Investigating the Effects of an Advance Warning In-Vehicle System on Behavior and Attention in Controlled Driving

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ABSTRACT
Advance warning systems constitute a class of in-vehicle systems that could influence and improve driving in the future, e.g. by warning of accidents or slippery roads. However, the effects of advance warning systems are still poorly understood and investigated. In this paper, we report from an experiment in a controlled driving situation where we investigate how such advance warnings affect driver behavior and attention. Our results showed that the advance warnings overall had a limited effect on the speed of the drivers, although they had a positive effect for some road conditions especially for slippery road conditions. Furthermore, our subjects had a significantly higher number of eye glances. In particular, they glanced at the system when warnings were issued.

Author Keywords
Advance warnings, driving behavior, attention, in-vehicle systems.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Car drivers today have more information systems in their vehicles than ever before and more advanced systems are perhaps on their way. These in-vehicle systems serve multiple purposes during driving including entertainment, navigational aid and mobile phone communication. Often research distinguishes between systems dealing with primary or secondary driving tasks [3, 13]. Primary driving task systems are related to maneuvering the vehicle, e.g. GPS systems while secondary driving tasks systems are not directly related to the maneuvering of the vehicle, e.g. car stereo systems.

With the increase of in-vehicle systems as well as the general technological progress, it is becoming possible to present an ever-increasing amount of information to the driver. Advance warning systems constitute a type of in-vehicle systems that could potentially influence and improve driving significantly in the future. Using the right kind of information in a proper and useful manner, it could be possible to assist the primary driving task by supporting the decision-making process and contribute to improving traffic safety. In-vehicle advance warning sign systems are designed to do just this. Their purpose is to provide the driver with up-front information about conditions ahead in order to enable the driver to make more accurate driving decisions [6].

The development of the technology that allows cars to gather and react to information about the driving context is well underway [21]. The Opel Insignia car comes with the Opel Eye system that recognizes traffic signs along the road and draws the driver's attention to them via a dashboard-based warning sign system [19]. Even though the Opel Eye system merely utilizes actual signs from the physical context, future advance warning systems could use or sense a wide array of contextual information to detect upcoming potential dangerous situations for the driver, e.g. slippery roads, accidents to name a few. Thus, with evolving technologies and network infrastructures, it becomes possible for cars to communicate wirelessly with each other and advanced networks to obtain traffic and road condition information.

But though the potentials of advance warning systems are quite promising and significant, such systems are still rather poorly understood and investigated [6]. Further, it still has to be examined what kind of advance warning information that promotes safer driving and which ones that merely distracts [5].

In this paper, we investigate different in-vehicle advance warning signs on their affect on driver behavior and attention. Through a controlled driving experiment, we exposed drivers to five different road or traffic conditions with and without advance warning signs in order to see how these affected the driving. First, we present related work on in-vehicle advance warnings signs. Secondly, we introduce the experiment, and the results from the experiment. Finally, we discuss and conclude our results.

RELATED WORK
A number of research studies have investigated some of the potential effects of advance warning systems [9, 15, 18]. In-vehicle collision avoidance warning systems in particular have received a lot of research attention (e.g. [4, 14]). Lee et al. [14] examined the effects of collision avoidance systems on driver performance by conducting two experiments in a high-fidelity driving simulator. The results from the first experiment showed that advance warnings helped distracted drivers react more quickly, than no warnings, and reduced the number of collisions by about 80%. The second experiment showed that undistracted drivers also benefit from the collision

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warning system, allowing them to brake faster. Ben-Yaacov et al. [4] support these results as they found beneficial long-term effects of in-vehicle collision avoidance warning systems.

Luoma and Rämä [15] investigated driver acceptance of in-vehicle traffic sign information. In their study, subjects were exposed to four different configurations of traffic sign information in the car, while driving on a real road. This included a visual sign, visual sign with auditory message, visual sign and auditory feedback based on driver behavior and visual sign with elaborate auditory instructions. Luoma and Rämä's study showed that the subjects accepted integration of traffic sign information in the car, and generally found it useful for improving traffic safety. Specifically, the visual sign information was rated most useful. However, several drivers encountered problems such as unintentional speed decreases and late detection of other road users and obstacles.

Hanowski et al. [9] identified comparable drawbacks as they examined the benefits of a dashboard-based in-vehicle information system that included an advance warning system. Drivers were warned 5 seconds in advance about incidents such as crash ahead, car entering from hidden entrance and emergency vehicle approaching from behind. Despite the minor side effects, the advance warnings were found to indicate a clear benefit to drivers.

Intersection crossings are another driving situation where in-vehicle advance warning systems have received some attention. Staplin and Fisk [18] conducted a number of research studies to determine whether advance warnings on left curves improved driver decision performance. Their evaluation studies were conducted in a laboratory setting where the participants were faced with decisions about whether to turn or wait at left curve intersections both with and without advance sign information. They found that the participants made faster and more accurate decisions when advance information was available.

In a similar experiment, Caird et al. [6] investigated whether in-vehicle advance warnings could potentially improve intersection performance of both younger and older drivers. Using a driving simulator, test subjects were exposed to two different Head-Up-Display-based advance warning signs, warning them of upcoming intersections. The results were then compared to baseline drives without any advance warning signs. During all the drives late yellow light changes were randomly interspersed at the intersections. The data recorded included vehicle speed before, during and after the intersections, the number of test subjects that stopped or ran the yellow light, eye movement behavior, as well as the subjects' response time at the late yellow light changes. The results showed that the advance warning signs caused an overall increase in the number of test subjects, who stopped at the late yellow lights. Furthermore, the intersection approach speed for all test subjects was decreased. Caird et al. argues that this caused the test subjects to make more accurate decisions regarding intersection traversal. The primary side effect of the advance warning signs was determined to be a tendency among the drivers to reduce speed in advance of intersections. Based on the results of their study, Caird et al. conclude that drivers who are inattentive or distracted as they approach intersections may benefit from in-vehicle advance sign systems. Similarly, attentive drivers, but who miss road information, may find advance warnings helpful. Both Caird et al. and Luoma and Rämä conclude that while in-vehicle advance warnings signs look promising, we need more research to further investigate the effects of this kind of system on driver behavior especially outside the laboratory [6, 15].

The adoption of laboratory experiments for more studies on advance warning systems could be a limitation when trying to understand the potential benefits on driving behavior. While laboratory experiments have advantages, e.g. limited safety risks, they suffer from a number of limitations, e.g. lack of realism. Bach et al. [2] found that the lack of sensory feedback from vehicles and context in simulated driving caused problems for subjects on speed maintenance. Goodman et al. [10] found that the absence of motion removes the kinesthetic cues that are present when driving in the real world. Also, since in-vehicle advance warning signs are closely related to the driving context, we need to investigate the effects when driving real cars.

AN ADVANCE WARNING IN-VEHICLE SYSTEM

We designed an advance warning system to present the driver with basic functionality in the dashboard including traditional information, e.g. speedometer, fuel gauge, trip meter and the cars operating temperature (see figure 1).

Figure 1. Interface with two warnings active - slippery road and left curve (KM/T is Danish for kilometers pr. hour).

The basic functionalities have a central position on the screen and are always visible, whereas the warning signs only are visible, when the driver approaches a given road or traffic condition. The system shows the current speed of the car by means of a Holux GPS unit, placed in the windscreen of the car. The GPS unit receives the current speed every second and through a Bluetooth connection sends it to a laptop which then displays it on the system. The speed is represented in 3x2 cm white digital numbers, on a black background, resulting in easily read numbers in high color contrast. The advance warnings are, when visible, depicted as 1.5 x 1.5 cm icons above the speed representation. The fuel gauge, trip meter and operating temperature are depicted in the lower part.

The system was developed in C# using Microsoft Visual Studio .NET 2008. Besides the aforementioned visual

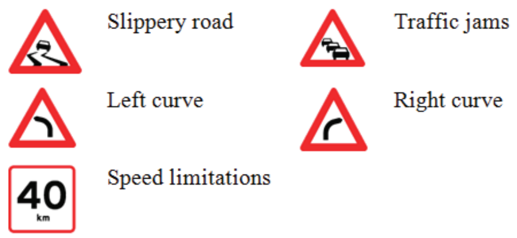

Figure 2. The included advance warnings in the system inspired by road signs used in Denmark.

information, the system prompts the driver with audio (earcons) and visual warnings (see figure 2) regarding the incident ahead. The system displays advance warning signs that would normally be recognizable to drivers as they have been chosen to mimic those from real life driving. The advance warnings appear in the dashboard 75 meters before the incident occurs where they are constantly lit, and again, when the incident occurs, when they start to flash. Besides the visual warnings, the system furthermore warns the driver with two different earcons one for each state of warning.

We issued the warnings 75 meters before the incident based on guidelines from the Danish Road Directorate [20]. They recommend the placing of traffic signs 50 meters before the incident for speeds below 60 km/h plus two seconds of reaction time to allow drivers to read and decode the traffic sign. We set this reaction distance to 25 meters based on an average of the recommended distances at 30, 40, 50 and 60 km/h.

EXPERIMENT

The purpose of our experiment was to investigate the effects of the advance warnings as implemented our in-vehicle system on driving behavior.

Experimental Design

We adapted a within-subject design with twelve subjects. In order to minimize learning effects, subjects were counterbalanced such that they alternated between the two conditions of the experiment, namely switching between starting with advance warnings from the system, and starting without (baseline). The dependent variable of the experiment was driving speed and eye glance behavior. The independent variables were the two conditions of driving with and without advance warnings.

Participants

12 subjects (5 females) participated in our experiment with ages ranging between 24 and 30 years (*M*=26.17, *SD*=1.85). All test subjects carried valid driver licenses and had done so for an average of 7.5 years (*SD*=0.65). The participants driving experience, in terms of how many kilometers they drove pr. year ranged from 50 to 25,000 km/year (*M*=6,354, *SD*=7,205). All of the participants stated that they, to some degree, had prior experience with in-car systems, mostly GPS systems.

Setting

The experiment was conducted on a closed circuit used for driving courses for training driving school pupils. The course consisted of various sections, three of which were equipped with water sprinklers along both sides, and were asphalted with a special epoxy/asphalt blend which, when wet, made the road slippery (the white sections on figure 3). The sprinklers could be turned on and off enabling us to vary the driving condition.

To increase realism, we included another car on the track in order to simulate real life driving, in the sense that the participants had to be aware of the other car and act accordingly. The vehicle used in the experiment had been fitted with our advance warning prototype system in such a way that the cars original speedometer was covered and no longer visible as shown in figure 4.

Procedure

At the onset of each session the participants were seated in the driver's seat of the car, and asked to adjust their seating position according to preference. The supervisor of the experiment then read an introductory text aloud explaining what was going to happen, and which configuration they were going to start with. If the participants were to start with advance warnings engaged, they were shown how the warning system worked, otherwise this was done just before the second part of the session. Furthermore, the participants were instructed to obey the normal traffic regulations with a general speed limit of 60 km/h, and to otherwise drive the car, as they would normally do. The participants were given the opportunity to familiarize themselves with the car.

Figure 3. The driving circuit used in the experiment. The two white sections in the middle, left of the picture are the slippery road sections.

When the participants felt they were ready, the supervisor instructed them to enter the course and throughout the session instructing the participants which direction to drive. Each session was divided into two parts; (each part around 6.5 km) 8 laps with advance warnings – 8 laps without. The two parts followed the same eight predetermined routes in the same order. During each of the two parts, the water sprinklers were initially turned off on the sections equipped with these, such that they were not slippery the first time around. The water sprinklers were then turned on without the participants knowing, making the two sections slippery, the second time the participants encountered them. The experiment was in part based on a Wizard of Oz approach, as we controlled the advance warnings. To ensure uniformity

Figure 4. Experimental setup with the system mounted on the dashboard.

we had placed inconspicuous markings, signifying to the observer when to turn on the warnings, around the track.

One of the authors drove another car around the circuit during the test in order to simulate real life traffic and to initiate the traffic jams. One of the authors of this paper was also responsible for turning the water sprinklers on and off at the right time. After the driving part of the session was concluded, we applied semi-structured exploratory interview guide, to collect the participant's thoughts on the use of advance warnings. Finally, participants were asked to fill out a questionnaire.

Data Logging

We implemented the possibility to automatically log the information currently in use by the system for instance; current speed, lap number, and advance warning description etc. As previously explained the data logging was initiated 75m before the road or traffic incident, were the observer turned on the warning. When the participants reached the area they had been warned about 75 meters later, they were once more warned with a different sound and a flashing icon. We distinguished between these two types of warnings, enabling us to analyze the effects of the advance warnings, on the driver's behavior prior to and during the part of the track which the participants had been warned about. The data logging was stopped when the participants exited the section. This procedure amounted in around 650 lines of log data pr. participant with one line of data being logged pr. second a warning was displayed.

Data Analysis

During the experiment we collected primarily two types of data namely speed logged in the system and video recordings to determine eye glance behavior. Firstly, we analyzed the speed data gathered by the data logging system. As stated earlier, the logging started when an advance warning was first activated (referred to as *state 1* of the incident) through the second state of the warning (*state 2*) until the incident is passed and the warning is turned off (*incident exit*). The equivalent data was also logged without warnings. The primary focus of the speed analysis was to determine how much the participants reduced their speed between when they received the first warning, to when they reached the incident in question, and then compare this to when they drove without warnings (baseline). In order to do this we needed to determine the average speed, at state 1 onset and state 2 onset for each incident, and then calculate the difference. We computed the average speed at incident exit, and the reduction in speed from state 2 onset to incident exit, in order to examine if the warnings had an effect after the participants had reached the incident.

Secondly, we analyzed how the speed of the participants developed over time, by calculating the average speed for each second based on all the speed readouts logged during each state. Because the speed of the participants, and therefore number of log entries, differed, we needed to select the lowest common denominator in terms of the number of entries. For instance if one of the logs contained five entries for a specific incident, and the remaining logs had seven entries, only the first five entries of all logs were used, ensuring comparable data. Where this method is applied, we refer to the data with the postfix "common", e.g. state 2 onset common. Finally, we determined the mean speed throughout state 1 and state 2 separately for all incidents, by calculating the average speed readout, using all log entries in each state. The above-mentioned procedure was carried out for all individual incidents, and then compiled according to incident type. The results were then subjected to two-tailed paired Student's t-tests to reveal any significant differences between the two conditions.

Thirdly, eye glances were identified from video recorded during the experiment, in order to evaluate the effects of advance warnings on eye glance behavior. By analyzing the video from the experiment frame by frame, eye glances were identified and categorized according to the following three categories according to duration inspired by [3]: (1) 0.5 seconds and below, (2) between 0.5 and 2.0 seconds, (3) above 2.0 seconds. We defined the duration of an eye glance as the time between when a participant moved his or her gaze away from the road and onto the system, and back onto the road. During the video analysis, eight videos were reviewed (due to quality issues four videos were discarded) by two reviewers who each reviewed five videos causing an overlap of two videos, which were analyzed by both reviewers. Initially, the two reviewers collaboratively analyzed one of the videos in order to ensure consistency in the analysis. An inter-rater reliability test of this analysis (using weighted Cohen's Kappa) gave K=0.84 corresponding to excellent agreement.

Finally, we also calculated the participants' reaction time, i.e. the time it took for them to react to a warning, which we defined as the time it took from a warning was emitted, and the participant had glanced down at the system to when the participant had his or her eyes back on the road. This would also enable us to calculate how far they drove during this time, using the logged speed data. Our approach was to count the number of frames in the video during this interval, convert the number of frames to seconds, and then crosscheck the number of seconds with the speed and warnings from the log to determine the reaction time and distance travelled. Eye glances that occurred within two seconds of a warning were assumed to correlate to that warning. This way we were also able to check if the participants were reacting to the warnings, and if that reaction changed over time.

RESULTS

In this section we will present the results of our data analysis. First we will present our analysis of the speed data collected by the system, organized according to warning type. Then we present the results of the eye glance and reaction time analyses.

Vehicle Speed

In this section we will present the results of our analysis of the vehicle speed data. Emphasis is put on the reduction in speed from state 1 onset to state 2 onset, and any other results will only be presented in-depth if they are of interest. Each warning type is addressed separately by presenting the results for all occurrences of that incident. If relevant, specific incidents in each type will be presented separately.

Left Curve Warnings

The experiment contained seven left curves in each condition (i.e. N=84). As seen in figure 5, the advance warnings had very little effect for the left curves. The speeds are very similar with and without warnings at state 1 onset, and reductions in speed between state 1 onset and state 2 onset also do not differ notably. Similarly, the mean speeds through state 1 and state 2 differ only marginally. The participants increase their speed before encountering state 2 onset for both conditions, i.e. the reduction is negative. This is caused by a specific left curve on the track that is encountered four times in all, where the entry speed is relatively low due to the layout of the track. However, removing these four left curves from our data, does not affect the results significantly.

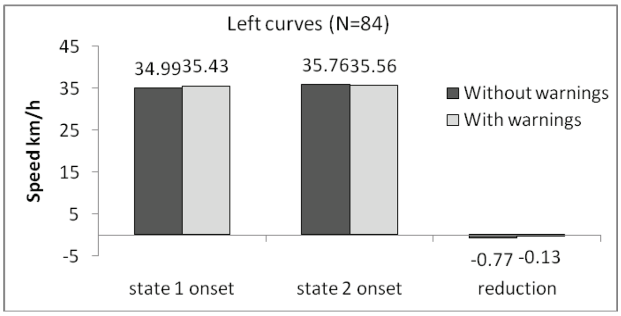

Figure 5. Speed at state 1 onset, state 2 onset and the reduction in speed between the two for left curves (N=84).

Right Curve Warnings

The participants encountered a total of five right curve incidents in each condition (i.e., N=60). As seen on figure 6, the advance warnings had negative effect here as the participants reduce their speed less between state 1 onset and state 2 onset with the warnings than without, which amounts to 6.75 km/h (*SD*=5.03) with warnings and 8.65 km/h (*SD*=5.10) without warnings, which a Student's t-test reveals as a significant difference, $t = 1.68$, $p = .026$. Comparing their speed at state 2 onset, the average speed with warnings is 36.60 km/h (*SD*=5.88) and 35.48 km/h (*SD*=6.41) without warnings, which reveals signs of a trend, $t = 1.68$, $p = .058$. The mean speeds throughout state 1 and state 2 do not differ notably.

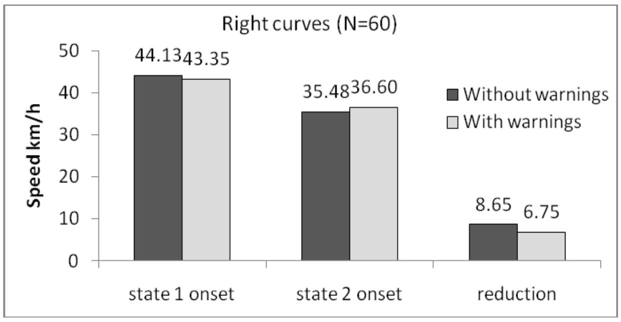

Figure 6. Speed at state 1 onset, state 2 onset and the reduction in speed between the two for right curves (N=60).

The track contained two unique right curves, the first of which was encountered four times in each condition (hence N=48). The speeds at state 1 onset for this specific right curve only, are still quite similar, but the speed reduction between state 1 onset and state 2 onset is larger without warnings at 9.81 km/h (*SD*=4.78), than with warnings at 7.31 km/h (*SD*=5.30), which represents a significant difference, $t = 2.01$, $p = .016$. This indicates that the difference must lie at state 2 onset, where the average speed with warnings is 34.31 km/h (*SD*=3.43) versus 33.13 km/h (*SD*=4.11) without warnings, which indeed indicates a trend, $t = 2.01$, $p = .054$. If we then look at the average speed reduction between state 2 onset and incident exit for this right curve, we also find a significant difference, $t = 2.01$, $p = .026$.

Slippery Road Warnings

The advance warnings had an effect for slippery road incidents as shown on figure 7. The participants drive 2.5 km/h slower with warnings at state 1 onset, than they do without warnings. This is not significant however.

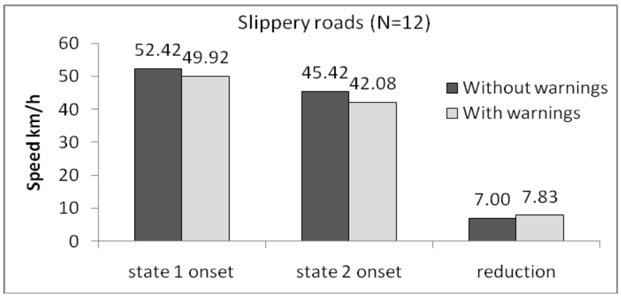

Figure 7. Speed at state 1 onset, state 2 onset and the reduction in speed between the two for slippery roads.

At state 2 onset, however, the average speed with warnings is 42.08 km/h (*SD*=7.48) versus 45.42 km/h (*SD*=8.51) without warnings, which suggests a trend, $t = 2.20$, $p = .054$. The pattern continues at incident exit, where the average speed with warnings is 34.75 km/h (*SD*=4.56) and 37.25 km/h (*SD*=6.11) without warnings. A Student's t-test reveals this difference of 2.50 km/h to be significant, $t = 2.20$, $p = .046$. Looking at the common log entries for incident exit, we see a strong significant difference between the average speed with warnings at 35.67 km/h (*SD*=5.15) and without warnings at 40.58 km/h (*SD*=6.85), $t = 2.20$, $p = .004$. However, the reduction in speed between state 2 onset common and exit common does not quite constitute a significant difference, t = 2.20, p = .086, with an average reduction of 6.42 km/h (*SD*=3.73) with warnings, and 4.83 km/h (*SD*=3.49) without warnings.

Throughout state 1 the mean speed is lower with warnings than without warnings, but even more so through state 2, where the mean speed is 36.56 km/h (*SD*=6.29) with warnings, and at 41.55 km/h (*SD*=7.61), somewhat higher without warnings. This difference of almost 5 km/h is significant, t = 2.20, p = .004.

Speed Limit Warnings

For all eight speed limit incidents (N=96), we see that the average speeds at state 1 onset are very similar, differing only by 0.07 km/h (see figure 8). The reductions in speed between state 1 onset and state 2 onset are also very similar. At state 2 onset, the speed is lower with warnings at 37.69 km/h (*SD*=3.94) than it was without warnings at 38.39km/h (*SD*=3.62). The difference suggests a trend, t = 1.99, p = .073. The results for the mean speeds throughout state 1 and 2 of do not reveal any differences. As the experiment contained two different speed limit sections, we can look at the results for the first speed limit separately (N=72), where the effects of the advance warnings were more substantial. Here, the decrease in speed between state 1 onset and state 2 onset is 11.89 km/h (*SD*=4.56) with warnings and 11.07 km/h (*SD*=6.08) without warnings, a difference that implies a trend, t = 1.99, p = .063.

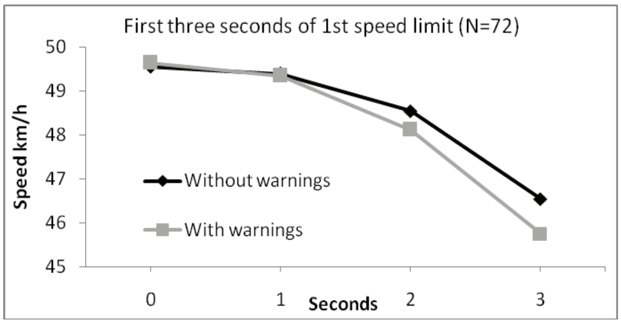

Figure 9. Speed for the first four seconds of state 1 of the first speed limit incident (N=72).

Figure 9 shows the average speed of the participants for the first four common log entries of the first speed limit incident. It shows that while the initial speeds are almost identical, the speeds develop differently over the course of the following three seconds. With warnings the participants reduce their speed earlier than they do without warnings. We found a significant difference, t = 1.99, p = .018, in the average reduction in speed between state 1 onset and the last common speed reading, with an average decrease of 8.13 km/h (*SD*=5.45) with warnings and 6.63 km/h (*SD*=5.54) without warnings. We found a significant difference, t = 1.99, p = .0012, between the average speed of 41.50 km/h (*SD*=4.26) with warnings, and 42.91 km/h (*SD*=3.78) without warnings.

Throughout state 2 of the first speed limit the mean speed with warnings is 37.59 km/h (*SD*=3.72) while it is 38.53 km/h (*SD*=4.06) without warnings, which indicates a trend, t = 1.99, p = .053. The mean speeds through state 1, on the other hand, do not differ notably.

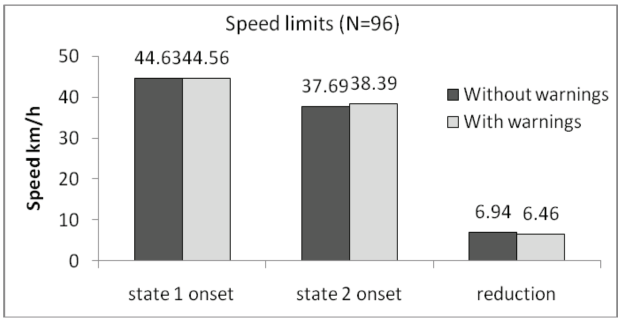

Figure 8. Speed at state 1 onset, state 2 onset and the reduction in speed between the two for speed limit (N=96).

Traffic Jam Warnings

During the experiment the participants encountered two different traffic jam incidents. Looking at the results of both traffic jams collectively (N=24), the average speeds at state 1 onset are remarkably similar across both conditions, and the average reduction in speed from state 1 onset to state 2 onset is exactly the same across the two conditions. Similarly, there are no noteworthy differences in the mean speeds throughout state 1 and state 2. We see that the advance warnings had a negative effect on the speed reduction. The participants increase their speed from state 1 onset to state 2 onset by 2.58 km/h (*SD*=3.75) with warnings and decrease it by 0.50 km/h (*SD*=3.73) without which represents a significant difference, t = 2.20, p = .048.

Combination of Slippery Road and Left Curve Warnings

Our experiment contained one incident where a left curve was combined with a slippery road and where two warnings were activated simultaneously.

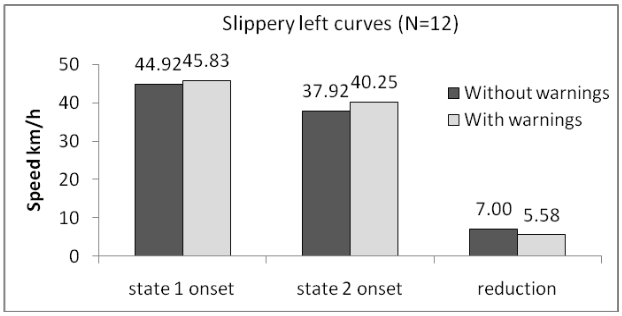

Figure 10. Speed at state 1 onset, state 2 onset and the reduction in speed between the two for slippery left curves.

The reduction in speed from state 1 onset to state 2 onset is 7.00 km/h (*SD*=5.74) with warnings, which is somewhat larger than without warnings at 5.58 km/h (*SD*=6.89). A difference that is only marginal, t = 2.20, p = .462. With warnings the average speed at incident exit is slightly higher than without warnings at 32.50 km/h (*SD*=3.09) and 31.42 km/h (*SD*=3.37), respectively. While this difference is not significant, we do see a trend, t = 2.20, p = .090.

Eye Glance Behavior

We classified the eye glances according to their duration; below 0.5 seconds, between 0.5 and 2.0 seconds and above 2.0 seconds. We identified a total of 1363 eye glances. 451 were categorized as being shorter than 0.5 seconds, 911 between 0.5 and 2.0 seconds and just one eye glance was longer than 2.0 seconds. Without warnings had the least number of glances of the two conditions, with 494 in all, compared to 869 with warnings, which is an increase of nearly 76%. The average number of glances is higher with warnings than it is without. This amounts to a strong significant difference, t = 2.36, p = .0065.

	Without warnings (N=8)	With warnings (N=8)
> 0.5 s.	28.5 (20.79)	27.88 (16.03)
0.5 - 2.0 s.	**33.13 (18.29)**	**80.75 (24.34)**
> 2.0 s.	0.13 (0.35)	0 (0)
Total	**61.75 (34.69)**	**108.63 (19.43)**

Table 1. Mean numbers of eye glances in different conditions and for the different categories (standard deviations in parentheses). Statistically significant differences at the 95% confidence level are highlighted.

The number of glances below 0.5 seconds in duration is very similar for the two conditions, with 228 without warnings and 223 with warnings. Our results show that it is in the number of glances between 0.5 and 2.0 seconds that the real difference lies. With warnings accounts for 646 eye glances in this category, compared to just 265 without warnings. A Student's t-test reveals this to be a strong significant difference, t = 2.36, p = .0028. In the last category, glances above 2.0 seconds, we found just one without warnings and none with warnings. We also looked at the number of times the participants looked down when the warning system displayed a warning, for both state 1 and state 2. For more than 91% of the warnings, the participants glance following the state 1 warning. The same holds for about 57% of the warnings at state 2. A Chi-square test shows this difference to be extreme significant, $\chi^2(1, N=8) = 55.38$, $p < .0001$.

DISCUSSION

Our results indicated that our advance warning system had some effects on driving behavior, but that they were somewhat quite limited. When comparing the speed of the subjects for the two conditions, they are astonishingly alike often with almost indistinguishable differences. However, we did identify some situations where the advance warnings had a positive effect on the speed.

First, for speed limit warnings, we found that the speeds develop differently for the two conditions in the first three seconds. With warnings the participants decrease their speed significantly more than without warnings. Another substantial result is the mean speed through state 2 of the slippery road incident. Here, the participants drove almost 5 km/h slower with warnings, than they did without. Other results also show that the advance warnings had a positive effect on the participants' speed for the slippery road. On the other hand, the effect of the advance warnings are negated in the right curves, since there is a significant difference in the average reduction in speed, which is higher in the no warning condition. While this may seem curious, it is perhaps an indication, that the many of the factors that influence the behavior of drivers are complex in nature.

Our results seem to challenge findings of similar studies [1, 5, 6]. Caird et al. [6] found that advance warnings reduced speed adopted by drivers through intersections. Their findings may be different from ours because of their simulator-conducted experiment. This could make the participants more likely to react to advance warnings regardless of whether or not it is necessary, since the sensation of speed provided by the context is not present. This is supported by Bach et al., who compared simulated and controlled driving, and they found that that the lack of sensory feedback in simulated driving caused problems with perceiving driving speed [2].

Furthermore, the fidelity of simulators means that participants are able to see less of their surroundings, which in turn may cause them to rely more on warnings. In contrast, participants in controlled driving are able to rely more on the available context information and therefore the warnings may not have the same effect. However, Kemeny and Panerai [11] state that in driving simulators with a large enough field of view, speed can often be estimated correctly by visual information. But Kemeny and Panerai also note that recent studies have shown that vestibular information has a more important role than previously assumed. Additionally, Kemeny and Panerai state that experiments regarding driver alertness, as in Caird et al. [6], can be carried out in driving simulators without the need for absolute simulation fidelity. Moreover, the amount of risk perceived by the participants is arguably bound to be higher in real life driving. Boyle and Mannering [5] investigated the impact of travel advisory systems on driving speed, suggests that while the average speed can be reduced by in-vehicle system advisory messages, drivers tend to try and make up for lost time by increasing their speed when the warning/advisory message is no longer relevant, which questions the net safety effects of advisory messages.

The incidents warned about were in some cases rather obvious. For instance, the slippery parts of the course were clearly distinguishable from the rest of the course due to their color. Had the road conditions been less obvious, the results could have been different. For example, had the experiment been conducted on public roads during winter with occasionally treacherous road conditions, the participants presumably would have benefitted more from advance warnings, as any unsafe road conditions would be less visible. This is in line with Luoma et al., who found that warnings about black ice conditions, which are harder to spot, has a greater effect on speed and the amount of headway between road users, compared to warnings in snowfall conditions where the hazardous road conditions are clearly evident [16].

The results of the eye glance behavior analysis reveal that the advance warnings attract significantly more glances. This result is perhaps unsurprising given that the visual nature of the warnings arguably attracts more visual attention. The results also show that when the participants are presented with an advance warning, they look down at the system in 91% of the cases, which indicates that the participants do detect the warnings when they are issued. Similarly, Caird et al. [6] found that drivers gazed at 75.4% of all warnings. However, there are also downsides to diverting attention toward the system. As de Waard et al. [7] note, whenever an in-vehicle system issues a notification, attention has to be allocated towards processing the information.

In another study, de Waard et al [7] investigated reactions towards an in-car enforcement and tutoring system were measured in young (*M*=37, *SD*=4.5) and elderly drivers (*M*=66, *SD*=3.8). de Waard et al. [7] found that the degree of acceptance of the system was higher for the elderly group of drivers who were pleased with the system. Even though the group of younger drivers believed the system to have a positive effect on traffic safety, they nevertheless disliked it. The findings of de Waard et al. [7] and Ponds et al. [17] indicate that a more balanced and representative age spread in our experiment may have produced different results. For instance, de Waard et al. [7] note that research has shown that elderly drivers overlook traffic signs more often, and speculate that these violations could occur out of inattention.

CONCLUSION

Overall, our experiment showed that the advance warnings had a limited effect on the behavior of the participants in experiment. The speed at the different road and traffic incidents were remarkably similar across the two conditions. We did see some beneficial effects of the advance warnings at particularly the speed limit and slippery road incidents. The use of the advance warnings caused the participants to make significantly more eye glances diverting attention away from the road and onto the in-vehicle system. In particular, they glanced at the system when the warnings were emitted.

Due to the ethical reasons, we chose to conduct our experiment at a closed training circuit instead of in real traffic. Real traffic driving could probably add substantial realism and perhaps different results.

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