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The effect of cognitive load on Detection-Response Task (DRT) performance during day- and night-time driving: A driving simulator study with young and older drivers

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ABSTRACT

Over the past 25 years, distracted driving and driver inattention have been one of the main risk factors for road traffic safety. Previous research has shown that increased cognitive load from non-visual activities take our mind off the driving task, by engaging our working memory resources. Studies have shown that engagement in these tasks results in a more concentrated gaze towards the road centre, reducing lateral deviation (e.g., reduced standard deviation of lane position (SDLP) and less high frequency steering reversals). The Detection-Response Task (DRT) is an International Organization for Standardization (ISO) standard used to study the impact of cognitive load, due to secondary task, on performance. This driving simulator study examined the effect of varying levels of cognitive load (using the n-back task) on driving and DRT performance. The effect of age and lighting conditions was examined by comparing the performance of a younger group of drivers (Age *Mdn* = 22) with that of an older cohort (Age *Mdn* = 66) during day- and night-time driving conditions. Results showed that young drivers' DRT performance was better at night-time compared to day-time, when compared to that of older drivers. Young drivers also performed better at the n-back task. Overall, an increase in cognitive load increased response time to the DRT task. In line with previous studies, an increase in cognitive load also reduced SDLP, but only in the absence of the DRT. These results provide new knowledge on drivers' detection of peripheral stimuli during different lighting conditions, and how these are affected by a cognitively loading, non-visual, working memory task. The implications of these findings on real-world road safety are discussed.

1. Introduction

According to the Task-Capability Interface Model (Fuller, 2005), driving outcome, in terms of both control, and crashes/near misses, is strongly influenced by a combination of drivers' capabilities and the demands of the environment on the driving task. Safe driving performance involves a combination of driver-related factors, such as information processing speed and capacity, efficient perceptual-motor coordination, and effective/timely response to hazardous events. However, performance can also be affected by other human factors, such as driver age (e.g., Horberry et al., 2006), personality/attitudes (e.g., Ulleberg & Rundmo, 2003), and

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impairments caused by distraction, fatigue, and alcohol/drugs (e.g., Arvin & Khattak, 2020; Petridou & Moustaki, 2000). Crash risk increases with higher speeds (e.g., Aarts & van Schagen, 2006), especially for more challenging road types (e.g., sharp bends), with other environmental factors, such as inclement weather conditions and those that affect visibility and/or driving conditions (fog, heavy rain, flooding) also increasing the likelihood of crashes (e.g., Abdel-Aty et al., 2011; Maze et al., 2006; Wang et al., 2017). One such environmental condition is night-time driving, with an increase in crashes (e.g., Plainis et al., 2006) fuelled by other environmental factors (adverse weather conditions, challenging road types; Klauer et al., 2006). Reduced visibility at night (Wood, 2020), combined with increased glare (especially for older drivers, Kimlin et al., 2017), is exacerbated by other human factors such as alcohol-related impairments (especially for younger drivers, Keall et al., 2005), and fatigue/sleepiness due to the circadian cycle (Jackson et al., 2011).

1.1. Driver distraction

Regan et al. (2011) differentiated between driver distraction and inattention by defining inattention as "insufficient, or no attention, to activities critical for safe driving" (p. 1775) and driver distraction as a form of driver inattention that results in the deviation of drivers' attention from critical driving activities to another driving or non-driving related activity (Regan et al., 2011).

Together with driver inattention, distracted driving is associated with an increased likelihood of fatal/serious injuries (García-Herrero et al., 2020), across the UK (Department for Transport, 2021), and around the world (e.g., Klauer et al., 2006; Robbins & Fotios, 2022). For instance, distracting activities contributed to six percent of all crashes across Great Britain (Department for Transport, 2021). This data is based on police presence at the scene, which report standard distractions from a list, such as: using mobile phones or other distractions inside the vehicle, and from external factors. This figure is much higher for naturalistic studies, with the 100-Car Naturalistic Driving Study in the US showing that driver inattention, including distractions, was the cause of 65% of near-crashes and 78% of crashes. This report cited secondary task engagement as the most frequent activity, followed by driving-related inattention and drowsiness (Klauer et al., 2006).

The effect of a competing task on driving performance is based on the resources required for each activity (Hallett et al., 2011 as cited in Oviedo-Trespalacios & Regan, 2021), although driving simulator and naturalistic driving studies have shown different effects on driving performance and vehicle metrics from secondary tasks (Engström, Johansson et al., 2005; Horrey & Wickens, 2006; Kountouriotis & Merat, 2016; Onate-Vega et al., 2020). Generally, based on Wickens' Multiple Resource Theory (Wickens, 2008), the effect of a competing task on driving performance is based on the resources required for each task, with those that take drivers' eyes off the road being more detrimental, for obvious reasons. In line with this theory, higher levels of lateral deviation are typically observed from visually demanding tasks, compared to those that allow drivers to keep their eyes on the road, but take attention and mind off the road, with the latter being similar to the demands required for hands-free mobile phone conversations. This sort of cognitive distraction defined as the attentional diversion towards thoughts that takes drivers' minds off the road (Hallett et al., 2011; Regan, 2010) as cited in Regan & Oviedo-Trespalacios, 2022). This is sometimes associated with a reduction in lateral deviation, often to values lower than that seen during baseline – no secondary task – conditions, especially in driving simulator studies (e.g., Cooper et al., 2013; Engström, Johansson et al., 2005; Kountouriotis & Merat, 2016), with less evidence of this behaviour seen in naturalistic driving studies (e.g., Fitch et al., 2013; Reimer et al., 2012). Using a simulator study, Beede and Kass (2006) report that cognitively demanding secondary tasks (talking on a hands-free phone) resulted in increased violations and attentional lapses, indicating the potential effects of cognitive distraction on situation awareness and safety.

The verbal version of the n-back task, a delayed digit recall task (Mehler et al., 2011), has been used regularly as a secondary cognitive task in driving studies for manipulating cognitive load (Čegovnik et al., 2018; Reimer et al., 2012; von Janczewski et al., 2021). Considered to rely on similar cognitive resources as those used during a hands-free mobile phone conversation (Mehler et al., 2011), the difficulty of this task is easy to manipulate, by increasing "n", which is why it is used regularly as a surrogate, but more controllable and easier to quantify alternative, to hands-free conversations (e.g., Fotios et al., 2021).

The detection-response task (DRT), adopted by the International Organization for Standardization (ISO 17488:2016), is often used in driving studies to measure drivers' available resources (van Winsum, 2018), and to determine the attentional demands of cognitively loading secondary tasks (ISO, 2016; Stojmenova et al., 2017; Stojmenova & Sodnik, 2018; van Winsum, 2018). Even though an increase in the self-reported workload has been observed with the DRT (Mehler & Reimer, 2021), this task is thought to have little or no effect on driving performance and is usually used as a tertiary task to determine the difficulty and impact of secondary activities on driving (Mehler & Reimer, 2021; Merat & Jamson, 2008). Auditory, tactile and visual stimuli have been used for the DRT, which are found to be equally sensitive to changes in cognitive load (Merat & Jamson, 2008; Stojmenova et al., 2017). Studies have also shown that presenting visual stimuli at different eccentricities has no effect on DRT performance (Merat et al., 2006; van Winsum, 2018; Victor et al., 2008), suggesting that the main mechanism behind reduced detection is the cognitive load from the competing task, rather than the visual demand of the DRT (Merat et al., 2006). Detection of visual stimuli using the DRT is found to be a reliable method for measuring decreased visual attention towards the periphery (Merat & Jamson, 2008), and the detection of peripheral safety–critical information (Vater et al., 2022; Wolfe et al., 2022), such as pedestrians. DRT performance is evaluated by measuring reaction times and hit rates, which are sensitive to the difficulty of the competing secondary task (e.g., Čegovnik et al., 2018; Engström, Aberg et al., 2005; Fotios et al., 2021; Mehler & Reimer, 2021; van Winsum, 2018).

1.2. Does driving safety vary between day and night?

Driving at night (after dark) has been shown to be riskier and more difficult than day-time driving (e.g., Evans et al., 2020; Fors & Lundkvist, 2009; Regev et al., 2018), and associated with increased injury severity (Anarkooli & Hosseinlou, 2016) and crash involvement (Regev et al., 2018; Sullivan & Flannagan, 2002). This is partly due to glare (Wood, 2020) and/or decreased visibility associated with night-time driving (Babić et al., 2020; Evans et al., 2020; 2022), as well as factors associated with night-time conditions, such as drug/alcohol- (Brady & Li, 2013; Jean Wilson et al., 2006), and fatigue-related impairments (Jackson et al., 2011).

Although drivers are aware of the visibility issues associated with driving at night (Evans et al., 2022), and report an increase in perceived risk, and driving difficulty across different conditions (Evans et al., 2020), various simulator studies have reported reduced hazard perception (Asadamraji et al., 2019), and decreased fixations on safety–critical areas (Garay-Vega et al., 2007), while driving at night, compared to day-time conditions. Driving simulator studies also report an increase in speed for day-time driving, when compared to night-time conditions (Bella et al., 2014; Gilandeh et al., 2018). Jägerbrand and Sjöbergh (2016) highlighted that the positive association between crash involvement and limited lighting levels could be related to the inability of drivers to suitably adapt their speed for the reduced visibility driving conditions. In contrast to the simulator studies, in a study conducted on approximately 60 million vehicles, the average speed of drivers was higher on roads without lighting at night, when compared to day-time conditions, or roads that were lit at night (Jägerbrand & Sjöbergh, 2016).

Despite a strong body of research on driver distraction, there is a shortage of studies on how distraction affects performance during night-time driving (Dukic et al., 2013; Sheykhfard & Haghighi, 2020; Yan et al., 2022; Yared & Patterson, 2020). Using a simulator study, Yared and Patterson (2020) highlighted that driving at night might require more attention for the driver, due to increased visual workload, and reduced illumination. While a naturalistic driving study conducted in Iran (Sheykhfard & Haghighi, 2020) revealed that drivers were more distracted by digital billboards at night, other studies have not shown any difference between day- and night-time conditions, either for the level of distraction caused by reading navigation system displays (Yared & Patterson, 2020), or the external billboards (Dukic et al., 2013). In a recent driving simulator study, Yan et al. (2022) found interactions between day- and night-time driving with distraction, due to mobile phone use. While driving performance was similar between day- and night-time driving without distraction, cognitive distraction (completing the 1-back task) resulted in increased SDLP during night-time driving on straight roads. In contrast, for day-time driving, SDLP was lowest when talking on the mobile phone, and highest when texting. This study also found an increase in speed during night-time driving, compared to day-time conditions. Given the limited evidence focusing on different forms of distraction during night-time driving, there is a need for further research in this area.

1.3. Aim of the present study

The current study investigates whether a cognitively loading secondary task (n-back) on the DRT, and driving performance varies between day- and night-time driving of two age groups (young and older). Based on the inhibitory effects of cognitive load on attention and visual scanning (e.g., Engström, Johansson et al., 2005; Reimer et al., 2012), we hypothesised that increasing difficulty of the n-back would reduce detection of the visual DRT targets. Furthermore, according to the Active Gaze model of steering (Wilkie & Wann, 2003; Wilkie et al., 2008), where we look is closely linked to where and how we steer, such that the direction of our gaze directly influences our steering response. Based on this model, we hypothesised a reduction in lateral deviation, due to a higher concentration of gaze towards the road centre, during the n-back task. The effect of lighting conditions and driver age on this performance was assessed by developing the following research questions:

(1) Do the effects of the n-back task on the DRT and driving performance differ between day-time and night-time driving?
(2) Do the effects of the n-back task on the DRT and driving performance between day-time and night-time driving vary between young and older drivers?

2. Method

2.1. Participants

Sixty participants were recruited for this study. However, due to technical errors with the simulator database, that was not related to participants' behaviour in the driving simulator, data from only 37 drivers are reported here. The final sample consisted of 20 young drivers, aged between 21 and 25 years old, and 17 older drivers, aged between 60 and 73 years old. The demographic characteristics of the sample are summarised in Table 1.

2.2. Apparatus

The study was conducted at the University of Leeds Driving Simulator (UoLDS), a Jaguar S-Type cabin encased by a 4 m spherical

Table 1
Demographic characteristics.

	Young (10 males, 10 females) ***Mdn* (*Min* − *Max*)**	**Older (12 males, 5 females)** ***Mdn* (*Min* − *Max*)**
Age	22 (21–25)	66 (60–73)
Annual mileage	6000 (3000–40000)	8000 (4000–15000)

projection dome, with a 300° projection angle and 8 degrees of freedom motion system (Fig. 1).

The experimental road included two-lane rural sections with a 60 mph speed limit, interspersed by two-lane urban sections with a 40 mph speed limit. The rural sections included both straight and curved sections, but, for analysis purposes, all n-back and DRT tasks (see below) were presented during the straight sections of the rural road only. No other vehicles were present in the driver's lane, but the road did contain oncoming traffic, presented at around six vehicles per kilometre.

2.3. Experimental design

The study followed a mixed design approach, including within-participant factors of lighting (day-time, night-time), cognitive task (baseline without n-back, 1-back, 2-back), and DRT (not present, present), and a between-participants factor of age (young, older).

2.4. Secondary task

In order to examine the effects of cognitive distraction on the detection response task and driving performance, a non-visual, auditory version of the n-back task (Mehler et al., 2011), was presented to participants, at three levels of difficulty (no-back as baseline, 1-back, and 2-back). Participants heard a list of 10 digits in each block, presented at regular intervals of 2.25 s. Digits were presented audibly via the driving simulator speakers, and participants had to repeat back the last but one (1-back), or last but two (2-back) digits. At the beginning of each block, a message was presented to indicate whether participants were required to complete the 1- or 2-back. The experimenter and a voice recorder were used to record responses.

2.5. Detection-response task

A visual DRT (ISO, 2016) was used to measure the effects of the secondary task (n-back) on cognitive load, following the same procedure as that applied by Merat and Jamson (2008). A visual stimulus (the graphical red circle - see Fig. 2) was presented to drivers within an area 2° to 4° above the horizon, and 11° to 23° to the left or right of the participant's forward viewpoint, with a visual angle of about 1° (see Fig. 2 for a day and night presentation of the stimulus). In line with the ISO guidelines, this stimulus was presented at a rate of every 3 to 5 s and remained on the screen for a maximum of 1 s. Each block lasted 30 s, resulting in the presentation of 7 to 9 stimuli per block.

Participants were requested to press a micro-switch button against the steering wheel as soon as they detected the target stimulus. The button was attached to the index finger of the driver's dominant hand (Fig. 3). If the driver responded to the stimulus within 1 s, the stimulus was turned off. If a response was not recorded within 1 s from the onset, the stimulus was turned off automatically after 1 s. Response time and miss rate were calculated to evaluate performance (ISO, 2016). As the DRT is visible in peripheral vision, participants were encouraged to avoid looking towards the circles, keeping their eyes towards the road ahead.

Fig. 1. The University of Leeds Driving Simulator.

Fig. 2. Day-time (left) and night-time (right) driving scenes, with the DRT small red circle shown in the road scene (Dot enlarged for visibility in this image).

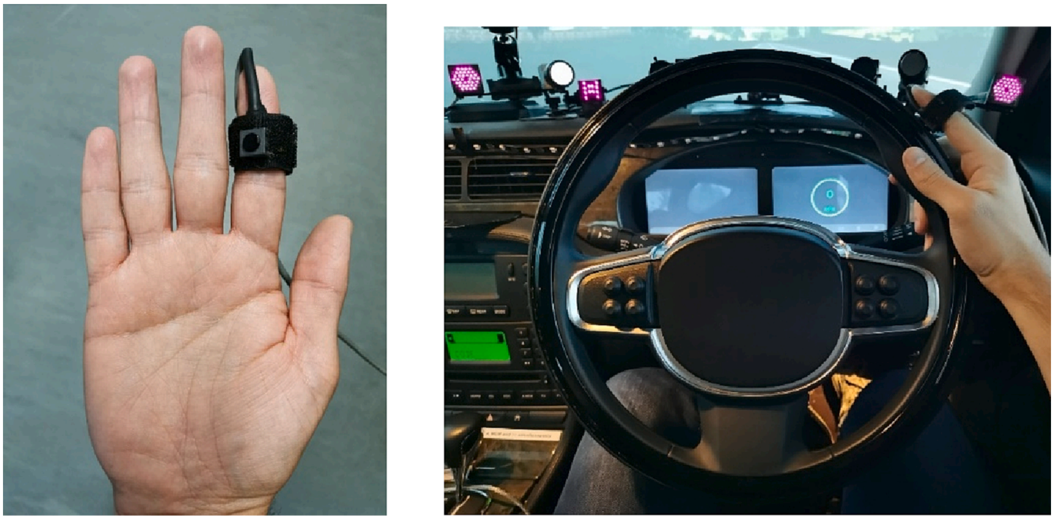

Fig. 3. The micro-switch button used for the study (left) and how it was used to provide a response (right).

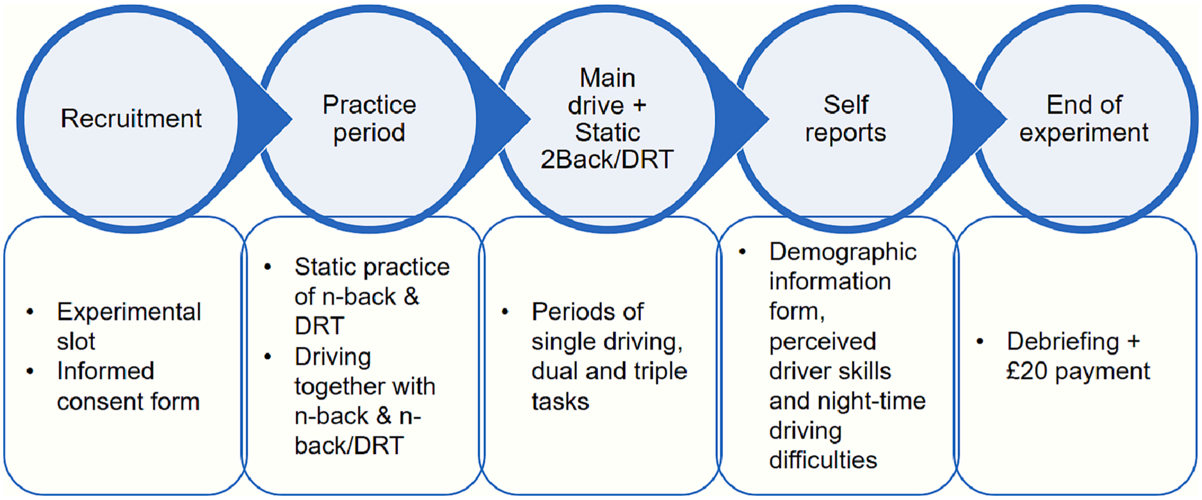

Fig. 4. The experiment procedure.

2.6. Procedure

The study was approved by the ethics committee of the School of Business, Environment and Social Services, University of Leeds (AREA 21–108). Recruitment was advertised via the UoLDS participant database and social media platforms. An online form was completed by interested participants, who were asked to confirm that they had a valid UK driving license for at least three years, were regular drivers, drove at least once a week, and had normal or corrected to normal vision. All eligible participants were then provided with an information sheet about the study and invited to participate.

On arrival, all participants received instructions about the experiment and provided informed consent. They then practiced the 1-back, 2-back, and DRT in isolation, followed by a short period of driving without any additional task, a period of driving with DRT, and a period of driving with DRT and 2-back. This lasted about 15 min. After completing the practice period, verbal consent was taken from each participant regarding whether they understood the tasks and did not experience any motion sickness. They then began the experimental drive, with half of the participants completing the day-time drive first. Each experimental drive lasted approximately 20 min. It should be acknowledged that the experiment itself took place during the day, and only lighting levels were manipulated to depict night-time conditions in the simulated world. The order of tasks for the experimental drive is outlined in Fig. 4.

Participants were asked to drive as they normally would in the real world and reminded that their first priority should be safe driving, followed by performance of the n-back and DRT. A 5-minute break was provided between the two experimental drives, and participants were also asked to complete a questionnaire on perceived driving skills and night-time driving difficulties, at the end of the second drive (results not reported here). The entire visit took approximately 60 min, and participants were compensated £20.

2.7. Data analysis

The percentage of correct responses to 1-back and 2-back and the miss rate and mean response time for DRT (ISO, 2016) were computed. For DRT, any response within the first 100 ms or later than 2500 ms from stimulus onset was considered a missed response. For driving performance, the mean speed (m/s) and the standard deviation of lane position (SDLP) were calculated using MATLAB R2020a. The baseline drive (driving without n-back and DRT) was calculated by averaging two straight blocks (one from the first free driving period and one from the last free driving period) to control for learning effects. These blocks were approximately the same length as the dual and triple task conditions, which included the n-back and DRT. Performance for the dual and triple task sections was calculated by taking the arithmetic mean of corresponding blocks. Data were extracted by using MATLAB R2020a and analysed using SPSS v26 and JASP 16.4.0. Analyses of Variance (ANOVA) were used to examine the aforementioned research questions in JASP. The Greenhouse-Geisser correction was applied when the sphericity assumption was violated, and Bonferonni corrections were applied for multiple comparisons to provide a pairwise comparison of the means.

3. Results

In this section, results are presented in terms of drivers' performance of the n-back task, followed by performance in the DRT, and finally, how engagement in these tasks affected the vehicle-based metrics of driver behaviour.

3.1. N-back Performance

Two separate three-way analyses of variance were conducted to examine the effects of age (young, older), lighting (day-time, night-time), and presence of DRT (without DRT, with DRT) on the percentage of correct responses for the 1-back and 2-back tasks, respectively.

Performance was quite high for both groups, as seen in Table 2, and the addition of the DRT did not seem to have a deleterious effect on n-back performance. Only the main effects of age group were significant for both the 1-back ($F(1, 35) = 9.74$, $p = .004$, $\eta_p^2 = .22$) and 2-back ($F(1, 35) = 10.10$, $p = .003$, $\eta_p^2 = .22$) tasks, with young drivers performing better than the older group in both the 1-back ($t = -3.12$, $p_{bonf} = 0.004$) and 2-back ($t = -3.18$, $p_{bonf} = 0.003$) tasks.

Table 2
The percentage of correct responses during 1-back and 2-back tasks as a function of DRT, lighting, and age group.

			1-Back		2-Back	
DRT	Lighting	Group	*M*	*SD*	*M*	*SD*
With DRT	Day-time	Older	94.34	6.82	81.86	12.92
		Young	97.59	6.93	95.00	7.10
	Night-time	Older	93.03	10.30	84.07	14.45
		Young	100.00	0.00	91.46	13.69
Without DRT	Day-time	Older	95.75	11.03	89.71	14.98
		Young	98.61	5.06	97.81	5.08
	Night-time	Older	95.10	8.54	81.62	17.47
		Young	98.89	2.91	93.44	12.08

3.2. DRT performance

Two separate three-way analyses of variance were conducted in order to test the effects of age (young, older), lighting (day-time, night-time), and cognitive task (baseline, 1-back, 2-back) on the miss rate and mean response time for the DRT.

For miss rate (Fig. 5), the main effects of age ($F(1, 35) = 8.79, p = .005, \eta_p^2 = .20$), cognitive task ($F(1.65, 57.66) = 11.92, p < .001, \eta_p^2 = .25$), and lighting ($F(1, 35) = 9.16, p = .005, \eta_p^2 = .21$) were significant. Overall, older drivers ($M = 6.02, SE = 0.80$) missed more stimuli than young drivers ($M = 2.81, SE = 0.73$ $t = 2.97, p_{bonf} = 0.005$). The percentage of missed responses was also higher at day-time ($M = 5.49, SE = 0.73$) compared to night-time ($M = 3.34, SE = 0.55, t = 3.03, p_{bonf} = 0.005$). Finally, the percentage of missed responses to DRT was significantly higher during the 2-back ($M = 7.03, SE = 1.03$), than baseline ($M = 3.00, SE = 0.58, t = -4.34, p_{bonf} < 0.001$) and 1-back conditions ($M = 3.22, SE = 0.59, t = -4.10, p_{bonf} < 0.001$), with no significant difference between the no task and 1-back conditions ($t = -0.24, p_{bonf} = 1.00$).

For the mean response time (Fig. 6), the main effects of age ($F(1, 35) = 12.13, p = .001, \eta_p^2 = .26$), lighting ($F(1, 35) = 5.88, p = .021, \eta_p^2 = .14$) and cognitive task ($F(2, 70) = 56.90, p < .001, \eta_p^2 = .62$), as well as the interaction effect of age group and cognitive task ($F(2, 70) = 5.20, p = .008, \eta_p^2 = .13$) were significant.

Young drivers ($M = 0.63, SE = 0.02$) were quicker than older drivers ($M = 0.75, SE = 0.03, t = 3.48, p_{bonf} = 0.001$) for response to the DRT stimuli. Both groups of participants showed faster reaction time at night ($M = 0.71, SE = 0.02$), compared to day-time ($M = 0.68, SE = 0.02, t = 2.43, p_{bonf} = 0.021$). In addition, the mean response time to the DRT increased from the baseline ($M = 0.60, SE = 0.02$), to 1-back ($M = 0.70, SE = 0.02$), to 2-back ($M = 0.77, SE = 0.02$). The pairwise comparisons for baseline and 1-back ($t = -6.23, p_{bonf} < 0.001$), baseline and 2-back ($t = -10.62, p_{bonf} < 0.001$), and 1-back and 2-back ($t = -4.39, p_{bonf} < 0.001$) were all significant.

In terms of the interaction between age group and cognitive task (Fig. 7), older drivers' mean response time increased gradually from baseline to 2-back. For older drivers, the difference in reaction time to DRT was significant between baseline and 1-back ($t = -5.07, p_{bonf} < 0.001$), baseline and 2-back ($t = -9.39, p_{bonf} < 0.001$), and 1-back and 2-back ($t = -4.32, p_{bonf} < 0.001$). A similar trend was also observed across young drivers, showing an increase in reaction time from baseline to 1-back, and 2-back. However, only the pairwise comparisons of baseline with 1-back ($t = -3.69, p_{bonf} = 0.007$) and 2-back ($t = -5.47, p_{bonf} < 0.001$) were significant. The difference in mean response time to DRT across the 1-back and 2-back was not significant for the young drivers ($t = -1.78, p_{bonf} = 1.00$).

Young drivers' mean response time to DRT in the baseline block was significantly lower than that of the older drivers' mean response time to DRT during both the 1-back ($t = -4.93, p_{bonf} < 0.001$) and 2-back ($t = -7.59, p_{bonf} < 0.001$). Finally, young drivers' mean response time to DRT with the 1-back ($t = -5.50, p_{bonf} < 0.001$) and with 2-back ($t = -4.49, p_{bonf} < 0.001$) was significantly lower than older drivers' response time with the 2-back.

3.3. Driving performance

In order to investigate the impact of age, lighting, DRT, and cognitive distraction on driving performance, two separate 2 (age: young, old) by 2 (lighting: day-time, night-time) by 2 (DRT: without DRT, with DRT) by 3 (cognitive task: baseline, 1-back, 2-back) mixed ANOVAs were conducted on the mean speed and SDLP as dependent variables.

For mean speed (Fig. 8), a small but significant difference was observed for age ($F(1, 35) = 9.46, p = .004, \eta_p^2 = .21$), cognitive task ($F(2, 70) = 7.62, p = .001, \eta_p^2 = .18$) and the interaction effect of age group and cognitive task ($F(2, 70) = 3.48, p = .036, \eta_p^2 = .09$). Young drivers ($M = 26.01, SE = 0.29$) were seen to drive faster, compared to older drivers ($M = 24.69, SE = 0.40, t = -3.08, p_{bonf} = 0.004$). Additionally, the average speed was lower during the 2-back conditions ($M = 25.16, SE = 0.36$) compared to the 1-back ($M = 25.52, SE = 0.36, t = 3.89, p_{bonf} < 0.001$).

In terms of the interaction between age group and cognitive task (Fig. 9), older drivers' mean speed during 2-back blocks was significantly lower than that of older drivers' mean speed without the n-back task ($t = 3.19, p_{bonf} = 0.032$) and with 1-back ($t = 4.02$,

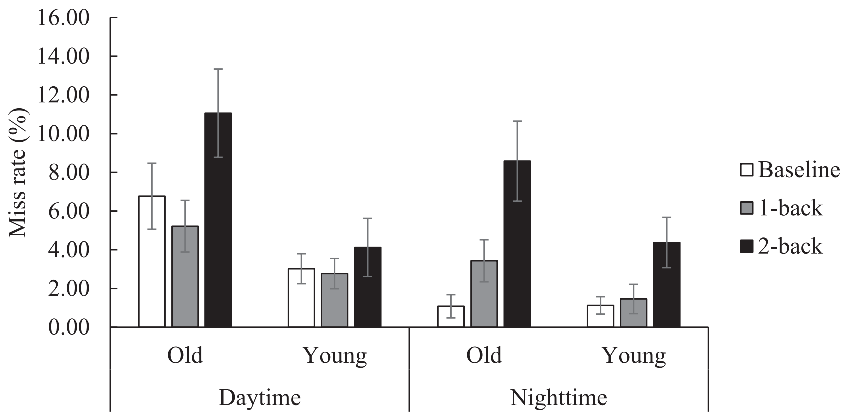

Fig. 5. The percentage of missed responses as a function of lighting, cognitive task and age *Note. The error bars represent the standard error.*

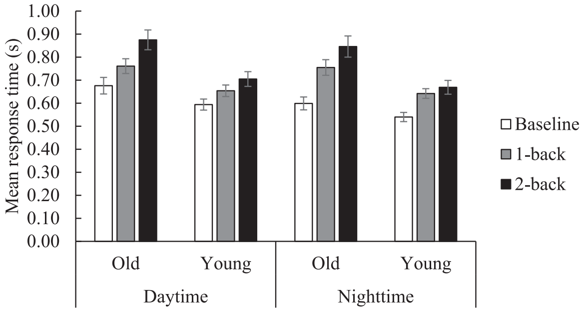

Fig. 6. Mean response time to DRT as a function of cognitive task, age, and lighting *Note. The error bars represent the standard error.*

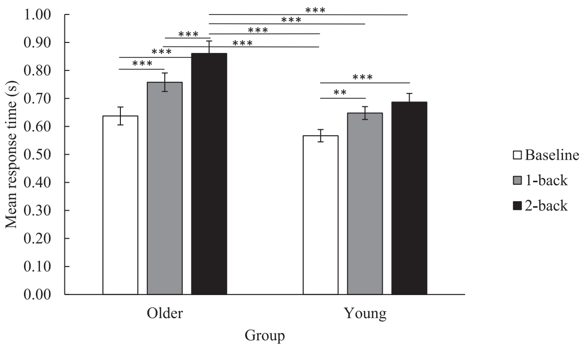

Fig. 7. Mean response time to DRT as a function of cognitive task and age *Note. The error bars represent the standard error, and significance values are presented as * = p <.05, ** = p <.01, *** = p <.001.*

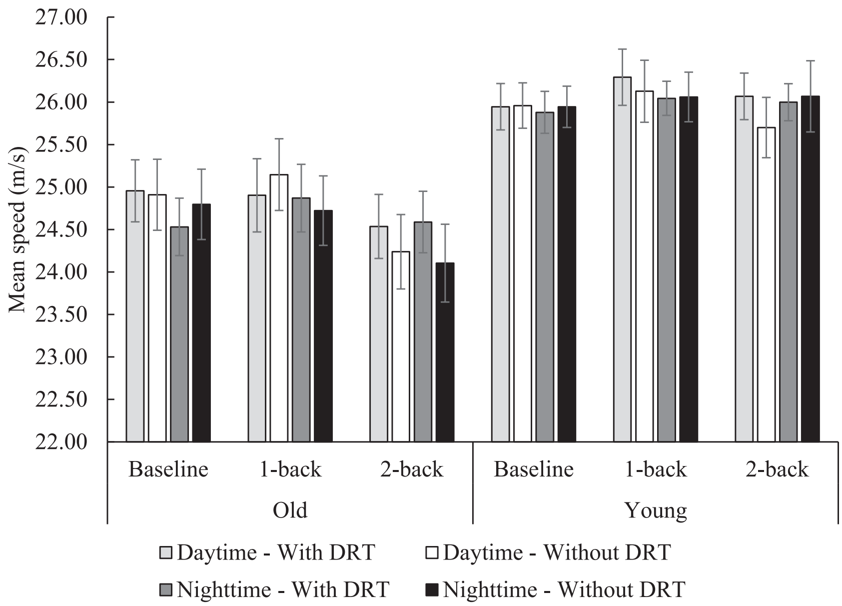

Fig. 8. Mean speed (m/s) as a function of cognitive task, lighting, DRT, and age *Note. The error bars represent the standard error.*

$p_{bonf} = 0.002$), and young drivers' mean speed without the n-back task ($t = 3.55$, $p_{bonf} = 0.015$), with 1-back ($t = 4.00$, $p_{bonf} = 0.004$), and with 2-back ($t = 3.61$, $p_{bonf} = 0.013$).

For the standard deviation of lane position (Fig. 10), the main effects of cognitive task ($F(1.71, 59.91) = 16.00, p < .001, \eta_p^2 = .31$), lighting ($F(1, 35) = 10.96, p = .002, \eta_p^2 = .24$), and DRT presence ($F(1, 35) = 9.50, p = .004, \eta_p^2 = .21$), and the interactions between DRT and age group ($F(1, 35) = 6.07, p = .019, \eta_p^2 = .15$), DRT and cognitive task ($F(2, 70) = 15.30, p < .001, \eta_p^2 = .30$), and DRT and lighting (F

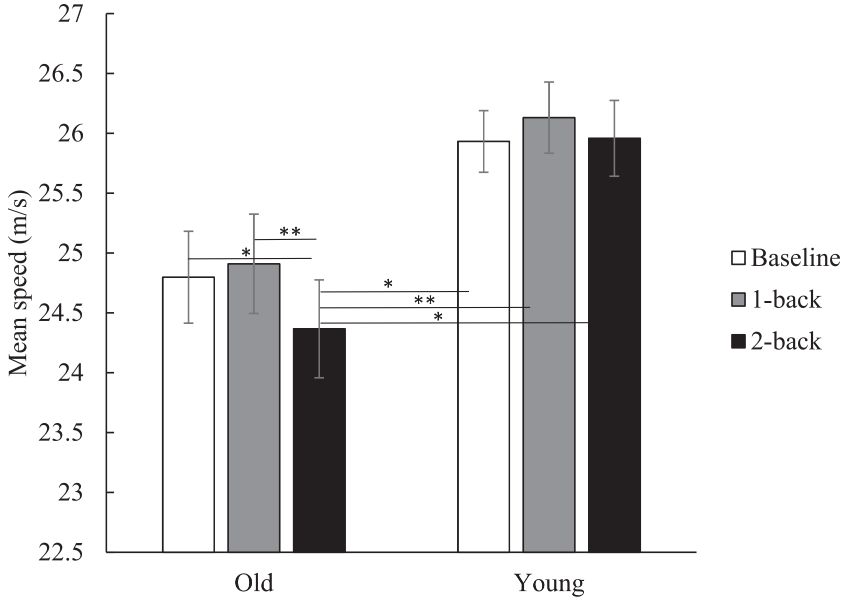

Fig. 9. Mean speed as a function of cognitive task and age *Note. The error bars represent the standard error, and significance values are presented as * = p <.05, ** = p <.01, *** = p <.001.*

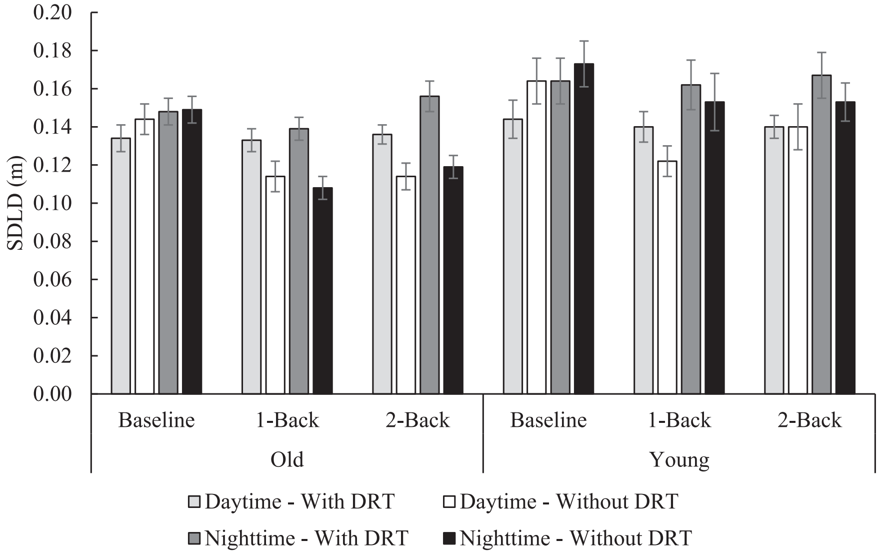

Fig. 10. SDLP as a function of cognitive task, lighting, DRT, and age *Note. The error bars represent the standard error.*

(1, 35) = 6.13, p =.018, η_p^2 =.15) were significant.

Higher SDLP values were observed at night (M = 0.15, SE = 0.01) compared to day-time (M = 0.14, SE = 0.01, t = 3.31, p_{bonf} = 0.002). In addition, SDLP with DRT (M = 0.15, SE = 0.01) was higher than without DRT (M = 0.14, SE = 0.01, t = 3.08, p_{bonf} = 0.004). For the cognitive task, SDLP was lower during 1-back (M = 0.13, SE = 0.01, t = 5.59, $p_{bonf} < 0.001$) and 2-back (M = 0.14, SE = 0.01, t = 3.56, p_{bonf} = 0.002) blocks compared to the baseline condition (M = 0.15, SE = 0.01). But there was no significant difference in SDLP between the 1-back and 2-back (t = 2.03, p_{bonf} = 0.138).

The interaction effect of DRT and age group (Fig. 11) revealed that older drivers' SDLP was higher in the presence of DRT, compared to driving without DRT (t = 3.77, p_{bonf} = 0.004).

The interaction effect of DRT and lighting (Fig. 12) indicated that SDLP at night-time driving was higher with DRT than without DRT (t = 3.92, p_{bonf} = 0.001). These night-time SDLP values with DRT were also higher than day-time values both with DRT (t = 4.01, p_{bonf} = 0.001), and without DRT (t = 4.48, $p_{bonf} < 0.001$).

Finally, the interaction effect of DRT and cognitive task (Fig. 13) indicated that drivers' SDLP was significantly lower during 1-back

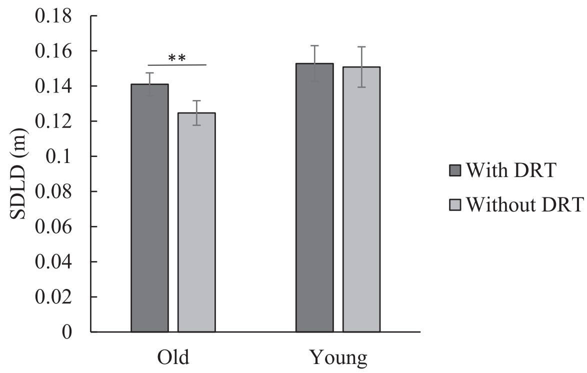

Fig. 11. SDLP as a function of DRT and age *Note. The error bars represent the standard error, and significance values are presented as* * = *p* <.05, ** = *p* <.01, *** = *p* <.001.

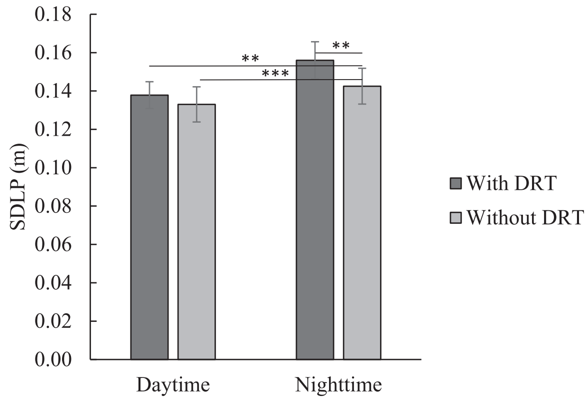

Fig. 12. SDLP as a function of DRT and lighting *Note. The error bars represent the standard error, and significance values are presented as* * = *p* <.05, ** = *p* <.01, *** = *p* <.001.

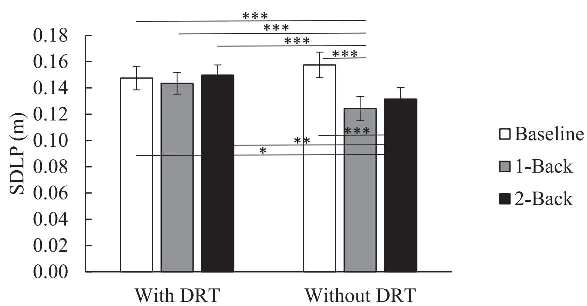

Fig. 13. SDLP (m) as a function of cognitive task and DRT *Note. The error bars represent the standard error, and significance values are presented as* * = *p* <.05, ** = *p* <.01, *** = *p* <.001.

without DRT than when the n-back tasks were accompanied by DRT (SDLP for DRT without the n-back ($t = 4.88$, $p_{bonf} < 0.001$), with 1-back ($t = 4.27$, $p_{bonf} < 0.001$), and with 2-back ($t = 5.33$, $p_{bonf} < 0.001$)). In the absence of DRT, SDLP was significantly lower during 1-back ($t = 7.44$, $p_{bonf} < 0.001$) and 2-back ($t = 5.76$, $p_{bonf} < 0.001$) than the baseline condition – no n-back and DRT.

4. Discussion

The aim of this driving simulator study was to examine the impact of cognitive load on the detection of a peripheral visual target, and the driving performance of a group of young and older drivers. The effect of lighting on detection of peripheral stimuli was also examined by comparing performance during day-time and night-time driving conditions.

4.1. Discussion of the main findings

Supporting the age-related decline in cognitive functioning (Gajewski et al., 2018), our results indicate several behavioural differences between young and older drivers, in terms of performance in the n-back task, the DRT, and driving. Supporting the previous findings of Reimer et al. (2012), young drivers completed the 1-back and 2-back tasks with more correct responses than older drivers, irrespective of lighting conditions or DRT presence. In line with previous studies (Fotios et al., 2021, Strayer et al., 2015; Svetina, 2016), young drivers showed better DRT performance by detecting the stimuli earlier and missing fewer stimuli than older drivers. Finally, in line with the findings of a systematic review focusing on behavioural differences between older drivers, and other age groups (Depestele et al., 2020), the older drivers in our study drove slower compared to young drivers, especially with increased cognitive load. Specifically, we found that older drivers' speed was significantly lower during the more demanding 2-back task, suggesting some compensation/regulatory behaviour in driving, to manage the demand from the competing n-back task. This finding supports results from previous studies which show some form of behavioural adaptation in the driving task, when engaging in another task (Oviedo-Trespalacios et al., 2017).

Regarding driving performance, there was no difference in average speed between day and night-time driving, supporting the work of others (e.g., Bella et al., 2014; Jägerbrand & Sjöbergh, 2016). However, our results showed an increase in lateral deviation (as measured by SDLP) during night-time driving, especially in the presence of DRT. The DRT circles were also detected more often, and earlier, at night, compared to day-time driving conditions, which may be due to the salience of the stimuli during night-time conditions. The effect of the DRT on driving performance showed an interesting interaction with the n-back task, as outlined in more detail below.

Overall, our results support those of previous studies investigating the impact of cognitive distraction on DRT response time (e.g., Engström, Aberg et al., 2005; Fotios et al., 2021; van Winsum, 2018) and misses (Fotios et al., 2021), with increasing n-back difficulty causing a progressive decline in DRT performance, for both age groups. Previous studies have shown that this increase in cognitive load by a non-visual task, such as the n-back task, leads to a higher concentration of gaze towards the road centre, diminishing the detection of stimuli and hazards in peripheral vision (Beede & Kass, 2006; Jamson & Merat, 2005; Li, Markkula et al., 2018; Reimer et al., 2012). Therefore, the implications of such tasks on road safety needs further attention, especially for understanding how hands-free mobile phone conversations affect the detection of real-world peripheral targets. For example, it will be interesting to investigate the effect of this type of non-visual cognitive load on the detection of more realistic hazards on the road, such as cyclists and pedestrians, to establish how performance is influenced by contextual factors.

As outlined above, interesting results were observed in terms of drivers' lateral control, and its interactions with the DRT and lighting conditions. In line with previous studies (Cooper et al., 2013; Jamson & Merat, 2005; Kountouriotis & Merat, 2016; Li, Merat et al., 2018), addition of the n-back task resulted in an overall reduction in SDLP values, but only in the absence of the DRT. It seems, therefore, that there was some effect of the peripheral DRT on drives' lateral control, suggesting that they may have looked towards these circles (despite their clear visibility in the periphery), which then reduced the typical effect of the n-back task: reduced SDLP. The higher SDLP values for night-time driving in the presence of DRT also supports this hypothesis, since the red graphical circles were much more salient at night, resulting in a stimulus driven capture of drivers' visual attention. This hypothesis is also supported by the Active Gaze model of steering (Wilkie & Wann, 2003; Wilkie et al., 2008), which suggests that gaze and steering are linked, with gaze direction guiding steering behaviour. Consistent with Kountouriotis and Merat (2016), completing a task with a visual element (red circles) may lead to an increase in SDLP. An alternative hypothesis for this increase in SDLP may be that steering control was marginally affected by manual response to the DRT (see Kountouriotis et al., 2016, for similar results). Future studies may resolve these issues by investigating drivers' gaze patterns when both DRT and n-back are required.

5. Recommendations for future research and study limitations

In light of these findings, a number of practical suggestions can be made. Recent real-world studies, especially in North America, show increasing engagement of drivers with their mobile devices (e.g., Cambridge Mobile Telematics, 2022). According to Horrey and Wickens (2006), the effects of mobile phone use on driving performance may be even more severe in the real world than in driving simulators. Therefore, a better understanding of how these conversations affect hazard detection and avoidance in complex real-world studies needs further work. While some authors (e.g., Young, 2012) refer to the "protective effect" of hands-free mobile phone conversations (e.g. because they keep drivers awake during a long monotonous drive), Carsten and Merat (2015) suggest that most of these real-world studies do not consider the effect of such mobile phone conversations on detection of peripheral hazards, with analyses focusing on rear-end crashes only. Since cognitively demanding (non-visual) tasks actually reduce SDLP, drivers may believe their lane keeping is actually "improved" (when compared to baseline). Indeed, this is also not always considered an issue from a policy perspective, as most countries prohibiting engagement with mobile devices during driving, only restrict this to hand-held and eyes-off road tasks. Therefore, we need better understanding of the consequences of hands-free conversations on driving performance in a range of settings. Targeted education and awareness programmes may be useful to inform road users about the likelihood of increased reaction time (or total failure) to detecting peripheral targets, as a danger associated with hands-free phone conversations. This may be especially important for driving in complex urban environments, and further work in this context would help inform more accurate policy advice, which is of course not as easy to enforce. It remains to be seen what effect technological implementations such as driver monitoring systems or assistance from applications such as Google's "Drive Mode" and "Lifesaver", or Apple's "Driving Focus" might have in this context. Although we are aware of some recent studies considering the benefit of these, which prevent user engagement with their phone during driving (e.g., Monk et al., 2023). Awareness of age-related differences in these tasks is important, particularly for older drivers, who may require compensatory strategies and adjustments in their driving habits. Since driving at night can be challenging for drivers and may involve various behavioural adaptations (Rudin-Brown & Jamson, 2013), there may be some value in medical checks, refresher courses, and targeted support and campaigns that could have long-term benefits for road safety as age-related problems may persist and attention demands may vary across individuals and driving conditions.

Our results showed that the older drivers in this study tried to manage multi-tasking during driving and the n-back task, by reducing their speed. Real world studies also suggest that this group of drivers are less likely to be involved in distraction-related crashes (Regev et al., 2017), while they manage their safety by avoiding or reducing night-time driving (Charlton et al., 2006; Devlin & McGillivray, 2016; Moták et al., 2014). Contrary to the older drivers, young drivers' speed control in this study was not significantly different between day- and night-time driving. The lack of behavioural adaptation of young drivers to night-time driving has also been reflected in real-world studies (e.g., Jackson et al., 2011; Martiniuk et al., 2013; Regev et al., 2018) and highlights an area for further investigation and potential intervention.

This study showed how drivers' attention was captured by the DRT stimuli during the night-time driving conditions. Further work could usefully examine how this result translates into detection of more salient pedestrians at night, aided by a range of reflectors (e.g., Hemeren et al., 2017; Kwan & Mapstone, 2006), and how such detection is affected by engagement in a competing cognitive load task, such as the n-back or hands-free phone conversations. The effect of different lighting conditions, and light from other traffic, is also worth considering here, since the lighting conditions were fixed in the current study.

In terms of study limitations, this study used a visual stimulus for the DRT, which was found to attract drivers' visual attention, and increase lateral deviation. The salience of the red circles was also different between the two environments. Although visual stimuli were intentionally used in this study, as a surrogate for detection of road-based objects during day and night-time conditions, future studies may compare the effect of cognitive load on overall resource limitations, by using auditory or tactile versions of the DRT (Engström, Aberg et al., 2005; Merat & Jamson, 2008). It is worth noting that although the lighting in the driving simulator was set to simulate night-time driving conditions, the study was carried out during day-light hours. This means that the effects of circadian rhythms, such as reduced alertness and increased fatigue and sleepiness during the night (Sinclair & Swart, 2021), may not have been taken into account in this study. Therefore, additional research may shed further light into the applicability of the results to real-life night driving situations. Finally, the use of the n-back task is more favourable for these controlled studies, since its effect on driving is easier to quantify. However, assessing the effect of more naturalistic hands-free phone conversations on driving performance and peripheral hazard perception during day- and night-time driving will provide more ecologically valid results.

CRediT authorship contribution statement

İbrahim Öztürk: Methodology, Conceptualization, Formal analysis, Writing – original draft. **Natasha Merat:** Methodology, Conceptualization, Writing – review & editing, Supervision, Project administration. **Richard Rowe:** Methodology, Conceptualization, Writing – review & editing. **Steve Fotios:** Methodology, Conceptualization, 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.

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***Data access** statement*

The data that support the findings of this study are available on request from the corresponding author (I.O., i.ozturk@leeds.ac.uk).

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