FAMILIARIZATION WITH CRITICAL SITUATIONS WHEN USING A FORWARD COLLISION WARNING: EFFECTS ON DRIVER-SYSTEM INTERACTIONS.

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ABSTRACT: A Forward Collision Warning (FCW) could avoid a large number of rear-end collisions by informing distracted drivers of the danger. However, the FCW generates false and nuisance alarms, or cannot indicate some dangers. These critical situations could lead to unsuitable reactions and diminish acceptance if drivers have a poor understanding of the system's operations. This research aims at evaluating the benefit of familiarization with these situations. In a simulator study we compared drivers' behavior and their acceptance according to whether they used the system in a familiarization session. Results show that familiarization led to better understanding of the FCW, thus making driver/system interactions more effective and safer. However, familiarization had no effect on drivers' acceptance and even decreased their confidence in self-performance. We addressed practical applications for the deployment and rollout of FCW systems.

Rear-end collisions account for 25% of all road accidents [1]. They are the most frequent crash type which constitutes 5% of all fatalities and 53% of all injuries on U.S. highways [2]. In-depth analysis shows that drivers' distraction is the main contributing factor, especially when the drivers are involved in a secondary task [3].

The Forward Collision Warning (FCW) is likely to reduce the number and the severity of these collisions by informing distracted drivers of the critical decrease in the distance from the lead vehicle. However, drivers do not accept the FCW easily. It has been shown that acceptance determines the way which drivers interact with automation (e.g. [4]). For example, the operators do not accept and "disuse" a system that is not reliable, annoying or disturbing [5, 6]. Ideally, the FCW should inform the drivers that he/she must react to avoid a collision. But in fact, the system sometimes fails to provide precise information: for example, the FCW can generate false alarms – i.e. a signal when the danger is absent – when detecting stationary objects located outside the road. False alarms thus strongly decrease the system's reliability and the drivers' trust [7, 8]. On the other hand, the FCW can miss some risk of rear-end collision when the target is out of the beam range (e.g. at a hill crest or in sharp turns). These omissions have even more negative impact than false alarms [9]. Moreover, most of the time the FCW indicates situations where the drivers would be careful (e.g. when following closely). But less frequently, the system also indicates situations where the drivers would brake sharply (e.g. when the lead vehicle suddenly stops). Consequently, drivers' response must be adjusted according to the situation [10].

If drivers have a poor comprehension of the FCW's operation, then they may react in an unsuitable way in response to false alarms or when they follow too closely, whereas they may react late when a danger is not indicated or when they face an imminent danger. Drivers' comprehension is thus a key to determine when and how they have to react to the situation. Studies on driver-centered design – the adaptation of the driver/machine system to the operator, the task, and the automation's characteristics (e.g. [11]) – succeeded in clarifying the meaning of alarms by modulating their format and/or their timing in accordance with the situations or the drivers' individual differences (e.g. [12, 13, 14, 15, 16]). However, most of the researchers conclude that these adaptations failed to significantly improve drivers' acceptance because the alarms still remain too frequent. In fact, there are many occasions where close following is not dangerous. 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. [17]). Then, the FCW triggers nuisance alarms which are often perceived as false alarms by the drivers [10].

A solution could consist of improving the comprehension of the FCW's functioning. Once the drivers understand when and why an alarm is issued, drivers could be more tolerant towards the system. Studies in Field Operational Tests (FOT) provide information on the way to instruct drivers. Generally, they received oral or written descriptions of the system's purpose, its operation, and the human/machine interface before a practice training (e.g. [14, 17, 19, 20]). Especially, [20] were particularly attentive to the drivers' training, comprehension, and knowledge refreshing. Nevertheless, the FCW was regarded as unacceptable because of false or nuisance alarms. In driving simulator situations, familiarization with the FCW and details about its operation change greatly amongst studies (see [9] and [18] for example).

The literature on the impact of drivers' comprehension is poor. To the best of our knowledge, system comprehension has never been used as an independent variable. The ideal way to instruct drivers is not determined yet. However, FOT suggested that drivers appeared to "probe" the system's function in extreme conditions to better understand capabilities and limitations [14, 19]. Then, confronting the drivers with critical situations could be effective to improve the knowledge of the FCW. To create these situations on a driving simulator would be convenient and safer.

The present research aims at evaluating changes in the drivers' behavior and their acceptance of the system according to their familiarization with the FCW on a simulator. We hypothesize that using the system in critical situations (i.e. when alarms are useless or absent) increases the acceptance and the effectiveness of the driver/system interactions. In addition, we suggest that this knowledge is more effective when drivers experience the situations rather than read a written description. To avoid possible bias related to the individual differences, we neutralized factors which would influence the drivers' acceptance: age, sensation seeking, and preferential headway (see [12, 18]).

1. METHOD

1.1 Participants

Twenty seven drivers took part in the experiment (20 males, 8 females). Data obtained in a practice session were used to determine the composition of three independent homogeneous groups: a "control group" (10 drivers), an "unfamiliarized group" (10 drivers), and a "familiarized group" (7 drivers; see the design and procedure section for a detailed description). Mean age was respectively 38.7 years in the control group (min=24, max=52, SD=10.86), 42.25 years in the unfamiliarized group (min=26, max=53, SD=9.5), and 43.1 years in the familiarized (min=27, max=49, SD=9.5). Sensation seeking score (cf. [21]) was respectively 0.53 (SD=0.17), 0.5 (SD=0.16), and 0.52 (SD=0.16). Preferential time headway was (cf. [18]) 3.36 s (SD=0.89), 3.1 s (SD=1.07), and 3.6 s (SD=3.6). Participants had more than 5 years of driving experience and drove more than 10 000 km per year. Statistical analyses show no difference between groups.

1.2 Apparatus

The experiment took place at the Renault Technical Center for Simulation (CTS) on the driving simulator CARDS2, which used the software SCANeR II. The simulator was fixed-base for this research. The projection system consisted of three Barco Sim4 which provided a 150° horizontal image in the forward visual field. Two LCD screens located on the side mirrors provided a rear view.

The driving simulator was equipped with a FCW which 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:

$Dw = Vl \times RT + Vf^2 / (2 \times Df) – Vl^2 / (2 \times Dl)$,

where Dw (m) is the warning distance, Vf (m/s) the speed of following driver, Vl (m/s) the speed of leading vehicle, Df (m/s^{-2}) the assumed deceleration of the following vehicle, Dl (m/s^{-2}) 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 Dl and Df were fixed at 5 m/s^{-2}.

The visual interface was displayed on the dashboard, in front of the driver. It 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 cabin was also equipped with a distractive device consisting of a 10 x 15 cm screen located on the dashboard, above the gear lever, and a keyboard located on the floor, in front of the gear lever. The distractive task (Fig.1) consisted of locating a target circle (150 mm in diameter, 4 mm in thickness) among 35 distracters (125 mm in diameter, 3 mm in thickness). 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.

The drivers' involvement in a distractive task when they encountered a danger provided the advantage to create situations where relevant alarms were more useful while critical situations increased the likelihood of unsuitable reactions.

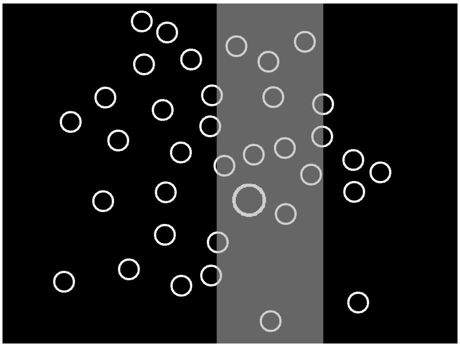

Fig.1. Schemata of the distractive device: the grey bar indicated the target zone.

1.3 Design and procedure

The experiment included three sessions: a practice, a familiarization, and a test session. In the practice session, participants were familiarized with the simulator and their preferential time headway was recorded. First, they drove on a dual carriageway without traffic for 10 min. Then, they followed a vehicle at a minimum safety distance, i.e. the distance just below what seemed dangerous according to their usual driving. They had to continuously adapt this distance while the speed of the lead vehicle oscillated between 70 to 90 km/h. Afterwards they practiced the distractive task when the vehicle was stopped. Finally, they performed the car-following and the distractive task simultaneously. After driving, the participants filled out questionnaires about their background and demographic characteristics. The total practice session lasted 30 to 45 min.

In the familiarization session, participants interacted with traffic in two runs: one in which they were accompanied by the experimenter and the other alone. Each run lasted 8 min. They encountered situations where the FCW did not give a warning: (1) a parked vehicle, (2) a parked vehicle which started slowly in front of them, and (3) an oncoming vehicle in a bend. They also encountered situations that triggered relevant alarms: (4) the lead vehicle stopped by an emergency braking (-5 m/s-²), (5) the lead vehicle slowed down and accelerated smoothly (+/-2 m/s-²). The run ended when (6) the participants overtook a slow vehicle that triggered a nuisance alarm. After the drive, participants filled out a self-assessment questionnaire about their driving (self-confidence and self-performance). 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 four types of events occurring between the way there and back: (1) in two scenarios, a vehicle crossed a junction at 3 s from the drivers. Drivers were not necessarily required to brake to avoid it. (2) In two scenarios, a vehicle merged the way in front of the driver from a time headway of 1 s. Again, drivers were not necessarily required to brake to avoid a collision. (3) In two scenarios, drivers were expected to overtake a heavy vehicle speeding at 70 km/h. There was no threat in these situations. (4) In four scenarios, the lead vehicle broke (-3 m/s-²) without stopping completely. Drivers could avoid a collision by braking reasonably. The test session ended with a scenario where an emergency braking vehicle stopped (-5m/s-²). Drivers had to brake sharply to avoid a collision. The distractive task systematically started 1.5 s before the beginning of each event, 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 filled out again self-assessment questionnaires on their driving (self-confidence and self-performance).The total test session lasted about 65 min.

Experimental conditions differed according to the given instructions and the usage of the FCW. With the data obtained in the practice session participants were homogeneously distributed into a "control group", an "unfamiliarized group", and a "familiarized group". In the control group, drivers never used the FCW either during the familiarization, or the test sessions. Here, the participants drove in the familiarization session presented as a familiarization with the simulator where the experimenter familiarized the driver on speed, position on the road, and following distance. Data obtained in the test session was used as the baseline driving performance without the FCW to compare driving performance with the FCW.

In the "unfamiliarized group", drivers used the FCW in the test session only. Drivers started the familiarization session with reading written instructions about the FCW's functions. This note specified the different states of the system (i.e. inactive below 50 km/h, active above 50 km/h, alert triggered) and some critical situations when using it (i.e. 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). The FCW was presented as an aid to avoid collisions if the lead vehicle suddenly brakes hard. Here, the participants drove without the FCW in the familiarization session presented as for the control group, i.e. a familiarization with the simulator. Unfamiliarized drivers filled out additional questionnaires about the FCW after the familiarization (trust, performance, and acceptance) and the test session (trust, performance, mental effort, and acceptance). Then, they gave an a priori judgment about the system based on the read instructions and the situations encountered without the system in the familiarization session. They also gave a posteriori judgment after using the system in the test session.

In the familiarized group, drivers used the FCW both in the familiarization and the test sessions. As in the unfamiliarized group, drivers started the familiarization session by reading the same written instructions on the FCW's functioning. Here, participants drove with the FCW in the familiarization session which aimed to become familiar with the FCW. The experimenter described the system's operation in the encountered situations by explaining why alarms were triggered or not. Familiarized drivers filled out the same additional questionnaires as in unfamiliarized group after the familiarization and the test sessions. Then, they gave a posteriori judgment on the FCW after using the system in both sessions.

Data was analyzed with non parametric (khi² test, Mann-Whitney's U test) and parametric statistics (factorial ANOVAs, ANOVAs on repeated measures, Student's t test).

2 RESULTS

2.1 Number of alarms and collisions

Control drivers (20.6%) and unfamiliarized drivers (23.56%) received more alarms apart from the scenarios than familiarized drivers (4.22%), i.e. they followed the lead vehicle more often too closely (respectively: $\chi^2 1=4.82$; $p<.03$ et $\chi^2 1=6.66$; $p<.02$).

Collisions occurred exclusively in the last scenario (i.e. emergency braking vehicle). Familiarized drivers had no collisions whereas 20% of unfamiliarized drivers and 40% of control drivers collided. Control drivers had significantly more collisions than familiarized drivers ($\chi^2 1=3.66$; $p=.055$) whereas differences with unfamiliarized drivers were not significant.

2.2 Type of reactions

The time between the start of events and the drivers' reaction (brake or accelerator release) was shorter for familiarized and unfamiliarized compared to control drivers ($F(2,425)=31.25$; $p<.000$).

The reactions to the merging vehicle scenarios were different according to the group: the majority of familiarized drivers (83.34%) and unfamiliarized drivers (72.32%) broke or released the accelerator whereas only a minority of control drivers (39.14%) reacted (respectively: $\chi^2 1=6.12$; $p<.02$ and $\chi^2 1=5.82$; $p<.02$).

There is also an order effect for crossing junction scenario: on the way there, all drivers reacted in a similar way when a vehicle crossed the junction, i.e. they released accelerator and broke. But on the return, half of the familiarized (50%) and unfamiliarized drivers (53.84%) already released accelerator when the vehicle started crossing the junction whereas almost all of the control drivers (90%) were still accelerating (respectively: $\chi^2 1=4.41$; $p=.035$ and $\chi^2 1=4.79$; $p=.03$).

2.3 Behaviour before events and during alarms

During the 1.5 s before the beginning of events (i.e. when the distractive task started), familiarized drivers went slower than drivers of the other groups ($F(2,25348)=22$; $p<.000$). Their time headway was also longer ($F(2,16217)=59.37$; $p<.000$).

Between the start and the end of alarms (Table.2.), control and familiarized drivers were driving faster than unfamiliarized drivers ($F(2,31417)=85.2$; $p<.000$). However, unfamiliarized drivers decelerated slightly more sharply than familiarized drivers, who decelerated more sharply than control drivers

(F(2,31417)=171.7 ; p<.000). Consequently, the time headway of the familiarized group was longer than of the unfamiliarized one, which was longer than in the control group (F(2,30059)=39.77 ; p<.000). Taken together, these results suggest that familiarized drivers reacted more smoothly then unfamiliarized and control drivers. However, familiarized drivers maintained longer time headway and lower speed before the beginning of the events. Then, their reaction was more suitable and safer since they ultimately kept longer time headway when the alarm ended without reacting abruptly.

Note that there is a specific result for overtaking scenarios where familiarized (2.1 s) and unfamiliarized (2.32 s) drivers started to overtake much earlier than control drivers (12 s: F(2,10148)=8.5 ; p<.000).

Table.2. Behavioural variables: mean (standard deviation).

	Variables	Control group	Unfamiliarized group	Familiarized group	p
Before events	Speed (km/h)	88.37 (0.13)	88.56 (0.1)	87.8 (0.19)	.000
	Time headway (s)	5.67 (0.26)	5.6 (0.22)	6.08 (0.35)	.000
	Deceleration (m/s-2)	0.008 (0.005)	0.007 (0.004)	0.008 (0.007)	.87
During alarms	Speed (km/h)	82.05 (0.2)	79.61 (0.26)	81.63 (0.41)	.000
	Time headway (s)	4.04 (0.3)	4.81 (0.34)	5.57 (0.45)	.000
	Deceleration (m/s-2)	0.74 (0.02)	1.7 (0.03)	1 (0.05)	.000

2.4 System comprehension and self-assessment

For each event, we asked the drivers "Is it true that the FCW triggered an alarm in this situation?" The Mann-Whitney's U test shows that familiarized drivers made fewer errors than unfamiliarized ones (p<.045). Nevertheless, familiarized drivers were more inclined to believe that the FCW did not trigger an alarm when a vehicle merged in front of them (p<.032).

After the familiarization session, familiarized drivers were less confident in their driving performance (t(14)=3.39; p<.004) and their ability to master the simulator in comparison with control drivers (t(14)=3.24; p<.005).

After the test session, familiarized drivers assessed their global driving performance as being lower than did control drivers (t(14)=2.24; p<.04). However, familiarized and unfamiliarized drivers estimated that avoiding the emergency braking vehicle was easier than did control drivers (respectively: t(14)=2.55; p<.02 and t(20)=2.91; p<.008).

2.5 Acceptance and mental effort

The rating of the acceptance scale (cf. [22]) did not differ between familiarized and unfamiliarized drivers neither after the familiarization nor after the test session. Acceptance increased for both groups after the test session ($F(3,45)=19.79$; $p<.000$). Utility was greater than satisfaction ($F(1,16)=9.31$; $p<.007$). Also, the mental effort did not differ between the groups (NASA NTLX score). Note that the frustration caused by the use of the FCW (i.e. satisfaction, contentment, or interest vs. discouragement, irritation, annoyance, or stress) tended to be higher for unfamiliarized than for familiarized drivers ($t(15)=1.95$; $p<.069$).

3 DISCUSSION

The familiarization with critical situations when using the FCW produced different effects. First, it led to a better understanding of the system, thus making driver/system interactions more effective and safer. Familiarized drivers adopted longer time headways, they tended to react more quickly than control drivers and more smoothly than unfamiliarized drivers. Familiarized drivers also reduced their speed and increased their time headway before events. In accordance with [23], it seems that they saved time to compensate for attentional impairment. This result suggests that the familiarized drivers paid more attention to the headway control rather than relying on the FCW. This interpretation is in line with better anticipation in situations where the FCW did not issue a warning (crossing junction scenarios). Moreover, familiarized drivers succeeded in avoiding a collision with the emergency braking vehicle, suggesting that the familiarization induced safer behavior even in emergency situations. Lastly, using the system tended to be less frustrating when drivers were familiarized. In sum, the familiarization with critical situations provided a great benefit.

However, the familiarization provided no advantage in some situations. All users of the FCW began to overtake slow vehicles much earlier than control drivers, suggesting that the system should encourage the drivers to escape quickly from the unsafe zone behind the lead vehicle. However, precipitating the maneuver could also be negative for safety (e.g. [24]). Here, the familiarization was not ineffective in avoiding this behavior. Furthermore, all FCW users reacted more often than control drivers when a merging vehicle triggered an alarm. The impact on safety is not obvious but it could be surprising for a driver who follows the users too closely. In this latter case, we suspect that the reaction could be due to the lack of familiarization with this situation which was not experienced in the familiarization session, nor evoked in the written instructions. Familiarized drivers therefore reacted to these alarms, but after the test session they had difficulty to recall an alarm was triggered. Thus, the knowledge acquired in the familiarization session was not extended to the FCW’s functioning in new situations.

The familiarization also impacted negatively the drivers’ self-assessment. This result is consistent with [25] who found that “error training” led to a better driving performance but reduced drivers’ confidence. We propose that experiencing critical situations amounted to experience “error” of the FCW. Then, familiarized drivers could be more cautious in their ability to avoid danger. In addition, we assume that learning the FCW’s functioning constituted an additional task. In accordance with [26], we assume that when drivers performed this additional test, they could feel a decrease in their primary driving performance. Moreover, familiarized drivers had no opportunity to interact with traffic without being assisted by the system. Therefore, they may have had more difficulty in estimating their own driving capacities. However, despite the fact that reducing drivers' confidence obviously increased safety, its long-term impact in real conditions still is an open issue.

Lastly, the familiarization had no effect on the drivers' acceptance of the system. This result is surprising considering the more efficient driver/system interactions. However, the experimental design may account for this finding; first, drivers were systematically distracted when a danger occurred. The alarms were thus quite relevant and helpful for all system users. Second, the studied FCW was not very adaptive and dangers were frequent (about 1 alarm per 3 min). In line with previous research, we assume that the alarm rate was too high to be accepted (see [27]). Finally, individual differences were neutralized across experimental groups. But drivers' age, sensation seeking and preferential time headway are known to influence the system's acceptance. Consequently, the familiarization possibly increased the acceptance of some drivers, but this effect could not be observed with the present design of the study.

4 CONCLUSION

The familiarization with critical situations when using the FCW on the driving simulator improved safety behaviors significantly. Thus, this kind of familiarization could be useful in FOT where instructive situations are constrained by the unfolding events or self-created by the drivers. Familiarization on a driving simulator provides 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.

On the other hand, the familiarization on simulator was disconnected from acceptance improvement or extension of knowledge to new situations. Further research should study the impact of the familiarization by taking into account the factors that are likely to influence the drivers' acceptance. Since the exhaustive replication of critical situations cannot be reasonably envisaged, research should also evaluate which type of situations included in the familiarization can or cannot be generalized.

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