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

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Abstract

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

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

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

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

Introduction

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

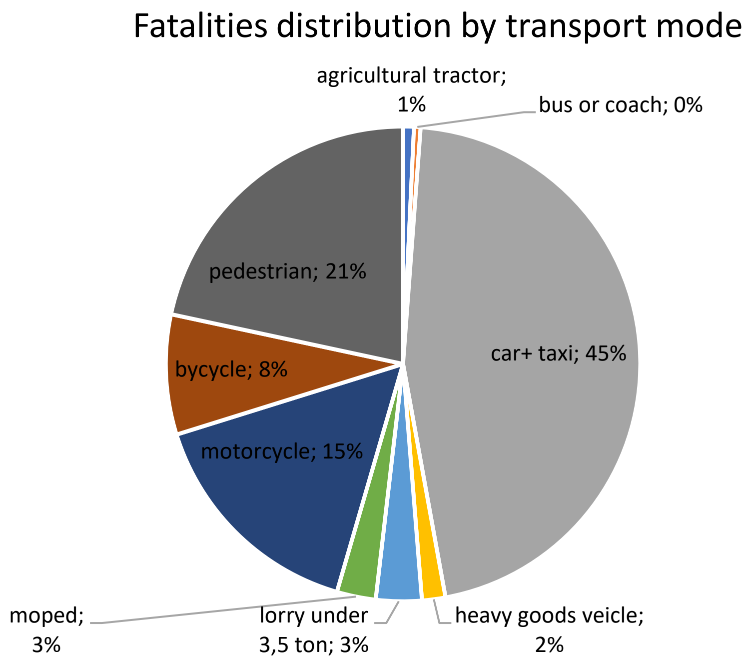

Figure 1 – Road fatalities distribution by transport mode in Europe in the year 2018 [2]

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

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

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

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

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

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

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

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

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

Method

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

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

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

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

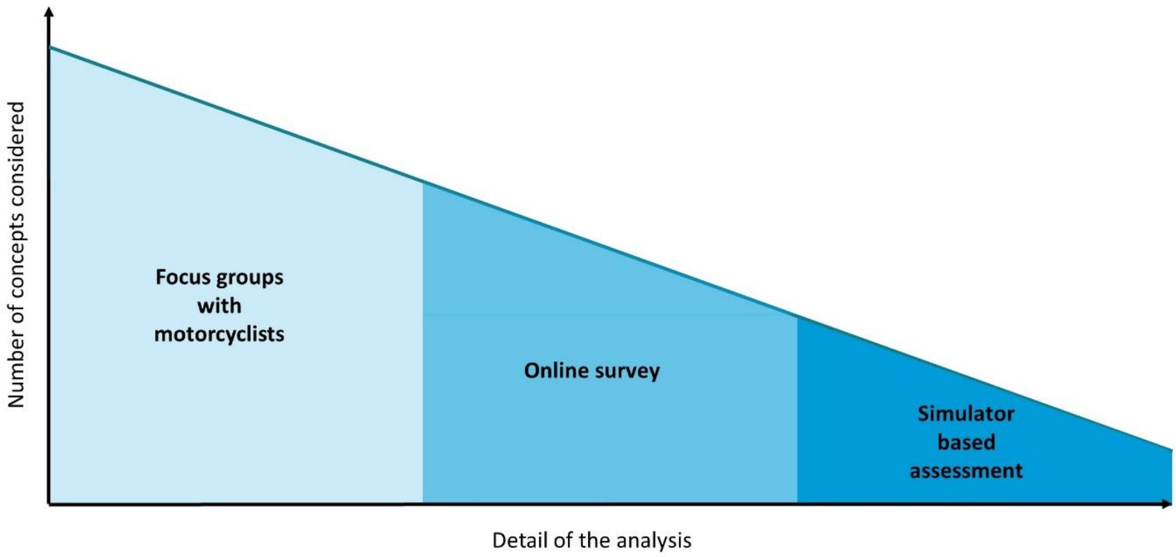

Figure 2 – Steps of the analysis in relation with the number of concepts analyzed and the quantitiative detail of the analysis

Qualitative acceptability of different HMI concepts through focus groups

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

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

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

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

Quantitative acceptability of HMI concepts through an online survey

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

The survey was composed of three parts:

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

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

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

Simulator based assessment and HMI concept acceptance

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

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

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

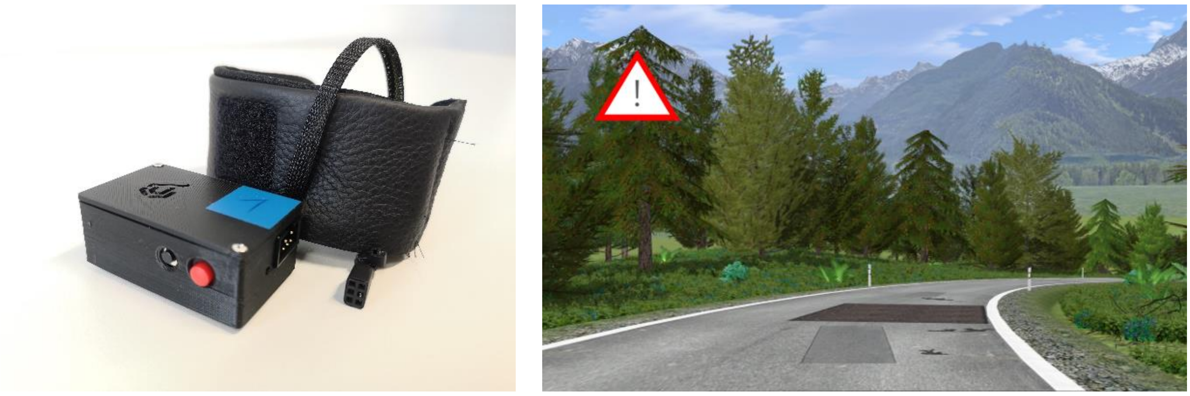

Figure 3: Haptic device (left) containing a bracelet and the controller. Simulated Head-Up Display warning icon (right).

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

Figure 4 - Static motorcycle riding simulator at WIVW.

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

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

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

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

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

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

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

Results

Qualitative acceptability of different HMI concepts through focus groups

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

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

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

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

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

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

Quantitative acceptability of HMI concepts through an online survey

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

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

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

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

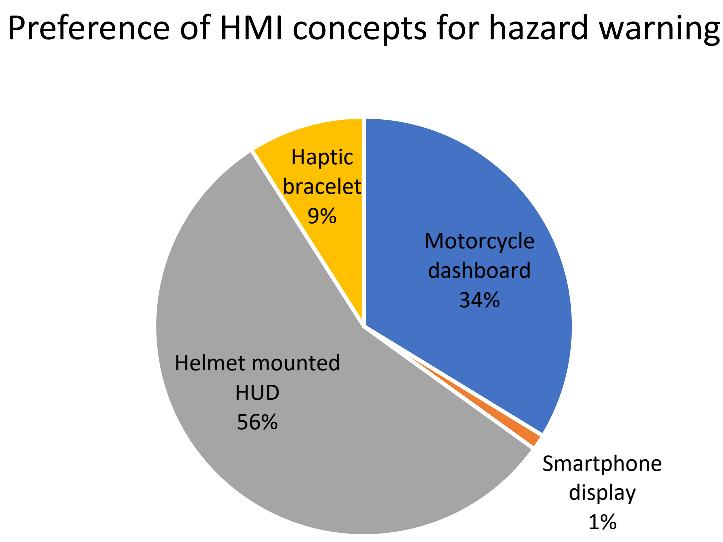

Figure 6 – Acceptance of four HMI concepts for hazard warning

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

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

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

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

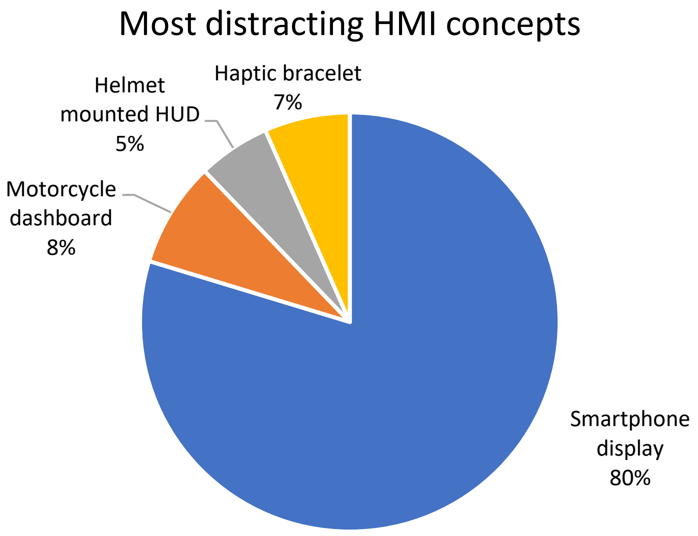

Figure 7 – Distribution of the most distracting HMI concepts as defined by the respondents of the online survey

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

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

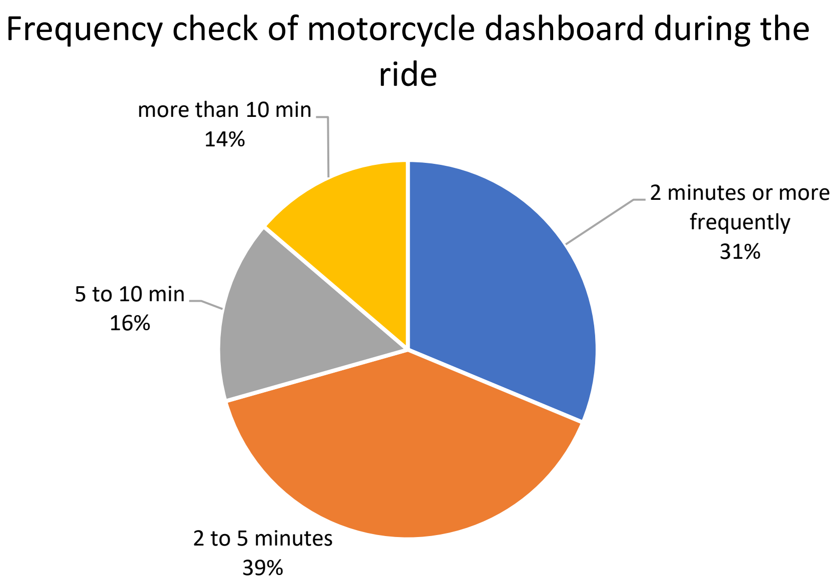

Figure 8 – Subjectively estimated frequency of gazes towards the dashboard while riding.

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

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

Simulator based assessment and concept comparison

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

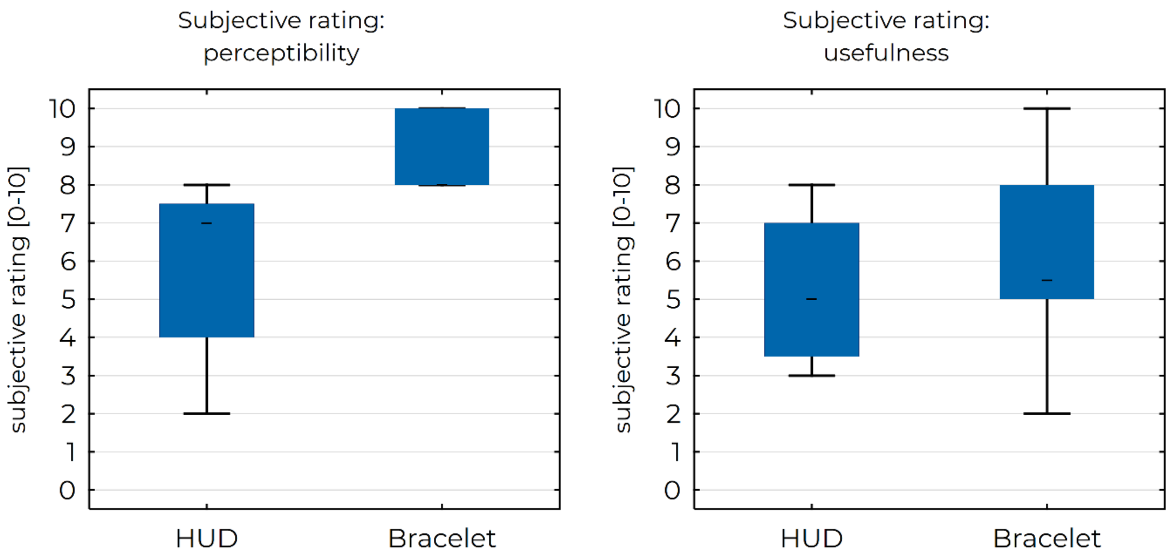

Figure 9: Ratings on warning perceptibility (left) and usefulness (right) as a function of warning concept (HUD or bracelet).

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

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

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

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

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

Discussion

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

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

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

Conclusions

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

Acknowledgment

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References

[1] European Commision, "Goal 3. Ensure healthy lives and promote well-being for all at all ages," 07 2020. [Online]. Available: https://ec.europa.eu/sustainable-development/goal3_en#target-3-6.

[2] CARE Database, "MOBILITY AND TRANSPORT - Road Safety," 07 2020. [Online]. Available: https://ec.europa.eu/transport/road_safety/specialist/statistics_en#.

[3] DEKRA Automobil GmbH, "Motorcycle Road Safety Report 2010," 2010.

[4] A. Sevarin et al., "Evaluation of the Potentila of Advanced Rider Assistance Systems for the Actula Accident Scenarios," in *Ricardo Conference*, 2017.

[5] Bosch, "Advanced Rider Assistance Systems," 07 2020. [Online]. Available: https://www.bosch-mobility-solutions.com/en/products-and-services/two-wheeler-and-powersports/rider-assistance-systems/advanced-rider-assistance-systems/.

[6] M. Gruber et al., "Effectiveness assessment of a generic collision mitigation system for motorcycles at junctions," in *ESAR - Expert Symposium on Accident Research*, 2018.

[7] V. Huth et al., "Predicting the acceptance of advanced rider assistance systems," *Accident Analysis & prevention,* 2013.

[8] V. Huth et al., "Intelligent intersection support for powered two-wheeled riders: a human factors perspective," *IET Intelligent Transport Systems,* 2011.

[9] S. Will et al., "Powered Two-Wheeler HMI Design for Cooperative Intelligent Transport Systems (C-ITS)," in *18th IFZ Conference*, 2018.

[10] K. Ito et al., "Head-up display for motorcycle navigation," 2015.

[11] R. Häuslschmid et al., "Can a Helmet-mounted Display Make Motorcycling Safer?," in *23rd International Conference on Intelligent User Interfaces*, 2018.

[12] M. Song et al., "An on-road evaluation of connected motorcycle crash warning interface with different motorcycle types.," *Transportation Research Part C: Emerging Technologies,* 2017.

[13] V. Huth et al., "Comparison of two warning concepts of an intelligent Curve Warning system for motorcyclists in a simulator study," *Accident Analysis & Prevention,* 2012.

[14] O. Nyumba et al., "The use of focus group discussion methodology: Insights from two decades of application in conservation," *Methods in Ecology and Evolution,* July 2017.