Towards developing a head-up display warning system - How to support older drivers in urban areas?

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Abstract

Driver warning systems are essential, when pursuing safer urban areas. The complexity here is very high, which is a problem especially for older drivers as they are over-represented in urban crashes. The aim of this driving simulator study (two experimental groups and one control group with respectively 12 older drivers, aged > 65 years) was to determine what kind of head-up warnings (between-subjects factor: Stop sign warning (SW), Caution sign warning (CW)) might have the best effect on the driving performance of older drivers (compared to control group) in scenarios with different criticalities. The results show that in most scenarios, the brake reaction times in the SW group were significantly shorter compared to the CW and control group. Furthermore, the SW led to the highest maximum braking value, whereas the CW group led only to somewhat higher maximum braking values as compared to the control group. The SW warning is recommendable for critical scenarios, which demand an immediate driver reaction. In less critical situations, it might be sufficient to raise the drivers' attention, which is why the CW should be triggered. Accordingly, a two stage warning system combining both strategies (warning and acute warning) is being tested in further studies.

Introduction

In contrast to rural areas, the interaction of drivers with other road users is much more frequent in urban areas. Here the density of repeatingly crossing road users is at its maximum. In these areas, drivers have to continuously divide their attention between various objects of interest (e.g., oncoming vehicles, vulnerable road users). Overall, accident statistics indicate that more critical traffic situations, like intersections, lead to a higher death rate (Statistisches Bundesamt, 2012; Morgenroth et al., 2009). Furthermore, accidents in urban areas are relevant for older drivers (> 65 years) as they are over-represented in these crashes (McGwin & Brown, 1999; Evans, 2004). This group of drivers seems to have the greatest difficulty negotiating in highly critical situations, as indicated by their high percentage of crashes, which

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might be due to a weaker driving performance as to factors such as declines in vision, hearing, reaction time and cognitive functions (Marshall et al., 2010).

As far as in-vehicle technology is concerned, warning systems are being developed to improve safety in driving. They especially aid drivers who are at greater risk of crashes and significantly reduce the number of fatalities (Marshall et al., 2010). These systems are of great benefit in notifying the driver with regard to own lack of attention, guiding the driver's attention to critical objects and in supporting the driver to keep safe distances to cars in front (Staubach, 2009; Alm & Nilsson, 1995). The extent of changes in behaviour due to such systems is dependent on how drivers detect, understand and particularly on the design of the human–machine interface (Weller & Schlag, 2004). Unfortunately, human factors which may limit system performance have not been taken into consideration (Kantowitz, 2000; Hancock & Verwey, 1997), since system effectiveness does not only depend on the design of the system, but also on the joint performance of system and driver. Until now, most of the studies on supporting drivers with warning systems are looking for a unique function, valid for all drivers, in all possible situations, leaving the age of the driver as well as different complexities of situations disregarded. Yet, when looking at urban areas it becomes clear that not all situations are of the same criticality. Situations with suddenly crossing pedestrians are more critical than for instance a sudden braking lead vehicle, when the distance between the vehicles is large.

From this perspective, different critical situations demand drivers to either slow down or stop their vehicle to avoid a collision. For example in highly critical situations the best reaction may be an emergency braking, which might be induced by a stop sign, since this sign is coupled with coming to a stop. However, less critical situations might merely require the driver to slow down gradually, which might be achieved through a caution sign, since this sign suggests being attentive. Through this, the question arises what kind of warning type might have the best effect on driver performance in situations with different criticalities. As part of the research project UR:BAN (Manstetten et al., 2013; www.urban-online.org), the aim of this study was to first create scenarios with various difficulties in order to find out what warning types have positive effects on the driving performance of older drivers in different critical situations and second which warning type is best suited for highly critical, critical and moderately, critical scenarios.

For the current study the warning types were presented in a Head-up display (HUD) since many advantages of using a HUD for that (e. g. shorter glance duration to the HUD, drivers are not forced to taking their eyes off of the road) have been outlined by previous research (Ablassmeier et al., 2007). Traffic signs were used as warning symbols, as these are known to all drivers from driving license training and everyday traffic (Alves et al., 2013; George et al., 2012; Plavsic et al., 2009). It was expected that a stop sign warning (SW) would encourage the driver to an emergency braking action, whereas a caution sign warning (CW) would lead to slowing down.

The current study was conducted in a driving simulator including four scenarios, varied by the criticality (highly critical, critical and moderately critical) as well as the characteristics of the critical object (e.g., pedestrian, vehicle and obstacle). Variations of scenarios as well as the types of warning will be described in more detail in the method section (*Driving Scenarios and Simulation*).

Method

Participants

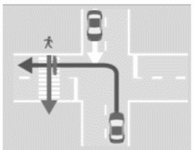
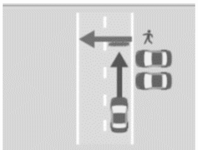
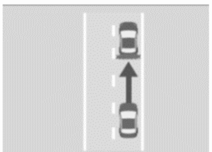
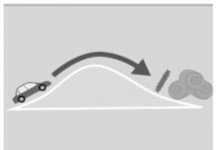
A total of 36 subjects (29 male, 7 female) were divided into two experimental conditions (SW, CW) and a control condition. Each condition consisted of 12 subjects. The mean age of participants in this study was 71.9 years (SD = 4.4 years), owning their driving license on average for 49.7 years (SD = 7.7 years) and driving about 12000 km annually. Subjects were recruited from a database of older drivers of the Technische Universität Braunschweig. Subjects were trained (on the same day as the experiment to increase compliance) in the driving simulator of the Technische Universität Braunschweig. The training contained three driving roads. In the first, the participants drove on a straight rural road, followed by an urban road, to enable participants to train acceleration and deceleration. The last urban road contained intersections where the participants had to turn left or right, in order to get familiar with this behaviour. Participants who developed simulator sickness had to be excluded from the study (n = 16 out of 52 trained participants overall). In the study, all remaining participants (n = 36) had normal or corrected-to-normal vision. Participants were compensated for their time by either choosing to receive a box of chocolates or eight Euros an hour.

Driving Scenarios and Simulation

Table 1 gives an overview of all scenarios and their criticality. In each scenario the ego vehicle, driven by the participant, travelled through a simulated urban road and had to make a turn when it was indicated by a voice output and an arrow in the speedometer. In the *Pedestrian 1* scenario, the driver had to make a left turn at an intersection. While turning, a pedestrian crossed the ego vehicle´s road. In the *Pedestrian 2* scenario as a pedestrian, who was hidden by parking cars, suddenly crossed the ego vehicles path. In the *Vehicle* scenario, a lead vehicle came to a sudden stop. In the *Obstacle* scenario, the driver was confronted with a hay bale hidden behind a hill. The different scenarios, as seen in Table 1, were created using the driving simulation software SILAB (Krüger, Grein, Kaussner & Mark, 2005; see www.wivw.de).

This study was conducted in the fixed base driving simulator of the Department of Engineering and Traffic Psychology at the Technische Universität Braunschweig. It consists of a seat box with a steering wheel with force feedback, accelerator and brake pedals and two LCD screens serving as rear-view mirrors. The virtual scenery is projected onto three screens (left, ahead, right), providing the drivers with a 180° field of view at about 2.1 m distance from the driver’s seat. Using driving simulators makes it possible to control variables in the scenery as well as to accurately measure driving performances, which are difficult to survey in the field. Furthermore, an evaluation of warning systems in critical situations cannot easily be achieved in on-road studies, since drivers might be harmed.

Table 13: Description of scenarios used in the study

Scenario	Pedestrian 1	Pedestrian 2	Vehicle	Obstacle
Picture				
Criticality	Critical scenario	Very critical scenario	Moderately critical scenario	Moderately critical scenario

Warning types

For the present study two different kinds of traffic signs were used as warning symbols. The warning was presented in a HUD, projected over the roadway, not obscuring the view of drivers. The size of the stop sign warning (SW) in the HUD was 19x17 cm; the caution sign warning (CW) was 21x19 cm. The presentation of the different warning symbols happened about 2.5 s before the critical event occurred (e.g., crossing pedestrian, braking vehicle). The duration of the warning was individual for every subject, since the onset and the offset of the warning was triggered at particular flow points. In the present study there were two experimental conditions, the SW and the CW, as well as a control condition receiving no warning at all. It was expected that these two different warning signs would lead to different driver reactions. Table 2 gives an overview of the three warning conditions.

Table 14: Warning types and warning symbols

Warning types	*Presentation in HUD*
Control (C)	No warning
Stop sign warning (SW)	
Caution sign warnings (CW)	  

Procedure

After reading and signing a consent form, the participants were instructed in written form about the procedure of the experiment. Drivers were told to drive as they normally would in their own vehicles and to obey all traffic rules (e.g., speed limits).

Next, drivers completed a training drive (lasting about 25 min) in order to get familiar with the simulator and prevent simulator sickness. The test drive began after the training drive. During the experiment the researcher was seated in a separate room, having the opportunity to communicate with the participant via a microphone. The test drive lasted about 15 minutes. Afterwards, the subjects were asked to answer two questions concerning the criticality and surprise of each scenario. Next they were debriefed about the purpose of the study, reimbursed and thanked for their participation. The overall duration of the trial was about 1.5 hours. The order of the scenarios in the test drive was not counterbalanced, since the effects of the warning types were of interest (order of scenarios: *Pedestrian 1*, *Pedestrian 2*, *Vehicle*, *Obstacle*).

Data analysis

Driving data was logged by the simulation software SILAB (Krüger et al., 2005). Participant's subjective data was logged by using a two-stage rating scale (see Table 3, 15-point rating scale, Heller, 1982). First, one of the five labelled categories (*low* to *high*) was chosen and then refined by choosing one out of three subcategories (-, 0, +), which were later transformed into numbers from 1 to 15. Table 4 gives a summary of the dependent variables (Driving and Subjective Data) measured.

Table 3. Subjective rating scales to measure the dependent variables criticality and surprise of the four scenarios (Heller, 1982).

low			rather low			moderate			rather high			high		
-	0	+	-	0	+	-	0	+	-	0	+	-	0	+

Table 4: Dependent variables regarded in this study

Variable		*Unit*	*Description*
Driving Data	Brake reaction time	s	Reaction time to pressing the brake pedal after warning was triggered
	Maximum braking value	%	The maximum braking value reached by participants
	Mean velocity at maximum braking value	km/h	Mean velocity participants had at their maximum braking value in the different groups and scenarios
Subjective Data	Criticality	1…15	"How critical was the experienced scenario?"
	Surprise	1…15	"How surprising was the experienced scenario?

For data analysis IBM SPSS Statistics 22 was used. A Kruskal-Wallis test was conducted to evaluate the subjective data, as well as an ANOVA with one within-subject factor (Type of Warning) for the driving data. A significance level of alpha $p = .05$ was adopted for all statistical tests. The error bars in the figures represent the standard deviation.

Results

Different criticalities of scenarios

In order to find out if the implemented scenarios were indeed of different criticalities (highly critical, critical, and moderately critical) a Kruskal-Wallis test was conducted to evaluate the differences among the four scenarios on median change in the subjective rating of participants surprise in each scenario. The subjective data in Figure 1 show significant differences between the four scenarios when looking at the criticality (χ^2 (3, N = 124) = 22.86, $p < 0.001$) and surprise rating (χ^2 (3, N = 122) = 16.66, $p < 0.001$). The *Pedestrian 2* scenario was rated as being a highly critical and highly surprising scenario, followed by the critical and surprising *Pedestrian 1* scenario. The obstacle and vehicle scenario were rated as being moderately critical and moderately surprising.

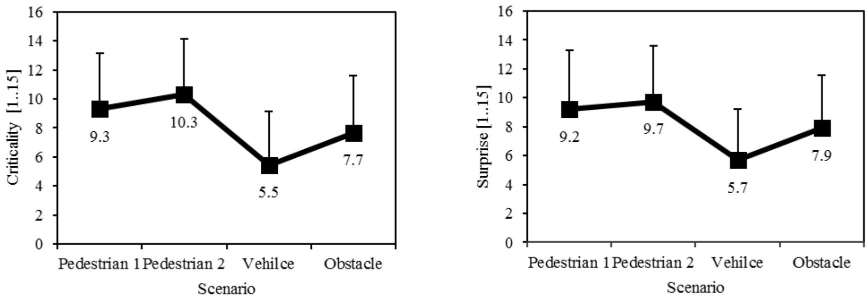


Figure 1. Subjective ratings (mean) of criticality (left) and surprise (right) in each scenario, including all participants.

Do warnings have a positive effect on brake reaction time?

The brake reaction time following the warning was recorded. It was expected that the experimental conditions (SW, CW) would have shorter brake reaction times compared to the control condition (C). For this analysis not all participants were considered. If subjects had only left the gas pedal without pressing the brake pedal, they were excluded from the examination, leading to dissimilar numbers of participants in the groups.

During the *Pedestrian 1* scenario, drivers had a very low velocity when making a left turn (M = 4.7; SD = 2.0). This influenced the brake reaction, in that drivers did not always have to press the brake pedal to avoid an accident with the pedestrian, this possibly being a reason why the brake reaction time in this scenario did not differ significantly between the three conditions (see Fig. 2 left). In the *Pedestrian 2* scenario (see Fig. 2 right) there were significant differences when considering the brake reaction time ($F_{(2,35)} = 4.06$, $p = 0.017$). Furthermore post-hoc tests showed that the control condition (C) had significantly slower brake reactions compared to the SW condition (p = 0.005). Both experimental conditions did not differ significantly in their brake reaction (p = 0.316).

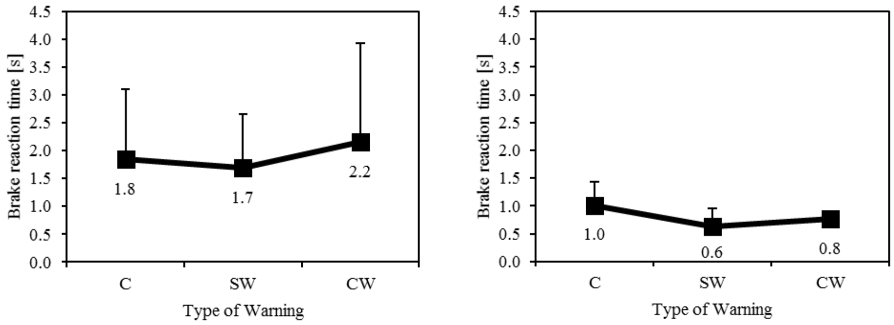


Figure 2. Mean brake reaction times in Pedestrian 1 (left) and Pedestrian 2 (right) scenario.

No overall significant differences concerning the brake reaction time were found in the *Vehicle* scenario. However, when looking at post hoc tests, there was a significant difference between the control and SW condition (p = 0.040), where the SW condition had significantly faster brake reactions compared to the control condition (see Fig. 3 left).

In the *Obstacle* scenario, there was an overall significant difference in the brake reaction time ($F_{(2,35)}$ = 6.36, p = 0.005). Post-hoc tests also showed that the control condition led to slower brake reactions compared to the SW condition (p = 0.001). Figure 3 (right) gives an overview of the brake reaction times in the *Obstacle* scenario.

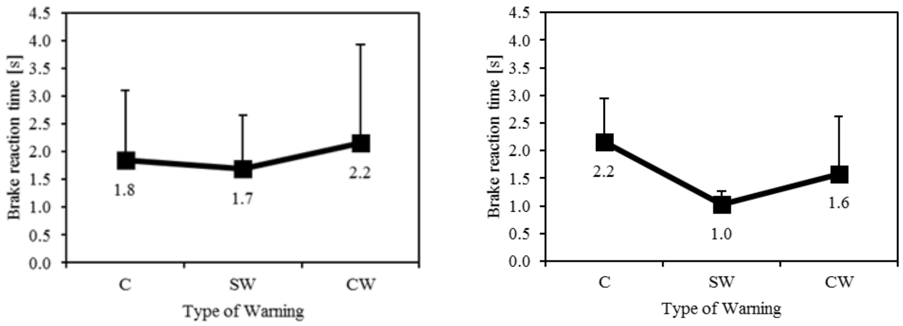


Figure 3. Mean brake reaction times in Vehicle (left) and Obstacle (right) scenario.

Do warnings have a positive effect on the maximum braking value?

After participants pressed the brake pedal, the maximum braking value reached was recorded. This variable gives information about the sturdiness (in %) of pressing the pedal.

For scenarios, *Pedestrian 1* and *Pedestrian 2* there were no significant differences between the three types of warnings. Figure 4 gives an overview of the maximum braking value in the *Pedestrian 1* (left) and *Pedestrian 2* (right) scenarios.

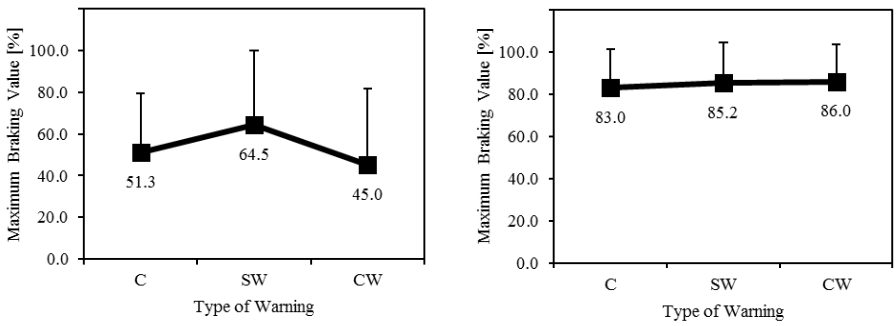


Figure 4. Mean maximum braking value in the Pedestrian 1 (left) and Pedestrian 2 (right) scenarios.

While there were no significant differences in the *Vehicle* scenario, there were significant differences in the *Obstacle* scenario ($F_{(2,35)} = 15.67$, $p < 0.001$). Post-hoc test in the *Obstacle* scenario revealed significant differences between the control and the SW condition ($p < 0.001$) as well as between the SW and the CW condition ($p < 0.001$). Figure 5 gives an overview of the maximum braking value in the *Vehicle* (left) and *Obstacle* (right) scenario. Overall, the SW condition had usually the highest maximum braking value in every scenario (except *Pedestrian 2*).

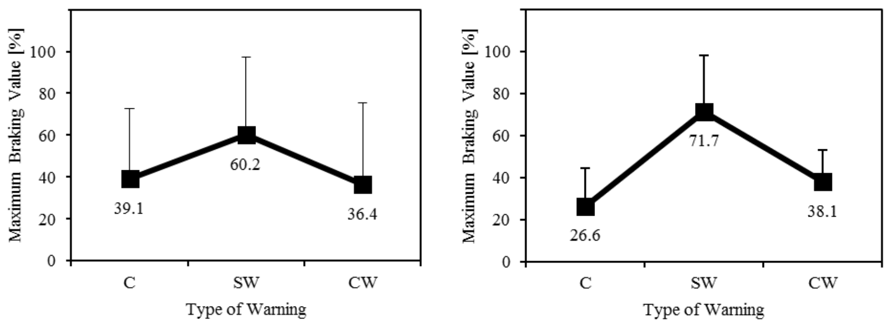


Figure 5. Mean maximum braking value in the Vehicle (left) and Obstacle (right) scenario.

Do warnings have a positive effect on the mean velocity at maximum braking value?

When participants reached their maximum braking value, also their velocity was recorded. This was done to see if participants had different velocities and if one of the experimental conditions rather led to slowing down more.

In the *Pedestrian 1*, *Pedestrian 2* as well as in the *Vehicle* scenario there were no significant differences in the velocity at the maximum braking value in the three conditions. When looking at the *Obstacle* scenario there was a significant difference in the velocity at the maximum braking value ($F_{(2,35)} = 12.94$, $p < 0.000$). As seen in Figure 6, the SW condition had a lower mean velocity at the maximum braking value compared to the control condition ($p < 0.001$), as well as compared to the CW condition ($p < 0.001$).

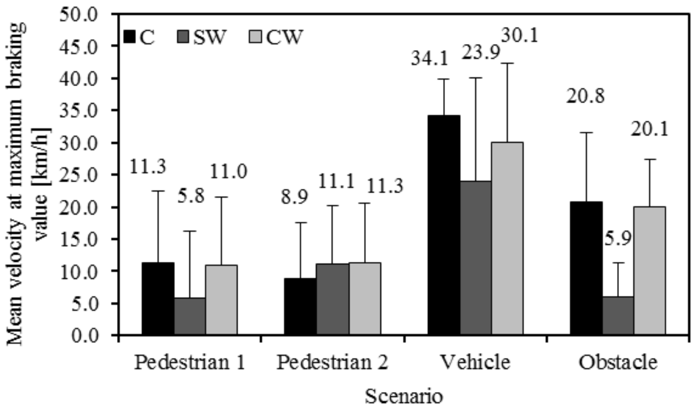


Figure 6. Mean velocity at maximum braking value in all scenarios.

Conclusions

The aim of this work was to create scenarios of different criticalities and to determine if warning systems have a positive effect on the driving performance of older drivers in urban areas.

The subjective data demonstrated that participants rated the *Pedestrian 2* and *Pedestrian 1* scenario as being (highly) critical and (highly) surprising, revealing that the four implemented scenarios were indeed of different criticalities. As of the results following the driving data, the brake reaction time in the SW condition was the fastest in every scenario, followed by the CW condition. In this study the SW condition had a positive effect on the shortening of the brake reaction time. Similar results are found when considering the maximum braking value. This variable was descriptively the highest in the SW condition, meaning that participants hit the brake pedal the strongest here compared to the CW and the control condition.

Furthermore, the SW condition led to almost always the lowest mean velocity when reaching the maximum braking value.

There are some limitations to this study that need to be mentioned. To test warning systems and their effect on accident reduction, it is important that critical situation occur. In this study though, older drivers had a very low amount of accidents. These results are in contrast to the findings from literature of an overrepresentation of older drivers in accidents. One possible explanation might be that the scenarios here were still not critical enough and need to be adjusted. Another reason might be the use of a driving simulator itself that contributes to these findings. Older drivers might have been especially cautious, as the driving simulator was new to them, leading to a compensatory behaviour, which they may not show in real traffic. In order to examine these factors closely, field studies are needed. Moreover, a selection bias might have occurred, since the old drivers volunteering for this study might be those that are in good shape and feel competent to drive. Besides, the warning in the *Pedestrian 2* scenario seems to have been triggered to late, since the results of all variables are almost the same in the three warning conditions. This scenario set up might need to be fine-tuned.

In summary, the results of the present study showed that it is important to know what behaviour a warning might trigger. In scenarios where the driver has to react immediately, the caution sign warning (CW) does not have a significant effect on the brake reaction time and maximum braking value. In such situations, the stop sign warning (SW) would be more suited. Examples of these kinds of situations are the *Pedestrian 1* and *Pedestrian 2* scenarios, in which a fast brake reaction is needed to avoid an accident. Yet, if a sudden and firm brake reaction is not needed, as in the *Vehicle* and *Obstacle* scenario, the SW warning could have negative effects (e.g., high maximum braking value). When a strong brake reaction is triggered other road users might perceive this behaviour as traffic blocking, leading to hazardous behaviours of other drivers (Dotzauer, 2013). In rather moderately critical scenarios leaving the gas pedal or slightly pressing the brake pedal might be sufficient, which might be by the CW.

The two different warning types in this study are to be used in different critical situations. Moreover, it is possible to create a warning cascade that combines these two warning types. For example, if a situation only requires the attention of the driver, the CW warning is triggered. If the driver reacts for example with a slight braking and the situation is not about to get more critical, the SW warning will not follow. Yet, if the CW warning did not raise the attention of the driver, it is possible to trigger an SW warning, so that the driver reacts immediately and a collision can be prevented. This warning cascade will be examined in future studies.

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