of what the industry can build and riders can wear.

The question is, given the ECE 22-05 head form specification and the new peak G criteria, what impact demands can the Foundation make that will approach but not exceed the limits of what manufacturers can build and riders can wear? How high can Snell set its demands and still obtain viable helmets in each size range? The Foundation possesses no real expertise in helmet design or materials but Snell certified manufacturers do. The Foundation posed this question in the form of a draft standard incorporating plausible but ambitious test requirements. When the industry responded with practical recommendations, the Foundation's directors weighed them, much like bids at an auction, to identify the most stringent set of requirements likely to yield useful, appealing headgear.

The resulting test impact severity demands are expressed in terms of first and second impact velocities for each of the six head forms on which helmets may be tested. The demands are too detailed for a simple statement. Instead, they are laid out in the following table.

M2010 Impact Testing							
Head Form		A	C	E	J	M	O
Circumference		50 cm	52 cm	54 cm	57 cm	60 cm	62 cm
Drop Mass		3.1 kg	3.6 kg	4.1 kg	4.7 kg	5.6 kg	6.1 kg
Test Criteria	Certification	275 G	275 G	275 G	275 G	264 G	243 G
	Enforcement	285 G	285 G	285 G	285 G	273 G	251 G
Certification Velocities	1st	7.75 m/s	7.75 m/s	7.75 m/s	7.75 m/s	7.75 m/s	7.75 m/s
	2nd	7.09 m/s	7.09 m/s	7.09 m/s	6.78 m/s	5.73 m/s	5.02 m/s
Enforcement Velocities	1st	7.48 m/s	7.48 m/s	7.48 m/s	7.48 m/s	7.48 m/s	7.48 m/s
	2nd	6.85 m/s	6.85 m/s	6.85 m/s	6.55 m/s	5.54 m/s	4.84 m/s

In general, the first impact is at 7.75 m/s regardless of head form size while the second impacts vary from 7.09 m/s for the smaller sizes down to 5.02 m/s for the largest head form size. The impact energies demanded for the medium and smaller head forms are generally lower than those required in M2005 even though the second impact velocities are higher. The total energies for the two largest head forms are about the same as for M2005 even though the second impact velocities are appreciably lower. In terms of the expected head mass to circumference relationships, though, riders with smaller hat sizes should be able to get better protection. There is no reason to believe that crash severity correlates with head size but helmets sized for smaller heads are required to withstand higher velocity impacts. Riders who wear Snell helmets will not all get the same level of protection but each will get as much protection as we can confidently demand in an appropriately sized helmet. Whether this seems unfair or undemocratic, it must also be regarded as a consequence of classical mechanics and the current state of helmet technology. It would be even less just to limit protection in all sizes to the best that could be demanded for the largest size.

Helmet Size Ranges

Formerly, a helmet which did well in Snell impact testing on the largest appropriate head form would do well in Snell testing on smaller head forms. Snell technicians applied a simple test to determine whether the crown of a particular head form made reasonable contact with the interior of a sample helmet. The largest head form making this contact was considered the largest appropriate. Comfort padding does not seem to affect this test. Even if the helmet appeared to fit a little more tightly, the head form never complained. However, there can be no certainty that helmets which do well on the largest appropriate ECE head form will also do well on smaller head forms. If a helmet is to meet requirements over its full range of sizes, it must be tested on the smallest as well as the largest appropriate head form. If the helmet does well against load concentrating impact surfaces like the hemisphere for the largest head form and against flat, load distributing surfaces for the smallest appropriate head form, it is reasonable to conclude it will do well on every intermediate head form.

Unfortunately, Snell has no objective procedure to identify a sample helmet's smallest appropriate head form. Instead, M2010 will require helmet manufacturers to declare the largest and smallest head circumferences for which a helmet is intended, first when the helmet is submitted for certification and then on the labeling after the helmet is accepted into the program. The largest appropriate head form will be the largest whose circumference is no greater than the largest declared head circumference and the smallest appropriate head form will be the largest whose circumference is no larger than the smallest declared circumference. If these two head forms are the same, M2010 requires five samples: four for testing and one for archiving and comparison to samples brought in for enforcement testing later. If the largest and smallest head forms appropriate to the helmet are not the same, M2010 calls for five samples configured for the largest intended size and two more configured with comfort padding for the smallest intended size. All the samples must be reasonably identical except for the fit padding. Four of the largest size will be tested on the largest appropriate head form and the fifth retained as an archive sample. The two samples in the smallest intended size will be tested on the smallest appropriate head form. For the model to be accepted into the program, each sample must meet all the criteria for all the tests applied to it.

Later, when helmet samples are brought in for standards enforcement testing, the helmets will be checked for the required labeling. Helmets must be clearly labeled with the largest and smallest head circumferences for which the unit is intended. The range of sizes indicated on the label must be equal to or within the size range for which the helmet was originally certified.

In Conclusion

The Snell Memorial Foundation's "2010 Standard for Protective Headgear for Use with Motorcycles and Other Motorized Vehicles" is in its final form. Testing has already begun and some helmet models have already met requirements for certification. The Foundation's M2010 program will take effect on October 1, 2009, when the first units become available for sale. However, the Foundation will continue to recommend units certified to M2005 for use in competition, casual recreation and transportation where permitted by local authorities.

In all likelihood, helmet models accepted into the M2010 program must still be appropriately homologated to ECE 22-05 for sale in Europe and/or manufacturer certified to Federal Motor Vehicle Safety Standard

218 for sale in the United States. Riders, though, will have an additional consideration beyond fit quality, comfort and style when they select protective headgear: they may also choose between helmets which meet mandatory requirements and those which demonstrably exceed those requirements.

It must be remembered also that M2010 certification will not guarantee perfect head protection. Snell certification labels will continue to state that “Some reasonably foreseeable impacts may exceed this helmet’s capability to protect against serious injury or death.” It is hoped, instead, that M2010 and, later, M2015 and M2020 will continue progress toward better, more protective headgear and toward a day when head injuries are no longer a major component of motorcycle crash outcomes.

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Improvement of Daytime Conspicuity of Motorcycles

Bessere Erkennbarkeit von Motorrädern am Tage

Dipl.-Phys. O. Bartels
BASt – Bundesamt für Straßenwesen, Deutschland

Abstract

In a research project BASt performed two test series to assess the frontal signal pattern on a motorcycle. In a first test series five different frontal signal patterns (passing beam, direction indicators, dedicated daytime running lights with different colours) and in a second test series six additional frontal signal patterns with different configurations of dedicated daytime running lights (white daytime running lights) installed on two motorcycles were compared with each other.

Test persons assessed the conspicuity of the motorcycles that were installed in front or next to a car in a static traffic situation from a distance of 50 m and 100 m for each signal pattern in a direct paired comparison.

Kurzfassung

In einer Untersuchung der BASt wurden zwei Versuchsreihen zur Bewertung des vorderen Signalbilds am Motorrad durchgeführt. In einer ersten Versuchsreihe wurden fünf verschiedene vordere Signalbilder (Abblendlicht, Fahrtrichtungsanzeiger, verschiedenfarbige Tagfahrleuchten) und in einer zweiten Versuchsreihe weitere sechs vordere Signalbilder mit verschiedenen Tagfahrleuchtenkonfigurationen (weiße Tagfahrleuchten) an zwei Versuchsmotorrädern miteinander verglichen.

Probanden bewerteten die Signalbilder an den Motorrädern, die vor oder neben einem Pkw in einer statischen Verkehrssituation aufgebaut waren, aus 50m und 100m Entfernung jeweils in direkten Paarvergleichen miteinander auf ihre Erkennbarkeit hin.

For further information please contact the Federal Highway Research Institute (BASt):

Für weitere Informationen wenden Sie sich bitte an die Bundesanstalt für Straßenwesen (BASt):

bast

Bundesanstalt für Straßenwesen – Federal Highway Research Institute

Brüderstraße 53

D-51427 Bergisch Gladbach

Telefon +49 (0) 2204 - 43 - 0

Telefax +49 (0) 2204 - 43 - 673

http://www.bast.de