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The effect of distraction on the detection of peripheral hazards to inform studies of road lighting to support drivers

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Abstract

Hazard detection is an important visual task when driving and, after dark, road lighting is used to support the performance of this task. Previous studies have tended to investigate the effect of changes in lighting on hazard detection but have not accounted for detection impairment due to cognitive distraction. As a precursor to testing the impact of distraction on hazard detection under different lighting conditions using a scale model road scene, this article reports an experiment conducted to investigate the degree to which distraction impairs detection performance, thus to validate the apparatus and experimental design. It was found that visual distraction led to significantly longer reaction times to the detection of three types of detection targets (a pedestrian, a road surface obstacle, and vehicle lane change) but that auditory distraction did not.

Keywords

Driving; Hazard detection; Cognitive distraction

1. Introduction

This study was carried out to support research of road lighting for drivers of motorised vehicles. Road lighting is the provision of overhead lamps at regular intervals along the carriageway to illuminate the road surface and enable a driver to see objects at a greater distance ahead than reached by the vehicle head lights. There is a reduction in visual function after dark ([Plainis and Murray, 2002](#)): road lighting is installed to mitigate this reduction and thus supports the performance of visual tasks such as hazard detection which contribute to safe driving ([CIE, 2010](#); [van Bommel, 2014](#)).

Many studies have investigated hazard detection under changes in lighting, such as variations in road surface luminance and light spectrum. Hazards tend to be detected in peripheral vision, and previous studies ([He et al., 1997](#); [Bullough and Rea, 2000](#); [Akashi and Rea, 2002](#)) suggest that higher luminances and higher scotopic to photopic luminance ratios (S/P ratios) increase detection performance. This may be evidenced by either an increase in detection probability or a reduction in reaction time (RT) from hazard onset to detection.

Experimental work investigating the effects of lighting tends to involve the participant focussing solely on the driving detection task. That situation does not represent a natural driving experience because drivers are frequently distracted from the tasks of safe driving by events inside and outside the vehicle ([Engström et al., 2017a](#)).

Distraction is engagement in activities not critical for safe driving ([Regan et al., 2008](#)) and driver distraction is therefore a form of driver inattention ([Engström et al., 2017b](#); [Regan et al., 2011](#)). Attending to tasks that are not primarily relevant to driving results in a diversion of attention that would otherwise be allocated to driving safely ([Patten et al., 2006](#)) and increases the risk of slower and less appropriate responses to the driving situation that demands their attention ([Anttila and Luoma, 2005](#)). Distraction impairs the driver's ability to utilise cognitive resources effectively, which hinders effective performance of the driving task ([Salvucci, 2019](#)). This arises because of the limitation of human attentional resources and the tendency of the brain to prioritise some tasks over others ([Patten et al., 2006](#)). It is crucial for research addressing the effects of lighting on driving performance to consider whether there is an interaction between lighting and the effects of distraction. It may suggest that previously established luminance thresholds are incorrect because they over-estimate target detection ability. In addition, it is possible that some lighting conditions mitigate certain impacts of distraction.

The relationship between distraction-impaired driving performance and road traffic collisions (RTC) has been explored through two approaches. The first approach is to investigate the association between RTCs and drivers' distraction as might be done using national RTC records where distraction is recorded (e.g., mobile phone use by the driver prior to the crash). Examples of such databases are the Fatality Analysis Reporting System (FARS) from the USA and the Crash Analysis System (CAS) from

New Zealand. The second approach is to assess the impact of distraction on driving tasks such as hazard detection in laboratory or other controlled settings (D’Addario and Donmez, 2019; Liang and Lee, 2010; Horberry et al., 2006).

Analysis of RTC records indicates that distraction is a causal factor in 8% (Bakiri et al., 2013) to 18% (Ascone et al., 2009) of RTCs. In contrast, an observational study using in-vehicle cameras and sensors to monitor over 35 million miles of naturalistic driving from more than 3500 participants found that drivers engaged in observable distracting activities about half of the time spent driving and that such distractions were involved in 68.3% of recorded RTCs (Dingus et al., 2016). From their naturalistic driving data, Dingus et al. (2016) estimated that distraction results in RTC risk twice that associated with ideal driving behaviour (i.e. alert, attentive and sober). Limitations of this approach are that only certain distractions are observable and self-reported distraction might underestimate the prevalence of those distractions which are illegal (such as using a mobile phone whilst driving). It is generally difficult to be confident of the extent to which distraction was a causal factor from naturalistic data. Indeed one type of distraction, conversation with passengers, means that passengers are present. However, passenger presence provides a protective effect rather than increasing RTC risk, provided that the driver and passengers involved are not young (Braitman et al., 2014; Geyer and Ragland, 2005; Vollrath et al., 2002).

The second approach is to experimentally investigate the impact of distraction on driving relevant tasks. Steering when driving involves both foveal (central) and peripheral vision (Land, 2006). Foveal vision is directed towards the lane ahead at the horizon to anticipate changes in the curvature of the road; peripheral vision is used for lane keeping, by monitoring lane edge markers and other vehicles. Hazards not located directly ahead thus require detection with peripheral vision: head and eye movements then transfer the detected object to foveal vision for detailed inspection. This results in alternation of gaze between the object and the lane ahead. Fotios et al. (2021) found that target detection in peripheral vision was compromised whilst conducting a parallel distracting task. The degree of impairment varied according to the difficulty of the distraction task. For older test participants in that work (aged 60 y and above), RT from onset to detection of a target increased from 0.61 s in the control trials (no distraction) to 0.82 s for distraction by an auditory n-back task (Mehler et al., 2011; von Janczewski et al., 2021) with n set to 2, the most demanding of the distraction tasks employed in that work. Similarly, the target detection error rate increased from 4.2% in the control trials to 14.7% in the distracted trials. That study (Fotios et al., 2021) also used a word generation task intended to simulate conversation (an auditory distraction found to give a similar impairment to visual detection as the auditory n-2 task) and a number fixation task (a visual distraction giving similar detection impairment as the auditory task with n-0). The distraction task label ‘number fixation’ in that study required participants to say aloud the single digit integer appearing briefly in place of the dynamic fixation cross to which they were instructed to visually fixate, and was therefore a visual distraction.

Other studies have investigated distraction in a driving simulator. This allows the inclusion of more realistic hazards (e.g. a pedestrian stepping onto the road from behind a parked vehicle, an oncoming vehicle turning across the driver's path or the vehicle ahead braking) and more realistic distractions (e.g. an oral general knowledge quiz to simulate conversation or changing the settings on the in-vehicle audio system) (D'Addario and Donmez, 2019; Liang and Lee, 2010; Horberry et al., 2006; Yang et al, 2023). Again, distraction has been found to impair performance, and in these studies, the performances measured were driving-related tasks such as RT to braking, speed control and steering control. Chaparro et al. (2004) also found that dual-task distraction (number addition) reduced participants' scores in driving-related tasks whilst driving on a closed road.

Kountouriotis et al. (2016) studied the impact of distraction when driving in a simulator. They imposed distraction using secondary tasks including those labelled as *non-visual* (counting back in steps of seven after hearing a three-digit number), and *baseline* (only driving). The non-visual distraction task resulted in increased gaze concentration towards the centre of the road compared to baseline driving, and thus away from hazards in a driver's peripheral field of view such as a pedestrian about to step into the road. In other words, when a driver is distracted, the increase in the driver's cognitive load causes their field of vision to contract (Yang et al., 2023). Lighting of higher S/P ratio enhances the detection of objects in peripheral vision (Lingard and Rea, 2002) and may thus be able to offset the impairment of cognitive distraction but that remains to be confirmed.

Previous studies investigating road lighting for hazard detection after dark have not accounted for the impact of distraction and may therefore give incorrect estimates of the relationship between lighting conditions and hazard detection. While distraction is expected to impair visual detection there may be situations in which lighting provides mitigation for the effect of distraction, such as the use of higher S/P ratios. The long-term goal of this research programme is to investigate optimal lighting conditions for hazard detection and the extent to which the effect of distraction on visual detection is mitigated by changes in the lit environment.

The experimental work reported here used a bespoke scale model of a road scene which was developed for this work to allow rapid and controlled changes in lighting conditions alongside controlled detection tasks and distractions. We used a scale model because precise control of lighting conditions is not possible in a simulator and is not easy to set up in a natural setting. To demonstrate that the apparatus is sufficient for purpose, we first explored the impact of visual and auditory distraction on visual detection, for one lighting condition. If the experiment is sufficient it will identify impaired visual detection in the presence of distraction. The experiment therefore tests the expectation that distraction impairs performance on a parallel hazard detection task to validate the apparatus and experimental design. Prevalent in-vehicle distractions are conversing with passengers on minor roads and using mobile phones on major roads (Robbins and Fotios, 2021, 2022; Sullman, 2012; Ponte et al., 2021). The

auditory task used in this work represented the distraction of conversation and the visual distraction represented looking at the keypad of a phone. The visual distraction therefore required test participants to direct their visual focus away from the road ahead and was therefore expected to have a greater impact on hazard detection than the auditory distraction task which did not.

2. Method

2.1 Set up

Hazard detection was investigated using a 1:10 scale model simulating a driver's view of a single-carriageway road with multiple lanes (Fig. 1). This apparatus was used in previous work (Fotios et al., 2018; Fotios et al., 2019) and was extended for the current work to include additional detection objects. The scale model is contained in a cuboid chamber of dimensions approximately 5 m long, 2.5 m wide and 1.5 m high, raised on stilts above the laboratory floor (Fig. 2, and 3). A participant sitting outside the chamber viewed the interior through an acrylic window at the bottom of one end wall. Two neutral density filters (each of transmittance = 0.5) were installed on the acrylic window to reduce the luminance from the participant's perspective with little effect on the spectrum.

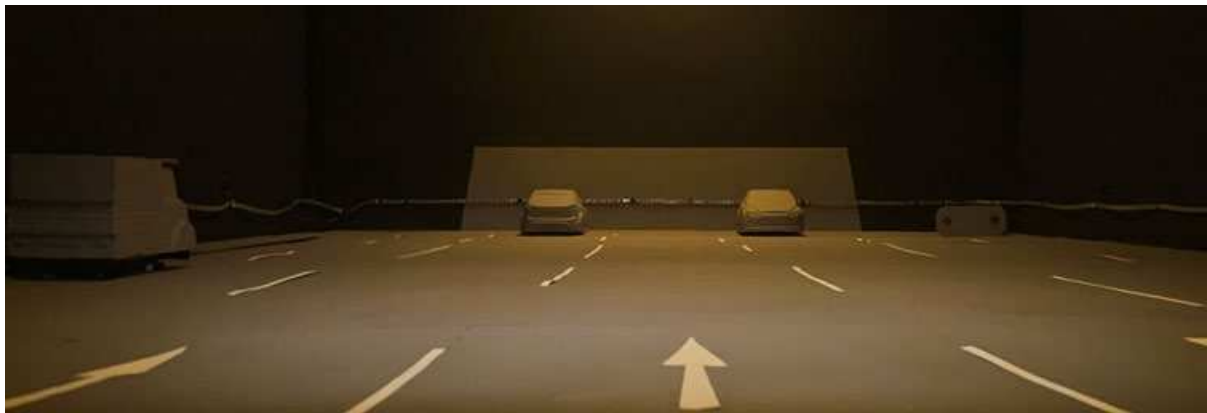


Fig. 1. The scene from just behind the observer's position. The photo was taken under the lighting condition used in this experiment. The objects presented a contrast of approximately 0.3 against their backgrounds and the lane markers a reflectance of approximately 60%. (Note: the device on the right-hand side was for simulating the glare from oncoming vehicles but was not used in this experiment).

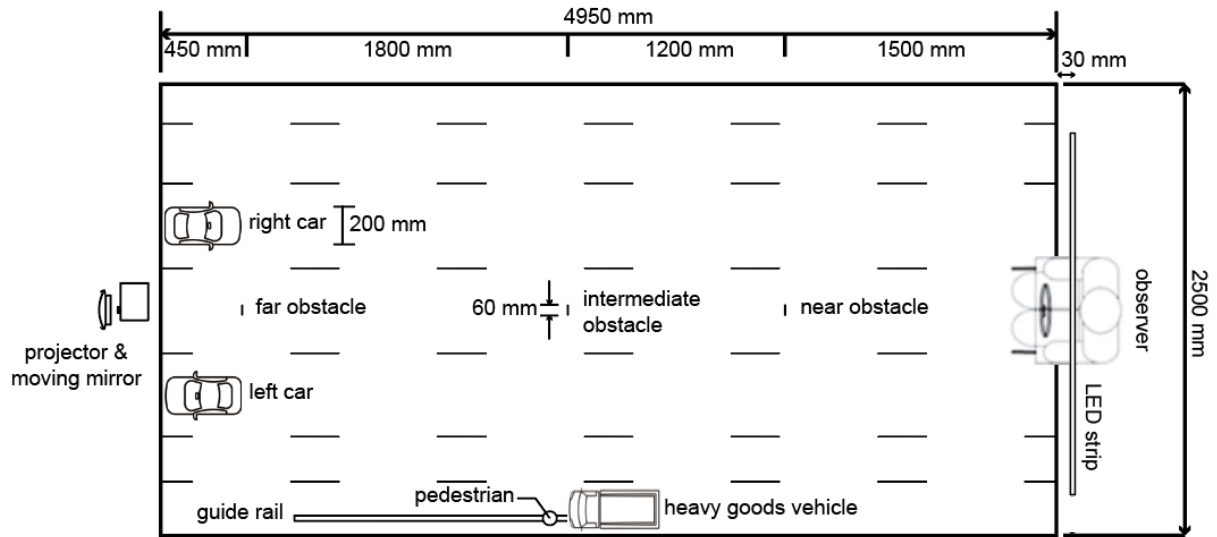


Fig. 2. Top view of the apparatus.

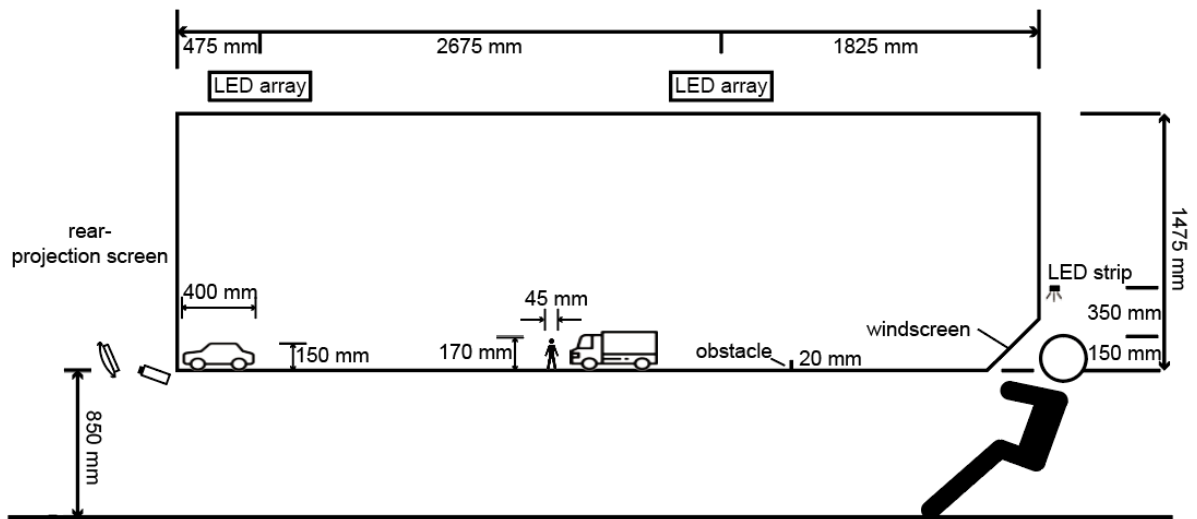


Fig. 3. Side view of the apparatus.

The chamber floor was constructed from MDF sheets painted predominantly in neutral grey (Munsell N5, reflectance = 0.2) to represent the diffuse reflectance of an asphalt road surface. Other interior surfaces of the chamber (the plywood sidewalls, plywood elements of the ceiling, and the end wall with the window) were painted matt black. The back wall of the chamber was formed by a dark-grey PVC rear projection screen. Lanes were delineated by broken white lines applied to the road surface. Test participants sat in a chair adjusted to position their eye level approximately 150 mm above the road surface.

The participant was seated in the middle of the carriageway so that their immediate view ahead was of a middle lane, with additional lanes to the left and right. In addition, there was a strip on the nearside (left-hand) edge representing a footpath or hard shoulder (Fig. 2). Two tuneable LED arrays simulated overhead road lighting: these enable control over the luminance and spectral power distribution although for the work reported here, only one setting was used.

2.2 Detection tasks

Test participants were required to detect three types of targets, each with a specific mechanism for indicating detection. Similar to the three hazards employed by Horberry et al., (2006) these offered different levels of hazard severity, ranging from an object on the road surface (most hazardous) to a pedestrian on the side of the road (least hazardous).

2.2.1 Road surface obstacle (Obstacle)

Participants were required to detect an obstacle suddenly appearing on the surface of the road ahead. Detection of this obstacle was indicated by pressing a foot pedal, representing the action of using a brake pedal. There were three obstacles, situated at near, intermediate and far locations in the driver's lane. The far obstacle was located 4.7 m ahead of the driver, a simulated distance ahead of 47 meters from the observer's eyes: this was the target used in previous work (Fotios et al., 2018). The near and intermediate obstacles were installed for the current work, on the same axis along the road as the far obstacle, but at simulated distances ahead of 29 m and 17 m from the eyes.

The obstacles were formed from a balsawood vane, 60 mm wide and painted matt grey (Munsell N5) to give the appearance at the far distance of an object of similar size to a car tyre lying on its side. These obstacles were normally hidden below the surface of the road, but at random intervals could be raised on a servo motor arm through a slot to a height of 20 mm. The far, middle and near obstacles subtended angles at the observer's eyes of 14.6 arcmin, 23.7 arcmin and 40.4 arcmin in height, and 121.3 arcmin, 7.1 arcmin, and 43.8 arcmin in width. The obstacles rose to a height of 20 mm in 1 s, remained for 2 s, and then took 1 s to drop back out of sight. This rate of growth in visual height is comparable

with the increase in the apparent size of a static obstacle approached when driving. Only one obstacle appeared per trial.

2.2.2 *Vehicles ahead changing lane (Lane change)*

The scene included two vehicles ahead, one in each of the lanes adjacent to that of the test participant's centre line of vision, located 4.7 m in front of the driver simulating a distance ahead of 47 m. The second detection task was to note when one or other of these vehicles moved from their home lane into the driver's lane, a lateral movement with the distance ahead remaining unchanged. The participant indicated detection by pressing a button on the steering wheel, an action similar to sounding the horn on a vehicle.

The two target vehicles were 1/10th scale body shells of a car (Ford Focus shape), painted the same neutral grey (Munsell N5) as the road surface and the lower section of the back wall. The rear of a car subtended an angle of 110 arcmin in height and 146 arcmin in width at the observer's eyes. Tail lights and headlights were switched off during trials so that detection performance was a function only of changes in road lighting. To enable lane-changing movements, the cars were connected through a slot in the road surface to carriages underneath on a shared linear guide rail. This rail was orientated perpendicular to the run of the road, spanning the three active lanes.

These cars followed two movement patterns: purposeful lane change and random in-lane drift. For the lane changes, motor drives were set to accelerate at 60 mm/s^2 up to (and down from) a lateral speed of 75 mm/s which completed a move from lane-centre to lane-centre in 6 seconds, simulating the typical speed of a lane change (Olsen et al., 2002). On arriving at the centre of the test participant's lane, the target car would immediately set off again with the same acceleration and speed settings to return to its original lane.

In-lane drift usually results from a driver's imperfect steering inputs. To simulate this, the cars were programmed for a continuous series of lateral moves at speeds between 5 mm/s and 15 mm/s (and acceleration of 4 mm/s^2) to random positions up to 40 mm on either side of the centre of the lane.

2.2.3 *Pedestrian*

The third detection task was the detection of a pedestrian on the hard shoulder on the left-hand side. The pedestrian was normally hidden from view behind a model heavy goods vehicle (HGV) parked on the hard shoulder. When initiated as a detection event, the model would move along the hard shoulder, parallel with the direction of travel, a similar context as that used in previous work (Åbele et al., 2019). The distance between the participant's eyes and the pedestrian when first revealed was 3835 mm (3690 mm forward and 1050 mm to the left). The pedestrian was 45 mm wide at the shoulder and 170 mm high subtending a height of 152.3 arcmin at this location. Detection of a pedestrian was indicated by the

participant operating a paddle switch behind the steering wheel, a similar action to flashing the headlights.

The HGV faced the driving direction and was stationary during the experiment. The HGV was a 1/10th scale body shell (classic Mercedes Unimog), also painted the same neutral grey (Munsell N5) as the other vehicles. Tail lights were switched off as with the other vehicles during trials.

The pedestrian figure was connected through a slot in the road surface to a carriage underneath on a one-meter guide rail, parallel to the run of the road, along the hard shoulder lane. The pedestrian target travelled along the guide rail at 120 mm/s, representing walking at 1.2 m/s. A complete trip along the rail took approximately 9 s, for which the model was visible to the participant for 7.7 s.

The pedestrian model was a 2D outline, with no moving parts other than its traverse along the side of the road. The main body of the pedestrian model was painted the same neutral grey (Munsell N5) as the road surface, with a diffuse reflectance of 20%. The colour grey was selected because it is neutral and maintains a consistent appearance regardless of variations in lighting design and illuminance levels. (Bhagavathula et al., 2021).

There were three versions of pedestrians as defined by their supposed use of visibility aids: none, in which the grey model simulated typical pedestrian clothing (Bhise et al., 1997), a high visibility vest; and a flashing LED. These are shown in supplementary material S1. The reverse side of the pedestrian model had a square piece (20 mm x 20 mm) of retro-reflective material from an ANSI 107 Class 2 vest which is typically used by both pedestrians and cyclists at night, as well as for occupational safety (Sayer and Mefford, 2004). This was positioned on the pedestrian's chest following previous work (Balk et al., 2008). The LED was mounted on the pedestrian's chest and displayed a flashing pattern, flashed at a rate of 2.5 Hz with a peak luminance of 0.15 cd/m². The LED was switched on only for these specific trials. When rotation of the pedestrian model was necessary this was done out of sight (behind the HGV). In the current work, we report responses to the pedestrian target merged across all variations of that model: differences in responses are discussed elsewhere (Moadab et al., 2023).

2.2.4 Auditory feedback

When the test participant indicated detection using one of the three response mechanisms, they received auditory feedback that their response had been registered and to indicate whether their response was correct. This feedback was the words “obstacle” when the pedal was pressed, “lane change” when the button on the steering wheel was pressed and “pedestrian” when the paddle behind the steering wheel was operated.

2.2.5 Data analysis

The detection data were cleaned to remove responses likely to be false alarms, responses given after completion of the detection event, and events where the participant did not respond. [Table 1](#) shows the number of cases omitted.

For the lane change, responses within 0.5 s from the onset of a vehicle lane change were excluded. Our approach followed a previous study requiring participants to tap the brake pedal in response to a visual stimulus, reporting that the range of response times was 0.45 s to 0.85 s with a median of 0.6 s ([Olson, 1989](#)); responses before 0.5 s would be more likely to include false alarms. Movement of a vehicle from its default position to the centre of the test participant's lane took 6 s, after which it started the return journey, and therefore RTs greater than 6 s were omitted. Thus, correct detection of a vehicle lane change was assumed to be those events detected between 0.5 s and 6 s from the onset of a lane change ([Table 1](#)).

For the obstacles, responses in the first 500 ms were excluded as likely false alarms. Similarly, responses after 3 s were ignored, as at this point, the obstacle would have moved back below the road surface ([Table 1](#)).

For the pedestrians, the HGV initially blocked the participants' view of the pedestrian. It took around 1.3 s for the pedestrian to become visible. After around 9 s, it arrived at the endpoint on the track. For this hazard, all the recorded responses were within this range and used for the analysis ([Table 1](#)).

Table 1

Response omitted for analysis of reaction time (RT) to hazard detection.

Detection target	Overall number of events	Number (and percentage) of responses omitted according to reason		
		RT<0.5 s	RT beyond detection event	Missing response
Obstacle	6480	3 (0.05%)	88 (1.36%)	1549 (23.90%)
Lane change	4320	0	17 (0.40%)	174 (4.03%)
Pedestrian	6480	0	0	362 (5.59%)

2.3 Distraction tasks

In parallel to responding to the detection tasks, participants were subjected to three levels of distraction. One condition involved visual distraction, one involved auditory distraction and there was also a control condition. Similar to the in-vehicle distractions employed by [Horberry et al. \(2006\)](#) these were intended to simulate the additional cognitive demands of distraction during driving.

2.3.1 Control

Participants were instructed to focus their visual attention on a cross projected onto the rear wall of the chamber. Rather than being static, the cross moved, following a random path within a circle of diameter subtending 10° at the observer's eyes, but with the lower fifth excluded to avoid the cross coming too close to the vehicles ahead. This movement represented the typical gaze behaviour of drivers (Winter et al., 2017) and was used to encourage participants to look ahead rather than looking toward any of the hazards, and thus to increase the likelihood that hazards were detected in peripheral vision. The cross presented a luminance of 1.3 cd/m^2 against the background luminance of 0.03 cd/m^2 , as measured using a Konica- Minolta LS-110 luminance meter with no other light sources present. It subtended a visual size of 34 to 54 min.arc at a viewing distance of approximately 5.1 m. The fixation cross was retained and extended in the other distraction tasks.

2.3.2 Visual distraction

For 500 ms in every 2 s the fixation cross was replaced by a random integer between 1 and 9. Participants were asked to indicate which digit appeared by pressing the corresponding digit on a small keypad (Storm Interface 720GFXi) located just above the steering wheel. The buttons on the keypad were white with the numbers 1 to 9 in black (Fig. 4). This task repeated the number fixation task used in previous work (Fotios et al., 2019) but with the oral response replaced here by a manual response, simulating the distraction of pressing buttons on an in-vehicle device such as a mobile phone or radio (Robbins and Fotios, 2021).

2.3.3 Auditory distraction

For the third distraction task, in parallel to following the dynamic fixation cross, participants were additionally required to give an oral response to an auditory stimulus. The stimulus was a synthetically voiced randomised series of letters. Eight phonologically distinct letters (A, B, C, F, G, H, I, K) were used, avoiding letters that might sound similar (such as B, D and E; and also, G and J), similar to previous work which used only ten letters (He et al., 2019).

These letters were randomised by the Python program which was used to control the distraction tasks. The interval between each letter was 5 s. They were played by an in-ear headphones and vocalised using the Google text-to-speech function. Oral responses given by participants were recorded by the experimenter. To aid the experimenter in this task, the letter sequence was also presented on their screen (but note that test participants could not see this screen).



Fig. 4. The steering wheel (showing two white buttons, either of which could be used to indicate the detection of a vehicle lane change), the foot switch to indicate the detection of an obstacle and the keypad for manual responses in the number fixation task. Note: the photograph was taken with room lighting switched on.

This auditory distraction was conducted as a delayed recall task, an *n*-back task in which participants were required to repeat aloud the sequence presented to them but delayed by ‘*n*’ letters (Mehler et al., 2016; Li et al., 2018). Here we used *n*=2 meaning participants repeated aloud the letter two before the current one. With *n*=2, this task presents a similar difficulty to that of a word generation task (Fotios et al., 2021), representing a discussion with a passenger which is a common driver distraction (Robbins and Fotios, 2022).

2.4 Lighting

Road lighting inside the chamber was simulated using two pairs of LED arrays (Thouslite 14-channel LED Cubes) located above the road surface. Light conditions for the road lighting luminance and SPDs were established using Thouslite LED Navigator-LC Software.

The experiment was completed under four lighting conditions, presented in a randomised order. The effect of lighting will be discussed in a further report: the current work focuses on the impact of distraction on detection and uses the data gained under one lighting condition. This was a vertical illuminance at the eye of 0.13 lx, corresponding to a luminance of 0.9 cd/m² at the location of the far obstacle and an average luminance on the road surface of 0.57 cd/m², with luminances as measured from the location of the observers' eyes using a Konica-Minolta LS150 meter. This average luminance lies between classes M4 (0.75 cd/m²) and M5 (0.5 cd/m²) (CIE 115:2010, EN 13201-2:2015). In terms of spectrum, the lighting had a correlated colour temperature of 2939 K, CIE 1931 chromaticity of *x*=0.45, *y*=0.42, and a S/P ratio of 1.0.

During these trials the only source of light was that of the overhead LED arrays simulating road lighting. All vehicle lights, including the headlights of the participants apparent vehicle, were switched off.

2.5 Experimental design

A within-subjects design was used, in which all test participants completed detection tasks under all three distraction conditions (control, visual distraction, and auditory distraction) and all four lighting conditions. However, for the purpose of this paper, only data from one lighting condition are reported, focusing on the effect of distraction on detection performance.

Each participant completed three blocks of trials, one for each distraction condition (control, visual distraction, auditory distraction), with the order of blocks randomised across participants. Within each of the blocks, the eight targets requiring detection (two vehicles, three obstacles and three pedestrians) were each presented three times in a randomised order ([Table 2](#)).

Table 2
Summary of detection target presentations in each block.

Target type	Number of trials	Description
Obstacle	9	Three presentations at each of the three obstacle locations: near, intermediate and far.
Lane change	6	Two cars, left and right of the driver's lane, repeated three times.
Pedestrian	9	Three pedestrians based on the level of visibility aid (none, flashing LED, and patch of high-visibility material) each repeated three times.

2.6 Participants

Sixty test participants were recruited from the students at the authors' university. The age range was between 18 to 31 years (median = 24), and the sample comprised 28 males and 32 females. This experiment was approved by ethics committee of the authors' university (reference number 049792 dated 19 October 2022). The participants received a small payment for taking part in this experiment.

2.7 Procedure

Prior to data collection, participants' vision was checked using a Landolt ring chart to measure visual acuity and an Ishihara test book to confirm normal colour vision. Participants wore corrective lenses for the acuity test and for the test trials if they usually did so when driving. The minimum standard for UK drivers is a visual acuity of at least 6/12 ([GOV.UK, 2019](#)) and all participants met this requirement.

Participants were then seated in the driver position in front of the apparatus, ensuring the foot pedal and steering wheel were in a comfortable position. The room lights were switched off and a period of 20 min for adaptation commenced. During adaptation, the experimenter explained the setup. A recording of ambient sound inside a moving car was played throughout all trials. Additionally, in order to avoid the mechanism sound being a hint for the detection task, participants were required to wear earmuffs throughout the experiment. The participants wore in-ear headphones inside the earmuffs during the auditory tasks only.

Participants were instructed to respond to the lane change, obstacle and pedestrian detection. They were asked to respond using the relevant response (pedal, button or paddle) as quickly as possible when a hazard was detected. Additionally, depending on the trial, the participants were also required to attend to the parallel distraction task.

Participants undertook a series of practice trials before the main experiment to gain familiarity with the stimuli and response mechanisms. These trials included all of the hazard detection events and the distraction tasks.

There was an interval of 5 s to 10 s between each hazard, the precise gap being chosen at random. No two hazards overlapped. The number of lane changes was balanced between the two cars. This created a total of 72 trials (3 distraction tasks x 24 trials per block). The order of the distraction tasks was randomised between participants. Each test session took approximately one hour.

3. Results

This experiment investigated the effect of distraction on the detection of peripheral hazards. Three types of target detection were analysed (road surface obstacle, vehicle lane change, and moving pedestrian) with detection performance characterised by two dependent variables – detection rate and RT.

3.1 Distraction task performance

There were two distraction tasks, the auditory and visual tasks, used to provide distraction to the hazard detection task. Across all trials, correct responses (i.e. correct letter or digit identification) to the auditory and visual distraction tasks were 81.9% and 92.9%, slightly lower than found (84.1% and 99.8%) for similar distraction tasks in previous work ([Fotios et al., 2021](#)) but indicating that participants were sufficiently engaged with the distraction tasks rather than ignoring them or responding randomly.

3.2 Detection rate

All sets of detection rate data were checked to determine whether they followed a normal distribution through consideration of measures of central tendency, skewness and kurtosis, inspection of histograms and box plots, and the Kolmogorov-Smirnov test. The results were mixed, with some variables exhibiting normal distributions while others did not. The results were therefore analysed using non-parametric tests. The outputs of these tests were corrected where necessary by Holm-Bonferroni adjustment to counteract the error of multiple comparisons (Holm, 1979). A target alpha level of 0.05 was used for all statistical tests. Fig. 5 shows the detection rates for the three types of detection tasks (obstacle, lane change, and pedestrian) for the three types of distraction tasks (control, auditory distraction and visual distraction). Fig. 5 also shows the results from previous work – this is discussed below.

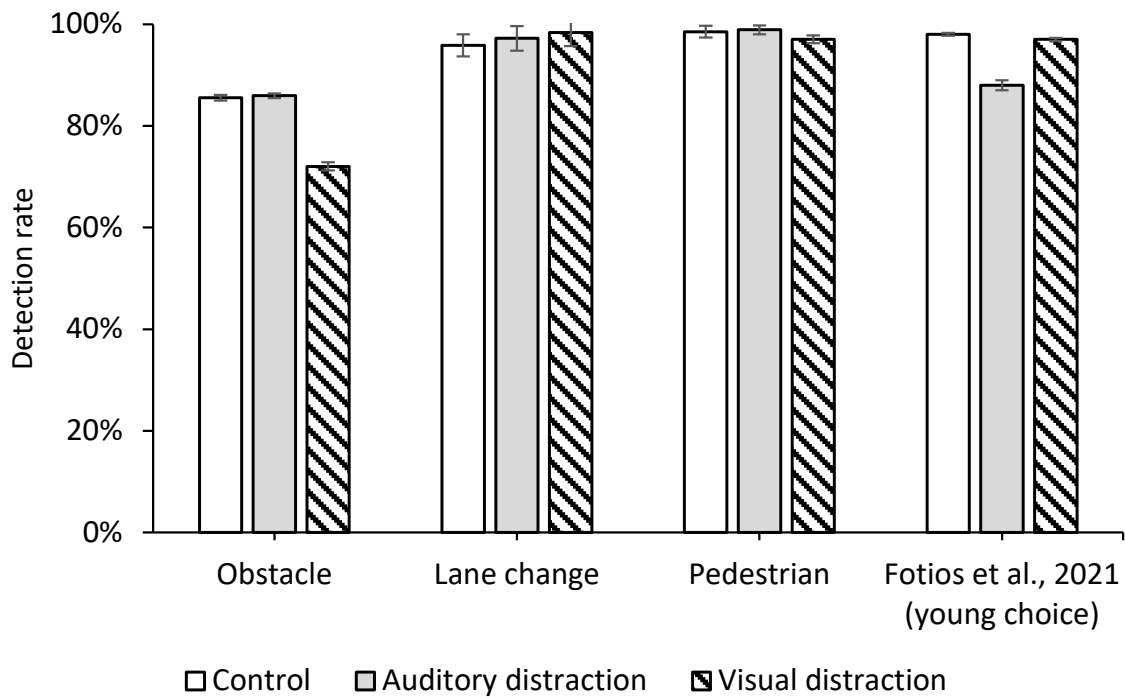


Fig. 5. Median detection rates for the three detection hazards according to the three distraction tasks. Error bars show the interquartile range. Also shown are results from the control, n-back ($n = 2$) and number fixation tasks in previous work (Fotios et al., 2021). "Young choice" refers to data from young participants (aged 18-25 years) using a choice response paradigm from Fotios et al. (2021).

Given evidence of non-normality in the distribution of these data the analyses were conducted using the non-parametric Friedman test. This suggested a significant effect of visual distraction on detection of the obstacle ($p < 0.001$, $X^2 = 30.89$) but did not suggest a significant effect of distraction on the lane change task ($p = 0.363$, $X^2 = 2.03$) or the pedestrian detection task ($p = 0.169$, $X^2 = 3.55$). The Wilcoxon test was used to compare distraction task effects for the obstacle only.

There was a non-significant difference in detection performance ($p=0.94$) between the control task (median = 88.9%, IQR = 77.8 – 100.0%) and the auditory task (median = 88.9%, IQR = 77.8 – 100.0%), but the visual distraction task led to a significantly lower detection rate ($p < 0.001$, median = 77.8%, IQR = 88.9 – 55.6%) than either of those.

3.3 *Reaction time*

The RT data were suggested to be normally distributed according to the measures stated above. [Fig. 6](#) shows the RT for the three types of detection task for the three types of distraction task. Analysis using one-way repeated measures ANOVA suggested statistically significant ($p < 0.001$) effects of distraction on RT to target detection for all three detection targets ([Table 3](#)). As with analysis of detection rates, t-test pairwise comparisons showed significantly longer RTs when performed in parallel with the visual distraction task, but did not find significant differences between the control and auditory distraction tasks. For obstacle detection, RT with visual distraction was significantly longer (mean = 1513.3, SD = 264.2) than within the control condition (trials without distraction) ($p < 0.001$, mean = 1347.7, SD = 244.1) and the auditory task ($p < 0.001$, mean = 1367.0, SD = 298.4). For lane change detection, RT with the visual distraction was significantly longer (mean = 2447.1, SD = 505.3) than with the control task ($p < 0.001$, mean = 2081.3, SD = 572.5) and the auditory task ($p < 0.001$, mean = 2095.4, SD = 508.0). For pedestrian detection, RT with the visual distraction was significantly longer (mean = 2505.3, SD = 606.5) than the control task ($p < 0.001$, mean = 2121.4, SD = 591.7) and auditory task ($p < 0.001$, mean = 2158.3, SD = 581.6).

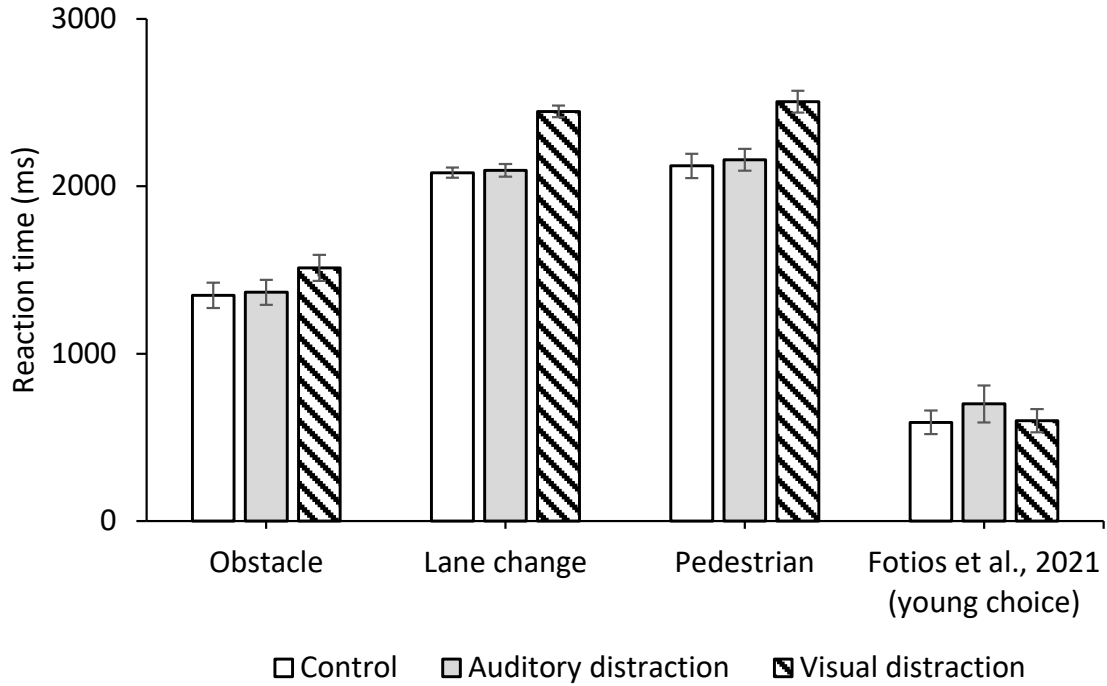


Fig. 6. Mean RT for detection of each of the three detection targets according to the three distraction tasks. Error bars show the standard error of the mean. Also shown are results from the control, n-back ($n = 2$) and number fixation tasks in previous work (Fotios et al., 2021). "Young choice" refers to data from young participants (aged 18-25 years) using a choice response paradigm from Fotios et al. (2021)

Table 3 The effect of distraction type on obstacle RT.

Main visual target	F-statistic (df)	p-value	Effect size (Cohen's <i>f</i>)
Obstacle	15.170 (2, 118)	<0.001	0.51 (large)
Lane change	19.731 (2, 118)	<0.001	0.58 (large)
Pedestrian	20.234 (2, 118)	<0.001	0.59 (large)

4. Discussion

Previous studies of lighting and hazard detection in the context of driving after dark did not consider the effect of distraction on the relationship between lighting and hazard detection performance. A bespoke scale model apparatus was developed to explore that relationship. As a first step in that investigation we sought to demonstrate that the apparatus was sufficient to reveal an effect of distraction upon visual detection. The apparatus would be considered sufficient if (1) it revealed a significant effect of distraction on detection performance, and (2) the outcomes of auditory and visual distractions were similar in direction to those found in studies better resembling natural driving. Identical performance to previous studies was not expected nor sought, since there are differences in the designs of the distraction and detection tasks, and indeed previous studies do not always reveal consistent effects. It was found that performance of a secondary task can impair the performance of a visual detection task, depending on the nature of that secondary task. Specifically, the visual distraction task used in this work

significantly impaired detection but the auditory distraction task did not. This impairment with visual distraction was revealed as a longer RT for all three detection targets, and a reduction in detection rate only for the obstacle detection task.

4.1 Comparison with previous work

Fig. 5 and 6 show the results of previous work (Fotios et al., 2021) which used a screen to present targets. To best match the current work we present results from their young sample (aged 18 y to 25 y) with the choice response (*choice* responses were given using a multi-button key pad requiring target location to be identified rather than the *simple* response where the space bar of a keyboard was used to indicate detection of a target at any location). While there are only small differences in detection rates (Fig. 5) the RTs from onset to detection of the targets in Fotios et al. (2021) were much shorter than the current experiment (Fig. 6). We suggest three explanations for this. First, the current work was more complex, with a greater variety of targets to be detected. Second, the choice response used in the current work may have been more complex, being the choice between three types of switches rather than one of four buttons on a box in the previous work. This did not affect the ability to detect a target but increased response latency. Third, the contrast of targets against their background was higher (approximately 23) than in the current work (approximately 0.3).

Consider next the conclusions drawn about different modes of distraction in situations which better resemble natural driving, i.e. through the use of a driving simulator or driving on a road. The current data suggest that visual distraction impairs performance on a visual detection task, but that auditory distraction does not. Previous studies have shown that, compared with baseline conditions, visual distraction impairs lateral control (i.e. steering) of a vehicle (Kaber et al., 2012; Young et al., 2013; Peng et al., 2014; Yan et al., 2022; Yang et al., 2023; Wu et al., 2024), longitudinal control (i.e. speed and distance from vehicle ahead) (Horberry et al., 2006; Kaber et al., 2012; Young et al., 2013; Peng et al., 2014; Wu et al., 2024) and hazard detection (Horberry et al., 2006; Liang and Lee, 2010).

For auditory distraction, however, previous studies present mixed results. Concerning lateral control, minimal to no effects were found (Liang and Lee, 2010; Rakauskas et al., 2004; Wu et al., 2024). When investigating vehicle longitudinal control some studies found impaired performance with auditory distraction (Rakauskas et al., 2004; Horberry et al., 2006) while others did not (Engström et al., 2005; Kaber et al., 2012; Tarabay and Abou-Zeid, 2018). The auditory distraction labelled as cognitive distraction by Liang and Lee (2010) failed to reveal a significant impact on hazard detection, similar to the current work, while Horberry et al. (2006) found that hands-free mobile phone conversation led to impaired performance.

4.2 Impact

The aim of this work was to test the effectiveness of a scale model apparatus for measuring the interaction between lighting conditions and distraction on a driving detection task, specifically to test that it would reveal impaired visual detection in the presence of distraction. The visual distraction task was found to impair hazard detection, which is consistent with the findings of previous studies about visual distraction when driving. The auditory distraction task did not significantly impair hazard detection, despite setting the n-back task to $n=2$, which is considered to be roughly the same effect as the cognitive events that drivers typically encounter during driving (Yang et al., 2023). Horberry et al. (2006) and Yang et al. (2023) also found visual distraction to be the more significant distraction.

The results also serve to confirm the impact of distraction on road safety. Previous research has shown long brake RT as a main factor leading to a high RTC likelihood (Li et al., 2019). Table 4 summarises changes in mean RT to the road surface obstacle, the pedestrian, and lane change under control, auditory, and visual distraction.

These results indicate that visual distraction compared to the control condition resulted in RTs approximately 166 ms, 384 ms, and 366 ms slower for the obstacle, pedestrian and lane change hazards respectively. Considering the UK highway speed limit of 70 mph (112 km/h), these delays translate to potentially dangerous increases in stopping distances to obstacles (4 m), pedestrian (12 m) and lane change (11.3 m), further highlighting the risk of visually distracted driving. This analysis assumes that differences between the control and distracted RTs have absolute validity for real-world driving which remains to be confirmed.

Table 4 Mean RT to obstacle, pedestrian, and lane change under control, auditory, and visual distraction

Main visual target	Mean reaction time (ms) according to distraction task		
	Control	Auditory	Visual
Obstacle	1347.7	1367.00	1513.3
Lane change	2081.3	2095.4	2447.1
Pedestrian	2121.4	2158.3	2505.3

4.3 Limitations

Conducting this experiment in a laboratory environment enabled any effect of distraction on hazard detection performance to be carried out in a safe environment. To better represent gaze behaviour when driving participants were required to track a dynamic cross in parallel with the hazard detection tasks, in part to ensure the use of peripheral vision for hazard detection, but unlike driving there was no penalty

for failing to do so. We are investigating this in parallel work using a driving simulator (Öztürk et al 2023).

The participants in the current experiment represented a relatively young age group (18 y to 31 y). With increasing age, there is a decrease in the ability to distribute cognitive attention between tasks performed while driving (McKnight & McKnight, 1993). Previous work has shown that young (19 y to 25 y) and older drivers (above 65 y) are more susceptible to distraction than middle-aged (35 y to 45 y) drivers (Karthauss et al., 2020). While distracted, compared to middle-aged drivers, older drivers overall driving performance was found to be worse (Fofanova and Vollrath, 2011). However, in general, older drivers reported lower engagement in distracting tasks while driving (Chen et al., 2016), presented higher situation awareness, and greater experience in dealing with challenging tasks (Kass et al., 2007; Paxion et al., 2014).

Existing research on peripheral detection in driving has primarily focused on younger and middle-aged adults (under 40 years), limiting the generalizability of findings to the elderly (Fotios et al., 2021). Fotios et al. (2021) included groups of younger (18 y to 25 y) and older (60+ y) participants. It was found that older participants responded more slowly and identified fewer targets compared to younger participants. Further research is required to investigate the exact effects of distraction on hazard detection in drivers of different ages.

In the current work, responses to auditory distraction were recorded manually by the experimenter. To ensure accurate differentiation, phonologically distinct letters were used for this task. Additionally, the letter sequence was displayed to the experimenter in advance, enabling them to prepare to enter participant responses correctly and with minimal delay. However, this method of recording may introduce errors due to experimenter errors, such as entering the wrong letter or responding slowly. This could be addressed in future studies by exploring alternative approaches that ensure reliable recording, such as automated scoring using speech recognition techniques (Monk et al., 2011) or recording participant responses using a voice recorder (Öztürk et al., 2023).

Different response actions were required for the different detection targets – a hand operated button and paddle for the vehicle and pedestrian targets and a foot switch for the road surface obstacle. It is possible that these different response mechanisms would incur different response latencies. There may have been different learning effects associating these actions with a specific target, adding a confound to the analysis. Further work is required to consider this.

During trials participants were required to maintain visual fixation on the moving target, but we did not measure the degree to which this fixation was maintained. Previous work using eye tracking to record gaze behaviour in a detection task suggests that participants are good at maintaining foveal

fixation (Fotios et al., 2016). The assumption that fixation was maintained in this specific experiment would require further validation.

5. Conclusion

An experiment was conducted to investigate the impact of distraction on hazard detection when driving. The experiment was conducted using a scale model of a road scene with three types of hazards (a road surface obstacle, lane change of another vehicle, and a pedestrian) and three levels of distraction (none, visual distraction and auditory distraction tasks). It was found that hazard detection was impaired by visual distraction but not by auditory distraction. This agrees with conclusions about the impact of visual and auditory distraction reported in previous work conducted using a driving simulator (Wu et al., 2024) which suggests that a scale model is suitable for further work about the interaction between lighting and distraction on hazard detection.

That distraction can impair hazard detection suggests a limitation of previous studies of lighting and hazard detection which did not consider the impact of distraction. Lighting standards require robust thresholds and thus those thresholds derived from work which did not consider distraction require further consideration. That the scale model used in the current work was sufficient to reveal an effect of distraction on hazard detection suggests it is suitable for further work exploring the relationship between hazard detection and lighting conditions.

CRedit authorship contribution statement

Steve Fotios: conceptualisation, funding acquisition, methodology, project administration, supervision, writing – original draft. **Nima Hafezparast Moadab:** formal analysis, investigation, methodology; writing – original draft. **Yichong Mao:** formal analysis, investigation, methodology; writing – original draft. **Richard Rowe:** funding acquisition, writing – review and editing.

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