Transportation Research Part F: Psychology and Behaviour 101 (2024) 332–339

Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

journal homepage: www.elsevier.com/locate/trf

Drivers' engagement in NDRTs during automated driving linked to travelling speed and surrounding traffic

Xian Liu [a,b,*], Ruth Madigan [a], Ehsan Sadraei [a], Yee Mun Lee [a], Natasha Merat [a]

[a] Institute for Transport Studies, University of Leeds, Leeds, UK
[b] School of Transportation, Southeast University, Nanjing, China

ARTICLE INFO

Keywords:
Automated vehicles
NDRTs
Glance behaviour
Distraction
Driving environment

ABSTRACT

Previous simulator and real-world studies with SAE Level 2 automated vehicles (AVs) have shown that, when compared to manual driving, drivers are more inattentive to the driving environment when automation is engaged, as reflected by fewer glances towards the forward roadway and side/rear view mirrors, and more focus on non-driving related tasks (NDRTs). Manual driving studies also suggest that drivers are more likely to engage in NDRTs during slow-moving or stationary traffic conditions. The aim of the current study was to understand whether NDRT engagement and visual attention patterns are impacted by the driving environment while drivers experienced a ride in a real-world SAE Level 3 AV. Forty-six video clips, from 32 drivers interacting with NDRTs during L3 motorway driving were analysed for this study. Due to the absence of externally facing cameras, the mean and standard deviation (SD) of driving speed were used as a proxy for assessing the surrounding traffic volume. The number of glances, and mean glance duration away from NDRTs per minute, were used as proxy measures for NDRT engagement. A generalised linear mixed model (GLMM) was used to investigate the effect of surrounding traffic on NDRT engagement. Results showed that the number and mean duration of glances away from the NDRT increased significantly when the SD of speed was high. The mean speed had a significant effect on the mean glance duration, with longer glances away from NDRTs when mean speed was low, compared to that in high speed. There was a significant effect of age on NDRT engagement, with older drivers less likely to engage in another task, while female drivers were more engaged in NDRTs than males. Overall, the results indicate that drivers' propensity to engage in NDRTs is impacted by the AV's speed, which is influenced by the volume of surrounding traffic. These results are useful for understanding the implications of surrounding traffic on drivers' self-regulated engagement in NDRTs in the real world during SAE Level 3 driving.

1. Introduction

With an increase in systems that allow more automated driving in the vehicle, the relationship between drivers and their cars is changing significantly. Six levels of driving automation (SAE L0-L5) are categorised by the SAE based on the functionality of the driving automation system (SAE, 2021). Currently, vehicles with Level 3 (L3) capability are starting to be available for the consumer in countries such as Germany, where it is legal for the driver to engage in Non-Driving Related Tasks (NDRTs) when the system is

* Corresponding author at: Institute for Transport Studies, University of Leeds, Leeds, UK.
E-mail address: liuxian@seu.edu.cn (X. Liu).

https://doi.org/10.1016/j.trf.2024.01.010
Received 28 September 2023; Received in revised form 12 January 2024; Accepted 15 January 2024
Available online 26 January 2024

engaged. However, use of these features is limited to certain areas and conditions (AFGBV, 2022), and drivers must prepare to intervene *"when the feature requests"* (SAE, 2021).

From a human factors perspective, there is some concern about the level of driver disengagement during L3, and the consequences of being "out of the loop" (Merat et al., 2019), especially if drivers are engaged in NDRTs, which can have detrimental consequences when a resumption of control from automation is required. Research suggests that response to a take-over is slower (Gold, Berisha, & Bengler, 2015; McDonald et al., 2019; Zeeb, Buchner, & Schrauf, 2015; Zhang, de Winter, Varotto, Happee, & Martens, 2019), and there is lower awareness of (poorer response to) road hazards (Zangi, Srour-Zreik, Ridel, Chasidim, & Borowsky, 2022), if drivers' attention is taken away from the road, and insufficient time is given for a Takeover Request (ToR). The resumption of control is particularly detrimental if drivers' eyes are taken away from the road due to a visually distracting NDRTs. Managing drivers' attention in such circumstances, and ensuring they are suitably ready to take over from automation, is therefore important.

Previous studies using L2 and L3 in driving simulators have shown that, compared to manual driving, drivers' gaze is less focused towards the road centre in L2 (Goncalves, Louw, Quaresma, Madigan, & Merat, 2020; Louw et al., 2019; Zeeb, Buchner, & Schrauf, 2016), and that there is a direct relationship between eyes away from the road centre and crashes (Louw, Madigan, Carsten, & Merat, 2017). Similar results have been reported in real-world L2 automated driving studies, with less glances towards the road, and more focus on NDRTs (e.g., engaging with mobile phones), when compared to manual driving (Morando, Gershon, Mehler, & Reimer, 2021; Noble, Miles, Perez, Guo, & Klauer, 2021). However, due to their absence from the road, there is currently little knowledge about how drivers will behave in more advanced, L3 AVs.

Results from naturalistic studies in manual driving have shown that the driving context and environment are critical factors for influencing drivers' engagement in NDRTs. For example, drivers are more likely to initiate phone calls, or engage in visual-manual phone activities in stationary traffic, compared to higher-speed driving conditions (Christoph, Wesseling, & van Nes, 2019; Funkhouser & Sayer, 2012; Ismaeel, Hibberd, Carsten, & Jamson, 2020; Risteska, Kanaan, Donmez, & Chen, 2021; Tivesten & Dozza, 2015). However, the demand imposed by manual driving is significantly different to that of automated driving. It can be argued that with an increase in the levels of automation, there is even less demand on the driver, further encouraging their engagement in NDRTs, e.g., to relieve boredom, because the resources usually dedicated to driving are no longer required for that activity. How such levels of automation affect driver engagement in NDRTs, and how the contextual environment, such as traffic conditions, affect this engagement is also not known. This is important for understanding how capable drivers will be of re-taking control from automation if required to do so.

To deal with this research gap, the aim of the present study was to investigate the pattern of drivers' engagement in NDRTs, when travelling in an L3 automated test vehicle, on a European highway, with different levels of traffic. We assumed that an increase in traffic would lead to a reduction in the travelling speed of the AV. Thus, we were interested to investigate whether this change in speed affected driver behaviour during automation, particularly in relation to the division of driver attention between an NDRT and the driving environment. It is hoped that findings from this research will provide a better understanding of the pattern and mechanism of engagement in NDRTs in different traffic conditions. This information can provide AV designers with better knowledge of driver behaviour, ensuring suitable human machine interfaces are designed to facilitate drivers' situation awareness and supervisory control during L3 driving.

2. 2.Method

2.1. Participants

Seventy-nine non-professional drivers (25 females, 54 males) aged between 25 and 70 years old ($M_{age} = 44.03$ years, $SD_{age} = 12.43$) took part an on-road study using an L3 automated vehicle. Participants responded to advertisements, and were chosen to be representative of the general population, with a slight bias towards possible electric and automated vehicle clients. They received €200-€250 of shopping vouchers for taking part in the study. Only participants who showed active engagement in NDRTs were included in the analysis, leading to the inclusion of videos from 32 participants (7 females, 25 males), aged between 25 and 70 years old ($M_{age} = 40.72$ years, $SD_{age} = 12.14$). More details on the selection process for these specific participants can be found in Section 2.4.

2.2. Automated vehicle and route

The study was conducted between January 2020 and March 2021, on a 95 km -long motorway section outside a busy European city. The road environment included both busy sections of traffic, and free motorway driving. All experiments took place in clear daytime weather, with no heavy rain or snow, and the drive lasted between 1 and 1.5 h.

Each drive started in manual mode, and the automated driving function (ADF) was available as soon as the vehicle reached the main motorway route. The SAE Level 3 ADF was capable of driving in its own lane at the designated speed limit, performing overtaking manoeuvres, and changing lanes at speeds of up to 110 kph. For safety reasons, the AV was also followed by a manually driven vehicle.

Participants' actions were recorded using 3 in-vehicle cameras: one camera positioned on the dashboard to capture their posture and head/facial movements, one camera positioned beside their right shoulder to capture hand position and dashboard information, and another to capture the position of their feet on the pedals. Data from these cameras was linked to the timestamps of the vehicle CAN bus data, which provided information such as travelling speed, acceleration, and vehicle positioning. External cameras were also set up to record the external environment, but, for GDPR reasons, the quality of images was not suitable for use in this study.

2.3. Experimental procedure and design

Prior to arrival, all participants were informed about the experiment, provided their informed consent, and completed a pre-experimental questionnaire collecting information about their age, gender, and AV experience (Yes/No). On arrival, the participants were briefed about the experimental procedure, familiarised with the AV's driving functions, and reminded of the motorway driving route. For safety and legal reasons, one experimenter (in charge of controlling that the AV system worked well) and one safety driver accompanied drivers throughout the study (see experimental set up of the AV in Fig. 1). A psychology researcher was also present for 20 of the participants' drives. The safety driver was seated in the passenger's seat and had access to an additional steering wheel and pedals, to intervene in the event of an emergency. The participants were asked to respect the rules of the Highway Code during manual driving and keep a safe distance to surrounding traffic participants. Additionally, they were told that the vehicle was equipped with internal cameras for recording oral statements, feet movements, facial expressions, and the frontal and rear driving scene.

Prior to the experimental drive, participants were given the opportunity to practice driving (3–4 km on a rural track), allowing familiarisation with the vehicle and the ADF, after which they began the experimental drive. Additional safety measures such as facemasks and full cleaning of the car were included due to the Covid-19 pandemic restrictions.

The automated driving mode became available in the motorway if the following three criteria were all fulfilled for the AV:

(1) It was located in the centre of the lane.
(2) It had approximately 2 s safety margin to the leading vehicle.
(3) It was driving at less than 110 kph.

At that point, the vehicle dashboard turned blue, and the message *'the vehicle is ready for automated mode'* was presented, along with an auditory alert. If the criteria for AV availability were not fulfilled, the experimenter instructed the participant to adjust the missing parameters. In order to hand over the driving task to the automated system, the participant was asked to release the acceleration pedal, and then push the 'R' button on the steering wheel. Once activated, the dashboard turned gold, and a sound was provided, which informed participants that they had activated the automated driving mode. During automated driving, the participants were given different instructions on acceptable activities during automation depending on which drive they were on. Each participant completed three drives in order to create a sense of familiarity with the AV over time.

In the first experimental drive, participants were instructed to hand over control as soon as the automated driving mode was available but they were always free to take over if they wanted to. While the automation was on, they were told that they could do whatever they liked, including engaging in an NDRT.

During the second experimental drive (15 days later), the participants were asked to drive one half of the motorway section manually and to activate the automated mode during the other half of the drive. There was no instruction regarding a secondary task for the period of automated driving.

Finally, in the third experimental drive (2 months later), they were instructed to activate the automation as soon as the automated driving mode was available, and they were encouraged to engage in an NDRT such as reading a book or playing on a smartphone. Immediately after the experimental drive, they completed the post-drive questionnaire, which incorporated questions on attitudes towards automation, and sensation seeking (results of the questionnaires not reported here). Finally, 20 of the drivers were interviewed, and asked how the automated vehicle influenced their behaviour (not reported in this MS).

Across all drives, participants were prompted by the AV to take over manual control of the vehicle one minute before the motorway exit, or 10 s prior to an unexpected event – in these situations the message '*You have 60 s (or 10 s) to take over control*' was displayed on the HMI dashboard, accompanied by an auditory cue. To take over the driving task, the participants had to press the button 'O' on the steering wheel, or press the acceleration pedal, or turn the steering wheel.

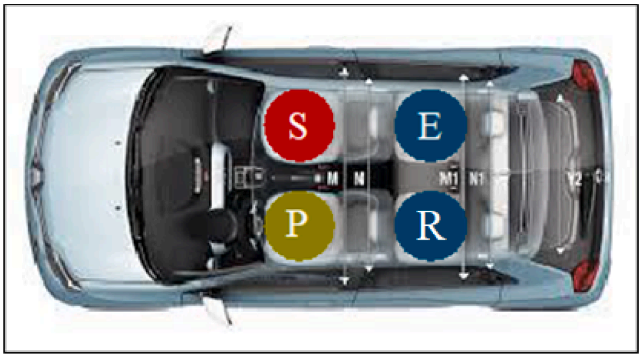

Fig. 1. Top view experimental demonstrator, including position of the participant (P), the safety driver (S), the experimenter (E), and the psychology researcher (R).

2.4. Data analysis

The videos from the 3 in-vehicle cameras were amalgamated into one video file per recording. This file was linked to the timestamps from the CAN bus data, so that it was possible to identify the exact time periods where the ADF was activated during each recording. However, due to issues with the video recordings, there were multiple video files per participant, leading to a total of 368 separate videos across the 79 participants. There was a range of 1 to 11 videos (M = 4.66, SD = 2.12) per participant, and the duration of these videos ranged from 25 s to 77 min.

In order to select appropriate video segments to analyse, the activation and end time points of ADF were obtained from the vehicle CAN bus data for each of the 368 videos. In total, there were 1841 segments where the ADF was switched on, ranging from 4 to 60 segments per participant (M = 23.30, SD = 10.53), with the duration of each segment varying from <1 min to 20.75 min (M = 1.96, SD = 1.36).

The purpose of the current analysis was to investigate drivers' engagement in NDRTs during automation. Therefore, the segments analysed needed to be long enough to allow drivers to become immersed in any NDRT. For this reason, only automation segments of longer than 5 min were included in the analysis. This led to a total of 225 videos to be analysed. Due to time constraints, only videos which had two or more suitable segments were included, which led to the selection of 129 videos with two or more segments of automation of greater than 5 min each.

Three video coders worked together to analyse the videos. The starting point was to browse the 129 video segments from the beginning to the end, ensuring the participant had engaged in an NDRT during the selected automation segments. For 57 of these videos, there was no engagement in any NDRT, while for a further 23 videos, participants only engaged in NDRTs for short periods of time (less than 1 min at a time), which would not be long enough to generate a real sense of being "out of the loop". In addition, due to the camera failure, there were 3 incomplete videos which had to be excluded from the analysis. This left a total of 46 videos (across 32 participants) where participants engaged in an NDRT for longer than 1 min at a time. These 46 videos came from 32 participants aged 25–70 years (M_{age} = 40.72 years, SD_{age} = 12.14). Due to the previously mentioned issues with the video recordings, there were 14 of the participants had two videos associated with their drives (meaning 28 videos in total from these 14 participants), and for 7 of these participants the videos came from two different drives. Across all of the videos, there were a total of 65 automation segments where participants were engaged in an NDRT (*mean* = 2.03 segments, *SD* = 1.18 segments), leading to **a total of 425 min of NDRT engagement across the 32 participants** (M = 13.28 min per participant, *SD* = 9.74 min). Table 1 shows the steps for selecting videos for analysis.

Once the relevant video segments had been identified, the coders worked together to develop a process for **measuring NDRT engagement**, by measuring **the number and duration of glances away from NDRTs**. The NDRT start time was the time at which the participant first moved their eyes away from the road and towards their chosen NDRT e.g. a phone, laptop or magazine. While engaged with NDRTs, all participants would occasionally look back up at the road or HMI panel. The start of the glance was the point at which participants' eyes moved away from the NDRT, and the end of the glance was the point at which their eyes moved back to the NDRT. The number of glances away from the NDRT and the glance duration for each of these were recorded on a minute-by-minute basis, until the end of the NDRT segment, which was the point at which the participant stopped engaging in the NDRT, and focused solely on the road and/or driving task. This minute-by-minute analysis was selected in order to capture the dynamic relationship between speed and glance behaviours during AV driving. The timestamp (based on the video output) for the start and end of each glance away from the NDRT was recorded in an excel file.

In order to ensure inter-coder consistency, five video were randomly chosen for an initial analysis, before embarking on the formal analysis process. All three coders analysed these five videos separately, and then checked their results to ensure consistency. Any discrepancies were discussed until a clear process for identifying glance times and durations was established. These discussions continued throughout the analysis process to ensure any uncertainties or new situations were understood by all coders.

Once all of the relevant time stamps for NDRT engagement and disengagement had been identified, the video-based data was matched with the CAN-bus data from the vehicle, to establish the mean and SD of travelling speed for each minute that participants engaged in the NDRT. The mean speed was used as a proxy measure for volume of traffic, with slower speeds indicating a higher density of traffic, and the SD of speed was used as a proxy measure for speed fluctuations, with a larger SD of speed indicating a greater variation in speed. It should be noted that speed data was recorded every 50 ms, leading to 1200 speed points for each minute of NDRT engagement. The mean and SD of speed were calculated for each minute of NDRT engagement, based on these 1200 speed points.

Finally, coders made detailed notes about participants' behaviours throughout the drive. These included descriptions of the type of task they were engaged in, notes on any unexpected changes in the dashboard HMI during the drive, and notes on any particular patterns of participant behaviour that were observed.

Table 1
Steps for selecting videos for analysis.

Screening steps	Videos left for analysis
Obtain original videos from cameras	368 videos across 79 participants
Only retain videos containing automation segments longer than 5 min	225 videos
Retain videos containing at least 2 automation segments longer than 5 min	129 videos
Exclude incomplete videos and the videos from participants who did not engage in NDRTs or had NDRTs durations of less than 1 min.	46 videos across 32 participants with 65 automation segments

2.5. Statistical analysis

The number of glances, and mean duration of glances away from NDRTs per minute were calculated to measure NDRT engagement. The mean and SD of driving speed per minute of NDRT engagement were used as proxy measures for the volume of surrounding traffic.

A Generalised Linear Mixed Model (GLMM) was employed to estimate the number of glances and mean duration of glances away from NDRTs during the 425 min of NDRT engagement from 32 participants (*mean* = 13.28 min per participant, *SD* = 9.74 min). In this analysis, the independent variables were the mean driving speed per minute, SD of driving speed per minute, age, gender, and AV experience (Yes/No), while the dependent variables were glance behaviours i.e. number of glances per minute and glance duration. For the analysis of number of glances per minute (count data), GLMM with the logit link function was selected; while for the analysis of glance duration (continuous variable) GLMM with identity function was selected. The p-value and t-value of 0.05 were used as the criterion for statistical significance. These analyses were processed in IBM SPSS v26.

3. Results

In this section, we outline the results of 2 GLMMs which were run to examine the relationships between surrounding traffic conditions (mean and SD of driving speed), demographic variables (age (Years), gender (Male/Female), AD experience (Yes/No) and NDRT engagement, operationalised as number of glances and mean glance duration away from the NDRT per minute.

Prior to running these analyses, a Pearson correlation analysis was used to assess the interplay between the number and mean duration of glances away from NDRT. For the 425 min of NDRT engagement, there were 107 min of video where participants were fully engaged in the NDRTs, and their glances did not move towards the road or vehicle area. Therefore, the correlation analysis was conducted on the remaining 318 min. Results showed that the correlation between the number of glances and mean glance duration away from NDRTs was not significant (r = -0.103, $p = 0.067$). Thus, the number of glances and mean glance duration can be treated as two separate dependent variables.

3.1. Number of glances away from NDRTs

In order to investigate whether the surrounding traffic influenced NDRTs engagement, a GLMM was first adopted to understand the relationship between the number of glances away from NDRTs per minute, and the mean and SD of driving speed. The age (Years), gender (Male/Female) and AV experience (Yes/No) variables were also added into the model.

Table 2 shows that SD of speed had a significant influence on the number of glances away from the NDRTs. While we wouldn't expect a 1kph change in SD of speed to lead to any difference in number of glances, this result suggests that a 10kph change in SD of speed would lead to a meaningful increase (0.34) in the number of glances away from NDRTs. Drivers' age also showed a significant effect, with less glances away from the NDRT for younger drivers, but the small sample size, combined with the small coefficient size suggests that caution is required when interpreting this result. Results also showed that female drivers were less likely to look away from the NDRTs than male drivers. Mean driving speed and AV experience did not affect the number of glances per minute away from NDRTs.

3.2. Mean glance duration away from NDRTs

Another GLMM was constructed to investigate the relationship between the mean glance duration away from NDRTs, the mean and SD of driving speed, age (Years), gender (Male/Female) and AV experience (Yes/No). Table 3 shows that mean speed had a significant, but small, influence on the mean glance duration away from NDRTs, where a decrease of 10 kph in mean speed, increased the mean glance duration away from NDRTs by 30 ms. There was also a significant effect of the SD of speed on mean glance duration, where a 1 kph increase in the SD of speed led to a 111 ms increment in mean glance duration away from NDRTs. Female drivers had a significantly shorter mean glance duration away from NDRTs when compared to male drivers (2736 ms vs 3091 ms). Age and AD experience did not influence the mean glance duration away from NDRTs.

Table 2
Results of the GLMM for number of glances away from NDRTs.

Parameter	Coefficient	SE	t-statistic	p-value
Mean speed (kph)	0.002	0.001	1.485	0.138
SD of speed (kph)	0.034	0.008	4.133	0.000***
Age (years)	0.019	0.005	3.768	0.000***
Gender (Female)	−0.494	0.128	−3.865	0.000***
AD experience (No)	−0.085	0.118	−0.716	0.474
Intercept	−0.288	0.245	−1.174	0.241
Number of observations	425			
AIC	1386.019			
BIC	1549.557			

Link function: Log; SE = Standard Error; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3
GLMM results for mean glance duration away from NDRTs.

Parameter	Coefficient	SE	t-statistic	p-value
Mean speed (kph)	−0.003	0.001	−4.322	0.000***
SD of speed (kph)	0.111	0.026	4.322	0.000***
Age (years)	0.011	0.017	0.635	0.526
Gender (Female)	−0.861	0.246	−3.506	0.001**
AD experience (No)	−0.143	0.371	−0.385	0.701
Intercept	1.940	0.706	2.748	0.006**
Number of observations	425			
AIC	2357.079			
BIC	2520.617			

Link function: Identity; SE = Standard Error; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

4. Discussion

Although it is assumed that increasing levels of automation will lead to increased driver engagement in NDRTs, there is little research investigating this issue in real-world environments. In addition, it is not known how the driving environment might impact on drivers' level of engagement with NDRTs during automation. The current study addresses these issues by investigating the pattern of drivers' engagement in NDRTs, when travelling in an L3 automated test vehicle, on a European highway. Specifically, we investigated whether any change in speed affected driver behaviour during automation, particularly in relation to the division of driver attention between an NDRT and the driving environment.

Fixation durations are a good metric of where drivers are placing their attention (Carrasco, 2011), and usually range from less than 100 ms to several seconds (Velichkovsky, Dornhoefer, Pannasch, & Unema, 2000). 200 ms has been set as a typical threshold to calculate fixations in automated driving research (Goncalves et al., 2020; Louw et al., 2017; Lu, Coster, & de Winter, 2017). Our results show that relatively small changes in the SD of speed, led to an increase in fixations towards the vehicle dashboard and roadway ahead. In fact, the number and mean duration of glances per minute away from NDRTs both increased when the SD of speed was high. A high SD of speed indicated that the AVs executed frequent deceleration-and-acceleration and go-and-stop driving behaviours to adapt to the fluctuation of driving environments (e.g., the deceleration of front vehicles, or the lane changing behaviour of adjacent vehicles). Therefore, it can be assumed that the increase in SD of speed triggered more and longer glances towards surrounding environment to look at what was happening to cause these motion changes. Previous studies, during manual driving, have shown that a higher SD of speed was associated with a higher risk of traffic crashes, due to the more complex and variable driving environment associated with this type of driving (Abdel-Aty & Pande, 2005; Abdel-Aty & Pemmanaboina, 2006), hence drivers might be more vigilant, with more, and longer, glances away from NDRTs to be ready to prevent a potential collision with other vehicles while the SD of speed was high. In contrast, a low SD of speed suggests a stable and monotonous travelling environment, which could potentially lead to boredom and inattention from driving-related tasks (Farahmand & Boroujerdian, 2018; Larue, Rakotonirainy, & Pettitt, 2010), thus encouraging drivers' engagement in NDRTs.

Mean travelling speed also had a significant effect on mean glance duration, with longer glances away from NDRTs when mean speed was low. The result was inconsistent with the findings of naturalistic studies in manual driving, where decreased speed was correlated with an increase in NDRT engagement, most likely due to the lower driving demand during low speed situations (Christoph et al., 2019; Funkhouser & Sayer, 2012; Risteska et al., 2021; Tivesten & Dozza, 2015), compared to higher speed situations where required reaction times would be shorter and stopping distances longer for manual driving (Wang, Quddus, & Ison, 2013). However, the demand imposed by manual driving is significantly different to that of automated driving, where the resources dedicated to motor control are no longer required. Although the effect size in the current study was small, the results are consistent with several highly-automated simulator studies (Beggiato et al., 2015; Jamson, Merat, Carsten, & Lai, 2013) where drivers showed longer duration of glances away from NDRTs during traffic congestion, and paid more visual attention to roadway due to heavy traffic. This may be because drivers allocated their attention according to the complexity of environments. In the high-density traffic, there were more vehicles around with complex interactions that could distract driver's attention from their NDRT.

It was found that age had a significant, but small influence on the number of glances away from NDRTs, with older drivers more likely to frequently look away from NDRTs, regardless of travelling speed. However, given the small effect size, more research is required to understand if a similar finding would emerge with a larger sample. Additionally, male participants in this study had significantly more, and longer, glances away from NDRTs than female drivers. This finding is interesting, as previous research has generally shown that female drivers hold lower levels of trust in AVs than male drivers (Hohenberger et al., 2016; Nordhoff et al., 2020; Zoellick et al., 2019), and less positive attitudes overall towards these vehicles (Hulse, Xie, & Galea, 2018). It may be that the male drivers in the current experiment were more interested in how the AV was working, and thus, had a greater desire to monitor the system and roadway environment. However, questionnaire results (not reported in the current paper due to space constraints) have shown no gender differences in trust in the AV system, or in attitudes towards technology. Future research should explore if this gender related difference emerges in different contexts, and with increased experience of automation.

Previous AV experience had no significant effect either on the number or duration of glances away from NDRTs. This might be because the AV experience (Yes/No) in the present study covered from L1 to L3. Result showed that 24 out of 32 participants had L1 or

L2 driving experience, but only 1 participant had L3 driving experience, which leads us to conclude that the L1 and L2 driving experiences had very weak effect on NDRT engagement in L3 driving.

Overall, our findings suggest that drivers' NDRT engagement was affected by the traffic environment surrounding the AV, reflected in the various visual interaction strategies with NDRTs at different driving speeds. Drivers increased their visual attention away from NDRTs while AVs were travelling in an environment with high speed oscillation or high density traffic. The oscillation might be the stimulus that induced drivers' attention away from NDRTs to check the cause of the change in vehicle behaviour, and caused them to allocate more visual resources from the NDRT to monitoring the driving environment. Such findings are useful for understanding the attention allocation mechanism behind engagement in NDRTs during automated driving, encouraging AVs designers to develop a suitable human–machine interface that facilitates drivers' situation awareness and supervisory control.

5. Conclusion

The aim of present study was to investigate the impact of driving environment on drivers' NDRT engagement in real-world L3 AVs. To do so, GLMMs were used to build the relationship between the metrics for driving environment (i.e., the mean and SD of driving speed) and the metrics for NDRT engagement (i.e., the number of glances and mean glance duration away from NDRTs).

The results showed that the number and mean duration of glances increased significantly when AVs were travelling with a high fluctuation of speed. Additionally, mean speed had a significant effect on mean glance duration, with longer glances away from NDRTs when travelling speed was low, compared to that in high speed. Age and gender both had significant effects on NDRTs engagement, with older and male drivers were more likely to look away from NDRTs. Taken together, the findings provide AV designers with better knowledge of driver behaviours and have important implications for balancing the benefits and safety issues brought from AVs. It is clear that the driving environment, or specifically the level of traffic congestion, had a significant effect on drivers' NDRTs engagement in L3 AVs, reflected in the change in glance behaviours in relation to different driving environments. Approximately 40 % participants (32/79) were willing to engage in a NDRT at least for one minute, which provides information on how many people are willing to trust L3 AVs in real-world environments, albeit with a safety driver on board.

To the best of our knowledge, this is the first study that explores the impact of driving environment on drivers' NDRTs engagement in real-world L3 AVs. Furthermore, the experimental design ensures the voluntary nature of the engagement in NDRTs, providing insights into how likely people are to engage in these types of actions during automation, even in very new vehicles. Despite the significant results gained from this study, there are several limitations that must be acknowledged. Firstly, the sample size was relatively small, which may limit the generalizability of the results. In addition, the process of selecting videos led to the inclusion of a potentially biased sample of those participants who were willing to engage in NDRTs on a prolonged basis. However, it was interesting to note that a large number of participants did engage in NDRTs, even in a real world, busy traffic environment, suggesting a high level of confidence in the AV. Finally, the number and duration of glances were coded manually, which may influence the accuracy of the results, but it is anticipated that this manual coding process can provide insights for computer programmers on how to identify and interpret relevant patterns of driver behaviours during automated driving.

CRediT authorship contribution statement

Xian Liu: Conceptualization, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Ruth Madigan:** Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing. **Ehsan Sadraei:** Formal analysis, Software. **Yee Mun Lee:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Natasha Merat:** Conceptualization, Methodology, Project administration, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors wish to thank Yves Page for his invaluable input and insights. The research leading to these results has received funding from the European Commission Horizon 2020 program, under the project L3Pilot, grant agreement number 723051. The content reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

References

Abdel-Aty, M., & Pande, A. (2005). Identifying crash propensity using specific traffic speed conditions. *Journal of Safety Research, 36*(1), 97–108. https://doi.org/10.1016/j.jsr.2004.11.002

Abdel-Aty, M. A., & Pemmanaboina, R. (2006). Calibrating a real-time traffic crash-prediction model using archived weather and ITS traffic data. *IEEE Transactions on Intelligent Transportation Systems, 7*(2), 167–174. https://doi.org/10.1109/tits.2006.874710

AFGBV. (2022). *Autonome-Fahrzeuge-Genehmigungs-und-Betriebs-Verordnung – AFGBV*. https://www.buzer.de/AFGBV.htm.

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*. Munich: Tagung Fahrerassistenzsysteme, 7.

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research, 51*(13), 1484–1525. https://doi.org/10.1016/j.visres.2011.04.012

Christoph, M., Wesseling, S., & van Nes, N. (2019). Self-regulation of drivers' mobile phone use: The influence of driving context. *Transportation Research Part F-Traffic Psychology and Behaviour, 66*, 262–272. https://doi.org/10.1016/j.trf.2019.09.012

Farahmand, B., & Boroujerdian, A. M. (2018). Effect of road geometry on driver fatigue in monotonous environments: A simulator study. *Transportation Research Part F-Traffic Psychology and Behaviour, 58*, 640–651. https://doi.org/10.1016/j.trf.2018.06.021

Funkhouser, D., & Sayer, J. (2012). Naturalistic census of cell phone use. *Transportation Research Record, 2321*, 1–6. https://doi.org/10.3141/2321-01

Gold, C., Berisha, I., & Bengler, K. (2015). Utilization of drivetime–performing non-driving related tasks while driving highly automated. In *Proceedings of the human factors and ergonomics society annual meeting,*.

Goncalves, R. C., Louw, T. L., Quaresma, M., Madigan, R., & Merat, N. (2020). The effect of motor control requirements on drivers ' eye-gaze pattern during automated driving. *Accident Analysis and Prevention, 148*, Article 105788. https://doi.org/10.1016/j.aap.2020.105788

Hulse, L. M., Xie, H., & Galea, E. R. (2018). Perceptions of autonomous vehicles: Relationships with road users, risk, gender and age. *Safety Science, 102*, 1–13. https://doi.org/10.1016/j.ssci.2017.10.001

Ismaeel, R., Hibberd, D., Carsten, O., & Jamson, S. (2020). Do drivers self-regulate their engagement in secondary tasks at intersections? An examination based on naturalistic driving data. *Accident Analysis and Prevention, 137*, Article 105464. https://doi.org/10.1016/j.aap.2020.105464

Jamson, A. H., Merat, N., Carsten, O. M. J., & Lai, F. C. H. (2013). Behavioural changes in drivers experiencing highly-automated vehicle control in varying traffic conditions. *Transportation Research Part C-Emerging Technologies, 30*, 116–125. https://doi.org/10.1016/j.trc.2013.02.008

Larue, G. S., Rakotonirainy, A., & Pettitt, A. N. (2010). Predicting driver's hypovigilance on monotonous roads: Literature review. In *1st International Conference on Driver Distraction and Inattention, Sweden*.

Louw, T., Kuo, J., Romano, R., Radhakrishnan, V., Lenne, M. G., & Merat, N. (2019). Engaging in NDRTs affects drivers' responses and glance patterns after silent automation failures. *Transportation Research Part F-Traffic Psychology and Behaviour, 62*, 870–882. https://doi.org/10.1016/j.trf.2019.03.020

Louw, T., Madigan, R., Carsten, O., & Merat, N. (2017). Were they in the loop during automated driving? Links between visual attention and crash potential. *Injury Prevention, 23*(4), 281–286. https://doi.org/10.1136/injuryprev-2016-042155

Lu, Z., Coster, X., & de Winter, J. (2017). How much time do drivers need to obtain situation awareness? A laboratory-based study of automated driving. *Applied Ergonomics, 60*, 293–304. 10.1016/j.apergo.2016.12.003.

McDonald, A. D., Alambeigi, H., Engstrom, J., Markkula, G., Vogelpohl, T., Dunne, J., & Yuma, N. (2019). Toward computational simulations of behavior during automated driving takeovers: A review of the empirical and modeling literatures. *Human Factors, 61*(4), 642–688. https://doi.org/10.1177/0018720819829572

Morando, A., Gershon, P., Mehler, B., & Reimer, B. (2021). A model for naturalistic glance behavior around Tesla Autopilot disengagements. *Accident Analysis and Prevention, 161*, Article 106348. https://doi.org/10.1016/j.aap.2021.106348

Noble, A. M., Miles, M., Perez, M. A., Guo, F., & Klauer, S. G. (2021). Evaluating driver eye glance behavior and secondary task engagement while using driving automation systems. *Accident Analysis and Prevention, 151*, Article 105959. https://doi.org/10.1016/j.aap.2020.105959

Risteska, M., Kanaan, D., Donmez, B., & Chen, H. Y. W. (2021). The effect of driving demands on distraction engagement and glance behaviors: Results from naturalistic data. *Safety Science, 136*, Article 105123. https://doi.org/10.1016/j.ssci.2020.105123

Tivesten, E., & Dozza, M. (2015). Driving context influences drivers' decision to engage in visual-manual phone tasks: Evidence from a naturalistic driving study. *Journal of Safety Research, 53*, 87–96. https://doi.org/10.1016/j.jsr.2015.03.010

Velichkovsky, B. M., Dornhoefer, S. M., Pannasch, S., & Unema, P. J. (2000). Visual fixations and level of attentional processing. *Proceedings of the 2000 symposium on eye tracking research & applications, Florida, USA*.

Wang, C., Quddus, M. A., & Ison, S. G. (2013). The effect of traffic and road characteristics on road safety: A review and future research direction. *Safety Science, 57*, 264–275. https://doi.org/10.1016/j.ssci.2013.02.012

Zangi, N., Srour-Zreik, R., Ridel, D., Chasidim, H., & Borowsky, A. (2022). Driver distraction and its effects on partially automated driving performance: A driving simulator study among young-experienced drivers. *Accident Analysis and Prevention, 166*, Article 106565. https://doi.org/10.1016/j.aap.2022.106565

Zeeb, K., Buchner, A., & Schrauf, M. (2015). What determines the take-over time? An integrated model approach of driver take-over after automated driving. *Accident Analysis and Prevention, 78*, 212–221. https://doi.org/10.1016/j.aap.2015.02.023

Zeeb, K., Buchner, A., & Schrauf, M. (2016). Is take-over time all that matters? The impact of visual-cognitive load on driver take-over quality after conditionally automated driving. *Accident Analysis and Prevention, 92*, 230–239. https://doi.org/10.1016/j.aap.2016.04.002

Zhang, B., de Winter, J., Varotto, S., Happee, R., & Martens, M. (2019). Determinants of take-over time from automated driving: A meta-analysis of 129 studies. *Transportation Research Part F-Traffic Psychology and Behaviour, 64*, 285–307. https://doi.org/10.1016/j.trf.2019.04.020