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Research Article

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The Advantage of Adapting a Driver Support System to the Prevailing Road Condition – Adaptive Versus Non Adaptive Forward Collision Warning

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Abstract

There is a great potential safety benefit of warning the driver for an imminent collision by the use of a Forward Collision Warning system. However, the systems that are tested and even introduced on the market today do not adapt to the prevailing road condition which might lead to problems when the road is slippery and the braking distance is longer. In this study, which was undertaken in the VTI driving simulator, the benefits of a system that is adaptive to the friction on the road compared to a system that does not consider friction was investigated with regard to driver behaviour, safety, acceptance and trust in the system. The results showed that there were great safety benefits of the adaptive system in terms of fewer collisions, longer minimum headway, and longer time to collision. The downside of the adaptive system was that it had a lower acceptance among the drivers. The reason for this is probably due to the fact that the system is more difficult to learn and that the number of perceived false and early warnings is higher. Further work has to be carried out to recognize how to reduce the number of these warnings, fostering improved acceptance.

Keywords: Forward collision warning; Safety; Trust; Simulator study; Slippery roads

Introduction

Several studies have shown benefits of user-adaptive driver assistance systems, both regarding user acceptance and driving performance [1-3]. This study sets out to investigate if adapting a Forward Collision Warning system (FCW) to the friction of the road can improve driver behaviour and thereby increase traffic safety and at the same time increase user acceptance. A Forward Collision Warning (FCW) is an on-board electronic safety device that has the potential to protect its host vehicle from collision with preceding traffic. The system continuously monitors traffic obstacles in front of the host vehicle and warns the driver when a risk of collision is imminent. Many studies have shown the benefits of FCW in reducing the number and severity of front-to-back collisions or 'shunts' [4]. There are also several studies looking at the drivers' acceptance and response to FCW, the Human Machine Interaction and algorithms differ however between the studies making it hard to draw any general conclusions. Abe and Richardson have in a series of simulator studies investigated how parameter settings such as when the warning is given, vehicle speed and distance between vehicles affect the drivers' behavior and trust in the system [5-8]. The results showed that an early warning lead to a higher trust in the system than a late warning. This in turn implies that drivers that are accustomed to an early warning have a greater tendency to react (i.e. brake) on false warnings and react late in critical situations when the warnings is absent, for instance due to technical errors. The trust in the system increased with increased time between warning and brake response, which the authors argue is due to the increased time the drivers have to decide on whether to react or not.

Abe and Richardson [5] also demonstrated that if drivers have already made an individual decision to brake prior to a FCW alarm, their trust in subsequent alarms is reduced. Drivers became more inclined to ignore the system, relying on their own individual judgements of impending danger and thus nullifying the potential benefits of the FCW. Wiese and Lee [9] took this work further and showed that poorly timed warnings can also adversely affect driver workload. Cotté et al. looked at the effect of false and unnecessary warnings in a simulator study where two different collision warning systems, one with many false warnings but few absent warnings and one with few false warnings and many absent warnings, were tested on a group of younger drivers (30-40 years) and one group of older drivers (> 65 years) [10]. The results showed that the drivers had a higher speed when driving with the first system while the brake reaction time was shorter with the later system. The older drivers also seemed to better understand the reason for the false alarms and had thereby a greater subjective tolerance for the false alarms. Lees and Lee investigated how drivers were affected by false alarms and unnecessary alarms [11]. The results showed that unnecessary alarms (deliberate, predictable and unusable) do not affect the trust in the system while false alarms (not deliberate, unpredictable and unusable) both reduce the trust in the system and the drivers' ability to understand how the system works.

Adapting the FCW to the prevailing road condition may make the system less predictable and thus more difficult for the drivers to understand how it works. This may then in turn lead to the drivers interpreting the warnings as both false and/or unnecessary which will have an effect on trust and driver interaction with the system. The aim is to find out whether this is true for the system tested and whether that diminishes the potential safety improvement of the adaptive system. The research questions are, does adapting the FCW system to road condition lead to:

- Gains in traffic safety in terms of improved driver behavior?
- Misinterpretations of the warnings?

- Decreased user acceptance with the system?

This experiment was one of three related experiments performed in the European project AIDE (Adaptive Integrated Driver-vehicle Interface). The other two experiments were carried out by The Netherlands Organisation for Applied Scientific Research (TNO) and Institute for Transport studies (ITS Leeds, UK) [3] and they focused on system adaptation to driver distraction and driver style. In all three experiments the same FCW algorithm was used.

Method

Systems investigated

There are two FCW systems studied in this experiment; one that adapted the warning to the predicted stopping distance based on the friction on the road and one that did not consider friction. This meant that the adaptive system issued the warning earlier on slippery roads than on dry roads which the non-adaptive system did not. The human machine interface for the warning was a sound signal triggered at a specified distance from the lead vehicle. The system was deactivated when the indicator was turned on so that it would not disturb during overtaking manoeuvres.

The FCW was based on the ISO-recognised Stop Distance Algorithm (SDA) [12]. The SDA was defined as follows:

$$D_w = \left(V_{driver} \cdot T_{driver}\right) + \left(V^2_{driver} \big/ 2d_{driver}\right) - \left(V^2_{drone} \big/ 2d_{drone}\right)$$

Dw [m] = warning distance

- Vdriver [m/s] = speed of following simulator driver
- Tdriver [s] = the assumed driver's reaction to an event
- ddriver [m/s^2] = assumed deceleration of the following vehicle
- Vdrone [m/s] = speed of leading drone vehicle
- ddrone [m/s^2] = assumed deceleration of the lead vehicle

The SDA had three fixed parameters: Tdriver, ddriver and ddrone. In this experiment the value for ddriver was set to 5 in dry conditions and 3.7 in slippery conditions for the adaptive system while it was set to 5 regardless of road condition for the non-adaptive system. The value 3.7 for ddriver in the adaptive system was chosen so that the criticality of the event would be the same when the system warned regardless of road condition. Tdriver was set to 0.5s and the real-time speeds of the two vehicles (Vdriver and Vdrone) varied as the simulation progressed. This algorithm is rather crude and is not as finely tuned as the algorithms used in the FCW's available on the market today. This means that the driver may receive more warnings, and especially short headway warnings than what would be expected for an on market system.

Test site

The study was carried out at VTI's driving simulator III (VTI's third generation moving base driving simulator) (Figure 1). It was used to create realistic sensations in a laboratory environment, including a:

- Cut-off passenger car cab
- Computerised vehicle model
- Large moving base system
- Vibration table
- PC-based visual system
- PC-based audio system

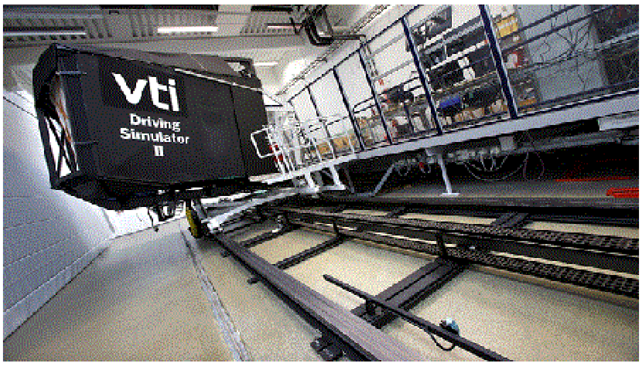

Figure 1: The VTI driving simulator III used in the experiment

The simulated car had a manual gearbox with 5 gears. The noise, infra-sound and vibration levels inside the cabin corresponded to those of a modern vehicle. The car body used in this experiment was a Volvo 850. In this experiment the car was also equipped with ABS-brakes.

The driving simulator model has been extensively validated. Simulation results have been compared to field test results of most standard vehicle dynamics manoeuvres (steady state driving in a circle, step input on the steering wheel and frequency response) with good correspondence. This work has been documented in a number of reports [13-15].

Experimental design

The participants were divided into two groups where half of them drove with the adaptive collision warning system and the other half with the non-adaptive system. The road surface was alternated between dry and slippery as they drove along so that if they started on the dry section this was changed to the slippery section after the first five kilometres and then back to dry again after another five kilometres, etc. The start condition was counterbalanced between the groups.

Participants

The study included 32 experienced drivers, 16 male and 16 female, and they were equally divided into the two groups. The mean age and standard deviation was approximately the same for both groups (mean 39.4 years and std 9.7 respective mean 42.2 years and std 12.4) as was the annually driven kilometres (mean 10075 and std 8928 respective 11019 and std 9554).

The selection criteria for participants in the experiments were: driver's license for five years; driving at least 5 000 km's per year; being an experienced driver and do not suffer from motion sickness. For participating participants received € 53 (500 SEK). All participants filled in an informed consent after receiving both oral and written information. There were some problems with simulator sickness in this study which meant that six persons had to abort the experiment early and had to be replaced. Data from those persons that were replaced are not included in the analysis.

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Scenario

The road in this study was a 37.5 km long road, 9 meters wide and with oncoming traffic. It was laid out in a rural setting with trees on both sides. The road surface was alternating between 4 dry and 4 slippery road sections of 5 km each (the last section was only 2.5 km), (Figures 2 and 3). The speed limit was 90 km/h.

Figure 2: Layout of the dry road in the study

Figure 3: Layout of the slippery road in the study

At each of these 5 km sections the drivers were exposed to one event forcing them to react by breaking their vehicle hard. For the first six events the vehicle in front was suddenly braking hard, the 7th event was a vehicle braking hard but without any break lights and the 8th event was a vehicle suddenly entering the road from a "lay-by" at the side of the road.

For each of the road sections there were five straights where an event could be triggered if the right criteria were fulfilled. There were also two straights were no event was triggered and this was to allow the driver to overtake the vehicle in front if he/she wanted to. The order of these straights was varied between the eight sections so that the driver should not be able to anticipate the behaviour of the vehicle in front.

The events were triggered on time headway, so that it was only triggered if the time headway to the vehicle in front was between 1 to 3 seconds. This was to make sure that the test driver was close enough to force a response, but not too close so that it would result in an immediate collision. The exception is the 8th event which was triggered at a specific point along the road. When an event had been triggered on a section no new event was triggered until the next section and if no event was triggered until the last of the five straights it was triggered regardless of the time headway. For some drivers this meant that they did not experience that event at all, because the distance may have been so long that they had lost visual contact.

Driver instructions

The drivers were instructed to drive in a way that they would normally do on a similar road with similar road conditions. They were also told to picture themselves in a situation where they were in a slight hurry, for instance if they were running late for a meeting. They were also informed that they could end the experiment at any time if they wished, without further explaining the reason thereof.

Procedure

As the participants arrived at VTI they first read the instructions for the experiment briefly explaining the system, the purpose of the experiment and the scenario. The instructions were the same for both groups, so it did not mention the adaptive part of the system. During the test run the drivers were repeatedly asked to rate their driving performance in the last minute on a scale from 1 (very bad) to 10 (very good) and they were given instructions on that as well. After reading the instructions the subjects filled in an approval to allow that the test was recorded on a DVD and that VTI had the right to use this material for scientific purposes, including conferences. Before entering the simulator they also filled out a questionnaire about their expectations of the system. This questionnaire contained questions on attitudes towards collision warning systems, whether they believed it would increase safety and comfort, how much they are willing to pay and also questions on where they thought they would use it and which drivers should be in the most need of such a system.

The first part in the simulator was a 14.8 km long training session to get familiar with the simulator, the FCW-system and the driving task. The first part of the training was on dry road and the second part was on slippery road. During the training they were told to drive close to the vehicle in front to activate the FCW-system and then to turn on the indicator so that the warning should stop. During the training the test leader could manually brake the vehicle in front and this was done so that the test driver should experience what it was like to perform an emergency brake; this was done on both dry and slippery road surface so that they would also notice the ABS-brakes. During the training the drivers were told that "if they wanted to overtake the vehicle in front and felt that the situation allowed it, feel free to do so". This was to promote more active driving and thereby a car following behaviour with shorter headway.

When the training was finished the vehicle stopped and the test leader made sure that the subject was feeling ok, had understood the driving task and that there were no further questions. The subject remained in the simulator during this time. If everything was ok the test proceeded to the actual experiment. This took approximately 35 minutes and during this time there were no communication between the subject and the test leader, except for the rating of driver performance. This was done twice on each 5 km section; once within the minute after an event and once when there had been no event during the last minute.

After the experiment the subjects had to fill out a second questionnaire repeating some of the questions from the first. This made it possible to study how the drivers' expectation differed from their experience. There were also some additional questions about trust and subjective rating of workload. Before leaving, the subject also filled out the proper forms allowing us to pay them the sum of 500 SEK (approximately €53) minus tax if applicable.

Measures and analysis method: There are two kinds of measures collected from this experiment; objective driving behaviour measures from the simulator data and subjective measures from the questionnaires.

Objective data on driver performance: Data was sampled from the driving simulator at 25 Hz and in Table 1 a list of sampled and calculated measures used in the analysis is displayed.

		Description	Unit
Sampled measures (25 Hz)	Speed	Speed of simulator vehicle	m/s
	Distance driven	Distance driven since start of experiment	m
	Headway	Distance between vehicles bumper to bumper	cm
	Brake activation	Oil pressure in brake cylinder making it possible to see when the test driver starts braking.	
	Accelerator pedal position	Given as a number between 0 and 1 making it possible to see when the test driver has released the gas pedal.	
	Speed of car in front	Speed of vehicle in front	m/s
	Event start	The time when the lead vehicle starts to brake	
Calculated measures	Headway at event start	Distance to lead vehicle at event start	m
	Speed at event start	Speed of the simulator vehicle at the start of an event	m/s
	Event brake reaction time	Time from lead vehicle braking to onset of subject brake activation	sec
	Event to accelerator off reaction time	Time from lead vehicle braking till subject releasing the gas pedal	sec
	Headway at warning	Distance to lead vehicle at warning	m
	Warning brake reaction time	Time from warning till brake activation	sec
	Warning to accelerator off reaction time	Time from warning till subject releasing the gas pedal	sec
	Minimum TTC	Minimum time to collision	sec
	Minimum headway	Minimum distance to lead vehicle	m
	Collisions*	Number of collisions	
*To avoid alarming the drivers and to make it possible to continue without losing realism, no actual collisions occurred, instead the lead vehicle was "pushed" in front of the simulator vehicle at a 1m distance. This was not noticed by the driver unless the difference in speed between the vehicles at the time of the collision was high and this was never the case.			

Table 1: The sampled and calculated measures on driver behaviour

The objective measures on driver behaviour are studied in two different ways. For measures that are based on event start (the start of an event is defined as the start of the preceding vehicles brake manoeuvre, or in the case of event eight where a vehicle is entering the road from a "lay-by", as when the vehicle has entered the roadway) all events are included. Examples of these measures are headway at event start and speed at event start. For the measures that are based on the warning only the events where the driver has started to brake 0.3 seconds after the warning or later are included. The Figure 3 is selected somewhat ad-hoc and may not necessarily mean that the drivers brake reaction is triggered by the warning, it may still be a reaction to the behaviour of the vehicle in front, but it does exclude events where the driver has reacted before the warning was issued. These measures are labelled "All events" and "Events where the driver has braked after the warning".

The analysis was carried out as an analysis of variance with System as a between subjects factor and Road condition as a within subjects factor. The model used was:

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y = System + Road_condition + gender + TS(gender*system) + System*Road_condition + Road_condition*TS(gender*system)

where:

System = Adaptive or Non adaptive (Fixed)

Road_condition = Dry or Slippery (Fixed)

Gender = Man or Woman (Fixed)

TS = Test subject (Random)

Brackets in the model indicate that the factor is nested.

Subjective measures

Before as well as after trying the system the participants answered questions about their attitudes towards collision warning systems; how much they would be prepared to pay to have such a system in their own car, in which situations they thought that the system could be useful, etc. In the questionnaire after driving they also answered questions on self-reported mental effort using the Rating Scale of Mental Effort [16] with the instruction "Please mark a horizontal line on the scale below to indicate your mental workload when driving with the Forward Collision Warning system that you have just experienced". The analogue visual scale ranged from 0-150 (no effort – extreme effort).

User acceptance was assessed with using the Van der Laan scale [17], giving a rating for satisfaction and usefulness of each FCW type. System trust was assessed using visual analogue scale, ranging from 0 (No trust) -100 (Complete trust) and the question was formulated "Please indicate how much trust you have in the frontal collision warning system used".

There are three main analyses of the questionnaires, and throughout the analysis the group that tried the adaptive FCW-system is compared with the group that tried the non-adaptive system. T-test at the p<0.05 level were used to observe differences. The first analysis was to compare the two groups' answers on the before questionnaire with each other to see if the two groups are initially equal and thereby comparable (1 in Figure 4). Secondly the two groups' answers on the after questionnaire are compared to see if there are any differences between the groups after experiencing the systems (2 in Figure 4). Thirdly those questions that are repeated in the two questionnaires are studied in more detail with paired T-tests to see if one of the systems better lived up to the subjects expectations or not. This was done by studying if any of the groups changed their responses significantly (3 in Figure 4).

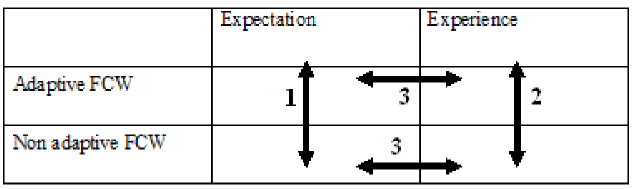

Figure 4: The design of the questionnaire analysis

Results

In this study there were eight critical events, four on dry roads and four on slippery roads that the drivers would encounter. The events where only triggered if predefined conditions with regard to speed and following distance were fulfilled. In all, the 32 drivers experienced 221 events out of 256 possible. The events where evenly distributed over the route they drove in the simulator and with regard to system and road condition.

Objective data on driver performance

Speed at event start: The speed of the test drivers at the start of an event differed significantly between dry and slippery road, such that the speed was approximately 3 km/h lower on slippery roads. The effect was not dependent of system, nor were there any interaction between system and road condition (Table 3). There was no significant effect of system or road condition on brake reaction time.

Safety: There are several indicators of safety in the measures obtained from the simulator; here the number of collisions, minimum Time To Collision (TTC) and minimum headway are used.

		All events	Events where driver brakes after warning
Dry road	Non adaptive	0	0
	Adaptive	0	0
Slippery road	Non adaptive	9	8
	Adaptive	3	2

Table 2: Number of collisions for the two systems

The numbers of collisions in this study are rather small and the results should be interpreted with caution, however, there are some effects worth mentioning. For instance; of the twelve collisions there were no collisions on dry road (Table 2) and a majority of the collisions were with the non-adaptive system. The analysis of variance (for events where the driver has braked after the warning) showed that there are significant effects (p<0.05) of both system and road condition as well as an interaction effect (Table 3).

For TTC (for events where the driver has braked after the warning) there was a significant effect of system as well as an interaction effect. The TTC was longer for the adaptive system and, for the non-adaptive system TTC decreases in slippery road conditions while it remains unaffected for the adaptive system (Figure 5, Table 3).

The minimum headway differ significantly between the two systems, such that the adaptive system gives a longer minimum headway. There is also a clear interaction effect where the min headway is increased for the adaptive system in slippery roads while it is decreased for the non-adaptive system (Figure 6, Table 3).

The three measures used to indicate the two systems effect on safety clearly showed that a system like the FCW benefits, from a safety point of view, to be adapted to the road condition. In this experiment it might even be the case that the system adds too much safety since TTC and Minimum headway actually increases on slippery roads compared to dry roads (Figures 5 and 6).

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Variable	Unit	Mean value (SD)				Effect system	Effect road condition	Interaction
		Non Adaptive system		Adaptive system				
		Dry	Slippery	Dry	Slippery			
Headway at event start	m	42.47 (22.89)	33.95 (20.00)	41.32 (21.29)	40.96 (13.47)	x	x	X
Speed at event start	m/s	82.97 (8.80)	81.29 (10.54)	84.89 (9.22)	79.77 (8.35)	x	F(1,213)=7.08 p=0.01 ηp2=0.03	X
Event brake reaction time	sec	1.23 (0.39)	1.35 (0.67)	1.19 (0.49)	1.17 (0.66)	x	x	X
Event to accelerator off reaction time	sec	0.74 (0.48)	0.82 (0.58)	0.58 (0.49)	0.59 (0.59)	x	x	X
Headway at warning	m	36.93 (21.14)	33.17 (13.12)	35.76 (18.52)	40.16 (10.23)	x	x	X
Warning brake reaction time	sec	0.39 (0.34)	0.42 (0.29)	0.32 (0.27)	0.75 (0.38)	F(1,143)=6.11 p=0.01 ηp2=0.04	F(1,143)=19.13 p<0.01, ηp2=0.11	F(1,143) = 13.99, p<0.01, ηp2=0.09
Warning to accelerator off reaction time	sec	0.18 (0.22)	0.15 (0.19)	0.11 (0.19)	0.28 (0.29)	x	x	X
Min TTC	sec	2.94 (1.71)	1.83 (1.51)	3.67 (2.09)	3.61 (1.53)	F(1,143)=19.82, p <0.01 ηp2=0.12	x	F(1.143)=3.61 p=0.05 ηp2 = 0.02)
Min headway	m	12.31 (8.24)	5.72 (5.63)	12.68 (6.14)	15.19 (9.10)	F(1,143) = 15,96 p<0.01 ηp2 = 0.10)	x	F(1,143) = 13.46 p <0.01 ηp2 = 0.08)
Time Headway	sec	1.73 (0.95)	1.30 (0.94)	1.66 (0.83)	1.80 (0.72)	x	x	x

Table 3: Effects of the dependent variables analysed presented with mean values and standard deviations (SD). Significant effects are presented with *F*-value, *p* – value and $\eta_p 2$. Trends have a p<0.1.

Warning brake reaction time System had a significant effect on brake reaction time (after warning), such that the adaptive system gave a longer reaction time. Also road condition had a significant effect on brake reaction time, such that the slippery road gave a longer reaction time. There was also an interaction effect between system and road condition, such that the slippery road condition gave an even longer reaction time with the adaptive system compared to with the non-adaptive system.

For the time from the warning until the driver applies the brakes there is a significant effect of road condition, with slippery road leading to a longer reaction time. There is also a clear interaction effect, where the reaction time unaffected for the non-adaptive drivers in slippery roads, while it is increased for the drivers of the adaptive system (Table 3).

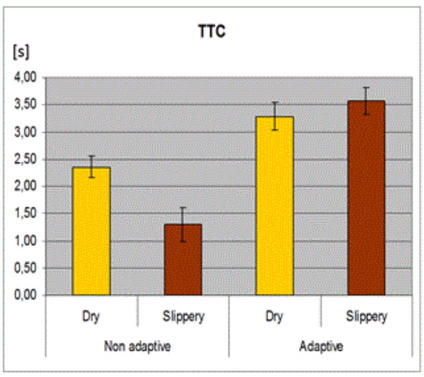

Figure 5: TTC for the events where the driver has braked after the warning

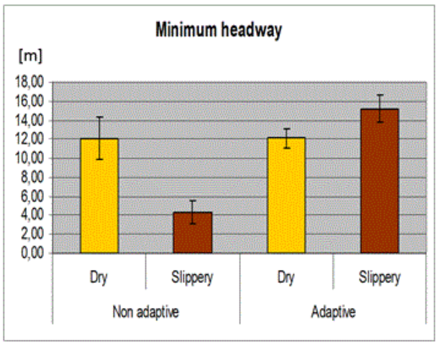

Figure 6: Minimum headway for the events where the driver has braked after the warning

This effect is most likely due to the fact that the events are less critical for the adaptive system, as was found for the safety measures above, giving the driver more time to react calmly. The interpretation is that the drivers use the system as a warning and then assesses the situation themselves before they react.

Subjective measures

Initial expectation of the system: Where nothing else is specified, the questions were answered on five-point scales. The two groups' expectations of the system before trying it did not differ on any of the questions. It can therefore be concluded that the two groups are comparable and that any differences that may occur when studying the experience of the FCW-system are due to differences in the two systems.

Experience of the system: When the two groups were compared against each other no difference could be found between the groups for any of the questions. Thus there are no differences between the two systems, which make the drivers experience them as two separate systems altogether. When comparing how the two groups had changed between expectation and experience however, some differences could be found. All participants believed that they would be more irritated when using the system compared to driving without any system after they had tried it ($t(31) = 3.97$, $p < 0.01$). Before trying the system they thought that it would have no effect on their irritation, but after they had tried it they thought irritation would increase.

Another difference between expectation and experience was that the drivers initially thought that they would use the system a lot in urban areas, but after trying the system they reduced their rating ($t(30) = 3.62$, $p = 0.03$).

Mental workload: Rated mental workload during the driving task was about the same for both groups. The mean value was 54.31 (std 29.9) for adaptive and 53.06 (std 32.5) for non-adaptive). This indicates "Rather much effort" on the RSME scale. Women rated a higher mental workload than men, 66.5 (std 27.4) compared to 40.9 (std 29.2) $p = 0.02$.

Other factors influenced by the system

The belief that traffic safety would increase was about the same (around four on a five pointed scale where 1 denotes decrease a lot and 5 denotes increase a lot, 3 denotes unchanged) for both groups before as well as after trying the system. Irritation when driving with the system was higher for the adaptive group, however not significant ($t(30) = 1.44$, $p = 0.10$). Stress induced by the system was rated higher by both groups after the experiment (3.5 compared to 4 on a five grade scale where 3 denote no change). The drivers did not think that the system would make them feel more supervised and this did not change after they had tried the system. They did not think that the pleasure to drive would change even though the adaptive group was a bit more sceptical after the experiment (2.7 where 3 denotes "unchanged"). Both groups thought that they would be more alert in traffic with the system; before as well as after trying the system.

Usage of the system: Both groups thought they would use the system less when they had tried it, compared to their expectation; the mean value was lowered from around 4 for both groups to around 3 for the adaptive group and 3.5 for the non-adaptive on a five pointed scale. On rural roads and motorways both groups thought they would use it about half the time, which was not changed during the experiment. Both groups thought they would use the system more in the evenings and at nights or in fog than in daytime or on slippery roads. This was stated before as well as after trying the system. The anticipation to use the system in rush hour traffic was decreased for both groups after the experiment.

Trust in the system: When stating their trust in the system from 0 meaning no trust at all to 100 meaning complete trust in the system, the results from the adaptive group was higher than from the non-adaptive group, mean value 73.4 (SD = 15.2) against 64.7 (SD = 18.9) but the difference is not significant.

Usefulness and satisfaction: To observe the drivers opinion on the systems' usefulness and their satisfaction thereof, the Van der Laan scale [16] was used. When using the scale the driver's rate how useful and satisfactory they find the system by rating a number of sub-scales (good – bad, pleasant – unpleasant etc), the scale goes from -2 to 2. The analysis showed that the drivers find the system quite useful, i.e. above 0, but were rather indifferent regarding their satisfaction of the system, i.e. close to 0. There is no significant difference between the drivers of the two systems (Figure 7).

Overall the drivers' view of the FCW was turned to less positive when they had experienced the system, so in some terms it did not meet their expectations. One reason may be that the system issued what may be perceived as false warnings. False warnings are here identified as warnings where the vehicle in front was not braking so the warning was triggered by something else, most likely too short headway, for instance when trying to overtake.

Subjective rating of driving performance: On dry as well as on slippery roads drivers with the non-adaptive system rated their driving performance significantly higher than drivers with the adaptive system. Both groups rated their driving performance higher on slippery roads than on dry.

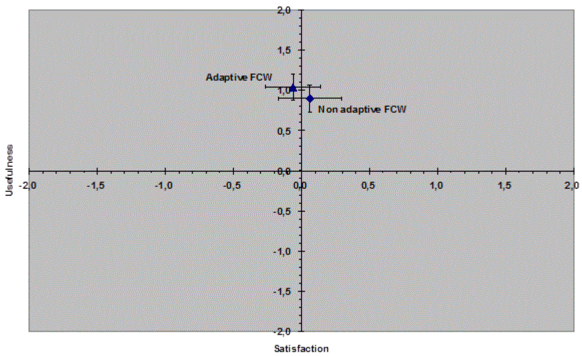

Figure 7: Usefulness and satisfaction according to the Van der Laan scale

Discussion

The purpose of this experiment was to investigate the benefits of adapting a FCW to the friction of the road. To be able to study this accelerated testing was used in the simulator, i.e. the drivers were exposed to a rather high number of critical events in various road conditions were the system could warn them of potential collisions in a short time. The events were evenly distributed over the route they drove in the simulator and with regard to system and road condition. This argues well for a comparison between the two systems but it also means that the accelerated testing in the simulator was successful since the drivers did not change their behaviour in such a way that they avoided the critical situations. This is well in line with findings on accelerated testing in simulator [18,19].

It is clear that the systems used in this study were quite crude compared to production systems and the FCW algorithm did issue a lot of warnings, especially short headway warnings, and this needs to be considered when interpreting the results. The focus is on the difference between the two systems, rather than on the actual level when interpreting the results in terms of acceptance, trust and safety.

The main result in this study is that safety is increased when the system adapts to the road condition (friction). This can be seen in the longer time to collision as well as the minimum headway for the adaptive system on slippery roads. Consequently the numbers of collisions are higher for the non-adaptive system on slippery roads.

The main difference in driver behaviour that can be related to the system being adaptive is the drivers' response to the warnings. For the adaptive system the reaction times between the warnings were issued until the drivers applied the brakes was longer than for the non-adaptive system. There was also an interaction effect in that the warning brake reaction time decreased for the drivers of the non-adaptive system on slippery roads compared to dry roads, while it was increased for the drivers of the adaptive system. This is interpreted as the drivers, after the warning has been issued, assess the situation and reacts accordingly. For the adaptive system the situation is less critical than for the non-adaptive system and the drivers can therefore react more calmly.

In contradiction to the findings that safety is increased the drivers of the non-adaptive system rated their driving performance higher than the drivers of the adaptive system, both on dry and slippery roads. Possibly this can be a result of the adaptive system being more difficult to learn and the drivers of the adaptive system got more warnings, especially on slippery roads. It may also be that the warnings were rather seen as a reprimand than a safety critical warning, and that this was more apparent to the drivers than that their own safety actually was improved.

For a system to be useful the drivers have to approve of the system, otherwise it will not be used, or not used correctly. Examples of this are studies of voluntary Intelligent Speed Adaptation systems that have shown that driver who do not approve of the system overrides it more frequently than drivers who approve of it [20]. In this case it was found that the drivers of both systems were less positive after they had experienced the system than before, but, for the drivers of the adaptive system the change was greater than for the others. For instance; the drivers of the adaptive system thought that their irritation when using the system, compared to not using it, would increase to a higher degree than the drivers of the non-adaptive system. They further thought they would use the system less in urban areas after they tried it than before and here this also differed from the drivers of the non-adaptive system. There can be several reasons for this, for instance the drivers of the adaptive system did get more warnings in slippery conditions, which can be experienced as a nuisance. The adaptive system may also be more difficult to learn and understand and the time exposed to the system in this experiment was not long enough to fully understand it.

In conclusion, there is a lot to gain in terms of safety by adapting the FCW system to the prevailing road condition. However, extra care has to be taken to improve the driver's acceptance of the system. By adapting the system to personal driving style, the annoying features of the system will be reduced. Further work has to be carried out to recognize how to reduce the number of perceived false or early warnings, fostering improved acceptance.

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