HOW THE INITIAL LEVEL OF TRUST IN AUTOMATED DRIVING IMPACTS DRIVERS' BEHAVIOUR AND EARLY TRUST CONSTRUCTION

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ABSTRACT

Trust in Automation is known to influence human-automation interaction and user behaviour. In the Automated Driving (AD) context, studies showed the impact of drivers' Trust in Automated Driving (TiAD), and linked it with, e.g., difference in environment monitoring or driver's behaviour. This study investigated the influence of driver's initial level of TiAD on driver's behaviour and early trust construction during Highly Automated Driving (HAD). Forty drivers participated in a driving simulator study. Based on a trust questionnaire, participants were divided in two groups according to their initial level of TiAD: high (Trustful) vs. low (Distrustful). Declared level of trust, gaze behaviour and Non-Driving-Related Activities (NDRA) engagement were compared between the two groups over time. Results showed that Trustful drivers engaged more in NDRA and spent less time monitoring the road compared to Distrustful drivers. However, an increase in trust was observed in both groups. These results suggest that initial level of TiAD impact drivers' behaviour and further trust evolution.

Keywords: trust in automation, automated driving, driver's behaviour

1. INTRODUCTION

Automated driving is currently becoming part of the traffic, and such technologies raise new questions. As automation capabilities progress, driver-vehicle interaction and cooperation evolve acutely (Navarro, 2019). For example, Highly Automated Driving (HAD, level 4, SAE, 2016) provides full control of the driving task, allowing drivers to entirely focus on Non-Driving-Related Activities (NDRA), as the vehicle can perform a minimum risk manoeuvre if the driver is unable to resume manual control.

Trust is a key element influencing Human-Machine Interaction (HMI) in many ways (Lee & See, 2004; Parasuraman & Riley, 1997), deeply impacting human-system overall performance (Lee & Moray, 1992), and being a determinant of automation use as well (Parasuraman & Riley, 1997; Schaefer et al., 2016). Trust in Automation (TiA) is commonly defined as *“the attitude that an agent will help achieve an individual’s goals in a situation characterized by uncertainty and vulnerability”* (Lee & See, 2004). It has been widely studied during past decades with automation experts (e.g., plane pilots, power plant supervisors, see Parasuraman & Riley, 1997) as a major reliance factor (e.g., Lee & See, 2004; Sheridan, 2019), but the wide range of drivers’ level of experience, abilities, and expectations combined with the high variety of driving contexts open a relatively new paradigm (Manchon et al., 2020). Trust in Automated Driving (TiAD) is defined here as the attitude a driver has about HAD, that allows to delegate of the driving task to the automation to improve safety and comfort, while the risk of accident exist.

TiA seems to be high when operators’ self-confidence is low, but low in the opposite situation (Lee & Moray, 1994). Most car-users might be prone to misjudge their driving skills leading to poor calibrated TiAD (Wintersberger & Riener, 2016). Trust calibration

describes the conformity of an operator's TiA with actual automation capabilities (Lee & See, 2004). When this calibration is not correct, two kind of situations may happen. Over-trust could lead to hazardous conditions when using this kind of system in traffic (Hancock et al., 2011; Hoff & Bashir, 2015; Parasuraman & Riley, 1997), as shown by the many accidents due to poor ADASs monitoring (e.g., NHTSA, 2017). Distrust might be equally dangerous in specific circumstances, for example if the driver maintained manual control when experiencing drowsiness. It is therefore important to understand drivers' trust calibration process to design well-accepted and safer automated driving systems that inspire a proper level of trust (Helldin et al., 2013; Zhang et al., 2019).

Three main TiA layers have been highlighted (Hoff & Bashir, 2015; Marsh & Dibben, 2003). The dispositional trust reflects the operator's stable and overall tendency to TiA and depends on factors such as age, gender, culture, and personality traits. The situational trust is influenced by current situational characteristics (e.g., workload, perceived risks) and the operator's contextual mental state (e.g., fatigue, mood). Finally, the learned trust is initially defined by prior experiences, beliefs, and knowledge then dynamically updated during interaction, depending on automation's features and design. These three layers have an increasingly strong influence on the operator's reliance on the automation (Hoff & Bashir, 2015).

The characteristics of the automation, mainly linked to learned trust, are known to influence human-robot trust (Hancock et al., 2011) and some of them have been studied in the context of TiAD using driving simulators or Wizard of Oz vehicles. For example, aggressive automated driving style seemed to decrease drivers' trust when lawful driving style increased it (Morris et al., 2017). This is coherent with previous results stating that

drivers most often preferred a defensive driving style (Strauch et al., 2019; Yusof et al., 2016). Nevertheless, other studies found no main effect of the driving style, comparing familiar (i.e., close to own manual style) vs. unfamiliar style (Hartwich, Beggiato, et al., 2018) or familiar vs. defensive vs. dynamic driving styles (Beggiato et al., 2020). In some case, automated driving had to anticipate and execute actions earlier than the driver would have done (i.e., letting a wider safe distance while overtaking) to get the same declared level of trust (Abe et al., 2018). It was also found that manual driving inspired more trust than automated driving to the passengers (Strauch et al., 2019). These results were later confirmed, showing the lack of familiarity and knowledge about such systems decreased passengers' level of TiAD, compared to a human-control (Schmidt et al., 2021). That may indicate that unexpected and sudden manoeuvres are likely to decrease drivers' TiAD. However, several studies showed Take-Over Requests (TOR) did not decreased trust and increased drivers' understanding of the system. The authors postulated TOR were therefore not considered as automation failures but rather as normal automated driving features in these cases (Hergeth et al., 2015, 2016, 2017). Nevertheless, another study found trust decreased after repeated TOR (Kraus, Scholz, Stiegemeier, et al., 2020), suggesting such critical situations may have a negative impact on TiAD in some cases.

Concerning drivers' related factors (influencing dispositional and initial learned trust), studies showed age (Hartwich, Beggiato, et al., 2018; Hartwich, Witzlack, et al., 2018) and personality traits (Kraus, Scholz, & Baumann, 2020) allowed to predict TiAD in some situation. Initial information given about the system performance may also have an impact on future trust construction (Kraus et al., 2019) because drivers' expectation and mental model are related to TiAD (Beggiato, Pereira, et al., 2015; Forster et al., 2019). Drivers'

trust seems to increase with knowledge about system features (Khastgir et al., 2018), and familiarization with TOR (Hergeth et al., 2017). A promoted TiAD (through textual or video information) was also linked with longer glance towards a non-driving-related task (NDRT) compared to a lowered TiAD (Körber et al., 2018). This engagement in NDRT seems to be a reliable indication of drivers' TiAD, and has been showed to correlate with the level of driving automation (Beggiato, Hartwich, et al., 2015) and the experience with the system (Forster et al., 2020). In addition, a correlation between lower self-reported trust and higher road monitoring have also been exhibited (Hergeth et al., 2016; Payre et al., 2017). Therefore, trust affects not only drivers' performance but also their visual strategies and non-driving related behaviour. Otherwise, initial level of TiAD seems to have an impact on further trust construction and automation use during HAD (Beggiato, Hartwich, et al., 2015; Hartwich et al., 2020), which is the main focus of this paper. The effect of the initial level of TiAD (among Trustful drivers vs. Distrustful drivers) on drivers' behaviour was examined during the early use of a simulated automated driving system, i.e., their 30 first minutes of experience with HAD. Because HAD will likely be implemented first for highway use or traffic jam (Wintersberger & Riener, 2016), and different surveys confirm this idea (Becker & Axhausen, 2017; Kaur & Rampersad, 2018), a monotonous highway scenario including two critical situations was used in this study. Trust questionnaires, gaze behaviour and NDRA were analysed.

Drivers' declared level of trust is known to increase over time when experiencing driving automation (Bueno et al., 2016; Gold et al., 2015; Hartwich, Witzlack, et al., 2018; Hergeth et al., 2016, 2017; Körber et al., 2018; Kraus, Scholz, Stiegemeier, et al., 2020). In the current experiment, it was thus hypothesized that drivers' level of trust will increase along

with HAD use (H1). A low initial level of TiAD might be due to a poor mental model concerning HAD systems, which is likely to be readjusted when drivers experience simulated HAD (Beggiato & Krems, 2013). It was therefore hypothesized the trust gain will be greater for Distrustful drivers than Trustful drivers (H2) and the differences between both groups will still be present at the end of the experiment (H3). Moreover, it has been argued that, for a correct trust calibration, operators need to experience system boundaries (Moray & Inagaki, 1999; Wintersberger et al., 2016). Considering the effect TOR have on drivers' TiAD (Hergeth et al., 2016, 2017; Kraus, Scholz, Stiegemeier, et al., 2020), it was expected that the critical situations will have an abrupt negative impact on drivers' trust to be then recovered gradually over time (H4).

2. METHOD

2.1. Participants

Forty healthy adults (20 females, $M = 38$ years old, $SD = 8.8$) participated in a driving task in a single session. All participants had a valid driver's license for a minimum of three years ($M = 18.5$, $SD = 9.3$) and drove regularly ($M = 6.3$ drives per week, $SD = 1.6$; $M = 15862$ kilometers per year, $SD = 12822$). Participants' perceived knowledge about AD was assessed during the recruitment process, on a 4-point scale (No knowledge, Basic knowledge, Intermediate knowledge, or Advanced knowledge). Among participants, 12.5% had no knowledge, 50% a basic knowledge, and 37.5% an intermediate knowledge. All drivers had normal or corrected-to-normal vision and they received 40€ of compensation for their participation. This research complied with the American Psychological

Association Code of Ethics and the European law on General Data Protection Regulation. Informed consent was obtained from each participant.

2.2. Apparatus

The study was conducted in a static driving simulator equipped with four 32" 16/9 LCD screens giving a 120° horizontal field of view (Figure 1). The rear view was displayed on three digital mirrors and dashboard information was provided by a 10" 16/9 LCD screen set behind the steering wheel. The driving simulation was controlled by the SCANeR™ Studio software developed by AV Simulation, France (<https://www.avsimulation.fr>). A 10.1" Xenarc tablet installed in the central console of the simulator was used as HMI. A sideband on the left of the screen included a pictogram informing about the current vehicle state (i.e., "Manual driving", "Available HAD" or "Activated HAD"), a button for HAD activation and specific pictograms when relevant. On the rest of the screen, an Android™ emulator with some games (e.g., Solitaire, Fruit Ninja, Mahjong) and an internet access

Figure 1. Driving simulator

was displayed. The driver video recording system was composed of four D-Link infrared cameras to investigate visual strategies and NDRA engagement.

2.3. Level of trust assessment

Initial level of TiAD was measured using a 10-item questionnaire on a 6-point Likert scale (Table 1) inquiring trust and trust-related dimensions such as perceived safety, intention to use in degraded conditions, and utility. The scale was designed to specifically assess TiAD, in accordance with previous works (see Table 1).

Table 1. Initial level of TiAD assessment scale

Questions	Origin
1 I would feel safe in an automated vehicle.	O'Cass & Carlson (2012)
2 The automated driving system provides me with more safety compared to manual driving.	Payre et al. (2016)
3* I would rather keep manual control of my vehicle than delegate it to the automated driving system on every occasion.	Payre et al. (2016)
4 I would trust automated driving system decisions.	O'Cass & Carlson (2012)
5 I would trust automated driving system capacities to manage complex driving situations.	Egea & González (2011)
6 If the weather conditions were bad (e.g., fog, glare, rain), I would delegate the driving task to the automated driving system.	Payre (2015)
7 Rather than monitoring the driving environment, I could focus on other activities confidently.	Egea & González (2011)
8 If driving was boring for me, I would rather delegate it to the automated driving system than do it myself.	Payre et al. (2016)
9 I would delegate the driving to the automated driving system if I was tired.	Payre et al. (2016)
Not at all ☐ ☐ ☐ ☐ ☐ ☐ Extremely	
10 How much do you trust automated driving systems?	Lee and Morray (1994)
0% ☐ ☐ ☐ ☐ ☐ ☐ 100%	

*Answers were inverted for scoring.

Before the experimental session, 90 potential participants were assessed with this scale by email. Homogeneity and internal consistency were good (Cronbach's $\alpha = .93$, McDonald's $\omega_h = .78$, and $\omega_t = .96$).

A *k-means* clustering method split them in two groups: Trustful drivers (high initial level of trust) and Distrustful drivers (low initial level of trust). The 20 most extreme participants of each group were selected: Trustful drivers ($n = 20$, 6F/14M, $M = 39.55$ years old, $SD = 9.09$) and Distrustful drivers ($n = 20$, 14F/6M, $M = 36.50$ years old, $SD = 8.50$). These trust scores served to establish participants' initial level of TiAD. The same scale formulated in past tense was used to assess final level of trust at the end of the experiment.

Dynamic level of trust was measured using a Single Trust Item ("I trusted automated driving system decisions.", item 3 from the previous scale, Table 1) on a 6-point Likert scale to investigate current drivers' level of trust after each scenario (Lee & Moray, 1994; Seppelt & Lee, 2019).

2.4. Procedure

Figure 2. Experimental protocol

Participants arrived at VEDECOM Institute and signed a consent form. They received a ten-minute practice to familiarize themselves with the driving simulator, and the automated driving (e.g., HAD activation, vehicle manoeuvres during non-critical situations,

pictograms, HMI, sounds). During the experimental task, participants activated HAD after merging into the highway. The vehicle speed was set at 130 km/h (the maximum allowed speed on French highways) on a three-lane highway, in a low-density traffic (3-6 vehicles per kilometre). Manual take-over was not possible to ensure that all participants experienced the same scenarios, and they were free to engage in NDRA (e.g., reading, texting, using the Android™ tablet, listening to the radio). After ten minutes of monotonous automated driving (P_1), participants were confronted with the first scenario (S_1), indicated by a sound and a specific pictogram 5 seconds before the event and they completed the first Single Trust Item right after (Q_1). The scenario was a roadwork area, signalled by traffic cones and a roadwork van. The vehicle strongly decelerated from 130 km/h to 90 km/h, at about 6 m/s^2 until the Time to Collision (TTC) with the roadwork area was 2.5 sec. It then changed from right lane to left lane and returned to the right lane after overtaking the obstacles. After the second ten-minute monotonous automated driving (P_2), the second scenario (S_2) happened, indicated by the same sound and a specific pictogram 5 seconds before the event, and followed by the second Single Trust Item (Q_2). This scenario was represented by a slow leading truck (90 km/h) driving on the right lane, forcing the vehicle to decelerate from 130 km/h to 90 km/h (at about 7 m/s^2 , until the TTC with the truck was 1.5 sec), as the left lane was occupied. Once the left lane was cleared, the vehicle overtook the truck and returned to the right lane. The order of presentation of the scenarios was counterbalanced. Finally, the third ten-minute period of monotonous driving (P_3) and the final 10-item trust scale (Q_f) terminated the experimental session (Figure 2). Participants were then interviewed for approximately 10 minutes about their overall feeling concerning the experiment and their behaviour during HAD.

2.5. Data analysis

Dependent variables included declared trust, glance count, glance duration and NDRA engagement frequency.

Trust scale were scored by adding each answer (reversing item 3, cf. Table 1). Scores were then converted in percentage ($s = (a_1 + a_2 + (7 - a_3) + a_4 + a_5 + a_6 + a_7 + a_8 + a_9 + a_{10} - 10) \div 50 \times 100$). Single Trust Item were converted in percentage ($s = (a_4 - 1) \div 5 \times 100$). To compare overall trust evolution, the fourth item from Initial and Final scales (the Single Trust Item) was used.

Visual strategies and *NDRA* data were processed by manual video-coding every tenth of a second. For each change in gaze direction, one glance to the previously monitored area was accounted (*glance count*), and the glance duration was added to the total glance duration towards this area, then transformed in percentage of the total glance time (*glance duration*). Areas of interest were defined as “Road”, “Rear Mirrors”, “Dashboard”, “NDRA”, “HMI Sideband”, “Tablet” and “Other” for all glances directed somewhere else. “Road”, “Rear Mirrors”, “HMI Sideband”, and “Dashboard” were grouped in a category “Driving environment” for analysis.

NDRA categories were defined based on participants’ most frequently observed activities: “Environment monitoring” when participants did nothing but monitor the driving environment, “Mobile phone use”, “Tablet use”, “Reading”, and “Radio use”. The other minor activities (e.g., grooming, drinking water, put glasses on) were combined in a new category “Other”.

Data and graphics were processed using R (R Core Team, 2017) and *ggplot2* (Wickham, 2016).

3. RESULTS

3.1. Declarative trust

The mean trust scores for the different questionnaires are reported in Table 3.

Table 3. Mean trust scores (%) for the Single Trust Items.

Time	Group	Mean	SD	95% CI	
				Low	High
Initial Single Trust Item	Trustful	74	16.03	66.97	81.03
	Distrustful	37	13.42	31.11	42.88
1 st Scenario	Trustful	81	23.82	70.56	91.43
	Distrustful	45	37.77	28.44	61.55
2 nd Scenario	Trustful	79	24.69	68.17	89.82
	Distrustful	46	31.19	32.33	59.66
Final Single Trust Item	Trustful	86	14.65	79.57	92.42
	Distrustful	57	28.49	44.51	69.48

A two-way mixed-design ANOVA (Group x Time, 2 levels: Initial assessment and Final assessment) was performed to investigate the effect of the experience on trust construction in Trustful and Distrustful drivers (Figure 3). There was a significant effect of the Group, $F(1, 38) = 77.6$, $p < .001$, $\eta^2 = .671$, and the Time, $F(1, 38) = 29.3$, $p < .001$,

Figure 3. Initial and Final trust scales.

$\eta^2 = .436$. The interaction Groupe x Time was also significant, $F(1, 38) = 9.32$, $p < .01$, $\eta^2 = .197$. In short, declared trust was found to increase for both Trustful and Distrustful participants during the interaction with the vehicle (H1), and the trust increase was higher for Distrustful drivers (H2).

Another two-way mixed-design ANOVA (Group x Time, 4 levels: Initial assessment, 1st Scenario (S₁), 2nd Scenario (S₂) and Final assessment) was performed to investigate scenarios' impact on drivers' early trust construction (Figure 4). There was a significant effect of the Group, $F(1, 38) = 32.7$, $p < .001$, $\eta^2 = .462$, and the Time, $F(3, 114) = 4.11$, $p < .01$, $\eta^2 = .098$. Post hoc tests using Bonferroni correction showed that the Initial assessment differed significantly from Final assessment ($p < .001$), but no other comparisons were significant. As expected, the differences between both groups were significant in the final assessment ($p < .001$), confirming H3.

Figure 4. Declared level of TiAD evolution on Single Trust Items; error bars = standard error

Motivated by the differences in trust reported by participants concerning the two scenarios (62.5% of the participants declared *Truck* scenario as more critical, 20% *Roadwork*

Figure 5. Declared level of TiAD depending on the Scenario;
error bars = standard error

scenario, 17.5% did not feel any difference), a two-way mixed design ANOVA was conducted (Group x Scenario type, 2 levels: *Roadwork* scenario vs. *Truck* scenario) (Figure 5). There was a significant effect of the Scenario type, $F(1, 38) = 11.86, p < .001$, $\eta_p^2 = .238$ for both Trustful ($p < .001$) and Distrustful ($p < .001$) confirming that drivers reported less trust after the Truck scenario than after the Roadwork scenario.

Data were therefore separated to analyse whether this difference had an impact on early trust construction (Figure 6). A three-way mixed-design ANOVA (Group x Time x Scenario Order, 2 levels: *Roadwork* → *Truck* vs. *Truck* → *Roadwork*) showed a main effect of the Group, $F(1, 36) = 32.8, p < .001, \eta_p^2 = .476$, and Time, $F(3, 108) = 5.29, p < .001, \eta_p^2 = .128$. The main effect of Scenario Order was not significant, $F(1, 36) = .007, p > .05, \eta_p^2 = .000$.

The interaction between Scenario Order and Time was significant, $F(3, 108) = 11.0$, $p < .001$, $\eta_p^2 = .234$. This revealed that, in sequence *Roadwork* $\rightarrow$ *Truck*, Initial assessment differed from S_1 ($p < .001$) and S_2 differed from Final assessment ($p < .001$), but in sequence *Truck* $\rightarrow$ *Roadwork*, Initial assessment differed from S_2 ($p < .01$). In short, early trust construction was found to differ according to Scenario Order for both Trustful and Distrustful participants.

Figure 6. Declared level of TiAD evolution, depending on the Scenario Order; error bars = standard error

3.2. Visual behaviour

Due to technical problems, two Trustful participants were excluded from the analysis. A two-way mixed-design ANOVA (Group x Driving Period, 3 levels: P_1 vs. P_2 vs. P_3) was conducted on glance count and glance duration. During monotonous driving, there was only a main effect of the Driving Period on glance count towards the Driving environment (Road, Rear-mirrors and Dashboard), $F(2, 72) = 18.6$, $p < .001$, $\eta_p^2 = .341$ (Figure 7), and towards the NDRA, $F(2, 72) = 3.54$, $p < .05$, $\eta_p^2 = .090$ (Figure 8). A post hoc test showed that glance count towards the Driving environment was reduced between P_1 and P_2 (p

273 < .001). In short, drivers' number of eyes movements decreased during HAD for both
 274 groups.

Figure 7. Glance count towards the driving environment during the automated Driving Periods; error bars = standard error

Figure 8. Glance count towards the NDRA during the automated Driving Periods; error bars = standard error

275 Concerning glance duration towards the Driving environment, results showed a main
 276 effect of the Group, $F(1, 36) = 4.64$, $p < .05$, $\eta_p^2 = .114$ and a main effect the Driving
 277 Period, $F(2, 72) = 4.28$, $p < .05$, $\eta_p^2 = .106$ (Figure 9). A post hoc test showed that glance
 278 duration was reduced between P₁ and P₂ ($p < .05$). There were no significant differences
 279 concerning glance duration towards NDRA (Figure 10). In short, drivers monitored road
 280 less frequently and during less time (H1) over HAD and particularly during the first ten
 281 minutes. Distrustful drivers tend to check the driving environment during more time than
 282 Trustful drivers (H3).

Figure 9. Proportion of glance duration (%) towards the driving environment during the automated Driving Periods; error bars = standard error

Figure 10. Proportion of glance duration (%) towards NDRA during the automated Driving Periods; error bars = standard error

In order to evaluate the visual behaviour evolution over time, a binary logistic regression with repeated measures (*logit*) opposing glances towards the driving environment (Road, Mirrors, and Dashboard) to all glances directed elsewhere (NDRA, Android™ tablet, and Other) was conducted. Temporal variables were time (squared) and 3 variables constructed from simple, squared, and cubed values of the distance to each of the Scenarios (S₁ & S₂).

The final model (Table 4, Figure 11) includes all the variables described above. The *logit* was controlled with Group, Gender and Conditions order. Reference variables are indicated in italic. Due to the high number of observations in the model, the *p*-values may

292 be higher than they would be with ANOVAs. The dynamic of the variation, on the other
 293 hand, can be fully considered.

Table 4. Influence of specific periods of time on glances directed towards the driving environment between Trustful and Distrustful drivers

	Trustful	
	β	Odds ratio
(Intercept)	4.672***	106.963
<i>Female</i>	-2.120*	0.120
<i>Distrustful</i>	2.080*	8.008
Time (²)	-0.113***	0.893
Interaction Time (²) x Group	0.007***	1.007
<i>Condition</i> $\Delta \rightarrow \text{truck}$	-0.937	0.391
Distance to Scenario		
Distance to S_1	1.348***	3.849
Distance to S_1 (²)	-2.152***	0.116
Distance to S_1 (³)	1.098***	2.999
Distance to S_2	1.364***	3.911
Distance to S_2 (²)	-3.533***	0.029
Distance to S_2 (³)	2.509***	12.301
<i>AIC</i>	521415.4	
<i>ROC</i>	0.669	
<i>Number of observations</i>	564787	

294
 295 The results of this model (Table 4, Figure 11) showed again that the probability to look
 296 towards the driving environment during critical scenarios was higher for Distrustful drivers
 297 than for Trustful drivers. Moreover, the probability to look towards the driving environment

Figure 11. Evolution of the probability to look towards the driving environment over time.

was higher immediately after the scenarios than during the next driving period (for both drivers). These results confirmed the H4.

3.3. Non-driving-related activities

Due to technical problems, two Trustful participants were excluded from the analysis. Two participants (1 Trustful and 1 Distrustful) did not engage in NDRA at all. During HAD, participants monitored the driving environment 21.9% of their time. The rest of the time, the most frequent NDRA they engaged in were mobile use for texting, calling, playing or web browsing (33.6%), tablet use for playing games and web browsing (17%), reading magazines or other documents (14.2%), and listening to the radio (3.75%). Other minor activities represented 9.15% of participants' time (Figure 12). A chi-square test of independence between Group and NDRA engagement was significant, $\chi^2(5, N = 38) = 27.272, p < .001$. Distrustful drivers were more likely to monitor the driving

Figure 12. Drivers' environment monitoring and NDRA engagement during HAD.

environment and less likely to engage in some NDRA (i.e., reading, radio use) than were Trustful drivers (H2).

4. DISCUSSION

The current study aimed to investigate the impact of (a) drivers' initial level of TiAD, (b) simulated HAD experience and, (c) safety critical situations on drivers' trust during the first interactions with automated driving. Drivers' early trust construction during these 30 minutes drives was examined through questionnaires, visual behaviours, and non-driving related activities.

4.1. Impact of initial level of TiAD

Reported trust was found to be consistently lower for Distrustful drivers than for Trustful drivers at each of the four assessments of trust made during the experiment. This result could indicate that pre-existing knowledge or beliefs influencing initial learned trust (Hoff & Bashir, 2015) can have a persistent effect on drivers' early trust construction during HAD. It therefore seems that 30 minutes of HAD is not enough to erase the difference in level of trust between Distrustful and Trustful drivers. A longer HAD experience may be needed to outweigh this initial level of trust, as shown in longer studies in other human-machine interaction contexts (Mayer, 2008; Sauer et al., 2015). In addition, although reported trust increased for both groups (9% in Trustful drivers and 38% in Distrustful drivers), participants declared differences in HAD perception, expectation and use intention. Thus, most of Distrustful drivers felt uncomfortable with the idea of using automated driving on road while Trustful drivers were enthusiastic about the NDRA engagement possibilities. The initial level of trust may therefore be used as a good indicator of HAD use and driver's behaviour in the early use of automated driving, and

car manufacturers should take this initial level of trust into account to provide the best feedbacks to drivers, depending on their needs.

Drivers' visual strategies were consistent with declared level of trust: Distrustful drivers spent 43.4% of their time monitoring the road while Trustful drivers only spent 28.3%. This confirms previous findings from Hergeth et al. (2016). Accordingly, time allocated to NDRA showed the inverse pattern (50% of the time among Distrustful drivers vs. 62.8% among Trustful drivers) which is consistent with Körber et al. (2018)'s results. Drivers' NDRA engagement confirmed the influence of the initial level of TiAD, as Distrustful drivers engaged less in some activities (e.g., reading, using the radio) and were more likely to monitor the driving environment. This brings new elements to support the comprehension of initial learned trust influence on early trust construction (Hoff & Bashir, 2015) in the context of HAD. Finally, the regression model showed an impact of the gender on gaze behaviours. Such effect was not found in other analyses (i.e., scores and NDRA engagement), nor in other studies (Feldhütter et al., 2016; Molnar et al., 2018; Schwarz et al., 2019). Yet, the imbalance in female/male distribution in both groups may have had an impact on these results, and further studies are needed to clarify the link between gender and initial level of trust.

4.2. Impact of HAD experience

Reported trust was found to increase over time, particularly during the first 10 minutes of the experiment. This is coherent with previous results showing an overall positive effect of the simulated HAD on trust (Gold et al., 2015; Hergeth et al., 2016). Similarly, Hartwich et al. (2018) observed a strong increase in trust during the first interaction with the system, followed by a stabilization. Glance behaviours are known to be modified by driving

automation introduction (e.g., Navarro et al., 2016, 2017, 2019). It was found in this experiment that participants glance behaviour changed over the driving session, in a similar way for both groups. Glance count towards the driving environment decreased by 28% while glance count towards NDRA decreased by 20%. This overall decreasing trend in glance count combined with a decrease in glance duration towards the driving environment indicated a change in drivers' visual strategy. Participants seemed not only to monitor less the road, but also to experience increasing periods of fixed gaze. This may indicate an increase in trust but may also be the result of a drivers' habituation to the driving simulation. Nevertheless, these data are coherent with previous results (Hergeth et al., 2016) and statements about trust influence on automation monitoring (e.g., Muir & Moray, 1996). This information raises concerns about drivers' ability to take manual control back in urgent situations if their mental representation of the surrounding environment is not up to date.

4.3. Impact of critical situations

The two scenarios presented in this experiment were realistic, common driving situations. Although scenarios were designed to be similar, they were perceived differently. Therefore, dissociating both scenarios provided information about how perceived safety may impact early trust construction. The results suggested that trust evolves differently depending on the exposure to critical situations. If drivers are exposed to a more critical situation at the very first interaction with automated driving, trust will not increase but will remain stable, to then grow gradually after a situation perceived as less dangerous. This may indicate that drivers are calibrating their trust and therefore are carefully observing the next AV action. Conversely, if the first interaction is perceived as safer than the second,

trust is likely to increase significantly (potentially leading to over-trust) but also to return to its initial level after the second event. This supports results from Walker et al. (2019) about the importance of early interaction in TiAD construction. Trust calibration seems indeed more irregular and this reduction in TiAD may lead to a manual recovery (Payre, Cestac, & Delhomme, 2016), possibly resulting in a poorly realized manoeuvre.

These results indicate that first experiences with automated driving systems may have a stronger influence on short-term trust calibration. Proper driver's training for automated driving is a current issue in human factors (Payre et al., 2016; Wintersberger et al., 2016). Our results suggest that it may be valuable to experience critical situation during the first interactions with automated driving, particularly for Distrustful people, in order to improve drivers' trust calibration. Nonetheless, given the small number of participants in each condition, this finding needs to be confirmed by further research.

4.4. Limitations and perspectives

In this experiment, take-over control of the vehicle was not allowed to guarantee that all participants experienced both scenarios. This methodological choice increased experimental control but was less natural, as participants could not return in manual control. Other studies are also required to investigate the influence of critical situations timing, during one or more sessions. As stated by Hoff and Bashir (2015), system malfunctions or operators' experience with the system may impact learned trust. Here, each condition occurred after ten minutes of HAD, in a single session, however, trust might evolve differently after longer HAD periods of use, multiple driving sessions or a higher number of critical scenarios experienced during HAD. Furthermore, it may be valuable to investigate the impact of other trust factors (Hoff & Bashir, 2015), such as

402 different driving environments or mental workload on drivers' behaviour during HAD use.
403 Moreover, simulated environment provided a widely replicable experiment, but decreased
404 participants perceived risk. On-road studies may explore TiAD related factors with a less
405 biased participants' safety feeling.

406 **5. CONCLUSION**

407 This study confirms previously established relations between self-reported trust and road
408 monitoring during HAD and give some hints on possible drivers' NDRA engagement
409 following HAD. It provides additional insight into the influence of initial level of trust on
410 further trust development during the first interactions with HAD. It also shows that drivers
411 with high initial levels of TiAD are more likely to engage in NDRA, compared to drivers
412 with low initial levels of TiAD. These initial levels of trust may influence the kind of NDRA
413 drivers engage in, as Trustful drivers seems to be more prone to read than Distrustful one.
414 Car manufacturers should be aware of these effects and may use simulated HAD to help
415 drivers to calibrate an appropriate level of TiAD depending on the capabilities of a
416 particular HAD system.

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6. REFERENCES

- Abe, G., Sato, K., & Itoh, M. (2018). Driver Trust in Automated Driving Systems: The Case of Overtaking and Passing. *IEEE Transactions on Human-Machine Systems*, 48(1), 85–94. <https://doi.org/10.1109/THMS.2017.2781619>
- Beggiato, M., Hartwich, F., Roßner, P., Dettmann, A., Enhuber, S., Pech, T., Gesmann-Nuissl, D., Mößner, K., Bullinger, A. C., & Krems, J. (2020). KomfoPilot—Comfortable Automated Driving. In G. Meixner (Ed.), *Smart Automotive Mobility: Reliable Technology for the Mobile Human* (pp. 71–154). Springer International Publishing. https://doi.org/10.1007/978-3-030-45131-8_2
- Beggiato, M., Hartwich, F., Schleinitz, K., Krems, J., Othersen, I., & Petermann-Stock, I. (2015). *What would drivers like to know during automated driving? Information needs at different levels of automation*. <https://doi.org/10.13140/RG.2.1.2462.6007>
- Beggiato, M., & Krems, J. F. (2013). The evolution of mental model, trust and acceptance of adaptive cruise control in relation to initial information. *Transportation Research Part F: Traffic Psychology and Behaviour*, 18, 47–57. <https://doi.org/10.1016/j.trf.2012.12.006>
- Beggiato, M., Pereira, M., Petzoldt, T., & Krems, J. (2015). Learning and development of trust, acceptance and the mental model of ACC. A longitudinal on-road study. *Transportation Research Part F: Traffic Psychology and Behaviour*, 35, 75–84. <https://doi.org/10.1016/j.trf.2015.10.005>
- Bueno, M., Dogan, E., Selem, F. H., Monacelli, E., Boverie, S., & Guillaume, A. (2016). How different mental workload levels affect the take-over control after automated driving.

448 *Intelligent Transportation Systems (ITSC), 2016 IEEE 19th International Conference On,*
449 2040–2045.

450 Feldhütter, A., Gold, C., Hüger, A., & Bengler, K. (2016). Trust in Automation as a Matter of Media
451 Influence and Experience of Automated Vehicles. *Proceedings of the Human Factors and*
452 *Ergonomics Society Annual Meeting*, 60(1), 2024–2028.
453 <https://doi.org/10.1177/1541931213601460>

454 Forster, Y., Geisel, V., Hergeth, S., Naujoks, F., & Keinath, A. (2020). Engagement in Non-Driving
455 Related Tasks as a Non-Intrusive Measure for Mode Awareness: A Simulator Study.
456 *Information*, 11(5), 239. <https://doi.org/10.3390/info11050239>

457 Forster, Y., Hergeth, S., Naujoks, F., Beggiato, M., Krems, J. F., & Keinath, A. (2019). Learning
458 and Development of Mental Models during Interactions with Driving Automation: A
459 Simulator Study. *Proceedings of the 10th International Driving Symposium on Human*
460 *Factors in Driver Assessment, Training and Vehicle Design: Driving Assessment 2019*,
461 398–404. <https://doi.org/10.17077/drivingassessment.1724>

462 Gold, C., Körber, M., Hohenberger, C., Lechner, D., & Bengler, K. (2015). Trust in Automation –
463 Before and After the Experience of Take-over Scenarios in a Highly Automated Vehicle.
464 *Procedia Manufacturing*, 3, 3025–3032. <https://doi.org/10.1016/j.promfg.2015.07.847>

465 Hancock, P. A., Billings, D. R., Schaefer, K. E., Chen, J. Y. C., de Visser, E. J., & Parasuraman, R.
466 (2011). A Meta-Analysis of Factors Affecting Trust in Human-Robot Interaction. *Human*
467 *Factors*, 53(5), 517–527. <https://doi.org/10.1177/0018720811417254>

468 Hartwich, F., Beggiato, M., & Krems, J. F. (2018). Driving comfort, enjoyment and acceptance of
 469 automated driving – effects of drivers’ age and driving style familiarity. *Ergonomics*, 61(8),
 470 1017–1032. <https://doi.org/10.1080/00140139.2018.1441448>

471 Hartwich, F., Schmidt, C., Gräfin, D., & Krems, J. F. (2020). In the Passenger Seat: Differences
 472 in the Perception of Human vs. Automated Vehicle Control and Resulting HMI Demands
 473 of Users. In H. Krömker (Ed.), *HCI in Mobility, Transport, and Automotive Systems. Automated Driving and In-Vehicle Experience Design* (Vol. 12212, pp. 31–45). Springer
 474 International Publishing. https://doi.org/10.1007/978-3-030-50523-3_3

476 Hartwich, F., Witzlack, C., Beggiato, M., & Krems, J. F. (2018). The first impression counts – A
 477 combined driving simulator and test track study on the development of trust and acceptance
 478 of highly automated driving. *Transportation Research Part F: Traffic Psychology and*
 479 *Behaviour*. <https://doi.org/10.1016/j.trf.2018.05.012>

480 Helldin, T., Falkman, G., Riveiro, M., & Davidsson, S. (2013). Presenting system uncertainty in
 481 automotive UIs for supporting trust calibration in autonomous driving. *Proceedings of the*
 482 *5th International Conference on Automotive User Interfaces and Interactive Vehicular*
 483 *Applications - AutomotiveUI '13*, 210–217. <https://doi.org/10.1145/2516540.2516554>

484 Hergeth, S., Lorenz, L., & Krems, J. F. (2017). Prior familiarization with takeover requests affects
 485 drivers’ takeover performance and automation trust. *Human Factors*, 59(3), 457–470.
 486 <https://doi.org/10.1177/0018720816678714>

487 Hergeth, S., Lorenz, L., Krems, J., & Toenert, L. (2015, June 22). *Effects of Take-Over Requests*
 488 *and Cultural Background on Automation Trust in Highly Automated Driving*.
 489 <https://doi.org/10.17077/drivingassessment.1591>

- Hergeth, S., Lorenz, L., & Vilimek, R. (2016). Keep Your Scanners Peeled: Gaze Behavior as a Measure of Automation Trust During Highly Automated Driving. *Human Factors*, 3(58), 509–519. <https://doi.org/10.1177/0018720815625744>
- Hoff, K. A., & Bashir, M. (2015). Trust in automation: Integrating empirical evidence on factors that influence trust. *Human Factors*, 57(3), 407–434. <https://doi.org/10.1177/0018720814547570>
- Khastgir, S., Birrell, S., Dhadyalla, G., & Jennings, P. (2018). Calibrating trust through knowledge: Introducing the concept of informed safety for automation in vehicles. *Transportation Research Part C: Emerging Technologies*, 96, 290–303. <https://doi.org/10.1016/j.trc.2018.07.001>
- Körber, M., Baseler, E., & Bengler, K. (2018). Introduction matters: Manipulating trust in automation and reliance in automated driving. *Applied Ergonomics*, 66, 18–31. <https://doi.org/10.1016/j.apergo.2017.07.006>
- Kraus, J., Forster, Y., Hergeth, S., & Baumann, M. (2019). Two Routes to Trust Calibration: Effects of Reliability and Brand Information on Trust in Automation. *International Journal of Mobile Human Computer Interaction*, 11(3), 17.
- Kraus, J., Scholz, D., & Baumann, M. (2020). What’s Driving Me? Exploration and Validation of a Hierarchical Personality Model for Trust in Automated Driving. *Human Factors*, 30. <https://doi.org/10.1177/0018720820922653>
- Kraus, J., Scholz, D., Stiegemeier, D., & Baumann, M. (2020). The More You Know: Trust Dynamics and Calibration in Highly Automated Driving and the Effects of Take-Overs, System Malfunction, and System Transparency. *Human Factors: The Journal of the*

512 *Human Factors and Ergonomics Society*, 62(5), 718–736.
513 <https://doi.org/10.1177/0018720819853686>

514 Lee, J. D., & Moray, N. (1994). Trust, self-confidence, and operators' adaptation to automation.
515 *International Journal of Human-Computer Studies*, 40(1), 153–184.
516 <https://doi.org/10.1006/ijhc.1994.1007>

517 Lee, J. D., & See, K. (2004). Trust in Automation: Designing for Appropriate Reliance. *Human*
518 *Factors*, 46(1), 50–80. https://doi.org/10.1518/hfes.46.1.50_30392

519 Lee, J., & Moray, N. (1992). Trust, control strategies and allocation of function in human-machine
520 systems. *Ergonomics*, 35(10), 1243–1270. <https://doi.org/10.1080/00140139208967392>

521 Manchon, J. B., Bueno, M., & Navarro, J. (2020). From manual to automated driving: How does
522 trust evolve? *Theoretical Issues in Ergonomics Science*, 1–27.
523 <https://doi.org/10.1080/1463922X.2020.1830450>

524 Marsh, S., & Dibben, M. R. (2003). The role of trust in information science and technology. *Annual*
525 *Review of Information Science and Technology*, 37(1), 465–498.
526 <https://doi.org/10.1002/aris.1440370111>

527 Mayer, A. K. (2008). *The manipulation of user expectancies: Effects on reliance, compliance, and*
528 *trust using an automated system*. Georgia Institute of Technology.

529 Molnar, L. J., Ryan, L. H., Pradhan, A. K., Eby, D. W., St. Louis, R. M., & Zakrajsek, J. S. (2018).
530 Understanding trust and acceptance of automated vehicles: An exploratory simulator study
531 of transfer of control between automated and manual driving. *Transportation Research*
532 *Part F: Traffic Psychology and Behaviour*, 58, 319–328.
533 <https://doi.org/10.1016/j.trf.2018.06.004>

534 Moray, N., & Inagaki, T. (1999). Laboratory studies of trust between humans and machines in
 535 automated systems. *Transactions of the Institute of Measurement and Control*, 21(4–5),
 536 203–211. <https://doi.org/10.1177/014233129902100408>

537 Morris, D. M., Erno, J. M., & Pilcher, J. J. (2017). Electrodermal Response and Automation Trust
 538 during Simulated Self-Driving Car Use. *Proceedings of the Human Factors and*
 539 *Ergonomics Society Annual Meeting*, 61(1), 1759–1762.
 540 <https://doi.org/10.1177/1541931213601921>

541 National Highway Traffic Safety Administration, , Department of Transportation. (2017). *INCLA-*
 542 *PE16-007*. <https://static.nhtsa.gov/odi/inv/2016/INCLA-PE16007-7876.PDF>

543 Navarro, J. (2019). A state of science on highly automated driving. *Theoretical Issues in*
 544 *Ergonomics Science*, 20(3), 366–396. <https://doi.org/10.1080/1463922X.2018.1439544>

545 Navarro, J., François, M., & Mars, F. (2016). Obstacle avoidance under automated steering: Impact
 546 on driving and gaze behaviours. *Transportation Research Part F: Traffic Psychology and*
 547 *Behaviour*, 43, 315–324. <https://doi.org/10.1016/j.trf.2016.09.007>

548 Navarro, J., Osiurak, F., Ovigue, M., Charrier, L., & Reynaud, E. (2019). Highly Automated
 549 Driving Impact on Drivers' Gaze Behaviors during a Car-Following Task. *International*
 550 *Journal of Human-Computer Interaction*, 1–10.
 551 <https://doi.org/10.1080/10447318.2018.1561788>

552 Navarro, J., Reynaud, E., & Gabaude, C. (2017). Eye movement analysis in dynamic scenes:
 553 Presentation and application of different methods in bend taking during car driving. *Le*
 554 *Travail Humain*, 80(3), 307. <https://doi.org/10.3917/th.803.0307>

555 Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse.
556 *Human Factors*, 39(2), 230–253. <https://doi.org/10.1518/001872097778543886>

557 Payre, W., Cestac, J., Dang, N.-T., Vienne, F., & Delhomme, P. (2017). Impact of training and in-
558 vehicle task performance on manual control recovery in an automated car. *Transportation*
559 *Research Part F: Traffic Psychology and Behaviour*, 46, 216–227.
560 <https://doi.org/10.1016/j.trf.2017.02.001>

561 Payre, W., Cestac, J., & Delhomme, P. (2016). Fully Automated Driving: Impact of Trust and
562 Practice on Manual Control Recovery. *Human Factors*, 58(2), 229–241.
563 <https://doi.org/10.1177/0018720815612319>

564 SAE International. (2016). *Taxonomy and Definitions for Terms Related to Driving Automation*
565 *Systems for On-Road Motor Vehicles*. https://doi.org/10.4271/J3016_201609

566 Sauer, J., Chavaillaz, A., & Wastell, D. (2015). Experience of automation failures in training:
567 Effects on trust, automation bias, complacency and performance. *Ergonomics*, 59(6), 767–
568 780. <https://doi.org/10.1080/00140139.2015.1094577>

569 Schaefer, K. E., Chen, J. Y. C., Szalma, J. L., & Hancock, P. A. (2016). A Meta-Analysis of Factors
570 Influencing the Development of Trust in Automation: Implications for Understanding
571 Autonomy in Future Systems. *Human Factors*, 58(3), 377–400.
572 <https://doi.org/10.1177/0018720816634228>

573 Schmidt, C., Hartwich, F., & Krems, J. F. (2021). Looking at Driving Automation from a
574 Passenger’s Perspective: Driving Experience and Gaze Behavior During Fully Automated
575 vs. Human Vehicle Control. In T. Ahram, R. Taiar, K. Langlois, & A. Choplin (Eds.),

576 *Human Interaction, Emerging Technologies and Future Applications III* (Vol. 1253, pp. 3–
577 9). Springer International Publishing. https://doi.org/10.1007/978-3-030-55307-4_1

578 Schwarz, C., Gaspar, J., & Brown, T. (2019). The effect of reliability on drivers' trust and behavior
579 in conditional automation. *Cognition, Technology & Work*, 21(1), 41–54.
580 <https://doi.org/10.1007/s10111-018-0522-y>

581 Seppelt, B. D., & Lee, J. D. (2019). Keeping the driver in the loop: Dynamic feedback to support
582 appropriate use of imperfect vehicle control automation. *International Journal of Human-*
583 *Computer Studies*, 125, 66–80. <https://doi.org/10.1016/j.ijhcs.2018.12.009>

584 Strauch, C., Mühl, K., Patro, K., Grabmaier, C., Reithinger, S., Baumann, M., & Huckauf, A.
585 (2019). *Real autonomous driving from a passenger's perspective: Two experimental*
586 *investigations using gaze behaviour and trust ratings in field and simulator*. 14.

587 Walker, F., Wang, J., Martens, M. H., & Verwey, W. B. (2019). Gaze behaviour and electrodermal
588 activity: Objective measures of drivers' trust in automated vehicles. *Transportation*
589 *Research Part F: Traffic Psychology and Behaviour*, 64, 401–412.
590 <https://doi.org/10.1016/j.trf.2019.05.021>

591 Wintersberger, P., Frison, A.-K., Riener, A., & Boyle, L. N. (2016). Towards a Personalized Trust
592 Model for Highly Automated Driving. *Proceeding of M&C*, 4, 8.

593 Wintersberger, P., & Riener, A. (2016). Trust in Technology as a Safety Aspect in Highly
594 Automated Driving. *I-Com*, 15(3). <https://doi.org/10.1515/icom-2016-0034>

595 Yusof, N. Md., Karjanto, J., Terken, J., Delbressine, F., Hassan, M. Z., & Rauterberg, M. (2016).
596 The Exploration of Autonomous Vehicle Driving Styles: Preferred Longitudinal, Lateral,
597 and Vertical Accelerations. *Proceedings of the 8th International Conference on Automotive*

598 *User Interfaces and Interactive Vehicular Applications - Automotive'UI* 16, 245–252.
599 <https://doi.org/10.1145/3003715.3005455>

600 Zhang, T., Tao, D., Qu, X., Zhang, X., Lin, R., & Zhang, W. (2019). The roles of initial trust and
601 perceived risk in public's acceptance of automated vehicles. *Transportation Research Part*
602 *C: Emerging Technologies*, 98, 207–220. <https://doi.org/10.1016/j.trc.2018.11.018>

603