Connected
Motorcycle
Consortium

Rider Reaction Time III

Warning Timing

Document Information

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1 Summary

Optimising the interface between the motorcyclist and the vehicle is an important contribution to improving motorcyclist safety. Advanced Rider Assistance Systems (ARAS) can play an important role in crash avoidance. This applies to both sensor-based systems and to safety applications based on Cooperative Intelligent Transport Systems (C-ITS). In most cases, however, riders themselves are still responsible for initiating an avoidance manoeuvre. To do this, the Powered Two-Wheeler (PTW) needs to communicate its knowledge to the rider in a reliable and timely manner.

This communication process, or rather the design of the assistance system in terms of warning timing, was the focus of this latest CMC (Connected Motorcycle Consortium) participant study. The study, conducted with $N = 30$ riders on a dynamic motorcycle riding simulator, provided empirical evidence for the following research question:

What are the effects of different levels of warning timing on rider reactions and acceptance of the assistance system?

Participants completed a 35 km ride on a virtual test track in adverse weather conditions. A C-ITS-based assistance system warned the riders of broken-down vehicles (Local Hazard Warning) that the riders could not yet see. The results indicate that riders prefer earlier warnings, while accepting that it may not be possible to reliably attribute the warning to an already visible threat. For the given scenario, significant safety benefits in terms of reduced situation criticality were measured for any warning timing earlier than a Time-to-Collision TTC = 1.7 s. Providing a warning in the range of TTC = 3.2 s improves acceptance as it is perceived on average as perfectly timed (not too early and not too late).

Reaction times measured were defined as the response time between the warning and any means of deceleration (throttle off and brake onset). The results show a significant safety benefit for the warning trigger conditions of 2.2 s and earlier. Average reaction times ranged from 700 ms to 1100 ms. Throttle off and braking were clearly initiated by the warning itself and independent of the warning timing. These new findings help to update rider behaviour models, e.g., for simulation purposes, and to tune the trigger conditions of rider assistance systems.

2 Background & Motivation

This report is a follow-up to an earlier CMC specification dealing with rider reaction times as response to different types of warnings (visual, auditory, haptic). The focus of the current report is the investigation of rider responses to different warning timings.

The potentially most significant safety benefit of an ARAS can be expected when riders do not recognise the potential threat themselves. In this case, the warning needs to alert the rider, direct their attention and - for more imminent crash warnings - provoke an avoidance manoeuvre. For this purpose, the appropriate timing of the warning is very important. It is obvious that this involves technical discussions about at which point in time any sensor technology can detect and trigger a reliable warning. Yet, the focus in this study is on the human factors side. How is rider behaviour affected by different warning timings?

The *optimised warning* timing should provoke a measurable safety benefit while being issued as late as possible. The later the warning is triggered, the more confident the detection algorithm is that a potentially dangerous situation is about to occur. It provides sufficient time for a rider reaction (time to perceive, recognise, process the information and initiate an action) and an avoidance manoeuvre (time to stop the vehicle / avoid the obstacle). Warnings that are *too early* may be perceived as unnecessary/ false positive warnings and decrease trust in the system. Warnings that are *too late* may result in too late responses, missed warnings / false negatives or even crashes.

In order to understand this relation between warning timing and rider reactions, a participant study was conducted. $N = 30$ riders completed a test course on rural roads on a motorcycle simulator. The virtual motorcycle was equipped with a C-ITS application able to detect local hazards such as a broken-down vehicle. The warning timing was varied across four levels based on the real-time calculated Time-to-Collision (TTC):

$$\text{TTC} = 1.7\ \text{s vs. TTC} = 2.2\ \text{s vs. TTC} = 2.7\ \text{s vs. TTC} = 3.2\ \text{s}$$

Apart from questionnaire data, rider reactions in terms of reaction times from warning onset to throttle off and brake onset were analysed. It is important to mention that this study provides new empirical evidence for point estimates and distributions of reaction times towards imminent crash warnings (ICW). It is also important to notice that the distribution of reaction times towards a warning on a real motorcycle in real traffic etc. might vary significantly as there is a huge number of additional factors influencing these reactions (e.g., type of motorcycle and its ergonomics, dashboard downward angle, type of warning addressing different sensory channels of the rider, rider skills and workload resulting from the scenario, behaviour of surrounding traffic …). At this stage, it is simply not feasible to vary all these potentially relevant influencing factors in a rather controlled way and in a naturalistic field test to get results on PTW rider reaction times.

The results of this study can be used to design ARAS trigger algorithms effectively in order to enhance its safety benefits while raising acceptance and trust among riders.

3 Methods

3.1 Motorcycle simulator description

The DESMORI dynamic motorcycle riding simulator has been used for the participant study (see Figure 1). It is equipped with a BMW F 800S as mockup, mounted on a six degrees of freedom hydraulic Stewart platform. The mockup enables the riders to interact with fully realistic controls, such as a usual handlebar, brake lever/pedal, clutch, gear selector, etc., with which they are familiar. The manual gear shift uses a sequential six-speed gearbox. An electrical actuator produces a steering torque at the handlebar at up to 80 Nm. The rider steers the motorcycle through a combination of steering torque and induced roll torque by shifting his / her weight. The cylindrical screen with floor projection and a diameter of 4.5 m and a height of 2.8 m provides 220° horizontal field of view. The two rear-mirrors are simulated by means of 7-inch TFT-displays while the dashboard is displayed on a 10-inch TFT-touchscreen. Sound is provided via body shakers, which are attached to the riders' individual helmets. Moreover, a shaker that is installed below the seat delivers vibrations from the engine and high frequent road roughness. A rope-towing mechanism simulates longitudinal forces such as wind drag on the rider's torso.

Figure 1: DESMORI dynamic motorcycle riding simulator at WIVW.

3.2 Test course

The test course had a total length of 35 km, which took approx. 30 - 35 minutes to complete. It consisted of different modules on rural roads including two kinds of test scenarios and a series of dummy scenarios without critical situations. As can be seen in Figure 2, there were two rural test scenarios, each of which were experienced four times per participant during the test ride (the geometry and resulting trajectories etc. were identical, while the virtual environment was changing to avoid any kind of expectations). In the first scenario, the obstacle was a broken-down passenger car blocking the right half of the PTW's lane. In the second scenario, the obstacle was a recently broken-down motorbike still blocking the left half of the

PTW’s lane. This design was chosen to motivate any kind of deceleration as response to the warning, which still did not require coming to a standstill. Alternatively, or additionally, swerving would be a possible avoidance manoeuvre as well. However, this requires a situation-specific assessment which part of the road is available to avoid the obstacle. This takes some time and time in turn increases the chance of deceleration as initial response. From an ethical point of view, the test scenarios were scripted to leave enough space on the PTW’s lane to avoid the obstacle without entering the opposing lane or leaving the road.

The order of the scenarios was randomly selected and permuted between participants. Both test scenarios had in common that the conflict partner was obscured by a field of ground fog and therefore could not be seen by the rider at the moment the warning was emitted in the ground fog section. To make the appearance of the ground fog more realistic, the overall weather conditions were set to a cloudy scenario, with a shortened visual range. As in the second RRT study, there was a rural baseline scenario without warning, but otherwise comparable conditions. During the test course, there were about twice as many dummy scenarios as test scenarios. These dummy scenarios were characterised by identical geometry, ground fog appearance etc., while no critical event happened. The aim of these scenarios was to prevent the ground fog from becoming a trigger for critical events on its own.

Figure 2: Local Hazard Warnings: PTW (left) and passenger car (right) test scenario with obscured obstacles due to ground fog (upper row) and recognisable obstacles when approaching the test scenarios (lower row).

3.3 Study procedure

Figure 3 illustrates the study procedure. All participants were welcomed and received an informed consent document providing all necessary information related to the study. It was followed by a 15-minute ride in a rural environment to familiarise themselves with the virtual vehicle control again. At the end of this ride the participants experienced the test scenario for the first time without a warning for baseline measurements. After successfully completing this ride, the participants received specific instructions for the test ride. Besides trip length, traffic regulations etc., it contained information on the C-ITS application. The working principle of Vehicle-to-X (V2X) communication was explained, as was the type of rider notification. The stated purpose of the study was to receive riders' feedback on this new type of safety application. The riders were not informed about the study's focus on the effects of varying warning timing. However, all participants were aware that variations in reception due to peripheral buildings, weather conditions, etc. could affect the warning timing. In order to ensure trust in the application, which increases the likelihood of a reaction towards the warning, there were only true positives in the test ride. After each test scenario, the riders answered three questions while riding. At the end of the appointment, a final interview was conducted and riders received an expense allowance.

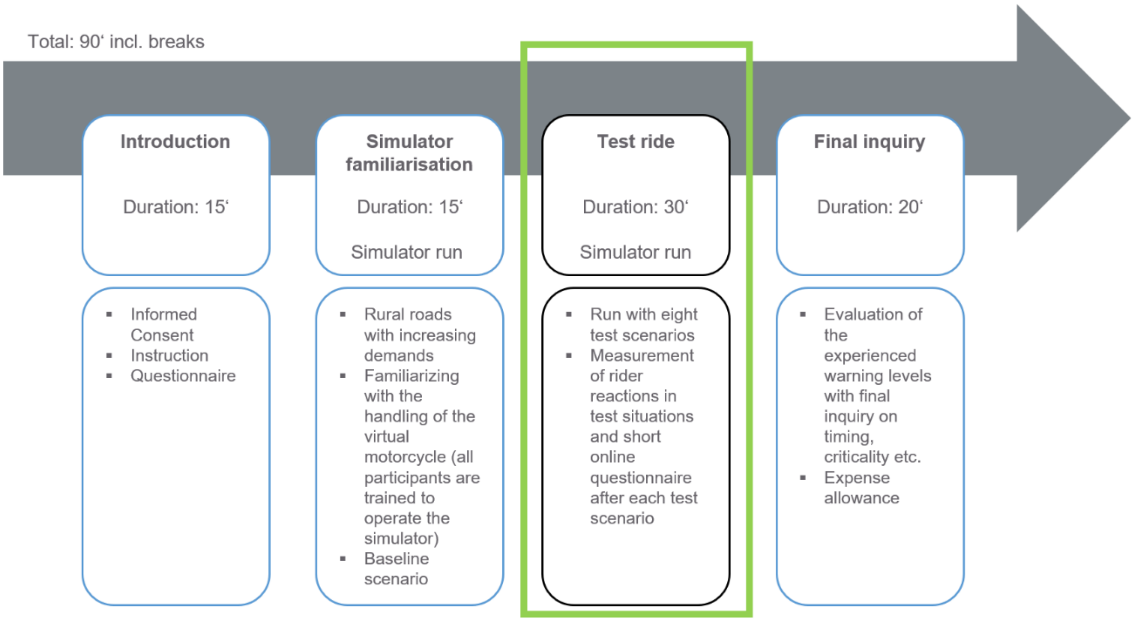

Figure 3: Schematic of the study procedure

3.4 Rider notification

Based on previous results from the RRT I and RRT II studies, a visual warning with mirror-mounted LEDs was chosen as rider notification. This type of warning represents a PTW-mounted visual solution. Eight Arduino-controlled LEDs with approximately 1000 mcd luminous intensity per LED were fixed on top of each mirror (see Figure 4). The LEDs provide a visual warning to the rider by flashing for 3 seconds with a constant frequency of 2 Hz in the colour red. The warning was designed in accordance with CMC's Basic Specification on HMIs referring to ISO2575: Road vehicles — Symbols for controls, indicators and tell-tales (ISO, 2021a) and ISO6727: Road vehicles — Motorcycles — Symbols for controls, indicators and tell-tales (ISO, 2021b).

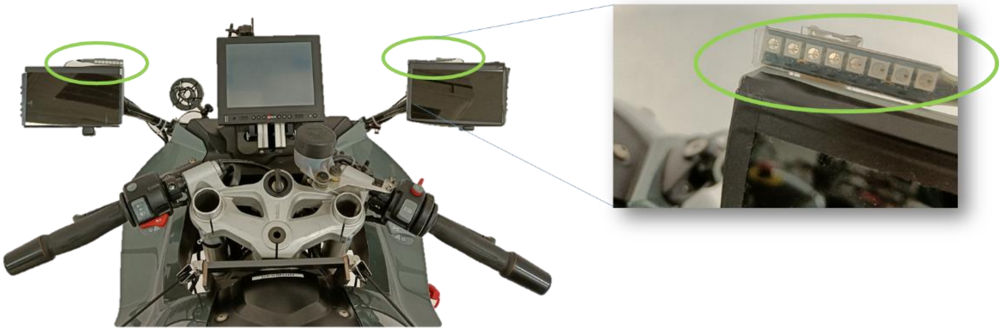

Figure 4: Simulator mockup with warning LEDs mounted on top of the mirrors.

There were four different warning timings to be compared: Time-to-collision (TTC) = 1,7 s vs. 2,2 s vs. 2,7 s vs. 3,2 s, which were experienced twice per participant. The order of the warning timings was permuted in eight versions to avoid sequence effects.

3.5 Metrics and statistical analysis

In addition to the questionnaire data, two different types of reactions were analysed (as in RRT II). Schematic representations of these metrics can be found in Figure 5.

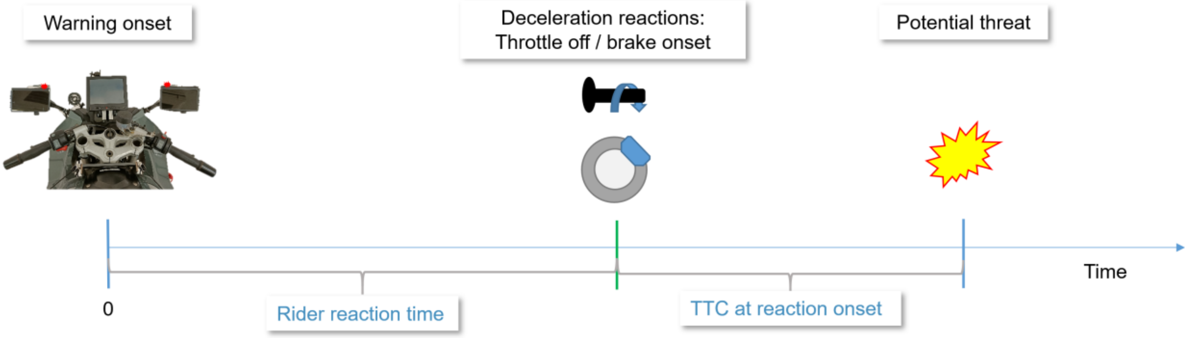

Figure 5: Schematic representation of different possibilities to calculate reaction times.

The starting time t_0 for any calculation is always the moment the warning is issued (warning onset). The following two types of reactions are analysed:

1. *Warning onset until throttle off.* This parameter measures the time between the warning onset and the release of the throttle twist grip as the potentially first and intuitive reaction to reduce the speed. A throttle twist grip release is defined as a complete release to the neutral throttle position.
2. *Warning onset until brake onset.* This parameter measures the time between the warning onset and the start of mechanical braking (either front or rear brake or both)

as a rider reaction for significant speed reduction. Brake onset is defined as an operation of any brake lever.

Depending on the evolution of each specific test scenario, throttle off and brake onset does not necessarily have to occur, if a rider judges the situation as sufficiently controllable and safe. Any rider response later than 300 ms after warning onset was regarded as a response to the warning. Furthermore, some riders start braking with the front brake without a full release of the throttle.

In addition to the vehicle dynamics data, questionnaire data was gathered. After every test situation the riders were asked whether the C-ITS application had emitted a warning. If the answer was positive, the riders were asked how they reacted. This information helps to interpret the riding data.

For instance, a rider may reply that they recognised the warning, but decided not to brake, as there was enough space on their lane to pass the obstacle.

The second question targeted the perceived warning timing. The answers were given on a 13-point categorisation scale, as shown in Figure 6.

way too early			too early			perfect	too late			way too late		
-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6

Figure 6: 13-point verbal categorisation scale.

The third question targeted the perceived criticality of the experienced situation. The answers were given on the situation criticality scale as displayed in Figure 7. All three questions were answered while riding.

Figure 7: Situation criticality scale (English version translated from Neukum, Lübbeke, Krüger, Mayser, and Steinle (2008)).

A final inquiry completed the appointment. The riders were asked to rate the recognisability of the rider notification that they were shown on a 16-point categorisation scale ranging from ‘0 impossible’ to ’15 very good’. Furthermore, they were asked how likely they would want such a warning also on a 16-point categorisation scale ranging from ‘0 not at all’ to ’15 very likely’.

As the perception of time may vary based on the experienced situation or the point in time when the warning was actually recognised, the riders should estimate the time they had left between the warning onset and the potential threat. They were asked whether they prefer an early warning even if they cannot relate it immediately to a potential threat or if they prefer a late warning even if they might have already seen the potential threat and reacted to it. Both questions were answered on a seven-point scale from ‘-3 strongly disagree’ to ‘+3 strongly agree’.

Different types of graphs are used to display the distribution of data. Scatterplots show the raw data. Boxplots display the central 50 % of data within the box. The central line is the median value. Whiskers show 1.5-times the inter-quartile range (IQR, i.e., height of the box) as a measure of variance in the data set. Alternatively, the whisker length is limited to the observed minimum or maximum if those lie below 1.5-times IQR. If those lie outside 1.5-times IQR the values are marked as circles or stars (outside 3-times IQR) indicating outliers and extreme values.

3.6 Panel description

The study has been approved by WIVW’s group in charge of ethical assessment. The strict ethical guidelines as defined in the standard operating procedures based on the Guidelines for Safeguarding Good Research Practice of the German Research Foundation (DFG) as well as the Code of Professional Ethics of the German Association of Psychologists (bdp) and the German Psychological Society (DGPs) have been followed.

A total of *N* = 30 riders participated in the study, of whom *n* = 4 were female. The panel covers a wide range of age groups and levels of riding experience, as can be seen in Table 1. All participants were recruited from the WIVW motorcycle rider panel, which consists of non-professional riders that had previously been trained to ride the simulator safely.

Table 1: Participant panel description (N = 30 with n = 4 female).

	Mean	***Standard deviation***	***Minimum***	***Maximum***
Age in years	36	12	19	69
Motorcycle mileage covered during the last 12 months in km	3 926	2 748	0	11 000
Motorcycle mileage during lifetime in km	65 103	73 379	2 000	300 000

4 Results

The analysed segments start with the warning onset and stop when the rider has passed the obstacle. For the analysis in chapter 4.3, it is the rider response which defines the start of the analysed segment. Detailed descriptive statistics can be found in chapter 7: Appendix. In total, there were *N* = 234 test scenarios recorded (30 riders x 8 test scenarios with 6 scenarios missing).

Table 2: Data set description.

Braking when arriving at the ground fog section (test scenario)	No braking 194 (82.9 %)	Braking 40 (17.1 %)
Throttle status when arriving at the ground fog section (test scenario)	Throttle open 156 (66.7 %)	Throttle off 78 (33.3 %)
Reactions earlier than 300 ms after warning onset	Brake onset 10	Throttle off 2

Out of these, a subset is used for the calculations (Table 2), which is always mentioned in the respective tables. This subset excludes riders who were already decelerating before the warning was issued or within 300 ms after warning onset. These deceleration reactions would not be interpreted as a response to the warning.

4.1 Throttle off

On average, the observed throttle off response does not vary significantly between warning timings (Figure 8). Reaction time median values lie between 667 ms and 750 ms and mean values lie between 697 ms and 1019 ms (see also chapter 7.1).

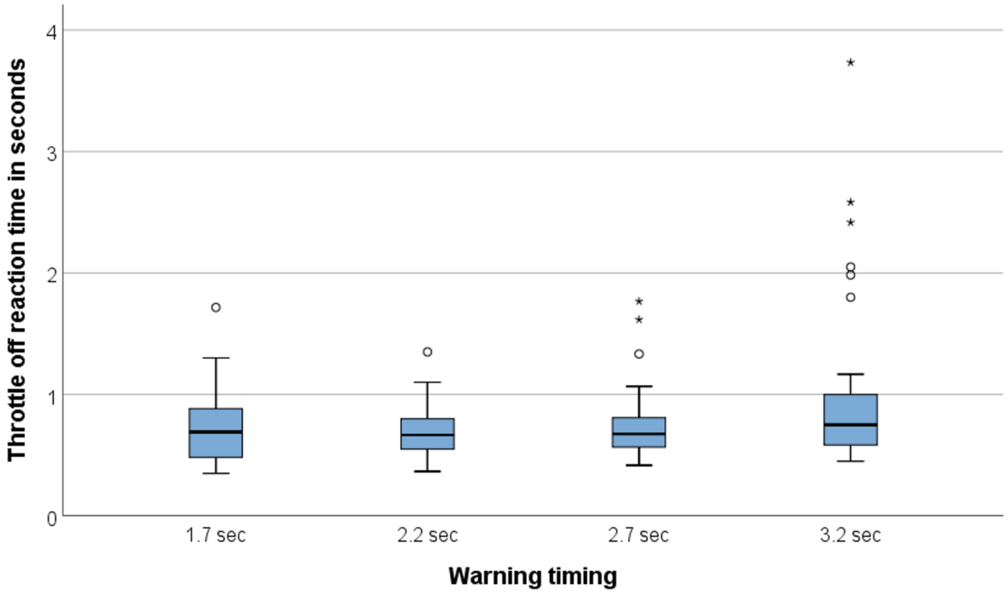

Figure 8: Boxplot of riders' throttle off reaction times after warning onset as a function of warning timing.

There is an observable variation within all levels of warning timing (Figure 9), and a tendency for the maximum values to increase with warning time.

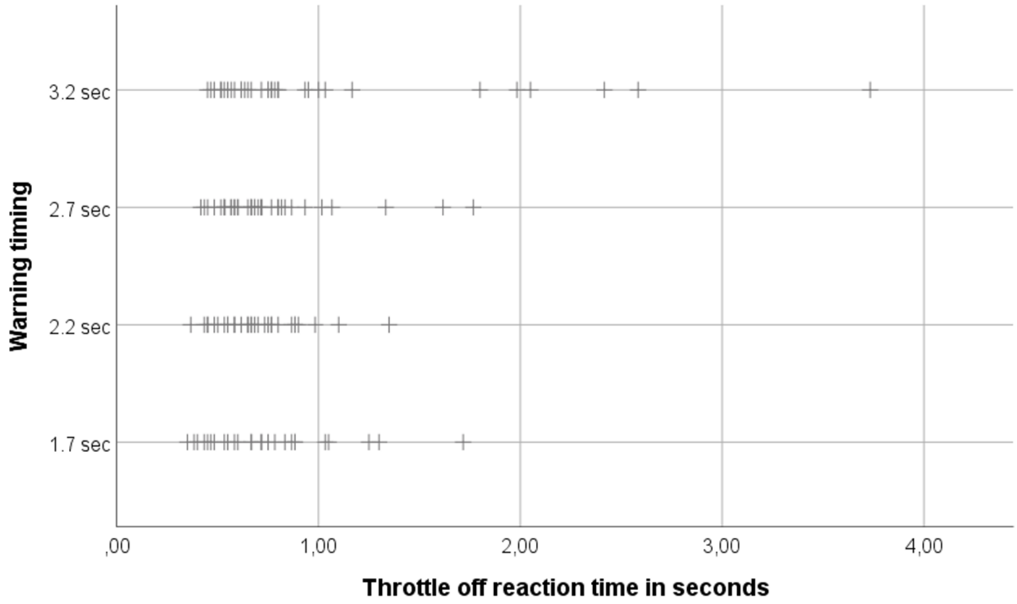

Figure 9: Riders' throttle off reaction times after warning onset as a function of warning timing.

4.2 Brake reaction

As for the throttle off responses, the observed brake onset does not vary significantly between warning timings (Figure 10). The reaction time means lie between 809 ms and 1141 ms (see also chapter 7.2). The median values fall within the range of 792 ms to 858 ms.

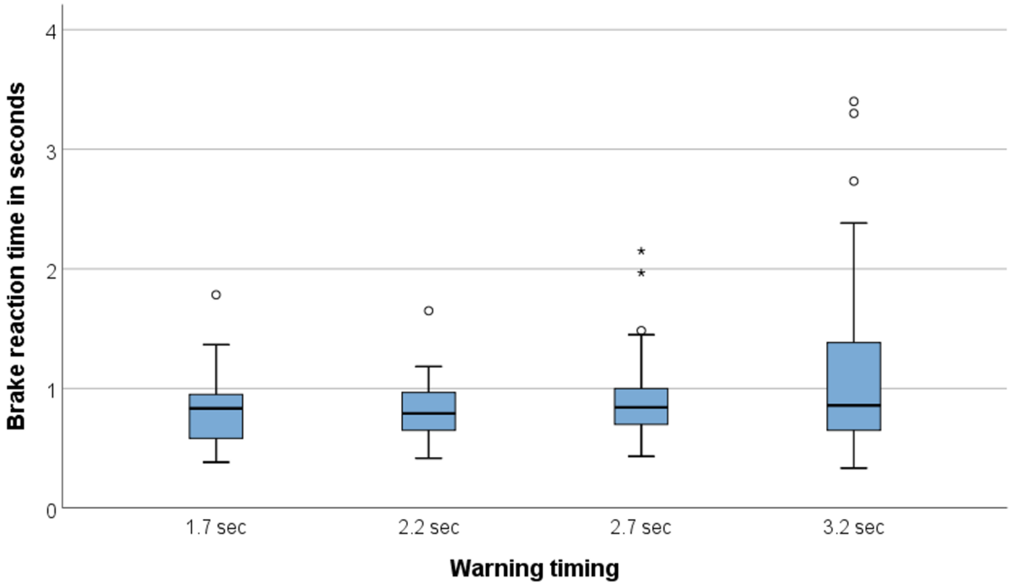

Figure 10: Boxplot of riders' brake reaction times after warning onset as a function of warning timing.

There is an observable variation within all levels of warning timing, again with generally increasing maximum values with increasing warning time (Figure 11).

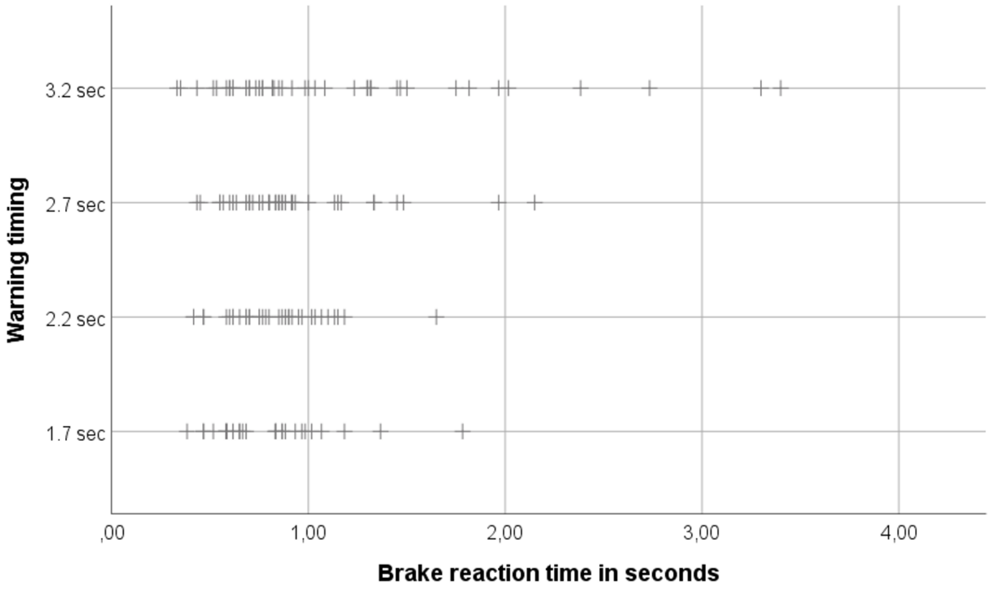

Figure 11: Riders' brake reaction times after warning onset as a function of warning timing.

4.3 Remaining time after reaction

The first reaction to occur (throttle off or brake onset) is used for the calculations. Since the reaction times across warning levels were comparable, the remaining time to collision after the reaction varies significantly (Figure 12).

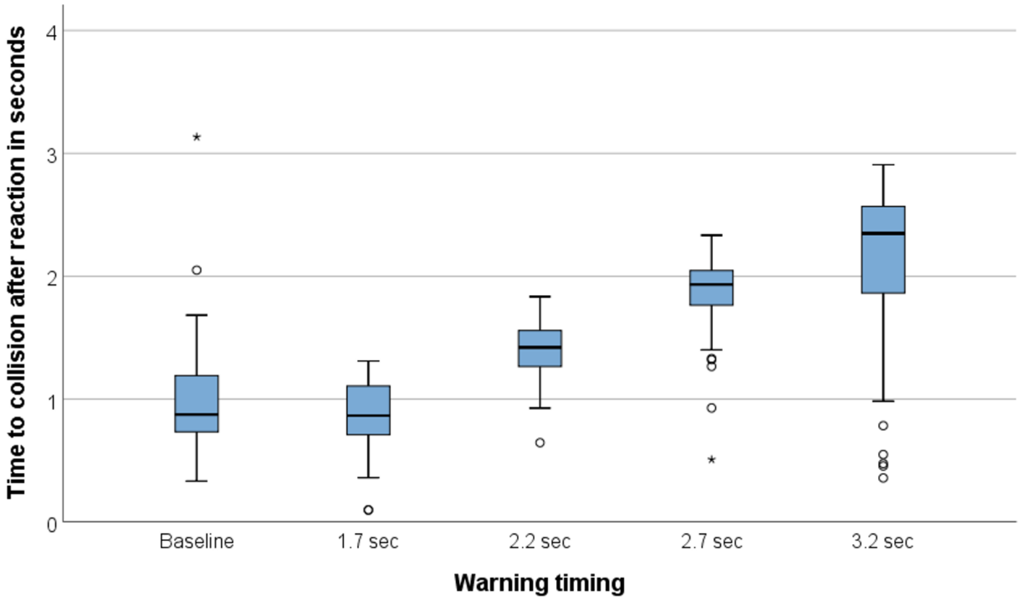

Figure 12: Boxplot of the remaining time to collision after the riders' first means of deceleration as a function of warning timing.

The earlier the warning, the more time available after the reaction has occurred. Baseline reactions are statistically comparable to reactions in the 1.7 s warning condition.

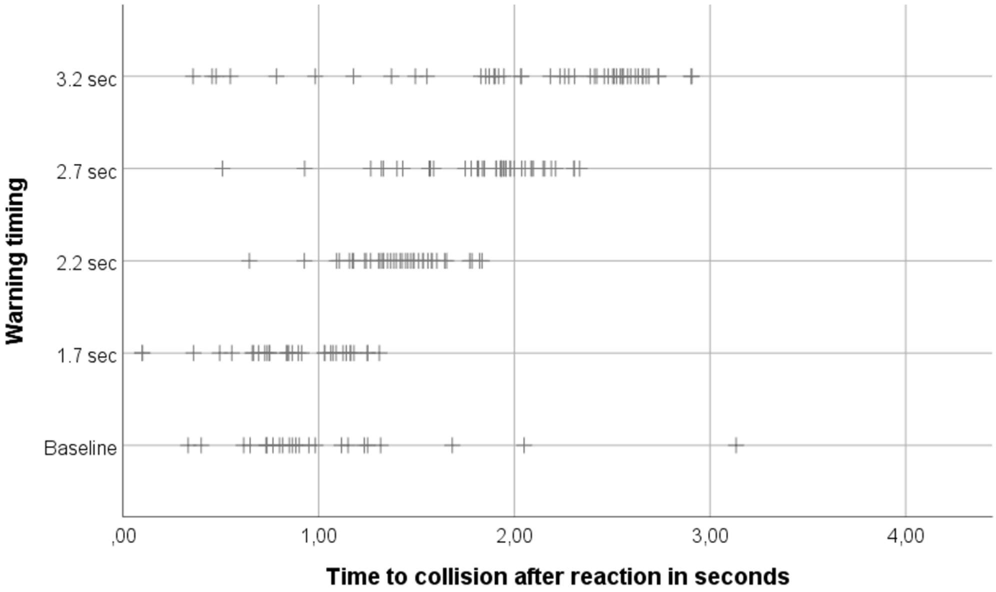

Figure 13: Remaining time to collision after the riders' first means of deceleration as a function of warning timing.

4.4 Subjective data

All riders stated that they have recognised the warning once it was issued (no missed warnings). This is an important precondition to be met before interpreting other results as response to the warnings. As indicated in the final interview, on average, the participants rated the perceptibility of the red LED warning as good to very good. The clear majority of riders described the warning concept as desirable to very desirable.

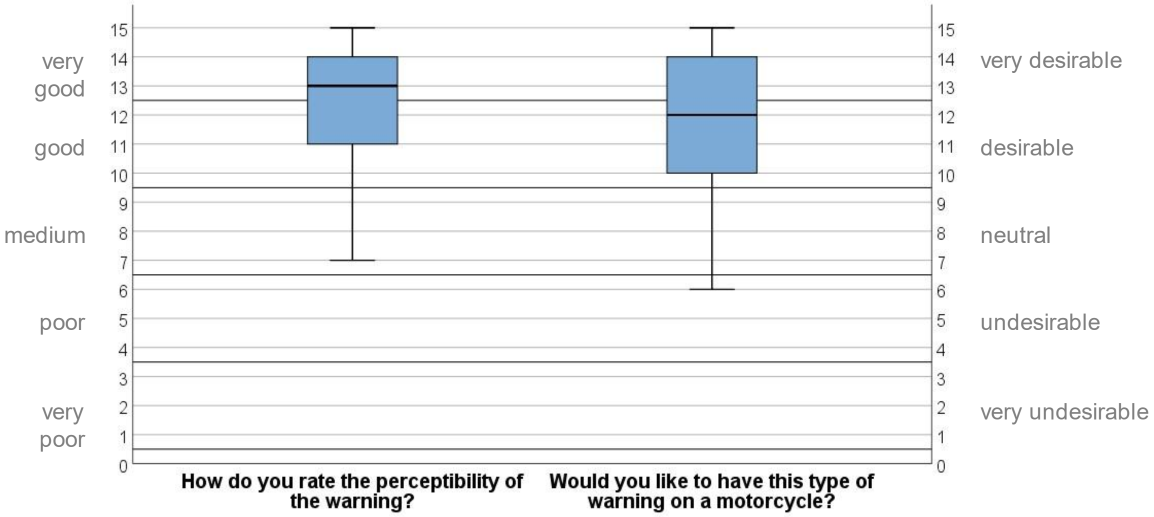

Figure 14: Rating of warning's perceptibility (left) and warning concept acceptance (right).

Once the warning was recognised, braking and avoiding the potential threat as a response to the warning are the clearly dominant strategies (Figure 15). Some people state that they first direct their attention willingly to the road ahead, while others claim to let go off the throttle. Only rarely, riders state to not react at all, even if the warning was recognised. There is no change in pattern in the type of reaction over time.

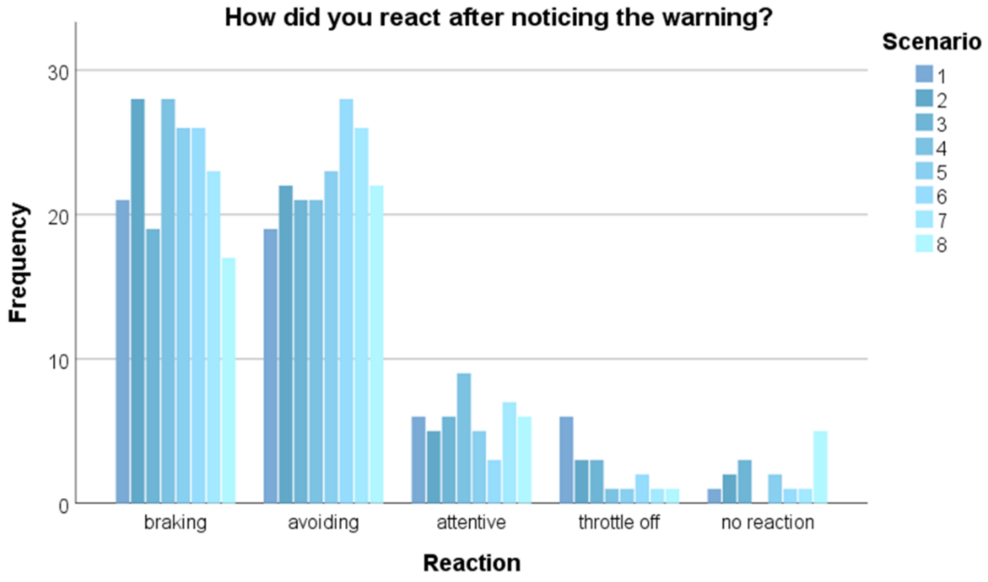

Figure 15: Claimed reactions as response to the warning for different scenarios.

Figure 16 shows the perceived situation criticality for the different test scenarios. As intended, all test scenarios created safety-critical situations ranging from uncomfortable to dangerous. Any warning timing decreased the perceived criticality compared to the baseline without warning ($F(1,25) = 38.27$, $p < .001$, $\eta_{\text{partial}} = .605$). Moreover, any warning timing earlier than 1.7 s tends to decrease the experienced situation criticality even further.

Figure 16: Situation criticality rating for baseline and different warning timings.

A repeated presentation of one specific warning timing leads to a situation perceived as less critical (first contact vs. second contact: $F(1,25) = 66.29$, $p < .001$, $\eta_{\text{partial}} = .726$). This pattern for first contact (1) and second contact (2) can be seen in Figure 17.

Figure 17: Situation criticality rating for baseline and all warning scenarios.

On average, triggering a warning in the given scenario at TTC = 1.7 s results in riders rating this warning as too late (Figure 18). Even 2.2 s and 2.7 s are on average perceived as slightly too late and only 3.2 s receives a perfect rating. However, any warning timing earlier than 1.7 s significantly improves the rating. Still, one must recognise that there is a certain spread.

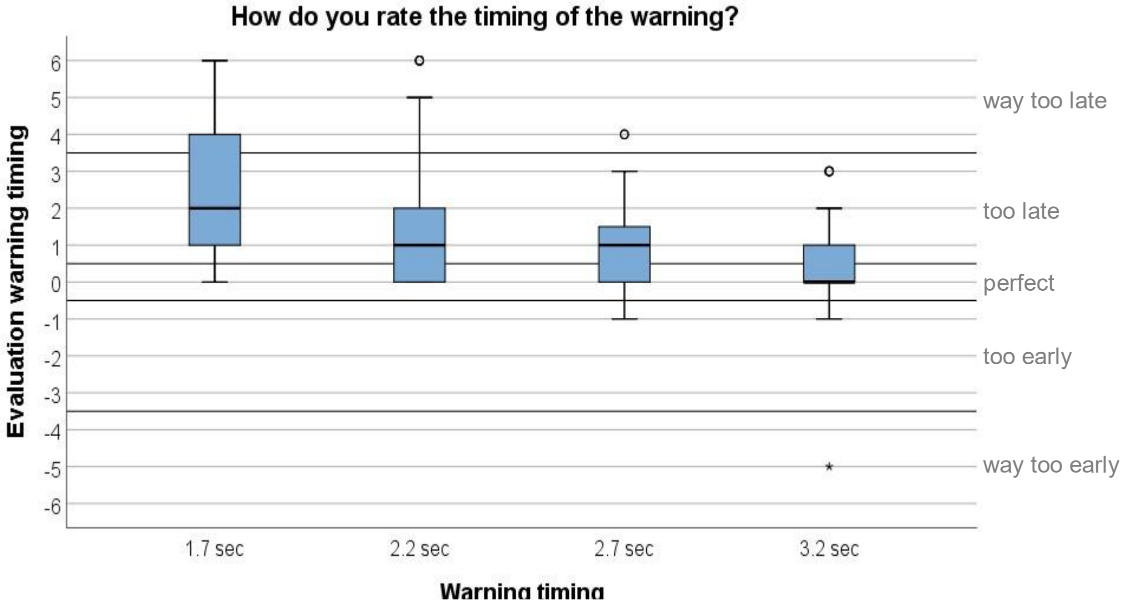

Figure 18: Rating of the different warning timings.

Once again, the second contact scenarios with the identical warning timing are perceived as being more appropriate (Figure 19). Additionally, no participant perceives any of the warnings as coming too early.

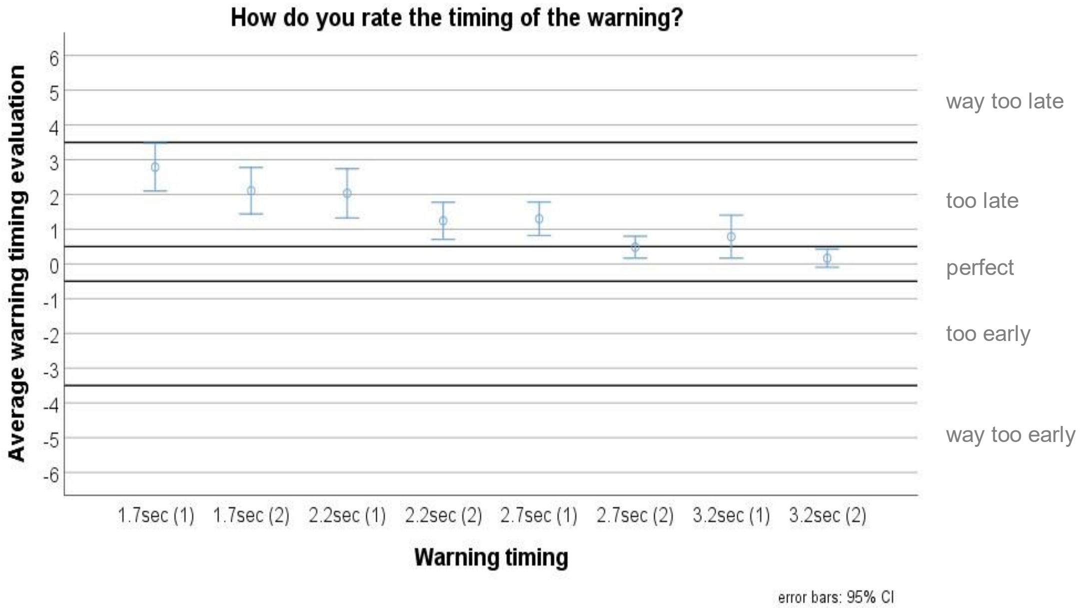

Figure 19: Rating of the different warning timings for all warning scenarios.

At the end of the study, the participants were asked if they would prefer an earlier or a later warning and what range of warning timings, they think they experienced in the study. On average, riders tend to underestimate the remaining time from warning onset to arrival at the hazardous situation (Figure 20). Moreover, the distribution of minimum times is right-skewed, indicating an underestimation by the majority of riders. The distribution of maximum times is left-skewed, showing that the majority of riders overestimate the time they actually had.

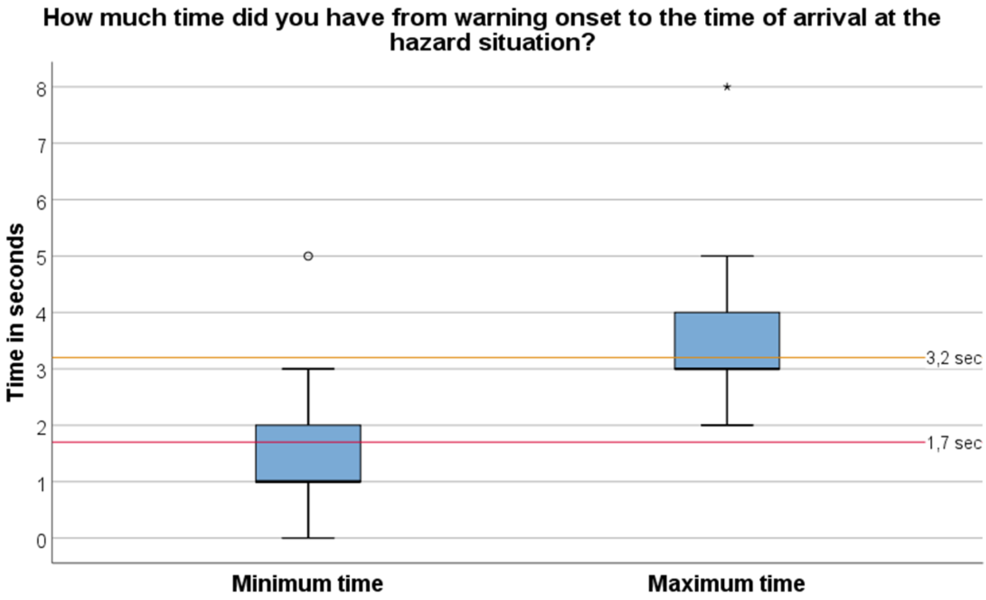

Figure 20: Estimated range of the experienced warning timings (an outlier value of 20 s for maximum time is not displayed).

In terms of personal preference, participants were fairly consistent in their preference for early warning timing (Figure 21). They accept that a warning is not immediately associated with a recognisable threat.

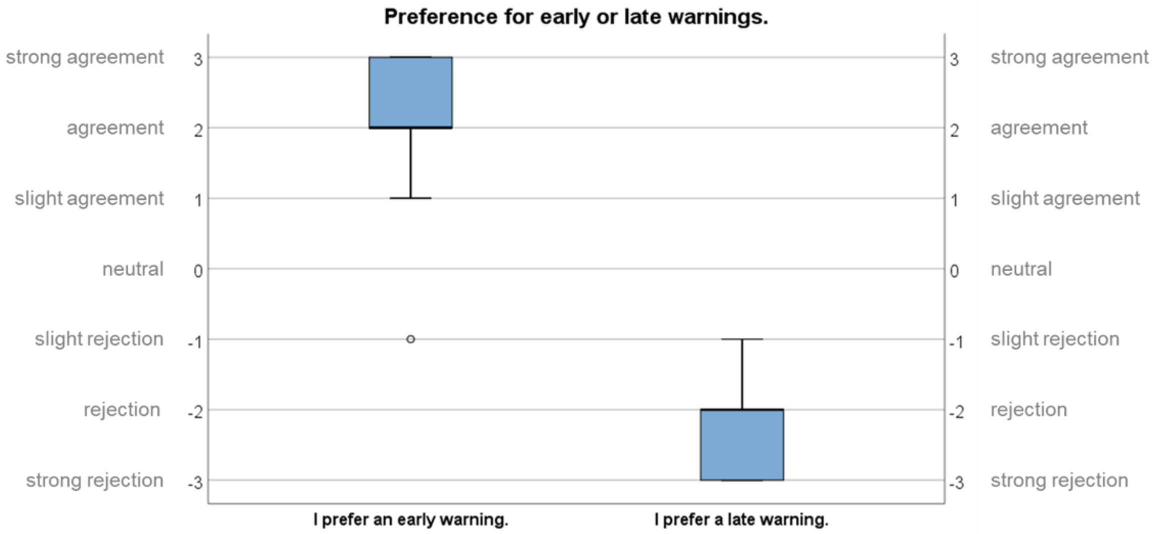

Figure 21: Preference for an early warning (left) or a late warning (right).

5 Discussion

This study investigated the effects of different levels of warning timing on rider reactions and the subjectively experienced safety benefit.

Questionnaire data

- **Riders prefer to have earlier warnings** for the given imminent crash warning scenario. They state that they accept that it might not be possible to reliably attribute the warning to an already recognisable threat.
- For the given scenario, significant safety benefits in terms of **decreased situation criticality** were measured for any of the four warning timings investigated (TTC = 1.7 s to TTC = 3.2 s).
- Yet, providing a warning with a **TTC = 3.2 s improves the acceptance even further** as it is perceived as being perfectly timed (not too early and not too late), on average.
- **Habituation** effect: once a specific warning timing has been experienced, the following scenarios with identical warning timing are perceived as less critical.
- The **effects of timing are exaggerated**. For late warnings, riders perceive to have even less time. For early warnings, riders think that they have had even more time than they actually had.

Deceleration reactions

- On average, throttle off responses were observed **700–1000 ms** after warning onset, braking responses **800–1100 ms**.
- Across different levels of warning timing, the **reaction times were comparable**.
- As a result, the **time** remaining between deceleration and potential hazard **increased with earlier warning timing**.
- Observed variations in reaction times and increasing maximum reaction times with increasing warning time may indicate some **delay between warning onset and**

warning recognition, as well as an **intentional delay**. The latter may indicate that riders are alert to the potential hazard, but wait to slow down until they recognise the need to do so.

Comparison with passenger car driver reactions

The previous CMC studies examined how reactions of PTW riders are similar to reactions of car drivers. The focus was on early advisory notifications and there was quite a difference observable. It took longer for PTW riders to react to such a notification as for car drivers. With the current simulator study and a focus on imminent crash warnings, the reactions between riders and drivers seem to be more similar. For instance, guidelines such as the ISO 15623:2013 (ISO, 2013) assume minimal driver reaction times of 0.4 s and maximum reaction times of 1.5 s before starting a response to a Forward Collision Warning. The SAE J2400 allows a maximum time of 1.18 s between warning onset and start of the drivers' response (SAE, 2003). Other passenger car simulator study results, for instance, Winkler, Kazazi, and Vollrath (2015) measured an average brake reaction time of 0.86 s with a purely visual generic warning in a HUD in a time-critical crossing scenario with a pedestrian. These values are in a comparable range to the observations in this study.

Limitations and advantages of the chosen approach

The study setup worked well. It was expected that a certain proportion of riders would slow down in the fog due to limited visibility. Yet, there were enough reactions as a response to the warning to base statistical analysis on. In reality, a major contributing factor to crashes is human error. The truly critical situations arise when riders are either visually or cognitively distracted and therefore fail to recognise a potentially critical situation in time. This is where assistance systems can show their greatest benefit. The study design aimed to simulate this visual distraction by obscuring the potential threat with a field of ground fog. Otherwise, one would measure reactions as a response to the threat instead of the warning. To avoid that riders already brake as soon as they are approaching the ground fog, dummy scenarios were included and the whole test ride was completed under adverse weather conditions. Still, some participants may already have been more attentive or riding more slowly when approaching the field of ground fog and this might lead to an overestimation of reaction times (people react faster, because they are prepared). However, given the research question at hand, the interest lies in the comparison between warning timings. A potential bias would occur across all conditions so that the relative measurements can still be interpreted.

6 Conclusion

In general, the study setup worked well as the riders experienced critical situations, recognised all warnings and chose appropriate action.

An important finding is that the type of warning has a significant impact on the rider's response in the specific scenario. Red flashing LEDs, as used in the study, clearly indicate an imminent threat and contribute to the observed stable reaction times across warning timing levels. Coding the warning criticality with the appropriate warning design (advisory vs. imminent crash, etc.) therefore becomes very important. This design choice shapes the rider's response and is related to the acceptance of the system. For example, the same LED warning concept, but with a slightly slower flash rate of 1.5 Hz, an earlier warning time of 3 seconds before the threat becomes visible, and an amber colour, was used in RRT II and conveyed a warning with an advisory notification character. This elicited mean deceleration responses of 1470 ms (urban scenario) and 2340 ms (rural scenario) instead of mean responses between 700 ms and 1000 ms in the current study. However, in the different RRT studies, riders perceived a match between the visual warning character and their required response and rated the different warnings as appropriate/desirable for the situation experienced.

Another observation was that the riders' reactions in the 1.7 s warning condition and the baseline condition without warning were comparable. The warning was given at about the same time as the potential hazard was perceived. Consequently, the 1.7 s warning did not provide any safety benefit in terms of reaction time, as the riders' focus was on the road ahead anyway. Regardless of this lack of reaction time benefit, the 1.7 s warning increased perceived safety and acceptance. Another aspect to consider is that even this late warning would still be beneficial if the riders were distracted and did not recognise the potential threat.

Riders who trusted the warning were observed actually slowing down in response to the warning. They did not just shift their attention, they actively decelerated. This gave them more time to reach the potential hazard in the three warning conditions between 2.2 s and 3.2 s. As observed before, even a late warning (in this scenario TTC = 1.7 s), given simultaneously with the visibility of the potential hazard, can be recommended because the riders felt safer, even though there was no benefit in terms of reaction times.

Important topics that remain underexplored in the PTW safety literature include how to handle false positive warnings (affecting system confidence, rider reactions, etc.), and rider reaction times in real-world riding conditions (assessing relative and absolute validity). The knowledge gained from this study will help understand riders' reactions to differently timed warnings and will allow for the design of beneficial assistance systems and more accurate rider behaviour modelling in simulations.

7 Appendix

The following subchapters summarise descriptive statistics regarding the different types of reaction times. The number of observations is always given in column ‘*N*’. This is important to notice as not every type of reaction was observed in every test trial.

7.1 Descriptive statistics: Throttle off reaction times

Theoretical baseline values cannot be calculated as there is no uniform warning onset from which to measure the reaction time. Descriptive statistics are given in ms.

Condition	**Timing**	***N***	***Mean***	***Median***	***Minimum***	***Maximum***	***Standard deviation***	***5th percentile***	***25th percentile***	***75th percentile***	***95th percentile***
Baseline	-										
Warning	1.7 s	26	744	692	350	1717	324	362	479	883	1571
	2.2 s	30	697	667	367	1350	214	403	546	817	1213
	2.7 s	36	747	675	417	1767	300	431	567	813	1639
	3.2 s	33	1019	750	450	3733	748	462	575	1017	2928

7.2 Descriptive statistics: Brake reaction times

Theoretical baseline values cannot be calculated as there is no uniform warning onset from which to measure the reaction time. Descriptive statistics are given in ms.

Condition	Timing	*N*	*Mean*	*Median*	*Minimum*	*Maximum*	*Standard deviation*	*5th percentile*	*25th percentile*	*75th percentile*	*95th percentile*
Baseline	-										
Warning	1.7 s	27	809	833	383	1783	305	417	583	967	1617
	2.2 s	34	824	792	417	1650	258	417	642	979	1300
	2.7 s	38	920	842	433	2150	374	449	696	1033	1979
	3.2 s	44	1141	858	333	3400	725	371	633	1417	3158

7.3 Descriptive statistics: remaining TTC after reaction

The calculations are based on the first type of reaction no matter whether this is throttle-off or brake onset. Descriptive statistics are given in ms.

Condition	Timing	*N*	*Mean*	*Median*	*Minimum*	*Maximum*	*Standard deviation*	*5th percentile*	*25th percentile*	*75th percentile*	*95th percentile*
Baseline	-	24	1040	875	333	3133	583	350	733	1213	2863
Warning	1.7 s	31	860	866	97	1310	313	99	694	1125	1275
	2.2 s	38	1405	1421	646	1835	245	913	1260	1563	1824
	2.7 s	44	1833	1933	509	2334	361	1013	1757	2050	2306
	3.2 s	48	2084	2348	358	2907	693	465	1859	2574	2828

Abbreviations

ARAS	Advanced Rider Assistance Systems
bdp	German Association of Psychologists
CMC	Connected Motorcycle Consortium
C-ITS	Cooperative Intelligent Transport Systems
DFG	German Research Foundation
DGP	German Psychological Society
HMI	Human-Machine Interface
IQR	Inter-quartile range
ITS	Intelligent Transport Systems
OEM	Original Equipment Manufacturer
PTW	Powered Two-Wheeler
TFT	Thin-film transistor (display)
TTC	Time-to-collision
V2X	Vehicle-to-X
WIVW	Wuerzburg Institute for Traffic Sciences

References

ISO. (2013). ISO 15623:2013 - Intelligent transport systems — Forward vehicle collision warning systems — Performance requirements and test procedures. Geneva: ISO.

ISO. (2021a). ISO 2575:2021 Road vehicles - Symbols for controls, indicators and tell-tales. Geneva: ISO.

ISO. (2021b). ISO 6727:2021 - Road vehicles - Motorcycles and mopeds - Symbols for controls, indicators and tell-tales. Geneva: ISO.

Neukum, A., Lübbeke, T., Krüger, H.-P., Mayser, C., & Steinle, J. (2008). *ACC-Stop&Go: Fahrerverhalten an funktionalen Systemgrenzen.* Paper presented at the 5. Workshop Fahrerassistenzsysteme - FAS2008, Karlsruhe.

SAE. (2003). J2400_200308 - Human Factors in Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements.

Winkler, S., Kazazi, J., & Vollrath, M. (2015). *Distractive or Supportive - How Warnings in the Head-up Display Affect Drivers' Gaze and Driving Behavior.* Paper presented at the 2015 IEEE 18th International Conference on Intelligent Transportation Systems.