DEVELOPMENT OF A SAFE DRIVING GUIDANCE SYSTEM THAT TARGETS 30 KM/H ZONES

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ABSTRACT: Traffic accidents between vehicles and vulnerable road users, and the senior part of the population particularly, is a traffic safety problem that must be addressed continuously. A safe driving guidance system such as an intelligent speed adaptation system that suppress the speed to prevent and mitigate accidents is an important measure that can address this traffic safety problem. In specific, the accidents targeted in this paper are those that appear in intersections. An intelligent speed adaptation system with acoustic and graphical information that is adapted to the driver’s characteristics to increase the compliance with the guidance provided by the system is developed. The results of these experiments indicated that a speed restraining effect could be determined of the system and different human-machine-interfaces were compared. The safe driving guidance system was also optimized to driver characteristics and a target value was presented with an optimal value. Implications for system design and human-machine-interaction is discussed.

KEYWORDS: intelligent speed adaptation, 30 km/h zones, HMI, speed suppression, driver characteristics, driving simulator

1. Introduction

To avoid fatal traffic accidents and protect vulnerable road users 30 km/h zones are introduced in areas were interactions and conflicts may occur between vehicles and vulnerable road users (VRU). For instance, in Japan there are many fatal accidents were senior persons and pedestrians fall victim. The mortality rates when pedestrians and cars collide reduces significantly (to less than 10%) at speeds of 30 km/h and lower, see Fig. 1 for an illustration of a 30 km/h road in Japan. However, over speeding is still an issue and to increase the speed compliance in these areas speed suppressions, e.g. through Intelligent Speed Adaptation (ISA) are an important safety measure.

Fig. 1. Example of 30 km/h road sign and marking in Japan.

ISA systems are a kind of driver support systems that has the capability of knowing the actual speed and speed limits. This information that an ISA system possess makes various implementations possible, and these could roughly be divided into two types. First, there is the control type were the vehicle motion is restricted, e.g. so that a certain speed limit cannot be exceeded even though the accelerator is pressed. In Europe, accident savings and cost-benefit was analyzed in a research project by Carsten and Tate [1]. They estimated that such a mandatory system could save 20% of injury accidents and 37% of fatal accidents. The second type include ISA systems of the information presentation type were drivers are informed about overspeed by means of different human-machine-interfaces (HMI). The concept of ISA can even be realized through implementations outside of the vehicle in for example smart phones equipped with GPS, implying a negligible cost for the end-user as pointed out by Carsten [2] in an editorial. A European study concerning the second type of ISA reported the results of a trial in Belgium. In the report of the Belgian trials Vlassenroot et al. [3] used a system that presented information in the accelerator pedal (a resistance when exceeding the speed limit). The results showed an overall reduction in the amount of speeding, although it was noted that differences between drivers were large and that there were still a fair amount of speeding going on in low speed zones. The active accelerator pedal ISA was also studied by Hjalmdahl and Várhegyi [4] who also found positive effects of the system in terms of more positive behavior towards other road users.

Both types of ISA systems have their advantages and disadvantages, although as stated in a report by Regan et al. [5], to be effective they should be activated as drivers usually revert to their normal (speeding) behavior when the system is inactive. Besides safety effects in terms of less accidents and injuries there are also other positive effects that may be expected such as energy savings and decreased emissions as was shown by Servin, et al. [6].

In this paper, the focus is on ISA systems of information presentation type, and development of a safe driving guidance system using graphical displays. The system was developed specifically to inhibit speed in 30 km/h zones where there are many conflicts between vehicles and vulnerable road users (VRUs), e.g.
intersections. In the development driver characteristics are considered and the system should thus be able to alter the presented information to the individual driver.

The overall aim of this study is to develop a safe driving guidance system targeting 30 km/h zones. The objective of this research is to utilize a fixed base driving simulator to: (I) evaluate the effectiveness of a safe driving guidance system, and (II) to optimize the proposed human-machine-interface (HMI) concept.

2. Method

2.1. General method

The study was designed with two main parts. First, a driving simulator experiment in which the safe driving guidance system was evaluated and different graphical HMI concepts to convey information to the driver were compared. Second, based on the results of the first experiment a second driving simulator experiment was set up utilizing the most promising HMI candidate from the first experiment with the goal to optimize the HMI.

Before being conducted the study was subjected to an ethical review by Kagawa University ethics committee.

2.1.1. Driving simulator

Both experiments were set-up in a stationary driving simulator at the faculty of engineering at Kagawa University. The use of driving simulators as a tool in this kind of research was successfully evaluated by Eriksson, et al. [7] who argued that driving simulators is a valid research tool for studying the interaction between humans and driving automation, also regarding fixed based driving simulators. The point of using driving simulator in HMI research has also been made by others, see e.g. Weir [8] who provides an extensive overview of the application of driving simulators for the development of in-vehicle HMI.

The car mock-up in the simulator consisted of half of a car. The simulator was set up with three screens for front and side view. The screens were placed 2.5 meters from the driver’s seat and had a size of 100 inches each. The two side screens were placed in a 45 degrees angle to the front screen. The graphics were projected to the screens. Furthermore, an additional screen was used to present the HMI of the ISA system. See Fig 2 for an illustration of the set up including the screen with the HMI and the driver view.

2.1.2. Experimental route in the driving simulator

The experimental route that was set-up in the driving simulator resembled a typical Japanese road with a 30 km/h speed limit, including intersections. The ISA system in the simulator administered a warning consisting of a beeping sound of 3.7 [kHz] when the travelling speed was above the allowed speed limit. The system also provided a beeping sound of 1 [kHz] approximately 30 meters before approaching an intersection to evoke the attention of the driver. The elements included in the graphical information and the sound that was utilized in the HMI was based on a pre-study were the effectiveness was clarified.

2.1.3. Statistical analysis

Time ratio of overspeed [%] was measured as an indicator of driving performance. This data that was collected in the experiments was analyzed with a repeated measures ANOVA that was computed to compare the different experimental conditions. Violations of sphericity assumptions were corrected using the Greenhouse-Geisser correction method. A significance level of .05 was used in the analysis.

All statistical analyses were conducted with IBM SPSS statistics software, version 24 [9].

2.2. Experiment 1

How driving speed is presented is important to encourage drivers to suppress their speed. Presentation of overspeed based on combinations of numerical displays, bar displays, and a target value was therefore implemented in the HMI, and the inhibitory effect was then compared in the driving simulator study. Please note that all graphical interfaces that were compared shared some common features such as an icon (suggesting a desired action, i.e. to slow down) and the current speed [km/h]. Besides the shared elements they were differentiated into five different HMI implementations that formed the experimental conditions together with a baseline driving were no system was being used (See Fig. 3 for a description of the HMIs that were used).

Fig. 2. HMI screen and driver view in the Kagawa University stationary driving simulator with a three-screen set-up.
The experiment enrolled 10 male college students holding a valid driver’s license, and the average age was 22.4 years ($SD = 1.2$), in consideration of ethics and ethical requirements informed consents were obtained from all participants.

2.2.2. Procedure

First the participant drove the experimental route and were subjected to the experimental conditions in the assigned order. The speed warning was administered when approaching an intersection in all conditions (30 meters before), besides the baseline condition were no system was used and thus no warnings provided. All drivers experienced all conditions.

The simulator driving was then followed by a subjective evaluation where the HMI was rated using a Visual Analog Scale (VAS), traditionally used for rating of pain in the medical field. The VAS was used to measure the degree of necessity of the system (“not required” 0% to “it is necessary” 100%), the level of comprehension/understanding (“did not understand” 0% to “I understand” 100%), and the momentary understanding (“did not understand” 0% to “I understand” 100%). This was done to capture usability aspects of the HMI.

2.3. Experiment 2

In the second experiment, the approach with a target value was continued and to set the target value optimally the theory of achievement motivation [11] was used as a reference. The theory predicts that increasing the motivation will lead to a sustained improvement of the suppressing effect. To achieve this the percentile schedule described by Galbicka [12] was used to improve performance so that it exceeded the past results, as constant learning is to be obtained. In addition to the driver’s skill, the target value was based on past overspeed rate as a target value (c.f. the real-time target value in the first experiment). It was hypothesized to increase the desired speed suppression. It is thus expected to be an effective means for speed suppression due to achieved motivation.

In experiment 2 there were three conditions based on overspeed data of the last five minutes of driving. The first condition was 20th percentile, the second was 40th percentile, and the third condition was 60th percentile. Each condition required 15 minutes of driving in the simulator and the target value was updated every minute.

Since the design was a within-subject design the participants experienced the experimental conditions in different orders that they were randomly assigned to.

2.3.1. Participants

The second experiment enrolled 13 male college student participants holding a valid driver’s license. The average age of the participants were 22.5 years ($SD = 1.3$). In consideration of ethics and ethical requirements informed consents were obtained from all participants.

2.3.2. Procedure

In the experiment, the basis of the target value bars was changed per the driver driving characteristics. This was done to increase their motivation to suppress their speed. Set conditions, using the overspeed data of the last five minutes and the top 20th percentile, 40th percentile and 60th percentile scores were used to set the target value presented to the driver. Each condition was experienced for an approximate of 15 minutes during which the target values was updated every minute. All drivers experienced all three conditions.
The driving in the simulator was followed by a subjective evaluation including a driving style questionnaire (DSQ) and a workload sensitivity scale (WSQ) [13].

3. Results

3.1. Experiment 1

The descriptive statistics of the time ratio of overspeed [%] data indicate a difference between driving with the system or not and that condition five, were the display had percentage, bar and target value information, had the largest difference suggesting that the system leads to less overspeed. The fifth condition also seem to differ from the other four conditions in that the time ratio of overspeed was the lowest in that condition, see Table 1 and Fig. 5.

Table 1. Means and standard deviations for time ratio of overspeed [%] in the five experimental conditions.

<table>
<thead>
<tr>
<th>Experimental condition</th>
<th>M</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>35.51</td>
<td>22.21</td>
<td>10</td>
</tr>
<tr>
<td>1. Percentage</td>
<td>11.16</td>
<td>9.27</td>
<td>10</td>
</tr>
<tr>
<td>2. Bar</td>
<td>11.54</td>
<td>11.67</td>
<td>10</td>
</tr>
<tr>
<td>3. Percentage and bar.</td>
<td>11.68</td>
<td>8.16</td>
<td>10</td>
</tr>
<tr>
<td>4. Real-time</td>
<td>12.05</td>
<td>9.06</td>
<td>10</td>
</tr>
<tr>
<td>5. Percentage, bar and target value</td>
<td>5.87</td>
<td>2.87</td>
<td>10</td>
</tr>
</tbody>
</table>

Fig. 5. Mean time ratio of overspeed (±SE) in the baseline and the five experimental conditions of experiment 1.

The data was then analyzed by calculating a repeated measures ANOVA where the within-subject factor was the experimental condition constituted of the five HMI displays. However, Mauchly’s test of sphericity indicated a violation of the sphericity assumption: \( \chi^2(14) = 70.11, p < 0.001 \). Therefore, a Greenhouse-Geisser estimate of sphericity was calculated to correct the degrees of freedom: \( \eta = 0.28 \). The results of the repeated measures ANOVA revealed a significant difference between the conditions: \( F(1.39, 12.55) = 15.78, p = 0.001 \).

A post hoc testing with the Bonferroni correction revealed that all five HMI condition elicited a reduction in the time ratio of overspeed compared to driving without any system at all (\( p \)-values < 0.05). We may conclude that the ISA system had a speed suppressing effect, regardless of which of the HMI that were used. However, no significant difference could be detected between the five different HMIs (\( p \)-values > 0.05).

The results from the subjective evaluation (Fig. 6) indicate that the target value condition was rated with the highest necessity and a high level of comprehension and momentary understanding, although the real-time condition had the highest comprehension and momentary understanding scores, although also the real-time condition had good ratings.

Fig. 6. Mean scores of the subjective evaluation for the five experimental conditions.

Even though the results of the first experiment did not show any significant difference between the five different HMI concepts in terms of driving performance, an overall interpretation of the data considering also the subjective evaluation point toward the display with percentage, bar and target value as the strongest HMI candidate. Based on this we continued the development to further optimize the target value in the second experiment.

3.2. Experiment 2

The descriptive statistics indicate that the experimental condition with a higher percentile had a marginally lower time ratio of overspeed, see Table 2 and Fig. 7.

Table 2. Means and standard deviations for time ratio of overspeed [%] in the three experimental conditions.

<table>
<thead>
<tr>
<th>Experimental condition</th>
<th>M</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 20th percentile</td>
<td>22.32</td>
<td>13.33</td>
<td>13</td>
</tr>
<tr>
<td>2. 40th percentile</td>
<td>20.61</td>
<td>13.05</td>
<td>13</td>
</tr>
<tr>
<td>3. 60th percentile</td>
<td>18.44</td>
<td>11.38</td>
<td>13</td>
</tr>
</tbody>
</table>

Fig. 7. Mean time ratio of overspeed (±SE) in the three different percentiles of experiment 2.
Fig. 7. Mean time ratio of overspeed ($\pm SE$) in the three experimental conditions of experiment 2.

However, a repeated measures ANOVA did not determine any statistically significant effect in time ratio of overspeed between the three experimental conditions: $F(2, 24) = 1.07, p = 0.36$

Yet the individual differences within each condition were large, and the results of speed limit exceedance rate for each participant, as seen in Fig. 8, indicate that a 60th percentile value was effective for most drivers (i.e. for 61.54% of the drivers).

The results of DSQ and WSQ evaluation (Fig. 9) indicate that drivers who responded best to the 60-perentile condition had a tendency for passive driving, consequently the target value had to be set closer to the current driving speed for effective suppression. Drivers who preferred the 40th percentile condition tended not to feel the psychological burden from changes in the environment, and had a carefree minded personality. Thus, it is believed that a higher target value could be effective for them. There were only a few drivers who performed their best with the 20th percentile value, they tended to be confident in their driving ability. For this group, the achieved target value is difficult, therefore the achievement motivation should be raised to reach an effective speed suppression for them. See table 3 for a description and characteristics of the drivers depending on the experimental condition in which they performed best.

<table>
<thead>
<tr>
<th>Preferred experimental condition</th>
<th>Characteristics of drivers</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>1. 20th percentile</td>
<td>Optimistic thinking, confidence in driving skills</td>
<td>Preferred a high target value difficult to achieve</td>
</tr>
<tr>
<td>2. 40th percentile</td>
<td>Cheerful, low mental workload</td>
<td>Prefer achievement to a realistic target value</td>
</tr>
<tr>
<td>3. 60th percentile</td>
<td>Anxiety, safety driving minded</td>
<td>The lower the target value, the more secure feeling and more sense of accomplishment</td>
</tr>
</tbody>
</table>

Table 3. Summary of results from the subjective evaluation.

4. Discussion

This study emphasized the development of a safe driving guidance systems, i.e. an ISA system targeting 30 km/h zones. The findings showed that drivers spent less time over speeding with the implemented ISA. This was true for all five HMI implementation, however, previous research by Young et al. [14] has shown that speed reduction is mainly effecting the maximum speeds, rather
than the average speeds, indicating that lower end speeds are increasing due to compensating behavior.

It was also found that target value information was the most successful HMI implementation. The target value was then optimized based on the achievement motivation theory [11] and characteristics of individual drivers. This approach to increase the motivation among drivers to use ISA could be one mean to overcome a troublesome finding by Jamson [15], namely that drivers who would have the greatest benefit of an ISA are also less likely to use it voluntarily. These characteristics appear as a promising indicator for how the target value should be set and an important factor for how the HMI should be adapted accordingly. However, further studies are needed to draw any certain conclusion regarding driver characteristics.

From a methodological perspective, the recruitment of young participants for this study is important to discuss since young drivers are inclined to speeding as noted by Gregersen and Falkmer [16]. This implies that caution ought to be taken before generalizing these findings to a wider group of drivers. The difference between experienced and young inexperienced drivers has also been shown in the study by Young et al. [14], further showing that this aspect is important to consider understanding the effects of ISA and for the development of the systems.

4.1. Conclusion

The first objective was to evaluate the effectiveness of the system and from the results of the first experiment it was concluded that the safe driving guidance ISA system with an HMI based on graphically conveyed information and sound beeps was effective to reduce speed. Furthermore, the HMI concept combining percentage, bar, and a target value in the graphical display was considered as the most promising HMI, although not significantly different in terms of driving performance, from the other HMI variations.

The second objective was to optimize the proposed HMI and in the second experiment the HMI with target value information that was used in the first experiment was further optimized. The optimization was based on previous driving according to a percentile scheme and the conclusion was that adapting the HMI to the individual driver can be positive for speed suppression, and that the 60th percentile scheme was suitable for most participants, although there were participants that had better results with the 40th percentile, and 20th percentile settings.

4.2. Future research

A great deal of research has been carried out regarding ISA systems (e.g. [1][2][3][4][5][6][14][15][17]) and for positive effects on for example safety, fuel consumption, and emissions to be realized then HMI research is one of the keys. The safe driving guidance system presented here still needs to account for long term effects. A study by Lai et al. [17] showed that the more an ISA system is used (i.e. system exposure) the more the driver is overriding the system suggesting that potential positive effects may decline over time. Therefore, a long-term evaluation of the developed concept is needed to see if this system that is more adapted to individual drivers has more success in the long term.

Since there were individual differences in terms of which percentile setting that was used in the second experiment and this could be connected to DSQ and WSQ, a next step is to do a larger study with more participant to further study this link that could be a further means to adapt the HMI to individual drivers.

This paper clarified and validated the effectiveness of ISA using a fixed based driving simulator, and we are currently working on a pilot study to validate the effectiveness of the ISA system in a real environment using a Mazda Axcela (in other markets also known as Mazda 3) as a test vehicle. Preliminary results are similar to those found in this study using driving simulator, indicating the validity of the Kagawa University driving simulator. It is our future study to validate the effectiveness with a larger number of test subjects in real world conditions.

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References

(13) M. Ishibashi: Driving style, operation load sensitivity check sheet development for the driver's characterization, Society of Automotive Engineers of Japan, 55(02), 9-12, 2002.