Driving with a multi stage warning system in the head-up display – How do drivers react upon it?

Susann Winkler, Juela Kazazi, & Mark Vollrath
Technische Universität Braunschweig, Germany

Abstract

Driver warnings are a good way to reduce accidents in urban areas as they support drivers in complex and critical situations. This was shown in a previous driving simulator study of the research project UR:BAN. Some critical situations might demand emergency braking, others might require mere attention re-allocation or moderate braking. Thus, a multi stage warning system (warning and acute warning) for the head-up display was developed inducing different driver reactions depending on the situation’s criticality and intervention requirements. A driving simulator study (N = 24 drivers; including eight urban scenarios) was conducted, in order to examine whether drivers understood this multi stage warning system and to what extent learning was required. The test included a first drive without any warning support, a learning phase and an end phase with previously unknown scenarios. The data show that the warning system is intuitively understood by the drivers, without learning being noticeably required and drivers differentiating well between the two warning stages.

Introduction

Assisting drivers in urban areas and their safety-critical situations (e.g., with collision warning systems) is a good way to promote safe driving. This is one of the aims of the research project UR:BAN (Manstetten et al., 2013; www.urban-online.org), from which the present study arose. Most accidents still occur in urban areas as compared to other road types. For example, they amounted up to 73.3% of all accidents on German roads in 2013 (Statistisches Bundesamt, 2014). The safety-critical situations, which one experiences in urban areas, are not only challenging for drivers, but also for assistance system developers. They show very diverse characteristics, such as concerning their location (e.g., at an intersection, on a straight or curved road), the type of critical objects involved in them (e.g., pedestrians, bicyclists, obstacles) and their behaviour (e.g., static or dynamic, accelerating or decelerating) as well as their criticality (low to high). Assistance systems have to gather and evaluate the respective information correctly as fast as possible in order to supply the drivers with the needed support (Gläser et al., 2014; Heimes & Nagel, 2002; Herrmann & Schroven, 2012). Depending on the safety-critical situations, the reactions required by the drivers to avoid a possible collision...
also differ (Schmidt et al., 2009; Khanafer et al., 2009), especially as the reaction intensity needed increases with the decrease of time-to-collision (TTC) (Dingus et al., 1998; Najm et al., 1994).

Assistance systems for collision avoidance, as focussed here, can be staged on a continuum with different urgency levels (Dingus et al., 1998) allowing drivers to optimally adapt their behaviour according to the respective requirements of critical urban situations. Such collision warning systems might start at a very early purely informative level, but become gradually intrusive with drivers further approaching the safety-critical situation, in order to activate them more and more strongly (Campbell et al., 2007; Naujoks & Neukum, 2014; Zarife, 2014). Finally, right before the imminent collision an acute warning or eventually an automatic vehicle intervention like an automatic emergency brake might be triggered (General Motors Corporation & Delphi-Delco Electronic Systems, 2002). On this described continuum many further warning stages are possible, from advising drivers to raise their attention and allocate it properly (information and prewarning) to demanding them to decelerate, start braking moderately (warning) and eventually to eliciting an emergency brake (acute warning) (see also Diederichs et al., 2010; Petermann-Stock & Rhede, 2013; Werneke et al., 2014; Winkler et al., 2016). However, in a given situation and depending on the reactions of the drivers, not all warning stages have to become active. Thus, the output of the collision warning system would be adapted accordingly, in order to support drivers optimally.

With such a warning system and especially by help of the earlier warning stages in the described continuum (e.g., prewarning or warning), drivers might already be able to prepare for upcoming safety-critical situations before they become highly critical, if they can be detected far in advance (for example by means of car2X communication, see also Engel et al., 2013; Nöcker et al., 2000; Röglinger & Facchi, 2009; Weiß, 2011). As soon as drivers adapt their driving behaviour appropriately, for example by releasing the accelerator pedal or even braking moderately, later warning stages like an acute warning can be avoided, which usually succeed earlier ones. However, a situation might also be very time critical and hard to detect for the system, so that a late warning (acute warning) might have to be given directly, in order to enable drivers to react very fast and strong, for example with an emergency brake. Therefore, a multi stage warning system, which supports drivers integratively and adaptively to the situation’s criticality and intervention need, seems optimal for drivers (Jones & Hansman, 2007; Naujoks & Neukum, 2014; Zarife, 2014), especially in urban areas.

According to these ideas and based upon the results of previous studies (Kazazi et al., 2015; Winkler et al., 2015), a multi stage warning system (for urban areas) was examined in this study with the focus on the two warning stages warning and acute warning. In less critical situations, like a lead vehicle braking in front of the ego vehicle keeping a safe distance, it triggers a first warning stage (warning), rather appealing to the drivers’ attention and readiness to brake if need be. Whereas, in highly critical situations or such with increasing criticality, a more forceful driver reaction is demanded, activating drivers strongly and quickly (second warning stage: acute warning). A head-up display (HUD) projects both warning stages into the
windshield as displaying sequential warning stages integratively in one display improves drivers’ response time onto warning presentations (Singer et al., 2014). The HUD as a location for warning presentation additionally allows drivers to perceive them right in their field of view without taking their eyes off the road (Ablaßmeier et al., 2007) and thus saves time for drivers to react upon them (Watanabe et al., 1999). Aim of the multi stage warning system is to trigger strong and fast brake reactions in drivers in order to avoid collisions or reduce collision severity. Therefore, a stop sign is presented in the HUD accompanied by an additional acoustic warning signal as an acute warning (second warning stage), when an upcoming situation demands it due to its increased criticality. However, preferably the system warns drivers sufficiently in advance so that the situation can be resolved by a moderate driver reaction, as elicited by a caution sign displayed in the HUD as a warning (first warning stage). Whether drivers intuitively understand such a multi stage warning system (even when experiencing it for the first time) or to what extent it has to be learned by drivers in order to trigger an appropriate reaction, still has to be investigated yet. Furthermore, it is still unclear how (well) drivers actually react upon both warning stages and can differentiate between them. Thus, these questions are examined in the presented study.

Summing up, this driving simulator study evaluates a multi stage warning system for urban areas based upon drivers’ behaviour in eight different safety-critical situations. Half of these safety-critical situations are analysed in detail for this paper, while the other half will be reported in a further paper. Firstly, possible learning effects through driving with the multi stage warning system in four repeated safety critical situations with different criticalities are investigated. The question is whether the frequent experience of the multi stage warning system in various critical situations might influence the driver reactions over time (e.g. faster brake reactions when the same situation is experienced again). Secondly, the differentiation between the two warning stages (first stage: warning, second stage: acute warning) is. As the first warning stage is presented quite early in a less critical situation, a more relaxed driver reaction is expected compared to the second warning stage, which would be presented in a more critical situation or if the former less critical situation becomes more critical. Thus, the driving behaviour (e.g., brake reaction time, time to maximum braking and maximum braking value) should differ between both warning stages.

Method

Multi stage warning system

Drivers were supported by a multi stage warning system, consisting of two warning stages (warning and acute warning). For its visualization a multicolour HUD was used. In form of traffic signs measuring maximum 15x15 cm (4° visual angle), both warning stages were projected driver-centered into the windshield right above the engine hood overlapping with the simulated driving scenery. For the first warning stage (“Warning the driver”), a caution sign was displayed in the HUD, when the time-to-collision (TTC, time left until the ego vehicle would collide with the safety-critical object, if the speed difference stays the same; Hayward, 1972) between the ego vehicle and the safety-critical object went below 8 s, but stayed above 2 s (see
Table 1). If the drivers did not react sufficiently or the situation was already that critical so that the TTC went below 2 s, a second warning stage (“Eliciting a last driver reaction”) was triggered. As can be seen in Table 1, in the second warning stage a sign was displayed in the HUD accompanied by an additional acoustic warning signal. The acute warning lasted until the ego vehicle crossed the virtual crossing point of the safety-critical object or collided with it.

Table 1. Implemented multi stage warning system with the two warning stages: warning ($W_1$; solely visual) and acute warning ($W_2$; visual and acoustic) including their timing based on the time-to-collision (TTC, Hayward, 1972) of the ego vehicle and the safety-critical object.

<table>
<thead>
<tr>
<th>Warning stage</th>
<th>Visual</th>
<th>Acoustic</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning ($W_1$)</td>
<td>-</td>
<td>-</td>
<td>2 s &lt; 8 s</td>
</tr>
<tr>
<td>Acute warning ($W_2$)</td>
<td></td>
<td>1 kHz (“Beep”)</td>
<td>&lt; 2 s</td>
</tr>
</tbody>
</table>

Driving simulator and implemented scenarios

For the study the fixed base medium fidelity driving simulator of the Technische Universität Braunschweig was used. Its seat box is equipped with typical car interiors like a steering wheel with force feedback, accelerator and brake pedals as well as three LCD screens with 1400x1050 px resolution serving as rear-view mirrors (left, middle and right). Moreover, four cameras are installed at the seat box, covering the drivers’ face, feet (for pedal operation), the scenery and a time stamp running with the scenery to synchronise the video with the driving data. The virtual urban scenery is projected onto three silver screens (left, ahead, right), providing the drivers with a 180° field of view at about 2.1 m distance from the driver’s seat. The driving simulation is created by the SILAB 4.0 software (from WIVW, Krüger et al., 2005; see www.wivw.de) and accompanied by an acoustic simulation of traffic sounds like wind and engine noises for a rather realistic impression of sitting in a real car.

An urban area with a speed limit of 50 km/h served as the test track. Drivers went straight unless a voice output and an arrow near the speedometer told them to turn. The four scenarios analysed are a subset of in sum eight examined scenarios with various criticality, which will be reported in a further paper. As described in Table 2, this paper comprises three less critical scenarios ($S_3W_1$, $S_4W_1$ and $S_5W_1$) with a bicyclist, a lead vehicle and an obstacle as safety critical objects and one quite critical scenario with a crossing bicyclist ($S_6W_2$). As the critical scenarios demanded drivers to react immediately with an emergency brake, a direct acute warning ($W_2$) was presented (see Table 1). In the less critical scenarios, drivers were solely required to decelerate moderately. Therefore the warning ($W_1$) was used. If the drivers did not react accordingly, eventually the acute warning followed.
driving with a multi stage warning system

Table 2. Depiction of the four examined scenarios and (first triggered) warning stages: \( S_3 W_1 \) Bicyclist, \( S_4 W_1 \) Lead vehicle and \( S_5 W_1 \) Obstacle (requiring a first stage warning – warning) as well as \( S_6 W_2 \) Bicyclist (demanding a direct second stage warning – acute warning).

<table>
<thead>
<tr>
<th>Scenario and warning stage</th>
<th>Picture</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_3 W_1 ) Bicyclist</td>
<td><img src="image" alt="Picture" /></td>
<td>When turning right at a t-junction with oncoming traffic a bicyclist hidden by parking vehicles crosses the ego vehicle’s path from left to right</td>
</tr>
<tr>
<td>( S_4 W_1 ) Lead vehicle</td>
<td><img src="image" alt="Picture" /></td>
<td>When following a lead vehicle decelerating onto 8.5 m/s and indicating a right turn, it stops suddenly at the intersection for a bicyclist crossing from left to right</td>
</tr>
<tr>
<td>( S_5 W_1 ) Obstacle</td>
<td><img src="image" alt="Picture" /></td>
<td>When driving straight ahead, a hay bale blocking the ego vehicle’s path suddenly becomes visible after being hidden from drivers’ sight by a curve</td>
</tr>
<tr>
<td>( S_6 W_2 ) Bicyclist</td>
<td><img src="image" alt="Picture" /></td>
<td>When turning left at an intersection with oncoming traffic, a bicyclist (activated by the ego vehicle crossing the centre line) crosses the ego vehicle’s path from left to right (contrary to in Germany allowed direction)</td>
</tr>
</tbody>
</table>

Experimental design and dependent variables

Drivers went through four learning phases (L, see Table 3), in order to be familiarised with the warning system. As can be seen in Table 3, in the first three learning phases (L1-L3) they were confronted with a repetition of scenarios in randomised order (within-subjects design), whereas the last learning phase (L4) comprised two new scenarios (one quite critical and one less critical scenario), onto which the learned knowledge was to be applied. Furthermore, L1 was directly attached to the training drive, comprising a quite critical and a less critical scenario, and in contrast to all following learning phases, drivers were not supported by the warning system in L1. In sum, every driver encountered sixteen safety-critical situations (two in L1, six each in L2 and L3, two new scenarios in L4). The scenarios experienced in L1 and L4 were interchanged between the drivers, leading to two groups of drivers (see Table 3), while the order of the scenarios within each learning phase was randomised.
Table 3. Organisation of the eight scenarios (S1–S8) over the four learning phases (L1–L4), being randomised within each learning phase, with the three specific warning system support forms (without – W0; warning – W1; acute warning – W2) and the two groups of drivers A and B, with the four scenarios analysed for this paper in bold (S3–S6).

<table>
<thead>
<tr>
<th>Group</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>S1W0, S2W0</td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
</tr>
<tr>
<td></td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
</tr>
<tr>
<td>B</td>
<td>S1W0, S2W0</td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
</tr>
<tr>
<td></td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
<td>S1W1, S2W1</td>
</tr>
</tbody>
</table>

In order to see how drivers react upon the multi stage warning system, the driving behaviour in each scenario was recorded. Table 4 describes the three driving parameters analysed in detail.

Table 4. Analysed driving behaviour variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Description of variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brake reaction time</td>
<td>s</td>
<td>Time from onset of the warning/acute warning until the pressing of the brake pedal</td>
</tr>
<tr>
<td>Time to maximum braking</td>
<td>s</td>
<td>Time from onset of the warning/acute warning until the maximum braking value is reached</td>
</tr>
<tr>
<td>Maximum braking value</td>
<td>%</td>
<td>Maximum pressing of the brake pedal after onset of the warning/acute warning until its offset in percent of the sample maximum</td>
</tr>
</tbody>
</table>

Participants

A total of twenty-four drivers were tested in a mixed design (13 female, 11 male; M = 26.8 years, SD = 8.2 years). The average driving experience was 9.2 years (SD = 8.5 years) and the annual mileage was mainly less than 3000 km. All participants had normal or corrected-to-normal visual acuity. Simulator training was required for participation in order to avoid simulation sickness. Drivers were compensated with 10 € for a successful participation or received course credits (if students at the Technische Universität Braunschweig).

Procedure

After being welcomed, the drivers received a written instruction about the objectives and the procedure of the experiment, signed a consent form and filled out a demographic questionnaire. Then the drivers received a 15 min training to get accustomed with the driving simulator. When the training was successfully completed, drivers were instructed about the multi stage warning system and evaluated it (system acceptance) a priori based on their expectations. The following test drive took about 15 min. Afterwards drivers filled out two post-hoc questionnaires (system acceptance and subjective ratings). Subsequently, an
interview about the warning system finished the experiment. Finally, drivers were thanked for their participation and compensated.

Data analysis

For data analysis IBM SPSS Statistics 21 was used. This paper analysed the four scenarios, which all 24 drivers experienced twice in learning phase L2 and L3. The results of the driving behaviour with the two warning stages are presented. The driver reactions upon the warning system in L2 and L3 were compared by paired t-tests (or Wilcoxon signed-rank tests if normality was not given) in order to look for learning effects over time. Furthermore, the driver behaviour was examined, in order to analyse how well drivers differentiate between the two warning stages. Concerning the warning stage differentiation, paired t-tests (or Wilcoxon signed-rank tests if normality was not given) compared the scenarios S₃W₁ and S₆W₁ with a warning to scenario S₆W₂ with a direct acute warning for L3. Learning phase L3 was considered here, as drivers by then experienced the warning system multiple times, so it supposedly had been learned sufficiently if needed.

The number of participants in the groups was reduced (see Table 5 in the results section), as drivers had to be excluded from statistical analyses and categorized as nonreacters, if they initiated a brake reaction before the onset of the warning system (including brake reaction times under 0.2 s), did not brake at all or were extreme outliers. For significant results, \( r \) is given as an estimate of the effect size. A significance level of \( p \leq 0.05 \), corrected by Bonferroni due to multiple tests, was adopted for all statistical tests. As only a few accidents occurred in the four scenarios considered, the number of collisions is not further regarded here (S₃W₁-L2: N = 1; S₄W₁-L3: N = 1; S₆W₁-L2: N = 6, L3: N = 2). The other scenarios, learning phases, and the subjective data will be reported in another paper.

Results

Learning to drive with the multi stage warning system

Table 5 shows the number of drivers who reacted to the warning, the acute warning or to neither of the warning stages (e.g., they started braking before the warning system onset) in the learning phases L2 and L3 for all four examined scenarios. In scenario S₃W₁, almost half of all drivers reacted consistently onto the warning in both learning phases. Yet, from the five drivers reacting to the acute warning in L2 none reacted upon it in L3 anymore, but rather shifted to reacting upon the warning (N = 3) or even beforehand (N = 1; see Table 5). This might indicate some learning effects. Similarly, in S₄W₁ half of the ten drivers, who had reacted to the acute warning in L2, already reacted to the warning in L3 and one even earlier. However, in general this scenario is rather diverse concerning the according driver reactions. As Table 5 further shows, for scenario S₆W₁ consistently most drivers reacted to the warning in both learning phases (N = 21), without anyone receiving an acute warning. In scenario S₆W₂ sixteen out of almost all drivers initiating a brake reaction upon the acute warning in L2, also did so in L3 (see Table 5). However, another seven drivers avoided an acute warning in L3, which again might indicate some learning effects. Overall, the difficulty of the three scenarios with a warning
seems to be slightly different. Especially in scenario $S_4$, it is difficult to compare the driving behaviour from $L_2$ to $L_3$, as for example only three drivers showed a break reaction upon the warning in both learning phases, which is why this scenario $S_4$ is not further regarded for the following statistical within comparisons.

Table 5. Number of drivers showing brake reactions onto the two warning stages (warning and acute warning) and excluded drivers ($\dagger$) over the two learning phases ($L_2$ and $L_3$).

<table>
<thead>
<tr>
<th>Learning phase</th>
<th>$S_1W_1$</th>
<th>$S_4W_1$</th>
<th>$S_5W_1$</th>
<th>$S_6W_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2 Warning</td>
<td>11 0 4 3</td>
<td>3 1 4 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2 Acute warning</td>
<td>3 0 2 5</td>
<td>4 1 1 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3 Warning</td>
<td>11 0 4 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3 Acute warning</td>
<td>3 0 2 5</td>
<td>4 1 1 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Drivers excluded due to inappropriate reactions (see above).

Regarding the driver behaviour over the learning phases $L_2$ and $L_3$ with the warning in scenario $S_1W_1$ there were no significant learning effects (see Fig. 1; brake reaction time: $t(10) = 1.31$, $p = .220$; time to maximum braking: $t(10) = 1.04$, $p = .321$; maximum braking value: $t(10) = -0.32$, $p = .758$). The same holds true for scenario $S_5W_1$ (brake reaction time: $t(20) = -0.40$, $p = .694$; time to maximum braking: $z = -1.23$, $p = .217$; maximum braking value: $t(20) = 0.03$, $p = .978$). Similarly for the acute warning, no significant learning effects could be found in scenario $S_6W_2$ (brake reaction time: $t(15) = 1.89$, $p = .078$; time to maximum braking: $t(15) = 0.33$, $p = .743$; maximum braking value: $t(15) = 2.01$, $p = .063$; see Fig. 1).

![Figure 4](image)

Figure 4. Mean brake reaction time, mean time to maximum braking and mean maximum braking value within scenario $S_1W_1$, $S_5W_1$ and $S_6W_2$ over the learning phases $L_2$ and $L_3$, displaying the number of participants ($N$) included at the bottom.
Differentiation between warning and acute warning

When comparing the two scenarios with a warning, \( S_3 W_1 \) and \( S_5 W_1 \), to scenario \( S_6 W_2 \) with an acute warning in learning phase L3, all three driving parameters differed significantly between the two warning stages in both within-subjects comparisons, \( S_3 W_1 \) vs. \( S_6 W_2 \) (brake reaction time: \( t(13) = 5.90, p < .001, r = .85 \); time to maximum braking: \( t(13) = 3.54, p = .004, r = .70 \); maximum braking value: \( t(13) = -4.68, p < .001, r = .79 \)) and \( S_5 W_1 \) vs. \( S_6 W_2 \) (brake reaction time: \( z = -3.52, p < .001, r = -.88 \); time to maximum braking: \( t(15) = -2.75, p = .015, r = .58 \); maximum braking value: \( t(15) = -5.16, p < .001, r = .80, \) see Fig. 2). As can be seen in Figure 2, in general the brake reactions were substantially faster and stronger with the acute warning and the time to maximum braking was also shorter for the acute warning compared to the warning.

![Brake process: warning S3W1 and S5W1, acute warning S6W2](image)

**Figure 5.** Mean brake reaction time, mean time to maximum braking and mean maximum braking value with the warning in scenario \( S_3 W_1 \) and \( S_5 W_1 \) and the acute warning in scenario \( S_6 W_2 \) for learning phase L3, displaying the number of participants \( N \) included at the bottom.

Discussion

This paper presents a driving simulator study on how drivers react upon a multi stage warning system (comprising two warning stages: warning and acute warning presented in the HUD) for collision avoidance in urban areas. The main question was whether drivers understood the difference between the two warning stages and if they profited from increasing experience with the warning system in different critical situations.

Almost all drivers reacted adequately to both the warning and the acute warning, when experiencing different safety-critical situations for the first time, which shows they are intuitively understandable. Yet, there were still some indications of a learning effect. For example, in their first experience of two out of three scenarios with a warning some drivers only showed a brake reaction when the warning had
escalated to the *acute warning*. In their second experience, most drivers reacted already to the *warning*. Thus, it seems that some situations are harder to comprehend with drivers either learning what the different warning stages mean or adapting their driving behaviour so that the situations escalate slower, which allows them to react already to the *warning*, the first warning stage of the multi stage warning system. Similarly, somewhat de-escalating driver behaviour is found in the quite critical scenarios with a direct *acute warning*, although a significant learning effect from learning phase L2 to L3 cannot be supported statistically.

Moreover, drivers can clearly distinguish between the two warning stages, which becomes obvious in their driving behaviour. The maximum braking value in the *acute warning* is significantly greater than in the *warning*. Similarly, the brake reaction time and the time to reach the maximum braking value in the *acute warning* are significantly shorter as well. While this corresponds to the intended difference between the two warning stages, it may also be due to the situations being of clearly different criticalities. Thus, drivers might also react differently as they are aware of this difference in the situations. Probably, both factors contribute to the difference in the drivers’ reactions. However, as was shown in previous studies with these quite critical situations there is also a benefit of the *acute warning* as compared to a control group without an *acute warning* (Kazazi et al., 2015; Winkler et al., 2015). Thus, it seems the concept and aim of the *acute warning* is well understood and supports the drivers to react adequately. Moreover, the drivers also seem to understand and react appropriately to the *warning*, as they thereupon brake less but in most cases sufficiently, in order to de-escalate the situation and prevent an *acute warning*. Consequently, the proposed multi stage warning system can be recommended as drivers show the intended driving behaviour.

To further undermine the benefit of the proposed multi stage warning system, more analyses based on the data recorded in the present study will follow in another paper. For example, the other scenarios and learning phases as well as subjective ratings of the warning system should also be considered. In order to see how well drivers apply their warning experience onto new situations, comparisons of the driving behaviour of unsupported (L1) and supported driving, at the beginning of the learning phase (L2) or at the end of all learning phases (L4), would be of interest. Likewise, the multi stage warning system should be investigated with drivers experiencing more stages succeedingly or when the system is actually integrated with other assistance systems having different aims like driver comfort (e.g., lane change or constriction assistance) or ecological driving (e.g., traffic light assistance). Consequently, further research on how to integrate and prioritise different assistance systems is needed.

References


