THE INFLUENCE OF STUDY DESIGN ON RESULTS IN HMI TESTING FOR ACTIVE SAFETY

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ABSTRACT

Active safety systems show great potential in preventing a large number of accidents. However, unless the system is completely autonomous, its actual effect will depend on how well it interacts with the driver. Therefore, Human-Machine-Interface (HMI) testing for active safety systems has become central in their development. For reasons of reproducibility and safety, HMI testing is usually carried out in a driving simulator or test track environment. These environments are different from real life driving. Unless the study design accurately reflects the conditions under which the system will be used, results will have low validity. Hence, study design becomes very important.

The influence of study design was shown in two HMI-studies of Forward Collision Warning (FCW) modalities carried out by Volvo Cars and Ford Motor Company in VIRTTEX, Ford's motion-based driving simulator. In each study subjects were exposed to a surprise FCW event, with most subjects receiving a FCW. Results show that distracted drivers' reactions to the warning correlated to their degree of previous exposure to warnings as well as the type of warning.

Drivers who had received other warnings in the vehicle prior to the surprise FCW event responded as intended to all warning types. Drivers who neither trained with nor were informed about any vehicle warnings prior to the surprise FCW event responded partially as intended to the warnings, with an interesting exception for verbal warnings. The results show that to achieve high validity in HMI evaluations, the study design can benefit from exposing drivers to warnings in a way that reflects their normal awareness of warnings in real life driving. It also suggests that developers could tailor HMI design to frequency of use, as well as benefit from keeping drivers adequately aware of the warning types a vehicle can provide.

INTRODUCTION

Traditionally, road traffic safety has been aimed at reducing the negative consequences of traffic accidents by building protection systems such as air bags, energy absorbing structures and seat belts. In recent years, this traditional approach has been extended towards accident prevention.

There are several reasons for this. One is that the technological development is beginning to make sensor-based detection systems available at low enough cost to begin considering volume introduction into vehicles. Another reason is that even though accident and injury rates show signs of decrease for many countries, this decrease is still far from the targets set. For example, fatalities in the European Union have shown a significant decrease in the past years, but even if this rate of decrease would continue, the EU target of 50 % reduction in fatalities between 2001 and 2010 [1] will not be met with current transportation safety methods (current projections predict about 35 % decrease in 2010 [2]). Moreover, the total number of accidents and injuries for the same area and time period show much less decrease than the fatality rate [3]. Looking at the US [4], the situation is similar. The number of people killed and injured per vehicle mile traveled has decreased, but since traffic volumes have been increasing, the total number of accidents and injuries shows very slight decreases over the last few years, and there is actually an increase in number of fatalities.

These trends have of course been noted by both EU and US road safety administrations, and large efforts are directed towards finding new means of reducing accidents and injuries in traffic. In these efforts, great hopes are held for active safety systems. Active safety systems show great potential for preventing a large number of accidents and injuries, and ideas for their development and implementation come in great varieties. At a quite abstract level, active safety systems can be categorized into two general groups; autonomous systems and interactive systems. An autonomous system detects or predicts a deviation from what is judged as the driver's intended path and evaluates any risks associated with that path and works through the vehicle to counteract either the deviation or any imminent risk, never involving the driver in the control loop. An interactive system also detects or predicts a deviation from what is judged as the driver's intended path and any risks associated with that path, but instead of acting through the vehicle, the system passes information about the current situation to the driver, prompting him/her to make the necessary corrective actions.

An example of an autonomous system would be Electronic Stability Programs (ESP). They detect when the vehicle starts to skid and works directly through the vehicle to counter the skid, without involving the driver in the control loop. An example of interactive systems is Forward Collision Warning (FCW), which alerts the driver when a forward collision seems imminent, but which does not take any action, such as braking or steering, by itself.

Autonomous systems have certain advantages. Their response variation for a particular situation is limited, and if need be, can be faster than most humans. On the other hand, a real driving environment in many situations still poses too much variability for an autonomous system to reliably determine the best corrective action. One reason for this is limitations in the information available to the vehicle about the environment. Another reason is the variability of intents in the driver population. For example, with ESP, even though the dynamics of a situation are known (such as slip angle and speed), it remains to determine whether the driver has put the vehicle in this state on purpose. If the vehicle is drifting unintentionally, then an autonomous action by the vehicle is warranted. If the drifting is intentional, then an autonomous intervention will most likely be considered a nuisance and the driver may switch the system off in the future, as s/he may consider it more of a hindrance than a help. Therefore, until more knowledge is gained on situational needs and prediction of driver intention and acceptance, interactive systems will continue to be an important approach in active safety.

Interactive systems give the driver information about the current state or situation but let the driver decide for himself how to act on the information. This means that the problem of predicting driver intentions is mostly removed. On the other hand, since the effectiveness of interactive systems is dependent on how well they interact with the users, Human-Machine-Interface (HMI) development and testing becomes a central tenet of interactive safety systems.

Since the performance of interactive systems are sensitive to drivers' expectations and behaviours, the study design must accurately reflect the conditions under which the system will be used, otherwise results will have low validity [5, 6, 7]. This is further enhanced by the fact that for reasons of reproducibility and safety, HMI testing is usually carried out in driving simulators or test track environments, which differ from real life driving in several aspects [8, 9].

The focus of this paper lies on the aspect of HMI study design which deals with how drivers are prepared before a study, in particular regarding how much information and training they receive. This is important because it relates to the question of everyday use. Different systems will have, or can be designed to have, different frequencies of interaction with the driver. For example, by setting warning thresholds very low in an application, a system can be made to interact with the driver almost every drive. However, if the warnings given do not reflect actual or perceived threat frequency, the driver's acceptance of the system will diminish quickly [10, 11], with limited or no system use as a result. System designers therefore aim for a minimum of false alarms. As a consequence, if a system is designed for a situation which does not occur very often, driver interaction with the system will be quite rare, and driver awareness of the system will most likely be quite low.

One aim of the two studies presented in this paper is to investigate if system awareness has consequences for HMI design. This is accomplished by studying whether different degrees of exposure to, and practice with, warnings prior to a surprise FCW event affect drivers' reactions to a FCW.

METHODOLOGY

VIRTTEX driving simulator

The two studies were conducted in Ford's VIRtual Test Track EXperiment (VIRTTEX) (Figure 1), a hydraulically powered, 6-degrees-of-freedom moving base driving simulator [12-15]. The motion system has a bandwidth in excess of 13 Hz in all degrees of freedom, and has performance specifications detailed in Table 1.

Table 1.
VIRTTEX motion performance specifications

	Acceleration	Velocity	Displacement
Longitudinal/ Lateral	> 0.6 G	> 1.2 m/s	± 1.6 m
Vertical	1.0 G	1.0 m/s	± 1.0 m
Pitch/Roll	> 200°/s^2	> 20°/s	± 20°
Yaw	> 200°/s^2	> 20°/s	± 40°

VIRTTEX is designed to accommodate a full-size, interchangeable vehicle cab, with a 2000 Volvo car used as the test vehicle for these studies. Tactile, visual and sound cues are provided to the driver in order to fully immerse drivers into the driving task. Realistic road, wind, and engine noises are played over a sound system, and the vehicle cab includes a steering control loader for accurate feedback of road and tire forces to the driver. The visual system in VIRTTEX is a non-collimated front-projection display system. The display surface is a spherical section with a radius of 3.7 m. Five CRT projectors are used to form the driving scene on the display surface. There are three projectors used for the forward field-of-view covering 180° x 39° and two rear projectors covering 120° x 29°. A PC-based image generator running at a fixed 60-Hz rate drives each visual channel. Each channel has a resolution of 1600x1200 pixels.

Figure 1. Ford's VIRTTEX driving simulator.

Common methodology for both studies

The drive for each study took place on a simulated section of a US interstate during daytime conditions. The road consisted of two 12-ft (3.7-m) lanes in each direction separated by a median. Fast-moving, overtaking traffic was present, and opposing traffic did not interact with the driver. Traffic density was moderate.

Drivers were given training and instructions before they entered VIRTTEX for their drive. Their primary task was to drive safely at 60-70 mph (96-112 kph) and to stay in the right lane for the entire drive. They were also given a ruse for the study purpose: drivers were told that the vehicle was equipped with a Lane-Keeping Aid (LKA) system and that the purpose of the study was to evaluate lane-keeping performance with the LKA system on versus off. The system might or might not be on during their drive. This ruse provided a reason for the drivers to participate in the experiment without telling them that one of the main purposes was to study driver reaction to a surprise FCW event. The ruse also provided drivers a compelling reason to carry out the secondary task: drivers were prompted throughout the drive to read back a sequence of 6 numbers appearing on a display located near the front of the passenger seat (Figure 2). The display was down and to the right of the driver's forward view, and was sufficient to make the driver visually distracted from the forward view. Note that the down angle involved in the distraction task (approximately 45 degrees) is outside of the Alliance of Automobile Manufacturers guidelines on the placement of telematics devices, so the results of this study cannot be used to make any inferences about the safety of glances to OEM-installed devices that comply with the guidelines. Instead, it is meant to model a distraction caused by something the driver has brought to the vehicle, such as a mobile phone, portable music player or other nomadic device.

Each number was displayed for 0.5 seconds, and the driver's task was to verbally read back the numbers as they were being displayed. In order to motivate drivers to complete the 3-second task, they were told that they would be graded on the sequence's correctness. The reason for using a distraction task of this duration is that glances away from the forward view for more than two seconds increases near-crash/crash risk by at least two times that of normal baseline driving [16].

Figure 2. Location of number display for secondary task.

Data collection

Relevant vehicle and experimental objective data was collected at 200Hz and is listed in Table 2. Four video channels were also recorded, capturing the forward view of the driving scene, the view of the driver from passenger side B-pillar, the view of the driver's face from the rear-view mirror perspective, and the view of the foot well (including the accelerator and brake pedals).

Table 2.
Relevant objective data collected for the experiments

Vehicle Parameters	– Steering angle – Lane position – Accelerator pedal position – Vehicle acceleration – Brake pressure
Experiment parameters	– FCW state (on/off) – Lead car position – State of the distraction task

FCW types

Drivers experienced a surprise FCW event at the end of their drive. Each driver was exposed to one of 3 different FCW types:

- **FCW_1**: Abstract warning with combined visual and audio presentation
- **FCW_2**: Abstract warning with haptic presentation
- **FCW_3**: Verbal warning with combined visual and audio presentation

For clarity, the FCW_1 system used in the study was not the same system as the Collision Warning system launched in the Volvo S80 MY2007. Note also that the downward angle for the distraction task in the study is on the limits for upward peripheral vision in relation to the visual presentation for FCW_1, so drivers responses to FCW_1 were most likely primarily driven by the sound rather than the light presentation.

Study design

A factor in both experiments was whether the secondary task occurred during the FCW event. In this paper, only those drivers with the secondary task during the FCW event (i.e., only distracted drivers) are considered. The main differences between the experiments were the distance to the lead vehicle during the FCW event, and the driver's interaction with other warnings prior to the FCW event. In both experiments, drivers were not told about the FCW warning prior to or during their drive.

Experiment 1 - Thirty-eight drivers balanced across gender and age (25-45 years old, and 50+ years old) participated. Additional training for this experiment included a description of an Adaptive Cruise Control (ACC) system. None of the drivers had previous experience with ACC systems so there were not any expectations on how the system should perform. Drivers were instructed how to activate and use the ACC system in order to reduce their workload.

Each drive lasted approximately 20 minutes. Shortly after the driver reached a speed of 65-70 mph, a vehicle (the lead vehicle) passed and pulled in front of the driver. The driver then activated the ACC system, with the lead vehicle speed varying between 60-65 mph. Experimentally, the ACC system was used in order to control the headway between the driver and the lead vehicle. Drivers practiced the secondary task at least two times in order to familiarize themselves with the task in the vehicle. After the driver was comfortable with driving (approximately 5 minutes into their drive), the secondary task was automatically activated at random intervals, uniformly distributed between 15-45 seconds.

After 22 secondary tasks, the driver experienced a surprise FCW event. With the lead vehicle traveling at 65 mph (105 kph) and positioned approximately 250 ft (76 m) in front of the driver's vehicle, the lead vehicle decelerated at 0.7 G for 4.0 seconds. This event occurred approximately 1 second into the secondary task so that the drivers were visually distracted. The ACC braking authority and warning were deactivated so that the only warning the driver experienced was one of the FCWs. The thirty-eight drivers were divided into groups that received FCW_1 (12 drivers), FCW_2 (12 drivers), or FCW_3 (14 drivers).

Experiment 2 - Forty-eight drivers balanced across gender and age (25-45 years old, and 50+ years old) participated. Two main aspects of Experiment 1 were changed for Experiment 2. First, drivers experienced a number of Lane Departure Warnings (LDW) throughout their drive. Secondly, the behaviour of the lead vehicle was modified in order to reduce the headway for the surprise FCW event. Drivers were told in their training that the vehicle was equipped with LDW and that they would be evaluating four different warning conditions during the drive. (Three conditions were abstract warnings with either audio or haptic presentation, and these were different from the FCWs. An additional condition was no LDW.) The ACC system was neither discussed nor used in this experiment.

Each drive lasted approximately 30 minutes. Approximately 2-3 minutes after the driver reached a speed of 65-70 mph, they practiced the secondary task at least two times to familiarize themselves with the task. The secondary task was then activated at random intervals, uniformly distributed between 15-45 seconds. Drivers experienced one of the four LDW conditions during different 6-minute segments of their drive. Each LDW condition was demonstrated at the beginning of each segment by having the driver exceed their lane boundaries. For each LDW-partitioned segment of the drive, each driver experienced:

- One true-positive warning (demonstration of LDW type)
- One true-positive distracted warning (forced lane deviation)
- One false-positive alert warning
- One false-positive distracted warning
- Five distraction foils (secondary task with no LDW)

A unique motion control strategy was developed to produce a forced lane departure. The forced lane departure was generated by adding a small yaw deviation sequence to the vehicle dynamics model. This modified vehicle dynamics information was sent to everything except the motion control algorithm. The driver appeared to be departing the lane visually, yet the driver did not experience any perceptible motion cues from the yawing. The strategy worked well for a drowsy driver experiment [17], and is described in more detail in [18].

After 36 events (the 9 events listed above for each of the four LDW conditions), the driver experienced a surprise FCW event. A vehicle passed the driver in the left lane and slowed slightly to match the driver's speed at approximately 130 ft (27 m) down the road from the driver. The lead vehicle instantaneously changed lanes into the right lane (driver's lane) when the first number of the secondary task was displayed. The lead vehicle then decelerated 0.5 seconds later (0.5 G for 3.0 seconds), activating a FCW while the drivers were visually distracted. Thirty-six of the 48 drivers were divided into groups which received FCW_1 (12 drivers), FCW_2 (12 drivers), or FCW_3 (12 drivers). An additional 12 drivers did not receive a FCW.

RESULTS

One of the main performance measures for both experiments was the driver's brake reaction time, defined as the time from the start of the FCW to brake onset. Using the definition in [19], brake onset was defined as the time at which the vehicle began to slow as a result of braking. Based on manual analysis of a portion of the data set, brake onset was defined as 124 ms prior to the vehicle crossing the 0.10 G deceleration level. Brake reaction times were statistically analyzed using a General Linear Model in MINITAB® [20] with age, gender, and FCW type as factors.

Another performance measure for both experiments was drivers' interpretation of the warning. One question in the post-drive questionnaire asked drivers to classify their reaction to the warning. The three categories presented in the results below are:

A: Driver did not notice the warning

B: Driver noticed the warning, but did not know what to do, or did not use it as a warning

C: Driver noticed the warning and reacted by braking and/or steering

Experiment 1

Figure 3 shows brake reaction time (RT) as a function of FCW condition for Experiment 1. The solid line indicates the average reaction times. Onset for displaying the last number in the secondary task varied between 1-1.5 seconds.

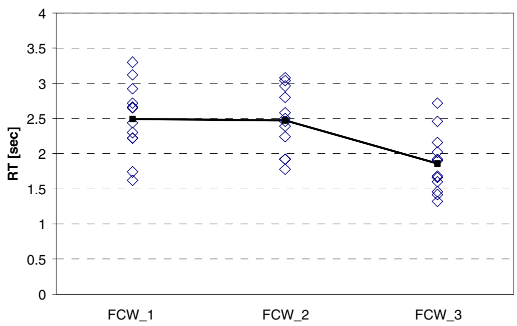

Figure 3. Brake reaction time as a function of FCW condition for Experiment 1. The solid line indicates the average reaction times.

Analysis of the recorded videos provided interesting information on drivers' reaction to the FCWs:

- FCW_1:
  - Five drivers read all numbers and did not look up.
  - Five drivers read some numbers, glanced up and then back down, and continued to read.
  - Two drivers looked up and braked.
- FCW_2:
  - Five drivers read all numbers and did not look up.
  - Five drivers read some numbers, glanced up and then back down, and continued to read.
  - Two drivers looked up and braked.
- FCW_3:
  - One driver read all numbers and did not look up.
  - Thirteen drivers looked up and braked.

In summary, the video analysis shows that the abstract warnings FCW_1 and FCW_2 were partially effective in diverting driver attention from the secondary task, since 14 of 24 drivers did look up. However, only 4 of these 14 braked. The verbal warning of FCW_3 was quite effective in diverting driver attention from the secondary task, since 13 of 14 drivers did look up and braked.

Figure 4 shows results from classifying driver interpretation of their FCW. The percentage of drivers claiming to notice the warning and react by braking and/or steering was much less for FCW_1 (50%) or FCW_2 (25%) compared to FCW_3 (71%). These results generally support the brake reaction times shown in Figure 3. However, the results in Figure 3 suggest that even fewer drivers noticed the warning and reacted by braking and/or steering for FCW_1 or FCW_2. It is possible that when filling out the questionnaire, drivers did not want to admit to not using the FCW as an appropriate warning.

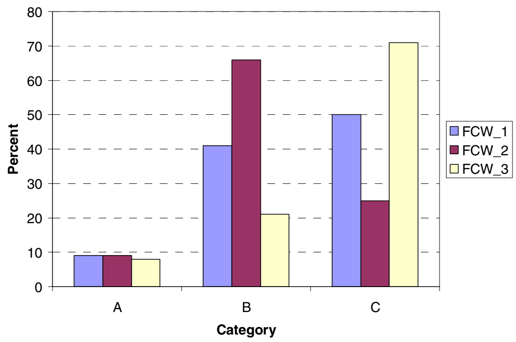

Figure 4. Driver interpretation of FCWs for Experiment 1.

Experiment 2

In Experiment 2, almost all drivers reacted to the FCW prior to the display of the last number in the secondary task. Only three drivers did not (two for FCW_1 and one for FCW_3), which is significantly less than in Experiment 1. This means that in the setup of Experiment 2, all three FCWs were effective in diverting driver attention from the secondary task to the forward driving view. Moreover, all the drivers who looked up gave a braking response to the imminent driving situation of Experiment 2.

Figure 5 shows brake reaction time as a function of FCW condition for Experiment 2. The solid line indicates the average reaction times. Onset for displaying the last number in the secondary task occurred at 2 seconds. Statistical analysis shows reaction times for the FCWs are not significantly different from each other, but all are significantly different from reaction times for the 'No FCW' condition ($p < 0.05$). In fact, the FCWs reduced reaction time by approximately 0.7 seconds compared to the 'No FCW' condition.

The reaction times for those receiving a FCW are also in agreement with the general classification given in [21] – reaction time is approximately 1.5 seconds for "surprised" drivers that are both unaware of the warning and unaware of the event. (The average reaction time for FCW_1 decreases from 1.85 seconds to 1.57 seconds after removing the two drivers that did not react to the FCW.)

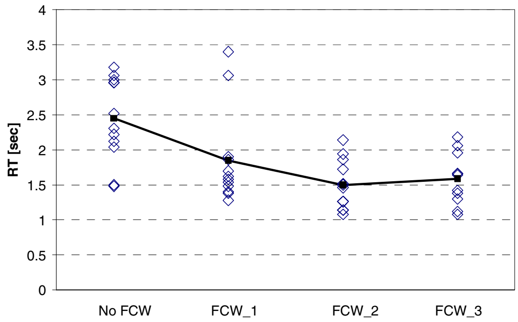

Figure 5. Brake reaction time as a function of FCW condition for Experiment 2. The solid line indicates the average reaction times.

Figure 6 shows results from classifying driver interpretation of their FCW. All of the drivers claimed to have noticed the FCW, and a majority of the drivers receiving each FCW claimed to react by braking and/or steering. These results generally support the brake reaction times shown in Figure 5.

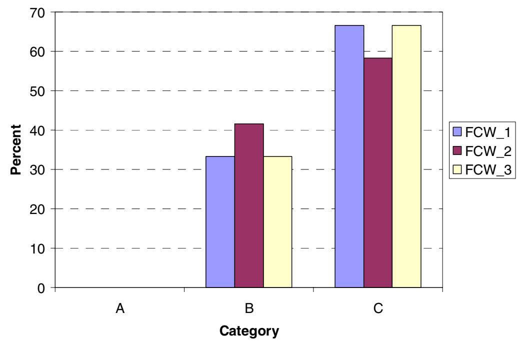

Figure 6. Driver interpretation of FCWs for Experiment 2.

Study comparisons

The results show that driver reaction to the FCWs depended on their degree of previous exposure to warnings, the type of warning, as well as the perceived level of imminent threat in the experimental situation. All FCWs succeeded in diverting drivers' attention from the secondary task to the forward road way. For the drivers in Experiment 2, this effect was almost uniform. This is likely due to these drivers previous exposure to a number of LDWs, which taught them that the vehicle can provide situational warnings, as well as trained them to respond to these warnings.

In Experiment 1, the FCWs success in diverting driver attention to the forward roadway was less pronounced. In particular, some drivers did not react to the abstract warnings (FCW_1 and FCW_2). This lack of reaction is likely a result of these drivers previous lack of exposure to warnings, i.e. not knowing what the abstract warning indicates, in combination with the very demanding nature of the secondary task. Since the secondary task was short in duration, not self paced and performance graded, drivers likely gave it very high priority at the expense of the primary driving task.

When it comes to the differences in braking responses, the more imminent FCW event in the second experiment (vehicle cut-in with 1-second headway) likely explains some of the improved braking performance in Experiment 2. Several drivers experiencing the abstract warnings in Experiment 1 (10 of 24) read some numbers, glanced up and then back down, and continued to read. Very few, if any, did this in Experiment 2. It is likely that the reduced headway in Experiment 2 (27 meters instead of 76) made up for the lack of realistic brakelight brightness in the simulated environment, and drivers perceived the FCW event in Experiment 2 as much more imminent than the event in Experiment 1.

An interesting exception to the differences between Experiment 1 and 2 in diverting attention from the secondary task and triggering a brake response is the verbal warning of FCW_3, to which drivers gave a braking response regardless of previous warning exposure and perceived level of imminent threat in the situation. It seems that the actual words spoken in a warning can trigger a driver reaction regardless of previous exposure to warnings and perceived level of threat in the imminent situation.

DISCUSSION

In this study one can say that the drivers' exposure to warnings was pushed to the endpoints of what could be called a frequency of interaction scale. One group had no warning knowledge at all prior to the FCW event, whereas the other group experienced many LDWs just prior to the FCW event. These two groups therefore represent the endpoints of such an interaction scale rather than normal use cases. Neither group reflects the type of interaction one would see in a production vehicle equipped with a FCW system, and also the study as performed in a simulator does not provide correct environmental and dynamic conditions for the driver. These things have to be accounted for when judging the results of the study.

Keeping that in mind, the results indicate a difference in performance between the drivers who had no previous knowledge of warnings which the vehicle could provide and the drivers who had practiced with LDWs several times during their drive before the FCW event. The trained drivers, i.e. those who had practiced warning interaction with LDWs prior to the FCW event, responded to all FCW types, and reacted significantly faster than the baseline drivers, which indicates that FCW has a good potential to reduce the number of forward collisions.

Reactions for the untrained drivers, i.e. those who were neither informed about warnings nor had practiced any warning interaction prior to the FCW event can be split in two groups. Most of the untrained drivers who received abstract warnings did respond to the FCW as intended by looking up. This is very promising. Interactions which are rare or occur for the first time place high demands on the user when it comes to situation recognition as well as transparency of prompted action(s), at least if compared to interactions which occur on a regular basis. In this regard, the drivers with no previous exposure to warnings were put in an extreme situation in this study, and yet most of them responded as intended to the abstract warnings.

Only a few of the untrained drivers braked, but as mentioned before, the lack of braking response is likely due the scenario in Experiment 1 not being perceived as immediately threatening.

Then there is the smaller group of untrained drivers which did not respond to the abstract warnings they received. This lack of reaction is not very surprising. If the driver neither knows that the vehicle has a warning capability nor what that warning indicates, then not reacting when the warning goes off is reasonable. This is even more so if the driver simultaneously is occupied with a demanding secondary task. The intensity levels in the abstract warnings given were not sufficient to "break through" to these drivers.

This difference between the trained and untrained drivers, i.e. the partial lack of response for the untrained drivers, still points toward a number of interesting questions and suggestions for future research. If these findings are corroborated in further studies, it would seem that future HMI studies of warning efficiency can benefit from adapting drivers' pre-event warning exposure to reflect a predicted normal frequency of warning interaction.

Moreover, the efficiency for one warning type seems to be influenced by the presence of other warnings. If a vehicle provides frequent warning interactions, the study seems to indicate that these can train the driver to react to warnings, which in turn influences reactions to less frequent warnings in a positive way. As this training effect probably depends on the alarms being mostly true positives, i.e. that they represent an actual threat situation, there may exist a negative training effect as well, i.e. many false warnings from one system would train the driver to ignore warnings from other systems. Evaluations of HMI efficiency for one warning type can therefore benefit from a complementary integrated evaluation with other warning HMIs to take learning transfer effects into account.

Also, results seem to indicate that HMIs which place themselves toward the lower end of a frequency of interaction scale may benefit from a different design compared to HMIs which are used on a more regular basis, by either increased intensity or a change of modality for rare warnings. The latter thought comes from the results for the group of drivers who were untrained but nevertheless reacted well to the verbal warning. It is possible that people act more immediately to verbal than abstract warnings for novel or rare situations unless the abstract warning provides transparency similar to the verbal warning, letting the driver interpret and react to the abstract warning just as instinctively. If these results are confirmed by future studies for English and other languages, then spoken warnings would seem an interesting HMI option for systems with low frequency of use.

However, since the results from Experiment 1 indicates that it is the content of the verbal warning rather than the driving situation at hand which triggers the driver's response, *extreme caution* would have to be exercised in issuing verbal warnings in order not to trigger an inadequate driver response to the imminent situation (such as braking when steering would have been more appropriate for example). A profound, real time understanding of the dynamic driving situation would therefore be a necessary prerequisite of verbal warnings. Also, language localisation must be dealt with as well as ways of determining that the current driver and the vehicle speak the same language.

The driver training achieved through warnings with frequent interaction could possibly also be attained through other means. For example, information about a vehicle's warning capabilities, including warning displays, could be given to the driver in the vehicle at regular intervals in form of a demonstration which plays on an in-vehicle display before start-up.

CONCLUSIONS

The results of the studies show that reactions to the FCW HMI partially depended on drivers' degree of previous exposure to warnings as well as the type of warning. Therefore, to achieve high validity in HMI evaluations, studies can benefit from exposing drivers to warnings in a way that reflects their normal warning awareness from real life driving. It also means that there are possibilities for developers to tailor HMI design for frequency of use. The means for doing this include possibilities such as verbal warnings, maintaining warning awareness through regular demos, and achieving a transfer of training effects by harmonising HMI development between HMIs with high and low frequency of use.

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