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Familiarization with a Forward Collision Warning on driving simulator: cost and benefit on driver-system interactions and trust

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Abstract - *Introducing Advanced Driver Assistance Systems (ADAS) into the vehicle could improve drivers' comfort and reduce road crashes. However, suitable methods are required to study driver/system interactions. In fact, ADAS generate critical use cases, i.e. situations where alarms, or absence of alarms, can be negative for safety. The present study aimed at evaluating the impact of getting familiar, by means of a driving simulator, with critical situations when using the Forward Collision Warning system (FCW). We hypothesized that experiencing the system's function in critical situations would improve drivers' performance and their trust in the FCW. We compared judgments and driving performance of three independent groups: a "control group" where drivers did not use the FCW, an "unfamiliarized group" where drivers used the FCW without having been familiarized with the system, and a "familiarized group" where drivers used the FCW after having been familiarized. Results showed that familiarization made driver/system interactions more effective and safer. Moreover, familiarized drivers rated the system more positively than unfamiliarized drivers. However, familiarization decreased drivers' self-confidence and did not prevent from haste when overtaking slow vehicles. We discussed the relevance of using a driving simulator in FCW's studies and the possibility to transfer skills and knowledge to field operational tests. Finally, we proposed possible improvements to make the familiarization with the system still more effective.*

Résumé - *Introduire des systèmes avancés d'aide au conducteur dans le véhicule pourrait augmenter le confort des conducteurs et réduire le nombre d'accidents. Toutefois, des méthodes d'évaluations adaptées sont nécessaires à l'étude des interactions conducteur/système. Les systèmes d'aide génèrent effectivement des cas d'usage critiques, i.e. des situations où les alertes, ou*

l'absence d'alertes, peuvent être négatives pour la sécurité. L'objectif de la recherche était d'évaluer l'impact de la familiarisation avec les cas critiques d'usage du Forward Collision Warning (FCW) sur simulateur de conduite. Nous avons testé l'hypothèse selon laquelle l'expérience du fonctionnement du FCW dans des situations critiques d'usage augmente la performance de conduite et la confiance des conducteurs dans le système. Nous avons comparé les jugements et la performance de conduite de trois groupes expérimentaux : un groupe contrôle où les conducteurs n'utilisaient pas le FCW, un groupe « non familiarisé » où les conducteurs utilisaient le système sans avoir été familiarisés et un groupe « familiarisé » où les conducteurs utilisaient le système après avoir été familiarisés. Les résultats montrent que la familiarisation rend les interactions conducteur/système plus efficaces et plus sûres. Par ailleurs, les conducteurs familiarisés ont des opinions plus positives sur le FCW comparé aux non familiarisés. Néanmoins, la familiarisation diminue la confiance des participants dans leur capacité de conduite. De plus, elle ne permet pas d'éviter que les conducteurs dépassent de façon trop précipitée les véhicules lents. Nous discutons la pertinence du simulateur pour l'étude du FCW et la possibilité de transfert des connaissances à la conduite sur route réelle. Finalement, nous proposons des améliorations pour rendre la familiarisation avec le système plus efficace.

Introduction

The present study forms part of the French MATISS project (Advanced Modeling of Interactive Simulation Techniques for Safety), which objective is to implement valid methodologies to study Advanced Driver Assistance Systems (ADAS) on driving simulators. Introducing ADAS technologies is a major challenge for road safety. In particular, warning devices could help drivers to avoid or limit the impact of a large number of accidents. However, using automation involves behavioral changes which may lead to unsuitable reaction, annoyance, distraction, overreliance, or attentional overload (e.g. Bainbridge, 1987; Kantowitz, 2000; Parasuraman & Riley, 1997). The development of ADAS therefore requires suitable methods to study driver/system cooperation so that their interactions are not negative for road safety.

The Forward Collision Warning system (FCW) well illustrates this point. The system aims at informing drivers of the critical decrease in the distance headway. The FCW has thus a potentially important safety benefit since one accident out of four is a rear-end collision where drivers were distracted. However, drivers are reluctant to use the system because it fails to provide precise information in many occasions. For example, FCW often generates nuisance alarms (NAs) – i.e. alarms triggered by events that do not pose a threat to the drivers (cf. Zador, Krawchuk, & Vaos, 2000). This is typically the case when the lead vehicle slows down in order to change direction or when the driver prepares to overtake another vehicle (e.g. LeBlanc, Eby, Bareket, & Vivoda, 2008). NAs may annoy drivers and lead to inappropriate reactions. On the other hand, some alarms are intentionally suppressed to limit false alarms – i.e. alarms triggered in absence of danger. For

instance, the FCW tested by General Motor Corporation (GMC, 2005) did not trigger alarms when it detects fixed targets because they usually correspond to objects out of the road (e.g. road signs). Furthermore, the system was unavailable below a minimum speed of 50 km/h which usually corresponds to situations where irrelevant targets are numerous (e.g. urban areas, traffic congestion). In addition, the FCW did not trigger alarms when it detects vehicles that do not move in the same direction as the equipped-car since they usually correspond to oncoming vehicles on adjacent lanes or stopping at junctions. However, alarm suppression may delay drivers' reactions and decrease the perceived effectiveness of the system (Parasuraman, 2000).

When using FCW, drivers must adjust their response according to the situation rather than react stereotypically. Consequently, drivers have difficulty to trust the FCW (i.e. to determine whether the system will help them identify hazards in situations characterized by uncertainty and vulnerability, cf. Bliss & Acton, 2003), making less effective drivers/system interactions. Field Operational Test studies (FOT) – where the accuracy of instructions and training are vital – suggested that detailed description of the system's function and training in normal operating situations are not enough for the driver to trust the system (e.g. GMC, 2005; Portouli & Papakostopoulos, 2006; Regan *et al.*, 2006; LeBlanc *et al.*, 2008). GMC (2005) noted that drivers appeared to "probe" the FCW function in extreme conditions to better understand its capabilities and limitations. In the same vein, Cahour and Forzy (2009) assumed that the projection into the use of a cruise control system improves trust and exploration of the device. The authors found that drivers knew more, produced less distorted reconstruction, and had a deeper level of understanding of the system's function after watching video recordings of critical situations than after reading written instructions. Thus, driving simulator studies may be helpful in experiencing such informative-critical situations in safe conditions.

The present research aims at evaluating the impact of the familiarization with some use cases of the FCW on drivers' behavior and trust in the system. We hypothesized that the knowledge of the system's function in critical situations would improve the performance of drivers who use the FCW compared to those who drive without. Furthermore, we expected that drivers' performance and trust in the system would increase more when this knowledge is acquired by practice than by reading a detailed description.

Method

Participants

Twenty nine drivers took part in the experiment (21 males, 8 females). Participants were distributed into three independent groups. In a "control group" (10 drivers; mean age = 38.6 years; SD = 10.88), drivers were not familiar and did not use the FCW during the experiment. In an "unfamiliarized group" (12 drivers; mean age = 41.95 years; SD = 9.2), drivers used the FCW without being familiar with the system. In a "familiarized group" (7 drivers; mean age = 43.1 years; SD = 9.5), drivers used the FCW after being familiarized. Participants had more than 5

years of driving experience and drove more than 10 000 km per year. Statistical analyses showed no difference in age and driving experience between groups.

Apparatus

The experiment was performed on the CARDS2 simulator at RENAULT-Technical Center for Simulation (Guyancourt, France). The simulator cockpit was equipped with a fully functional car dashboard, with force feedback steering wheel, clutch, brake and gas pedal, manual gear lever, and dashboard indicators. The simulator was mounted on a 6-DOF hexapod motion platform, allowing a displacement of ± 20 cm and a rotation of $\pm 20^\circ$. The image was projected on three screens in front of the cabin, providing a visual angle of 150° horizontally and 40° vertically. The rear image was displayed on two LCD screens located in the rear-view mirrors; the image of the inside mirror was incrustated in the front view.

Two additional screens were specifically added for this experiment (Fig.1.): one behind the steering wheel, to display the FCW system interface, and another one on the dashboard, above the gear lever, to display the secondary task interface. A small keyboard was fixed behind the gear lever, in order to interact with the secondary task

The motion platform was deactivated for this experiment. Hexapod motion platforms provide insufficient perception of longitudinal accelerations, especially during braking (Nordmark, Jansson, Palmkvist, & Sehammar, 2004). As time-to-collision perception involves mostly visual components (McLeod & Ross, 1983), it was expected for the present experiment that motion rendering would not provide a crucial cue.



Figure 1. Illustration of simulator setup, showing the FCW system displaying an alarm (red bar) and the secondary task interface (on the bottom right)

The FCW issued a single visual-plus-tone alert when the distance from the lead vehicle became too short to avoid a collision. The timing was determined by the ISO-recognized Stop-Distance-Algorithm (ISO 15632) defined as following:

$$Dw = V_l \times RT + V_f^2 / (2 \times D_f) - V_l^2 / (2 \times D_l),$$

where Dw (m) is the warning distance, V_f (m/s) the speed of following driver, V_l (m/s) the speed of leading vehicle, D_f (m/s²) the assumed deceleration of the following vehicle, D_l (m/s²) the assumed deceleration of the leading vehicle, and RT is the assumed driver's reaction time to an event. The RT value was fixed at 1.25 s, whereas D_l and D_f were fixed at 5 m/s².

The visual interface consisted of a light bar which could be presented in three states: (1) it was yellow below 50km/h when the system was inactive, (2) green above 50 km/h when the system was active, and (3) red when the distance from the lead vehicle became less than the warning distance. A three-bip-tone sounded when the bar changed from green to red; the bar remained red as long as the distance was too short.

The distractive task (Fig. 2.) consisted of locating a target circle (150 mm in diameter, 4 mm in thickness) among 35 distractors (125 mm in diameter, 3 mm in thickness).

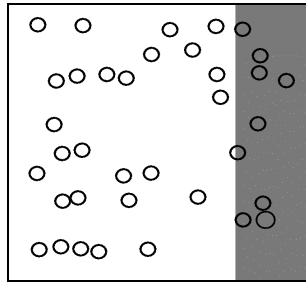


Figure 2. Schematic representation of the distractive task: participants selected the target zone by moving the grey bar

The participants selected the target zone by pressing two keys which moved a grey vertical bar. The task ended when they pressed a validation key that switched off the device. A new task started when the experimenter switched on the device.

Design and procedure

The experiment consisted in three sessions: a practice, a familiarization, and a test session. In the practice session, participants were familiarized with the simulator. They drove on a dual carriageway without traffic during 10 min. Then, they practiced the distractive task while following a car.

In the familiarization session, familiarized and unfamiliarized drivers started with reading written instructions about the FCW's functioning. This note specified the different states of the system (unavailable below 50 km/h, available above 50 km/h) and some critical use cases (no detection of vehicles which are stopped, or vehicles that have a differential speed greater than 70 km/h, or those that are

moving in a different direction than the driver). Then, all drivers interacted with traffic in two 8 min runs: the first one in which they were accompanied by the experimenter, who explained how to perform in the encountered situations, and the other one alone. Because control and unfamiliarized drivers did not use the FCW, the session was presented as making them familiar with the virtual environment. For familiarized drivers, the session aimed at becoming familiar with the FCW. All participants experienced situations where the FCW did not give a warning, i.e. they encountered a parked vehicle, a vehicle which started slowly in front of the driver, and an oncoming vehicle in a bend. They also experienced situations that triggered relevant alarms, i.e. they faced a lead vehicle stopping by an emergency braking (-5 m/s^2). Then, participants encountered situations likely to produce nuisance alarms, i.e. they faced a lead vehicle slowing down smoothly (-2 m/s^2). The run ended when the participants overtook a slow vehicle that triggered a nuisance alarm. Additionally, familiarized drivers tested freely the FCW by accelerating and slowing down while the lead vehicle moved at a constant speed of 90 km/h. After the drive, participants filled out a self-assessment questionnaire about their driving (self-confidence and self-performance). In addition, familiarized and unfamiliarized drivers filled out a questionnaire about the FCW (trust, performance, and acceptance). The total familiarization session lasted 20 to 25 min.

In the test session, participants were asked to drive a round trip on a rural dual carriageway. They were asked to maintain a speed of 90 km/h while doing the distractive task as fast as possible. However, safety remained their priority, i.e. they could neglect the distractive task if the situation required their attention. They encountered five types of events counterbalanced between the way there and the return. In two "junction scenarios", alarm was not triggered by a vehicle crossing the junction at 3 s from the drivers. In two "merging scenarios", alarms were triggered by a vehicle merging into the lane in front of the driver at a time headway of 1 s. Drivers were not necessarily required to brake to avoid a collision. In two "overtaking scenarios", alarms were triggered when drivers overtook a heavy vehicle moving at 70 km/h. In two "relevant scenarios", alarms were triggered by the lead vehicle braking (-3 m/s^2). In two "annoying scenarios", alarms were triggered by events which presented the same kinematics than "relevant scenarios", except that the lead vehicle activated the indicator 5 s before turning. Drivers could thus avoid a collision without braking if they started slowing down at the time the lead vehicle signaled its intention to turn. The test session ended with an "emergency scenario" where an alarm was triggered by an emergency braking vehicle (-5 m/s^2).

The distractive task started 1.5 s before the beginning of the scenarios, in such a way that drivers were always distracted when a danger occurred. To limit the task/event association, 9 distractive tasks were randomly assigned between events.

After the drive, participants again filled out self-assessment questionnaires (self-confidence and self-performance). In addition, familiarized and unfamiliarized drivers were asked to fill out questionnaires with regard to the FCW (trust, performance, mental effort, and acceptance). The total test session lasted about 65 min.

Results and discussion

Behavioral changes

Globally, FCW users (familiarized and unfamiliarized drivers) released accelerator or applied brake faster than control drivers ($F(2,425) = 31.25$; $p < .000$). However, only familiarized drivers kept longer time headways before the beginning of the scenarios ($F(2,16217) = 59.37$; $p < .000$), i.e. they gained time to react even when the FCW could inform them at the time they were distracted. These results are shown in Figures 3a and 3b.

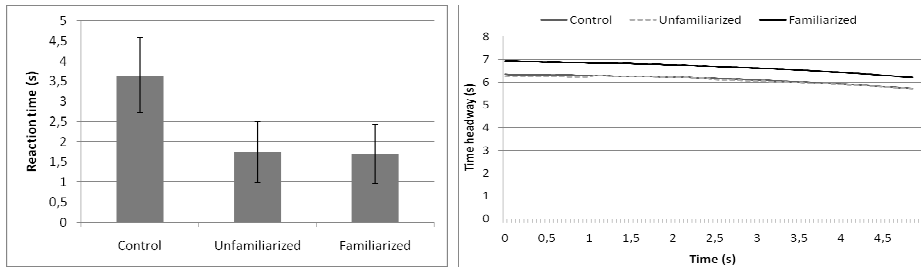


Figure 3. (a) Reaction time; (b) Time headway for 5 s before the beginning of scenarios

Between the onset of the scenario and the end of alarms (or when the vehicle left the driver's lane in junction scenarios), mean safety margin was higher ($F(2,30059) = 39.77$; $p < .000$) whereas mean deceleration was lower ($F(2,31417) = 171.7$; $p < .000$) for familiarized than for unfamiliarized drivers. This behavior obviously led to safer driving. In particular, familiarized drivers had no collisions whereas unfamiliarized (20%) and control drivers (40%) collided in the emergency scenario. These results are shown in Figures 4a and 4b.

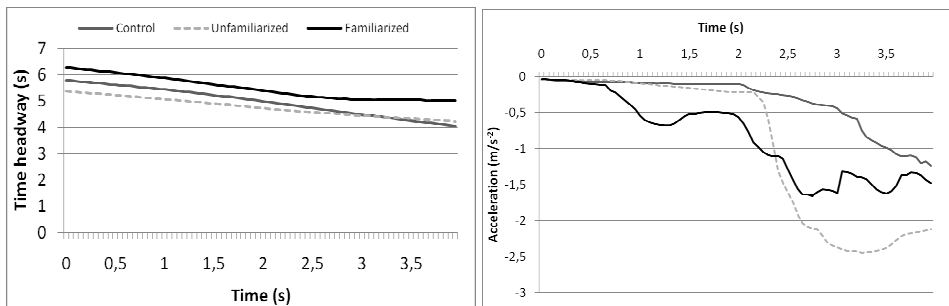


Figure 4. (a) Time headway for 4 s after the scenario started; (b) Deceleration for 4 s after the scenario started

Moreover, FCW users released the accelerator more often than control drivers before the lateral vehicle started crossing their lane in junction scenarios ($\chi^2 = 4.46$; $p < .04$). Alarm suppression thus led drivers to better anticipate this event.

There was no particular change in behavior amongst drivers in relevant and annoying scenarios. In fact, only 20% of the participants released the accelerator before the alert was triggered in annoying scenarios, i.e. few drivers slowed down when the lead vehicle activated the indicator. Because drivers were distracted, we suppose that they had difficulty in anticipating the lead vehicle's braking, thus making alarms relevant.

FCW led to negative effects for safety in overtaking scenarios, since FCW users spent less time behind the vehicle they overtook than control drivers ($F(2,10369) = 333.88$; $p < .000$). They changed lane about 6 s after the alert began whereas control drivers changed lane after 15.77 s. Hurry in overtaking maneuvers decreases the time to seek for oncoming traffic (e.g. Wilson & Best, 1982). Being familiar with the FCW did not prevent unsafe precipitation of the maneuver.

In merging scenarios, most of control drivers (60%) did not react when the vehicle merged into their lane whereas most of familiarized (82%) and unfamiliarized drivers (72%) released the accelerator or broke (respectively, $\chi^2_1 = 6.12$; $p < .02$; $\chi^2_1 = 5.82$; $p < .02$). However, deceleration was smoother for familiarized than for unfamiliarized or control drivers ($F(2,1783) = 58.3$; $p < .000$), i.e. being familiarized reduced reaction intensity. Alarms clearly elicited a reaction, but deceleration (between -0.06 and -0.16m/s^2) was not likely to create a threat, even when another vehicle followed closely FCW users.

Subjective changes

Concerning the drivers' self-assessment (Fig. 5a), familiarized and unfamiliarized drivers were prone to find scenarios easier to manage than did control drivers (respectively, $t(14) = 2.01$; $p = .063$ and $t(20) = 2.84$; $p < .01$). However, familiarized drivers were less confident in their driving performance (Fig. 5b) than unfamiliarized and control drivers after the familiarization session (respectively $t(15) = 2.16$; $p < .046$ and $t(14) = 3.24$, $p < .005$) or the test session (respectively, $t(15) = 2.01$; $p = .062$ and $t(14) = 3.39$; $p < .04$).

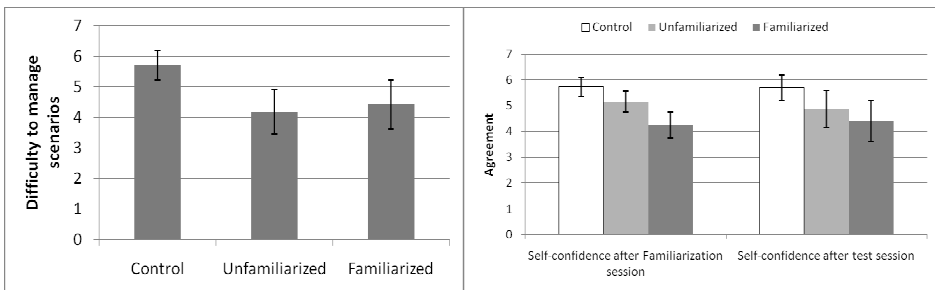


Figure 5. (a) Rating of difficulty to manage scenarios; (b) Rating of self-confidence after familiarization and test session

This result was expected since the presentation of negative aspects of the system may undermine trust and confidence (Cahour & Forzy, 2009). Also, it is

consistent with Ivancic & Hesketh (2000), who found that “error training” improved driving skills but decreased drivers’ self-confidence. In fact, the familiarization session may have amounted to error training since drivers learned how to deal with the error-prone FCW by reacting/not reacting when an alarm was present/absent. Nevertheless, the decrease in self-confidence is likely to explain that familiarized drivers kept longer time headways and adopted safer behaviors. Actually, familiarized drivers did not estimate that the mental effort was higher than unfamiliarized drivers. On the contrary, they found that the frequency of alarms was not higher than necessary whereas unfamiliarized drivers found that it was slightly too high ($t(16) = 2.2$; $p < .042$). Moreover, familiarized tended to rate the system more useful ($t(16) = 1.98$; $p = .063$), less frustrating ($t(15) = 1.95$; $p = .069$) and were willing to pay more to buy the system ($t(14) = 2.03$; $p = .061$). These results suggest that being familiar with the FCW was likely to have a positive influence on drivers’ trust. However, acceptance did not differ between groups; acceptance increased after the test session and utility became greater than satisfaction ($F(3,45) = 19.79$; $p < .000$).

Conclusions

FOT studies showed that drivers understood and used better ADAS after probing them in extreme conditions or after being projected into critical situations (cf. GMC, 2005; Cahour & Forzy, 2009). Our findings extended these results to a driving simulator where experiencing critical situations proved to be very relevant for the study of the FCW. First, the familiarization with critical use cases made driver/system interactions more effective and safer. Familiarization had also a positive influence on subjective rating of the system. Changes in behavior and subjective rating were more positive when drivers experienced situations than when they read written description. Thus, a preliminary handling of the system on a driving simulator could be useful in FOT where instructive situations are constrained by the unfolding events or self-created by the drivers. Driving simulators provide the opportunity to create situations where drivers can probe efficiently the capacities and the limitations of the FCW without taking risks. Short- and long-term effects of the knowledge transfer from simulator to real world would be interesting to investigate.

Regarding future applications, the familiarization session could be further improved to make it more effective. For example, our study showed that the FCW encouraged the drivers to escape too quickly from the warning zone indicated when they prepared to overtake a vehicle. A familiarization focused on this use case could counteract its negative effect for safety. Familiarization with the FCW also appeared to decrease drivers’ self-confidence. Further research should determine the real impact of this effect on the behavior adopted by familiarized drivers.

Lastly, our driving simulator study showed that FCW users were more careful towards dangers that were not indicated. This is a positive result since recent studies on driver-centered design recommended the suppression of as most alarms as possible (e.g. LeBlanc *et al.*, 2008). The driving simulator could thus be very useful to assess the effectiveness of such a system and its impact on safety.

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Keywords: Familiarization - Forward Collision Warning - Nuisance alarm - Alarm suppression - behavioral changes - subjective rating

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