Fully Automated Driving: Impact of Trust and Practice on Manual Control Recovery

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Objective: An experiment was performed in a driving simulator to investigate the impacts of practice, trust, and interaction on manual control recovery (MCR) when employing fully automated driving (FAD).

Background: To increase the use of partially or highly automated driving efficiency and to improve safety, some studies have addressed trust in driving automation and training, but few studies have focused on FAD. FAD is an autonomous system that has full control of a vehicle without any need for intervention by the driver.

Method: A total of 69 drivers with a valid license practiced with FAD. They were distributed evenly across two conditions: simple practice and elaborate practice.

Results: When examining emergency MCR, a correlation was found between trust and reaction time in the simple practice group (i.e., higher trust meant a longer reaction time), but not in the elaborate practice group. This result indicated that to mitigate the negative impact of overtrust on reaction time, more appropriate practice may be needed.

Conclusions: Drivers should be trained in how the automated device works so as to improve MCR performance in case of an emergency.

Application: The practice format used in this study could be used for the first interaction with an FAD car when acquiring such a vehicle.

Keywords: fully automated driving, manual control recovery, practice, trust

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INTRODUCTION

Trust as a Determinant of the Use of Automation

Since cars have become increasingly automated, the ultimate goal for driving automation is fully automated driving (FAD). Depending on the types and levels of automation (Parasuraman, Sheridan, & Wickens, 2000), FAD has high automation levels for (a) information acquisition (i.e., sensing and registering input data: lane marking, nearby objects), (b) information analysis (i.e., inferential processes and prediction: safe distance needed between vehicles), (c) decision selection (i.e., selection among alternatives: choosing secondary roads to avoid traffic), and (d) action implementation (i.e., executing the chosen action: overtaking, braking, accelerating, etc.). This technology is aimed primarily at increasing safety, reducing fuel consumption, and improving driver comfort by decreasing both the physical and mental workload. However, automation only effectively reduces active fatigue, not passive fatigue (May & Baldwin, 2009; Saxby, Matthews, Warm, Hitchcock, & Neubauer, 2013). FAD is an autonomous system that requires no intervention from the driver except in specific conditions (National Highway Traffic Security Administration's [2013] Level 3 of driving automation and above).

However, by examining how to enhance the joint human-system efficiency, previous studies have determined the potential misuses and abuses of automation (Lee & See, 2004; Parasuraman & Riley, 1997). The efficiency of an automated system often depends on the operators' level of trust in that system. Indeed, trust has been recognized as an important determinant of system performance (e.g., Lee & Moray, 1992) as well as one of the main predictors of automation use (Parasuraman & Riley, 1997). Therefore, there might be a correlation between trust and FAD driving performance. Trust is defined as *the attitude that an agent will help achieve an individual's goal in a situation characterized by uncertainty and vulnerability* (Lee & See, 2004, p. 54). Since trust is considered a dynamic process (Cohen, Parasuraman, & Freeman, 1998; Lee & Moray, 1994; Wickens & Hollands, 2000), an operator's trust in a system evolves as a result of experience with the system (Muir & Moray, 1996). Hence, the level of trust can vary after using an automated device and could be measured after a first interaction with the system. Therefore, it seems reasonable to measure trust *a posteriori* as operators face problems and difficulties when assessing a machine's capability, which has been found to sometimes lead to poor calibration (Muir, 1987, p. 530).

Previous research addressing calibration, which refers to the match between the abilities of the automation and the person's trust in the automation (Lee & Moray, 1992), has found that poor calibration can have different consequences such as overtrust or distrust. Overtrust occurs when the person's trust in the automated machine is greater than that warranted by the abilities of the machine, whereas distrust refers to a person not believing in the abilities of the automation (Lee & See, 2004, p. 55). Evaluating trust could help understand driver behavior in the FAD mode in terms of response time when manual control recovery (MCR) is needed, which is one of the most important interactions between the driver and the system. As it is impossible to design a perfect automated machine, the transition (i.e., the decision to make a transition, the time taken to do so, and the quality of the maneuver) between the fully automated mode and manual driving is crucial to the safety of the driver (Hoc, Young, & Blosseville, 2009).

MCR

Leaving the control loop is a potential consequence of automation (Kaber & Endsley, 1997; Stanton & Young, 1998). In this situation, individuals are disconnected from the activity in which they are engaged. Leaving the control loop may be problematic when MCR is needed, causing drivers to face difficulties when MCR must be performed in emergency situations (Desmond, Hancock, & Monette, 1998; de Waard, van der Hulst, Hoedemaeker, & Brookhuis, 1999). These results are consistent with a study led by Hoc, Mars, and Milleville-Pennel (2006), in which drivers used autosteering but had to manually recover control to avoid obstacles. The authors observed interference between the driving styles when drivers sought to regain manual control.

MCR difficulties could be explained as complacency because the drivers rely on the system to handle the driving tasks they would usually perform manually (Stanton, Young, Walker, Turner, & Randle, 2001; Young & Stanton, 2007). Contrary to a high level of trust, complacency is a psychological state characterized by a low index of suspicion (Wiener, 1981, p. 119), even though no consensus exists concerning the definition of this concept (Parasuraman & Manzey, 2010). Overtrust, which occurs when the trust surpasses a level warranted by the abilities of the automated machine (Lee & See, 2004, p. 55), could be evidence of complacency and is supposedly a major issue for initiating MCR in FAD. If operators totally rely on the automated system to drive their vehicle, they might not expect to have to recover control quickly (i.e., in an emergency situation), which could lead to longer delays when human intervention is needed. This is congruent with the assumption that a joint human-automated system can be improved if appropriately trusted (Wickens, Gempler, & Morphew, 2000)—that is, if overtrust and distrust are avoided. Further, as complacency might affect the safety of drivers when they trust the adaptive cruise control (ACC) excessively (Inagaki & Furukawa, 2004), investigating this phenomenon with fully automated vehicles is of potential interest.

Automated Driving Training, Practice, and Use

Human-system control transition in an automated system is of major concern to traffic safety enhancement if drivers are not fully trained (Inagaki, 2006). Brookhuis and de

Waard (2006) and Hoc et al. (2009) suggested that specific training should be considered to assist drivers to move to manual control safely. Similar suggestions have been made concerning the positive effect of crash avoidance training with autopilot-equipped aircraft (McClellan, 1994). Inadequate training was considered one of several factors leading to manual control errors in certain flight accidents (Federal Aviation Administration, 2013). Introducing FAD to nonprofessional drivers to practice new maneuvers such as engaging automation mode and recovering control could assist drivers when using such a system for the very first time.

Some driving automation studies have examined the time required to improve performance in Advanced Driver Assistance Systems (ADAS) usage. In a 130-km run split into five trials using ACC, Kopf and Nirschl (1997) demonstrated that drivers were able to understand the partially automated system behavior, resulting in fewer interventions from the driver as well as lower workload levels. Familiarity with the ACC operation was observed after 2 weeks of use (Weinberger, Winner, & Bubb, 2001), and according to the authors, this period was a major part of the learning process. Kopf and Simon (2001) also examined the different stages of ACC learning and found that operators first learnt how to operate the system to understand its limits and then used it according to the specificity of the driving environment. The concepts of learnability and self-explanatory systems were also highlighted by Manstetten et al. (2003), who sought to define the ADAS design features needed to facilitate learning. However, these studies did not give details regarding the explicit elements needed for the driving automation learning content. Several studies have highlighted the need to optimize driving automation learning stages (Saad et al., 2004).

The first skill needed when learning how to use FAD is maneuvering, as suggested in the Goals for Driver Education framework (Hatakka, Keskinen, Gregersen, Glad, & Hernetkoski, 2002). Therefore, practicing MCR is considered as learning basic FAD maneuvering skills and is examined in this study.

Even though it could be considered that the more practice a driver has, the better their performance, the question is how much training is needed to improve FAD skills. Assuming that such skills exist, the efficiency of a short practice session could be examined for nonprofessional drivers using FAD for the first time. This situation is congruent with a typical first interaction situation when acquiring a fully automated car.

HYPOTHESES

This study addresses the impact of trust in FAD and FAD practice on anticipated MCR as well as in cases of emergency in a driving simulator. For this reason, the question of behavior in the FAD mode is addressed by analyzing the effect of both practice and trust on reaction time in anticipated and emergency situations. Practice in this study is split into two conditions: simple and elaborate. Drivers with a low level of trust in FAD are expected to recover control in a perceived dangerous situation because they distrust the system (Lee & Moray, 1992) as they have little experience with this technology (Hypothesis 1). In terms of complacency because of overtrust, drivers with a high level of trust in FAD are expected to recover manual control slower than those drivers who have poor or moderate trust in the FAD (Parasuraman & Riley, 1997) (Hypothesis 2). Because they perform greater MCR, elaborate practice drivers are assumed to react faster than drivers who have had only simple practice when MCR is both anticipated and urgent (Hoc et al., 2006, 2009) (Hypothesis 3). Finally, an interaction effect between practice and trust on MCR performance is expected. It is assumed that elaborate practice moderates the negative effects of overtrust and distrust in FAD as the trust is better calibrated (Lee & Moray, 1992) (Hypothesis 4).

In order to test these hypotheses, participants were randomly assigned to the experimental conditions (i.e., simple vs. elaborate practice) to balance the groups for age and gender.

METHOD

Apparatus

The French Institute of Science and Technology for Transport, Development, and Networks' (IFSTTAR) driving simulator with a fixed platform was used (see Figure 1). The equipment had 10 screens and visual channels (2.44 m × 1.83 m) that provided a 360° view, as well as an

Figure 1. The driving simulator at the mobility and behaviour psychology lab (French Institute of Science and Technology for Transport, Development, and Networks).

instrumented vehicle. The instrumented vehicle was positioned in the center of seven screens with an additional triptych facing the driver, two screens on each side of the vehicle, and three screens fixed to the back of the vehicle. The refresh rate of these panels was 60 Hz. Seven of these panels were equipped with a classic video projector (F22 Projection Design, 1080p), whereas the other three had a Titan stereoscopic video projector (Digital Projection SX, 1080p). Different driving parameters (e.g., speed, acceleration, braking, etc.) were registered in accordance with the virtual traffic situation to which the driver was exposed. A tablet computer was fixed on the dashboard between the two front seats and loudspeakers were used in the simulation room. The same written and vocal messages were simultaneously displayed.

Participants

Sixty-nine drivers (37 males) who had valid driving licenses took part in the study, for which they received financial compensation. Drivers were recruited through an advertisement in the participant-recruitment section of a website dealing with science. Two questionnaires were completed by all participants, one before and one after using the simulator (see "Measures"). The mean age of the sample was 38.5 (*SD* = 14.9, min. = 20, max. = 75). All drivers had had their driving licenses for more than 19 years on average (*SD* = 14.9, min. = 1, max. = 51); they answered the questionnaire in August 2013 and had driven an average of 304 km during the week before the questionnaire completion (*SD* = 627, min. = 0, max. = 5,000). Participants were individually tested and then equally distributed among the two groups according to age and gender. Anonymity was maintained throughout the study.

Procedure

Participants were briefed by the researcher before the commencement of the study. They were told they would participate in an FAD study and they would have to perform three tasks: answering a computerized questionnaire, driving in a simulator, and answering a second computerized questionnaire. They were told they were free to resign from the study at any time, but none decided to do so.

In the pre-experiment questionnaire, the features of the fully automated car were described along with cases of its use: Automated driving is a vehicle automation system that masters all the driving functions, such as steering, accelerating, braking, maneuvering, and maintaining a safe distance between vehicles. Fully automated cars are certified and can be used by all drivers with a driving license. However, drivers are still responsible for the vehicle and must be seated in the driver's seat with the seat belt fastened. They were asked if they understood what FAD was and if they had a driving license. If they did, they then answered the questionnaire.

Then all the participants had a first run, a 5-minute familiarization stage, in which they could test the functionality of the controllers. The second run consisted of learning how to operate the automated driving system, which was the independent variable in the two modality study for simple and elaborate practice. Participants from these two conditions were given the following instructions:

> You are on a four-lane highway with two lanes of traffic in each direction. You are requested to manually start the engine, accelerate, and keep your speed as close to 130 km/h (80 mph) as possible. You

> should engage the FAD system as soon as you hear the vocal message and/or read the message on the smart phone fixed to the dashboard. You should leave the FAD engaged for the remainder of the journey unless you feel a need to resume manual control; otherwise you should drive in your usual style. The steering wheel suitably managed curves whilst maneuvering to increase the reality of the simulation.

Both practice runs lasted approximately 3 minutes. The first group followed a simple practice condition, which consisted of manually starting the engine, reaching 130 km/h, turning on the automated system, turning it off after 1 minute (anticipated MCR), and finally resuming manual control to stop the car. The second group followed the elaborate practice condition and explored the FAD system more deeply; after turning the FAD on, a car overtook the participants and then the automated car overtook another car. After the overtaking, participants were asked to quickly resume control from the automated driving system because it was going to shut down in 3 seconds. There were no cars ahead or behind the participants' vehicle. No danger or emergency messages were relayed. Afterwards, they were asked to turn the system on again and finally asked to resume manual control to stop the vehicle.

Manual control of the vehicle was granted instantaneously and always in a straight section of road so that it would be easier for participants to learn to master the vehicle. Because of the 130 km/h simulated inertia, the speed gradually decreased. To engage the FAD system, drivers had to use the headlight device (i.e., one input to engage it, another input to disengage it, always followed by vocal and written feedback on the tablet computer). To recover control, they could use the same device, the steering wheel, or the gas or brake pedal. Before any anticipated MCR, drivers were warned 30 seconds before control transition by four messages relayed simultaneously over the speakers and on the tablet computer (i.e., end of FAD zone coming soon, end of FAD zone, please resume vehicle control, autopilot mode deactivated when manual control was resumed). The volume was loud enough for participants to clearly hear the messages and none asked for these to be played louder.

Thereafter, both groups completed the same 18-minute run (see Table 1), in which they were asked to turn on the FAD system after accelerating manually up to 130 km/h with the possibility of resuming manual control whenever they wanted. While in the FAD mode, the car was overtaken, then overtook, braked, accelerated, and turned within the curves. Five minutes later, they were told to resume manual control (i.e., anticipated MCR), and a few minutes later, they were asked to switch on the FAD. Soon after being in FAD mode, the vehicle overtook a car, but while overtaking, a third vehicle suddenly pulled out in front of the driver unexpectedly, resulting in a very short headway between the two vehicles. This potentially dangerous situation was handled by the FAD system, but participants were free to resume control if they wanted to. Ten minutes after the beginning of the run, an alarm rang twice followed instantly by a vocal and written message telling the driver that the system was out of order (i.e., system failure). Participants were not aware that such an event would occur. The FAD system stopped 2 seconds after the alarm stimulus and the system failure vocal message (i.e., sudden MCR). The system failure event occurred in a straight section of the road and there were no cars ahead of or behind the vehicle. Speed and direction were proportionally affected to simulate 130 km/h inertia, causing the car to slow down and smoothly deviate to the right. Finally, participants were asked to turn on the FAD one last time and then to resume control (i.e., anticipated MCR) a few minutes after the order to leave the highway.

In the third part of the study, participants answered the second computerized questionnaire. They were then thanked for their time.

Measures

In the pre-experimental questionnaire, participants answered an FAD acceptability scale (Payre, Cestac, & Delhomme, 2014) (α = .79), followed by sociodemographic questions regarding gender, age, years with license, and the kilometers driven in the previous week. The FAD acceptability scale was composed of

TABLE 1: Description of the Two Different Practice Types and the Common Run

	Simple Practice	Elaborate Practice
Practice (3 min)	Manual driving to reach 130 km/h	Manual driving to reach 130 km/h
	FAD Activation	**FAD Activation**
		Overtaken by a car
		Overtake a car
		Quick anticipated MCR
		FAD activation
	MCR	MCR
Common run (18 min)	Manual driving to reach 130 km/h	Manual driving to reach 130 km/h
	FAD activation	**FAD activation**
	Overtaken by a car	**Overtaken by a car**
	Overtake a car	**Overtake a car**
	Brake	**Brake**
	Accelerate	**Accelerate**
	Turn into curves	**Turn into curves**
	MCR	MCR
	FAD activation	**FAD activation**
	Dangerous situation (cut-in)	**Dangerous situation (cut-in)**
	No event (1 min)	**No event (1 min)**
	Emergency situation (system failure)	**Emergency situation (system failure)**
	Emergency MCR	Emergency MCR
	FAD activation	**FAD activation**
	MCR	MCR

Note. Text in bold refers to the fully automated driving mode, whereas the plain text refers to the manual driving mode.

two dimensions, contextual acceptability (i.e., "I would rather keep manual control of my vehicle than delegate it to the automated driving system on every occasion"; "The automated driving system provides me with more safety compared to manual driving"; "If driving was boring for me, I would rather delegate it to the automated driving system than do it myself"; "If I had passengers in my automated car, I would rather drive by myself than delegate it to the automated driving system") and interest in impaired driving, (i.e., "I would delegate the driving to the automated driving system if I was over the drink-driving limit"; "I would delegate the driving to the automated driving system if I was tired"; "I would delegate the driving to the automated driving system if I took medication that affected my ability to drive").

In the postexperimental questionnaire, the FAD acceptability scale was used again. The internal consistency was judged to be acceptable at $\alpha = .79$. Afterwards, participants were asked randomized questions on trust in the FAD ($\alpha = .82$; 6 items): "Globally, I trust the automated driving system"; "globally, I trust my capacity to resume control if needed"; "I trust the automated driving system when overtaking"; "I trust the automated driving system to keep to a lane"; "I trust the automated driving system to avoid obstacles"; "I trust the automated driving system to keep distance from a vehicle ahead." A 7-point Likert-type scale was used, ranging from 1 (*I strongly disagree*) to 7 (*I strongly agree*). Postexperience trust toward automated aids has already been collected in previous studies (i.e., Dzindolet et al., 2003, p. 706).

TABLE 2: Mean Reaction Times for the Three MCR (in Seconds): Full Sample

	First Anticipated MCR (*N* = 63)	Emergency MCR (*N* = 60)	Second Anticipated MCR (*N* = 56)
M	8.7	4.3	6.8
Mdn	8.1	4.1	7.2
SD	2.7	1.2	2.5
Min.	3.6	2	2.7
Max.	15.2	8	13.9

Note. Data are missing for first MCR ($n = 6$), emergency MCR ($n = 9$), and second MCR ($n = 13$).

Performance measured reaction time (i.e., in seconds), starting from the beginning of the alarm signal or the anticipated MCR messages (i.e., audio broadcast and video display) to the first increment made by the operator, whether using the steering wheel or the gas or brake pedals. All MCR reaction times were measured while driving at 130 km/h.

Thirteen participants' recorded files from the simulator were affected by partial data loss (i.e., 6 before the first anticipated MCR, 9 before the emergency MCR, and 13 before the second anticipated MCR). Nonetheless, all were able to experience the full scenario, so all collected data were included in the analysis as there were no measurement errors and participants were all part of the population of interest (Orr, Sackett, & DuBois, 1991).

RESULTS

FAD Acceptability Descriptive Analysis

No significant difference, $F(1, 68) = 0.5$, $p = .83$, was observed between the two measures of the FAD contextual acceptability, measured before ($M = 4.4$, $SD = 1.3$, min. = 1.5, max. = 7) and after ($M = 4.8$, $SD = 1.4$, min. = 1, max. = 7) interacting with the system.

For the dimension interest in impaired driving, there was a significant decrease, $F(1, 66) = 4.8$, $p < .05$, $\eta^2 = .07$, between the mean score before ($M = 5.2$, $SD = 2$, min. = 1, max. = 7) and after ($M = 4.8$, $SD = 2.1$, min. = 1, max. = 7) interacting with the system. Two participants did not answer these items, as the choice of "not concerned" was available.

Finally, participants scored relatively high on the 7-point FAD acceptability scale, including both dimensions (a priori, $M = 4.8$, $SD = 1.3$, min. = 1.4, max. = 7; a posteriori, $M = 4.6$, $SD = 1.4$, min. = 1.5, max. = 7).

MCR Reaction Times Descriptive and Inferential Analysis

Drivers recovered control faster the second time that MCR was anticipated than the first time (see Table 2), $F(1, 54) = 584$, $p < .001$, $\eta^2 = .92$. This anticipated MCR reaction time improvement might be because the participants better understood the automated system, leading them to resume control before the messages were fully displayed.

The emergency MCR mean reaction times were faster than both anticipated MCR mean reaction times (see Table 2). Compared to the emergency mean reaction times, the first anticipated MCR mean reaction times were longer, $F(1, 56) = 141.9$, $p < .001$, $\eta^2 = .72$. Similarly, compared to the emergency mean reaction times, the second anticipated MCR mean reaction times (i.e., when participants were asked to leave the highway) were also longer, $F(1, 51) = 40.1$, $p < .001$, $\eta^2 = .44$.

Impact of Trust and Practice on Manual Control Recoveries

Participants scored relatively high on the FAD trust scale ($\alpha = .82$), measured after interacting with the system ($M = 5.23$, $SD = 1$, min. = 2.83, max. = 7). No significant difference was observed, $F(1, 67) = 3.3$, $p = .07$, between the two practice conditions (see Table 3).

Concerning the dangerous situations (i.e., a car suddenly cutting in front of the participants' vehicle while they were also overtaking), 6 out of 69 participants (8.7%) resumed control. No signifi-

TABLE 3: Impact of Trust and Practice on Manual Control Recoveries

	M		*SD*		Simple			Elaborate		
	Simple	Elaborate	Simple	Elaborate	1	2	3	1	2	3
1. 1st MCR reaction time	8.97	8.42	2.89	2.55						
2. Emergency MCR reaction time	4.43	4.09	1.21	1.23	.23			.00		
3. 2nd MCR reaction time	6.93	6.74	2.59	2.39	.71**	.00		.54**	.02	
4. Trust in FAD	5.03	5.47	.86	1.14	.25	.63**	.08	.11	–.08	.16

Note. FAD = fully automated driving; MCR = manual control recovery.
*p < .05. **p < .01. ***p < .001.

cant correlation (r = –.15, p = .22) between the level of trust and the likelihood of initiating MCR during this potentially dangerous situation (i.e., a cut-in situation) was found (Hypothesis 1).

For participants who followed the simple practice condition in the emergency scenario, a positive correlation (r = .63, p < .001) (see Table 3) was found between the level of trust in FAD and MCR reaction time. This indicated a negative effect for a high level of trust in the MCR in this condition (Hypothesis 2). No such correlation was found for participants who followed the elaborate practice condition (see Table 3).

None of the two anticipated MCR mean reaction times were significantly impacted by either practice conditions [i.e., first anticipated MCR, $F(1, 61) = .63$, $p = .43$; second anticipated MCR, $F(1, 54) = .08$, $p = .77$] or the level of trust (see Table 3) (Hypothesis 3).

Concerning the emergency situation, no significant difference was found, $F(1, 58) = 1.16$, $p = .29$, between the mean reaction times to recover control for participants who followed the simple practice session and for those who followed the elaborate practice session (see Table 3).

When included separately in a hierarchical stepwise linear regression, the practice z scores did not have an impact on the MCR reaction time in the case of emergency, whereas the trust in the FAD z scores were found to have an impact (see Table 4). In addition, the interaction of both dimensions had a significant impact on MCR. For the participants who followed the simple practice session, it was found that the more trust that was declared, the longer the reaction times. Therefore, it could be concluded that the elaborate practice condition mitigated the effects of a high level of trust in MCR reaction time (Hypothesis 4).

The impact of trust on reaction time as well as the interaction between trust and practice is shown in Figure 2.

Men had more trust in the FAD than women, $F(1, 67) = 10.27$, $p < .01$, $\eta^2 = .13$. However, no gender effect was found for the three different MCR reaction times.

DISCUSSION

The general aim of the present study was to highlight the impact of trust and practice on MCR performance when using FAD. A negative impact for a high level of trust in FAD on one aspect of driving performance (i.e., MCR reaction time) in an emergency situation was found when participants followed the simple practice condition. This negative impact was mitigated in the elaborate practice condition. Nevertheless, MCR is one aspect of automated driving performance, and further research should take into consideration other parameters, such as the quality of MCR, control of the vehicle, and safe maneuvering.

The first hypothesis was not confirmed: Recovering manual control in a potentially dangerous situation (i.e., a cut-in) was not found to be affected by the level of trust (Hypothesis 1). One explanation could be that this simulated event lacked realism and may have led partici-

TABLE 4: Hierarchical Stepwise Linear Regression of the Impact of Practice and Trust (*z* Scores) on Reaction Time in Emergency MCR ($N = 60$)

	Adjusted R^2	ΔR^2	Step 1	Step 2
Step 1	.05			
Practice			–.20	–.18
Trust in FAD			.26*	.35**
Step 2	.19	.14**		
Trust in FAD × Practice				–.39**

Note. Adjusted R^2 and R^2 change (ΔR^2) values were reported.
*$p < .05$. **$p < .01$.

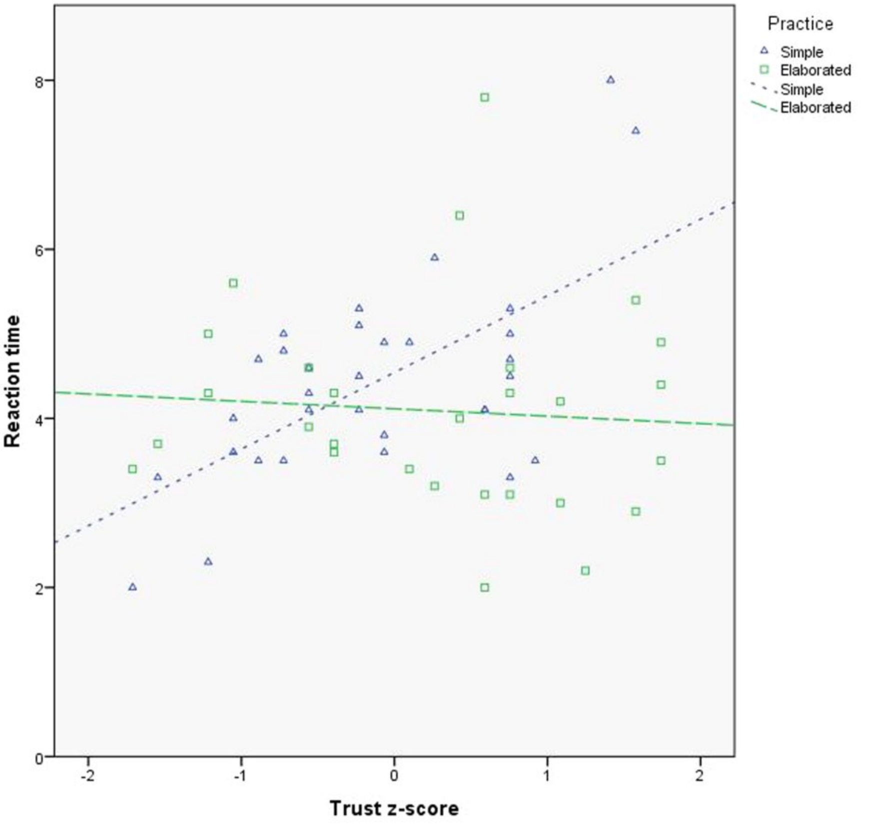

Figure 2. Interaction between practice and trust on reaction time (in seconds).

pants to perceive a low level of danger in this specific situation, resulting in a poor likelihood of initiating MCR. As expected, a high level of trust was positively correlated with MCR reaction time in an emergency situation (Hypothesis 2). Complacency could explain this result, as previously suggested by Hoc et al. (2009), as participants with a high level of trust in the FAD system might not have considered a potential failure of the system. The third hypothesis was not confirmed: Practice did not have a simple effect on MCR reaction time, whether anticipated or in a case of emergency (Hypothesis 3). It could be argued that the common run was an opportunity for both groups to learn more about how to use the FAD system, which was possibly more important for the simple practice group. Finally, the negative effect of trust on performance was mitigated in the elaborate practice condition, partially confirming the last hypothesis (Hypothesis 4).

Lee and Moray (1992) acknowledged that trust was an important determinant of system performance. Muir and Moray (1996) also found that there was an "inverse relationship between trust and the monitoring of the automation," meaning that the more trust there was, the less the system was monitored. This could explain why operators left the control loop, as out-of-the-loop performance has been found to be associated with "excessive human trust in computer controllers" (Kaber & Endsley, 1997). In the present study, this inverse relationship was confirmed in the simple practice condition but not confirmed in the elaborate practice condition. In the simple practice condition, drivers with the highest levels of trust had slower reaction times in the emergency scenario than those with lower levels of trust. No such differences were observed when participants followed the elaborate practice. Because both experimental groups trusted the FAD system, they were likely to supervise the system poorly. Hence, it can be assumed that unless drivers have practiced sufficiently, the more trust there is in the system, the more disconnected the driver may be from the driving activity.

The current study confirmed the results previously found in the same field (Inagaki & Furukawa, 2004) and provided more information on why automation slows braking responses (Neubauer, Matthews, & Saxby, 2012; Saxby, Matthews, Hitchcock, & Warm, 2008) or slows MCR (Young & Stanton, 2007) in an emergency scenario (i.e., system failure). This had been attributed to either passive fatigue (Desmond et al., 1998) or a decrease in attention resources (Young & Stanton, 2007) when drivers did not have a secondary task to perform. As previously suggested, complacency, characterized in this study by a high level of trust, can lead to difficulty when resuming manual control (Hoc et al., 2009). Thus, complacency could explain the longer reaction times in system failure scenarios for drivers who had high trust in the FAD dimension. This result was also congruent with Bainbridge's (1983) work, although the field of investigation was driving automation. Notwithstanding, this study was conducted in a simulator, which may have decreased the participants' feelings of lethal danger while using the FAD, and thus increased their levels of trust and acceptance of the system.

Elaborate practice was found to contribute to better calibrated trust in the FAD system, as the negative impact on reaction time was mitigated. Concerning calibration, it could be argued that an appropriate level of trust in FAD can be built with meta-trust, which is defined as "the trust a person has that another person's trust in the automation is appropriate" (Lee & See, 2004). It has also been argued that communicating ongoing feedback to users on the automation's reliability can help develop an appropriate level of trust in the system (Hoff & Bashir, 2014). First-time FAD users will probably share their experiences with nonusers, making them aware of the overall capabilities of the system. As the participants did not share their knowledge with one another, further research should investigate the impact of feedback and meta-trust on MCR performance. No significant differences were found between *a priori* and *a posteriori* FAD acceptability. However, concerning the dimension of interest in impaired driving, the mean score was significantly lower *a posteriori*, which could mean that participants were less confident in using such a system while impaired after experiencing a system failure.

Both practice runs by the participants were very short. However, the purpose of the study was to compare practice runs in terms of quality instead of quantity. Indeed, this kind of short practice session could be used by car dealers to show drivers how to recover control as this format was a typical first interaction situation. Although FAD policy remains in a legal limbo, showing people how to practice FAD basic maneuvers (i.e., engaging the system and recovering control) could significantly improve safety when drivers use such systems for the first time. Examining the impact of a longer practice session on the MCR performance should be examined as it could highlight other dimensions of MCR performance.

Generalizing this study's results should be done with caution. It is possible that some participants did not immediately understand that the system failure alarm referred to the driving system, not the simulator, so giving drivers more specific instructions (i.e., recover control instead of system failure) might help them recover control more safely (Inagaki, 1999). Because FAD knowledge might impact attitude and behavior while using such a system, further research should examine the effects of training (i.e., more developed practice) on FAD performance by telling drivers how FAD works, and what are its potentials and limits. FAD prototypes are driven by experts who know exactly how the technology they are dealing with works, whereas regular drivers do not have this specific knowledge. This could lead to a poor representation of the system, resulting in low performances. In the future, interaction with the system in the practice session should be emphasized to highlight the positive impact of practice on MCR performance. Moreover, although high values were reported in the results (i.e., reaction times around 8 s in the emergency situation), they were not considered outliers and were representative of interindividual variability. Indeed they come from the population of interest and no measurement errors were found. Eventually, the results of our study need further corroboration.

Finally, the effects of performing a task before resuming control should be examined in both anticipated and emergency situations, as the mental workload and having the hands occupied might have an impact on MCR.

CONCLUSION

The purpose of this paper was to emphasize the effect of trust and practice on MCR performance when using FAD. The results showed that unexpected events could lead drivers to have slower reaction times when they have a high level of trust in the system. These findings might help policy-makers and designers in different ways. On the one hand, a specific automated driving license could be a solution to train users to recover manual control in the most critical situations. On the other hand, designers should take into consideration that experience with the system improves MCR reaction-time performance; hence, incorporating a tutorial with specific feedback on how to cope with critical situations could improve the quality of the human-machine interaction.

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KEY POINTS

- Drivers should be taught how to use FAD.
- In simple practice conditions, a high level of trust can have a negative impact on emergency MCR reaction time.
- Elaborate practice mitigates the negative impact of overtrust on emergency MCR reaction times.

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