Exploring the interaction of distraction and passenger presence in relation to drivers' road traffic collision risk and hazard perception performance

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By

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Abstract

This thesis investigates the impact of distraction and passenger presence on driving performance and road traffic collision (RTC) risk, recognising human error as a primary cause of RTCs. Distraction is a significant factor in RTCs. While distractions like conversation and radio listening are known to depreciate driving performance and increase RTC risk, the influence of passengers on RTC risk remains debated.

Three experiments were conducted. Initially, distraction's effect on visual detection in an abstract context was explored to isolate distraction's impact from drivers' mental models of driving. Results indicated that more complex distraction tasks significantly impaired visual performance. Subsequently, RTC risks were analysed with and without distraction and passengers. Findings suggested differences in RTC risk among driver-passenger age groups, particularly for young drivers with young passengers.

The final experiment, influenced by the previous studies within this thesis, involved drivers performing a hazard perception task while distracted by a passenger seated either in the front or rear. The distraction task mirrored the highest complexity from the visual detection experiment, and the sample comprised the highest-risk group (young driver and young passenger). No significant differences were found in hazard perception performance between front and rear passengers, except for reaction time, which was slower with a front passenger.

These findings contribute to understanding distraction's impact on driving performance and RTC risk, particularly regarding passenger presence. The thesis provides a deeper exploration into these results, offering additional insights and discussions related to existing theories and research. Overall, the research highlights the complex interplay between distraction, passengers, and driving performance, providing valuable implications for road safety initiatives.

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Journal Paper Arising from Thesis Work

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Chapter 1: Introduction

1.1 The Need to Improve Driving Safety

This thesis concerns hazard detection when driving a motorised vehicle. Road Traffic Collisions (RTCs) are responsible for 1.3 million deaths and 50 million injuries globally every year, with RTCs being the leading cause of death for children and young people aged 5 to 29 [United Nations (UN), 2021]. In 2020, there were 115,584 RTCs in Great Britain [Department for Transport (DfT), 2022a]. The accumulated cost to the economy of the Great Britain related to RTCs was £4.56 million, entailing £2.16 million per casualty and £2.40 million for cleaning up all facets of the accident, of which fatalities were the main source of the cost at £1.93 million and £2.12 million respectively [Statista, 2021].

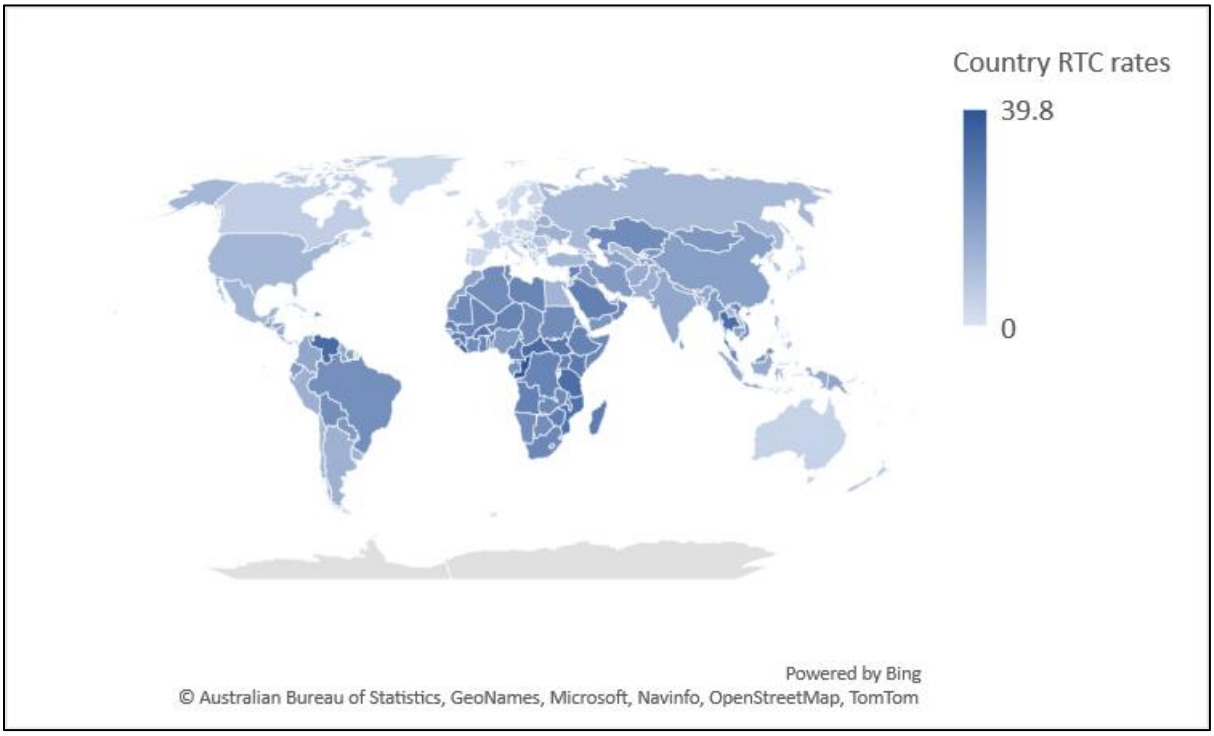
The United Nations Economic Commission for Europe (UNECE) estimates that RTCs cost 3% of their Gross Domestic Product (GDP) [UNECE, 2021], which is a measure of the total value of all final goods and services that are newly produced within the borders of a country over the course of a year [O'Neill, 2014]. This is a similar around to GDP spending on housing and the environment (2%), social services (3%), public order and safety (3%), transport services (4%), and defence (4%) [Statista, 2023]. Similarly, the World Bank estimates that actively taking measures to reduce RTCs can increase GDP by at least 6% [Bose, Marquez & Job, 2018]. Additionally, the reduction of cost related to all RTCs by the implementation of preventative measures was calculated at £2.5 million for 2021, calculated across casualties [DfT, 2022b]. Improving road safety is therefore beneficial for the economy.

Whilst there is an economic argument for reducing RTCs, there is also an associated human cost. The United Nations (UN) estimates that there will be a further 13 million deaths and 500 million injuries related to global RTCs in the coming decade [UN, 2021]. The UN therefore has set a key goal to halve road deaths and injuries globally by 2030 compared to 2010 figures within their third goal: Good Health and Well-Being [Henry & Shah, 2021]. Global RTC rates range from 0 to 39 per 100,000 population, which are presented in **Figure 1.1** to show how each country compares to one another.

Assessing whether the targets are being met is limited by the most recent global RTC statistics being based on 2016 data [International Transport Forum, 2022], meaning that the findings may be outdated. Complicating matter further is that some countries' most recent data are reported even earlier in 2013 [World Health Organisation (WHO), 2015], or provided later than 2016 by agencies within countries [Police Media Center, 2018; Australian Government, 2022; European

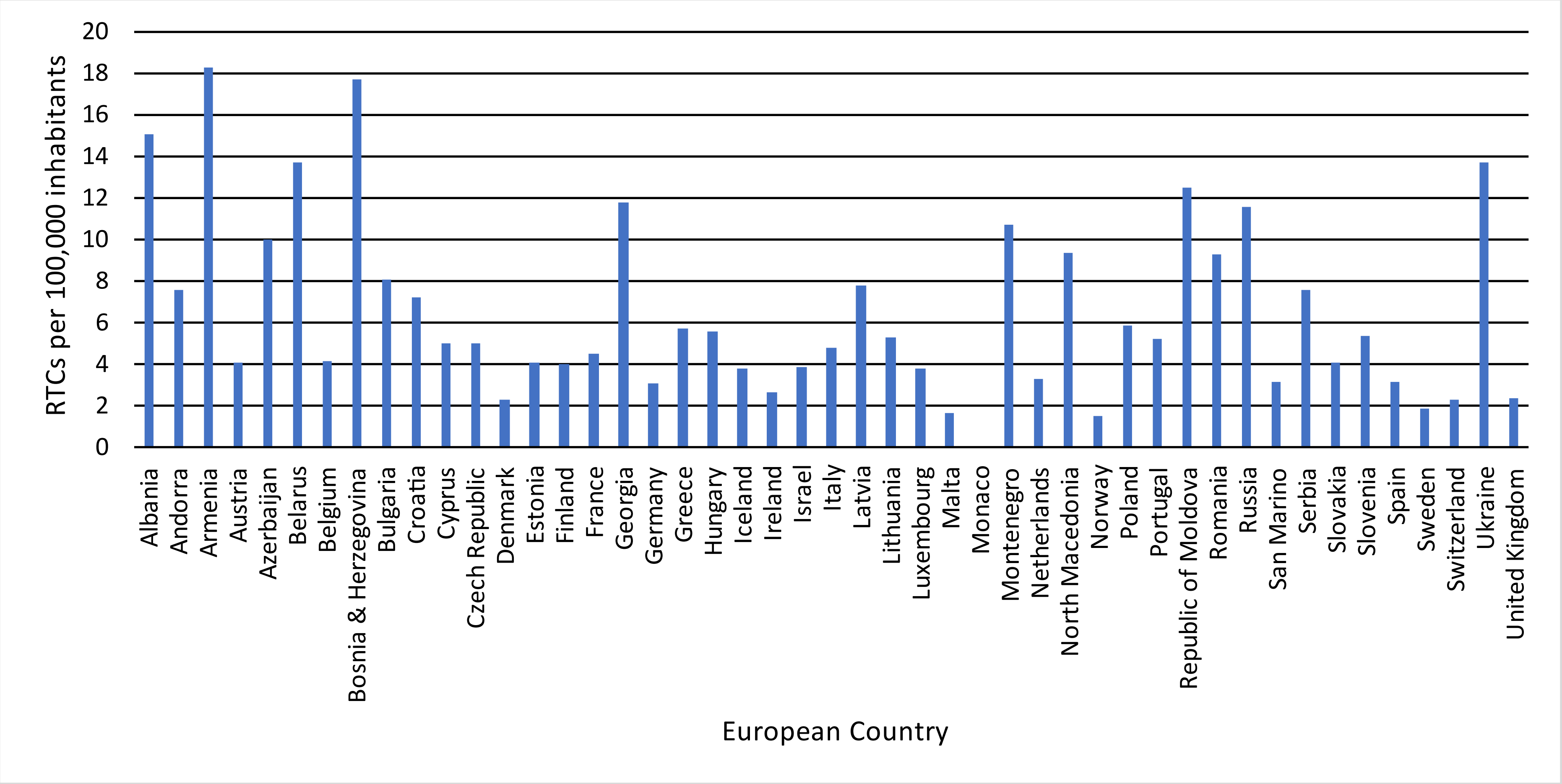
Transport Safety Council (ETSC), 2022; Transport Department, 2022; The Global Road Safety Facility, 2023a, 2023b & 2023c]. As such, any comparison is limited by the inconsistent reporting of data across countries, meaning that caution is advised when comparing global RTC rates.

Figure 1.1 **Global RTC rates**, between countries. Figures are based on per 100,000 population.



Comparing RTC rates around the world indicates that Europe has lower RTC rates compared to RTC rates of other continents, equating to roads that would be considered safer. Likewise, when comparing the United Kingdom (UK) with other European countries, the UK has relatively safe roads **(Figure 1.2)**. However, other than Monaco, there are no European countries where zero road deaths have been recorded, showing that the roads within these countries are associated with at least some risk to health. This means that further measures are required to improve not just road safety in the UK, but also Europe, and globally.

Figure 1.2 **RTC rates** per 100,000 inhabitants, across **European Countries**. Note that the data are taken from the most recent RTC rates recorded for each country, including data from 2013 (6.52% countries), 2016 (19.57% countries), 2019 (2.17% countries), and 2021 (71.74% countries).



To complement the UN target of Good Health and Well-Being, the UK has provided a national strategy to achieve a reduction in RTCs. Indeed, a framework has been created within the Vision Zero project, which is a multi-national road traffic safety project that aims to achieve a highway system with no fatalities or serious injuries involving road traffic [Belin et al., 2012]. Given that central tenet of the policy is that all RTCs are preventable, and road safety policies remain influenced by Vision Zero, this project remains relevant [Zwetsloot et al., 2017]. Unlike the UN goal that simply states a goal with minimal strategy, Vision Zero attempts to provide a more substantial plan of action to minimise the risk of an RTC [Kim et al., 2017]. This entails several measures that have occurred in the UK passed by government, including research into interventions that will help drivers improve their driving [House of Lords, 2020].

Whilst not all councils within the UK have directly subscribed to Vision Zero, various cities have declared their Vision Zero targets since 2007, when Blackpool became the first town to declare their target [Marshall, 2007]. This was followed by Brighton and Hove (and the wider Sussex region), Bristol, Edinburgh, Glasgow, and London [Road Safety Partnership for Edinburgh, 2010; Glasgow City Council, 2021; TfL, 2021; West Sussex County Council, 2021]. In this regard, the UK has road safety targets at not only an intentional level with the UN goal, but also on a local level throughout the various councils adhering to Vision Zero principles.

One factor that may facilitate road safety is that UK traffic levels are anticipated to reduce due to the Cycling Walking Investment Strategy (CWIS), which measures walking and cycling for stages; the UK government defines a stage as a change in transport mode [DfT, 2022b]. The aims are:

- Increase the percentage of short journeys in towns and cities that are walked or cycled from 41% in 2018 to 2019, to 46% in 2025.

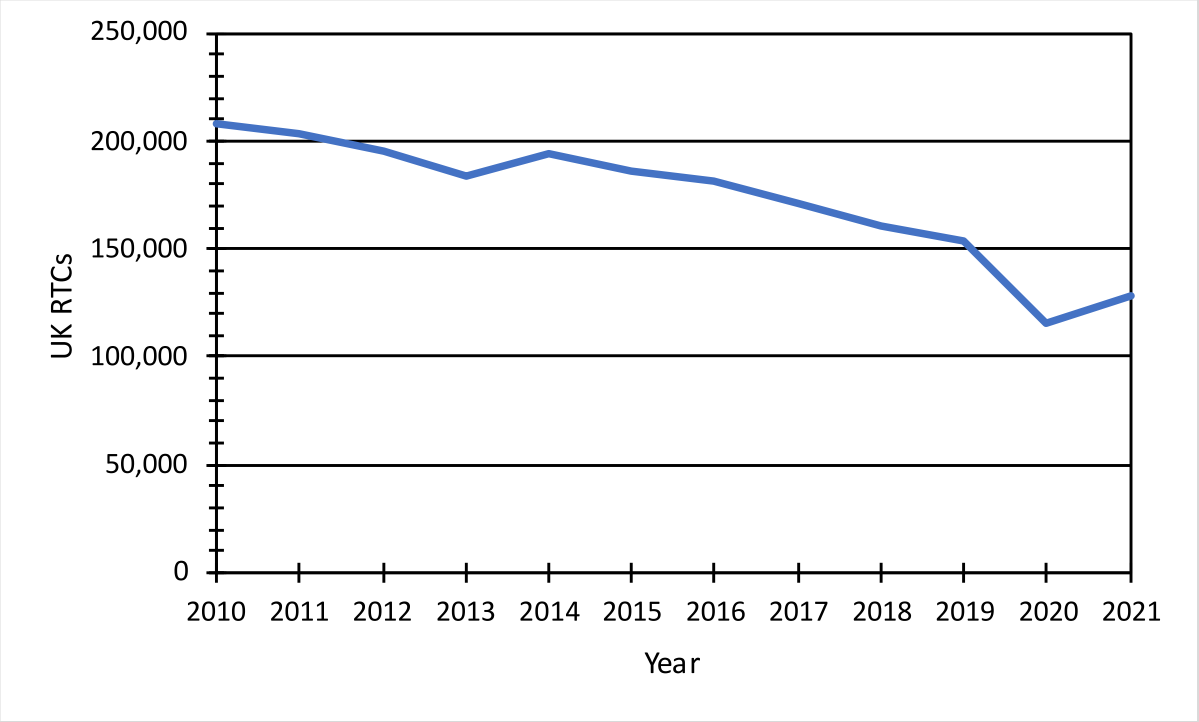
- Increase walking activity, where walking activity is measured as the total number of walking stages per person per year, to 365 stages per person per year in 2025.

- Double cycling, where cycling activity is measured as the estimated total number of cycling stages made each year, from 0.8 billion stages in 2013 to 1.6 billion stages in 2025.

- Increase the percentage of children aged 5 to 10 who usually walk to school from 49% in 2014 to 55% in 2025.

A combination of Vision Zero and CWIS mean that the impact of any road safety measures should be accentuated due to reduced traffic levels. However, vehicle drivers will still exist, meaning that RTCs remain a pertinent issue to address. As such, road safety targets have been set by the government since the implementation of Vision Zero, which targets a 40% reduction in all people (increasing to a 50% reduction in children) killed or seriously injured, and a reduction of 10% in the slight casualty rate of RTCs [House of Commons Transport Committee, 2008]. These targets can be assessed by exploring the statistics that DfT published, showing how road safety has changed over time from 2010 onwards **(Figure 1.3 and Table 1.1)**.

Figure 1.3 UK **overall RTCs** over time between 2010-2021 [DfT, 2022a].



Overall, RTCs therefore appear to be steadily decreasing every year, with a 39% decrease between 2010 and 2021. When compared to other countries, the UK has a generally low rate of RTCs [IRTAD, 2021], and is the third safest country in Europe behind Norway and Switzerland [DfT, 2019; House of Lords, 2020]. UK roads are thus relatively safe.

Table 1.1 **Percentage increase/decrease of overall RTCs** relative to previous year between 2010-2021 [DfT, 2022a].

Year	Relative change from the previous year
2010	*n/a*
2011	-2%
2012	-4%
2013	-6%
2014	+6%
2015	-4%
2016	-3%
2017	-6%
2018	-6%
2019	-5%
2020	-25%
2021	+10%

Whilst RTCs appear to be reliably reducing every year, except for 2021 which was potentially confounded by the effects of COVID lockdown, the trends are more nuanced for the type of casualty experienced. For instance, slight injuries have been gradually reducing in general over time, but mortality has barely changed **(Figures 1.4 and 1.5, and Table 1.2)**. 2020 experienced a notable decrease compared to 2010 in mortality rate related to RTCs, but the COVID pandemic lockdown measures must be taken into consideration.

For instance, 2021 provided a notable decrease in fatalities compared to 2010 rates, but a potential reason for this is that traffic levels were still depreciated to the extent that they were equal to 2002 levels (298 and 300 billion vehicle travelled respectively) [DfT, 2022c]. There is therefore a need to not just reduce the number of RTCs, but to diminish the severity of injuries for drivers that experience an RTC, given the progress in reducing slight injuries but lack of progress in reducing fatalities.

Figure 1.4 **UK RTCs** that resulted in **slight injury** between 2010-2021 [DfT, 2022d].

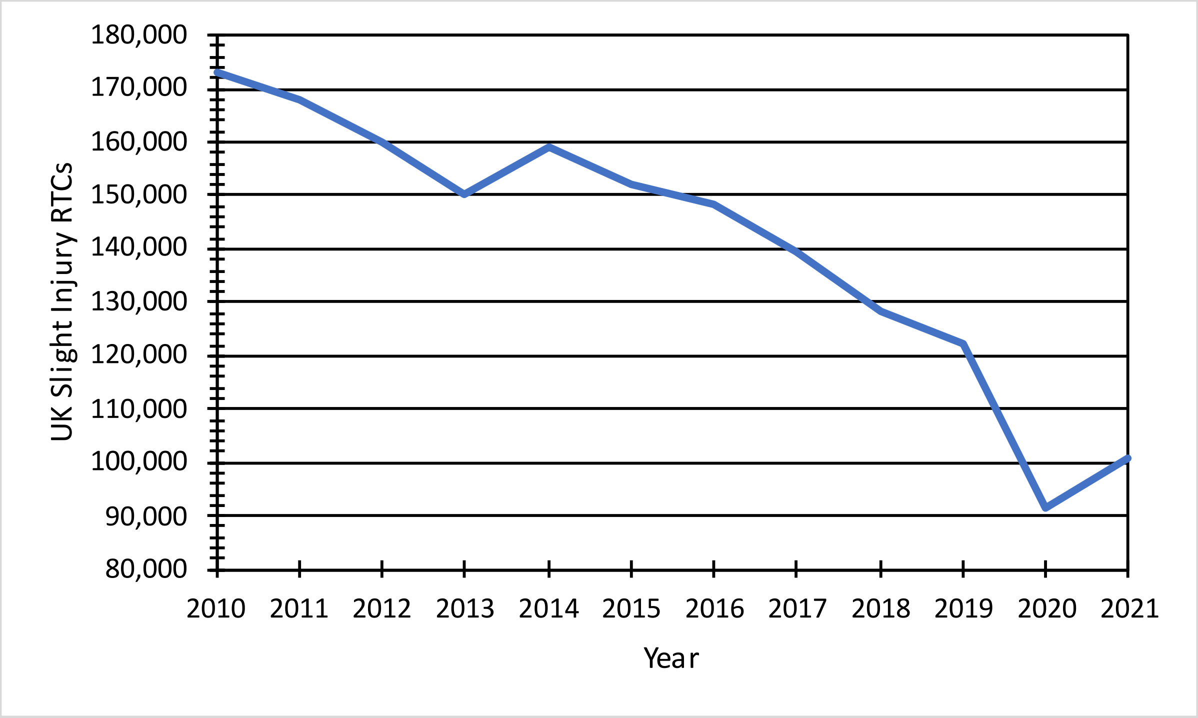


Figure 1.5 **UK RTCs** that resulted in **deaths (fatalities)** between 2010-2021 [DfT, 2022a].

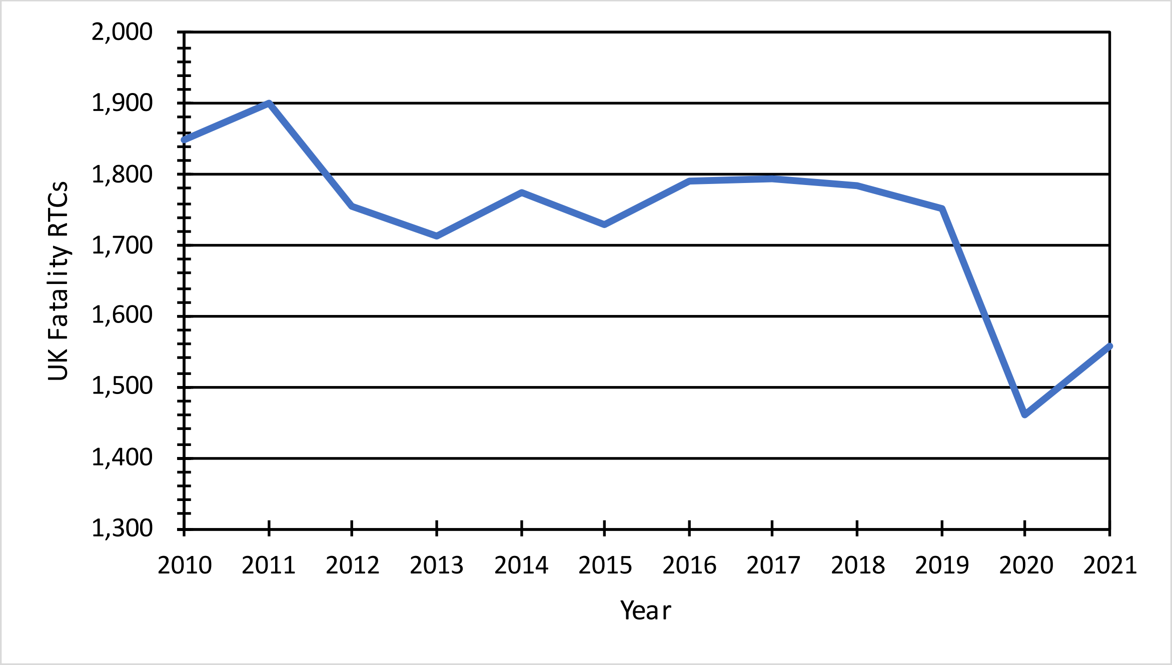


Table 1.2 **Percentage increase/decrease of deaths or slight injuries** between 2010-2021, relative to 2010 RTCs [DfT, 2022a; DfT, 2022d].

Year	Killed	Slight Injuries
2010	Baseline: 1,850	Baseline: 173,040
2011	+2.76%	-3.05%
2012	-5.19%	-7.45%
2013	-7.41%	-13.29%
2014	-4.05%	-8.11%
2015	-6.49%	-12.04%
2016	-3.13%	-14.14%
2017	-3.08%	-19.49%
2018	-3.57%	-25.74%
2019	-5.30%	-29.39%
2020	-21.08%	-47.17%
2021	-15.78%	-41.77%

1.2 Factors related to RTCs

Most incidents involving all modes of transport where people are injured or killed are attributed to human error [Rumar, 1985; CAA, 1998; Allahyari et al., 2008; Kyriakidis et al., 2015; Dingus et al., 2016; Weber et al., 2018]. Indeed, one study attributed human error to be a contributory factor in 94% of all RTCs [Read et al., 2021]; the remaining factors include the road environment (road design, road signs, pavement, and weather conditions) and the vehicles (equipment and maintenance, and damage), as well as a combination of all three [van Schoor et al., 2001; Papantoniou et al., 2017; Kassu & Hasan, 2020]. Consequently, to create measures that can reduce the majority of RTC cases, understanding how to reduce human error is crucial.

Behavioural factors are therefore important considerations related to human error when considering RTCs, which can be further classified by driver control, summarised by Petridou & Moustaki (2000) in **Table 1.3**. The mechanisms that underpin the summary that Petridou & Moustaki (2000) provide is that when RTCs relate to human error, the effective operation of a vehicle is impeded by the volitional or involuntary engagement of activities that are detrimental to the driving activity.

Table 1.3 **Human error/associated effect categories** related to driving performance. [Petridou & Moustaki, 2000].

Category	**Behavioural effects**
Reduced capacity on a long-term basis	Inexperience, aging, disease and disability, alcoholism, drug abuse
Reduced capacity on a short-term basis	Drowsiness, fatigue, acute alcohol intoxication, short term drug effects, binge eating, acute psychological stress, temporary distraction
Increased risk-taking behaviour with long-term impact	Overestimation of capabilities, macho attitude, habitual speeding, habitual disregard of traffic regulations, indecent driving behaviour, non-use of seat belt or helmet, inappropriate sitting while driving, accident proneness
Increased risk-taking behaviour with short-term impact	Moderate ethanol intake, psychotropic drugs, motor vehicle crime, suicidal behaviour, compulsive acts

Haghi et al. (2014) provide further supporting evidence for the categories that Petridou & Moustaki (2000) stipulate related to human error. They summarise that human error is either predicated by risk-taking or being unable to effectively manage focus on the task of driving, which they define as a lapse. They also show that there is an influence of driver age on whether there is engagement with risk-taking behaviour. Drivers aged <24 are more likely to engage in riskier behaviours, whereas drivers aged 65+ are more likely to experience a lapse in focus. These respectively are referred to as violations (intentional behaviour) or errors (unintentional behaviour) [Cuenen et al., 2015; Walshe et al., 2017]. A limitation to their findings however is that they are based on surveys, requiring self-report data that is difficult to verify due to respondents either deliberately stating false information or misremembering information [Paulhus & Vazire, 2007].

Regardless of the specific form of human error, the factors proposed above increase the inattention of a driver, defined as insufficient or no attention to activities where focus is expected. This is discussed frequently in driving literature as the main factor in RTCs [Ledesma et al., 2010; Cunningham & Regan, 2018; Chen et al., 2019; Bucsuházy et al., 2020]. However, explanations of inattention and the various forms of attention it incorporates, including distraction, are typically conflated in the literature [Young & Salmon, 2012; Gershon et al., 2019]. Additionally, the definition of inattention is inconsistently defined between studies, and their conceptual relationships not clarified [Regan et al., 2011].

For instance, Yanko & Spalek (2013) conflate the idea of more efficient processing that leads to reduced neural activity with drivers not being attentive to the scene. In another study, Eberhart et al. (2000) make a distinction between sleepiness and inattention, but do not explain which facet of inattention they are focusing upon. Both studies are measuring inattention related to driving, in which the concept of distraction is alluded to, but both studies do not incorporate mutual aspects of inattention and distraction. This inconsistency means that methods for exploring these concepts may not be comparable. The subsequent consequence is that the practical implications could be flawed.

Regan et al. (2011) attempted to rectify the lack of consensus in the definition of inattention by incorporating multiple aspects. This includes when attention is restricted (physical restrictions by biological factors, such as visual defects), misprioritised (focus is on one aspect of driving compared to another that is more critical for safe driving), neglected (no focus on aspects critical for safe driving), cursory (hurried processing of information relevant for safe driving, but not sufficient for effectively acting on information for safe driving) or diverted (attention is focused on a non-driving secondary task, resulting in insufficient or no attention to activities critical for safe driving; synonymous with the concept of distracted driving). From these categories of inattention, distracted driving is the most prominent factor related to RTCs [Wundersitz, 2019; Cao et al., 2022].

There are many forms of distraction, including mobile phones, diverting thoughts away from the task of driving to alternative non-driving thoughts, conversing with passengers, picking up objects within the vehicle, and adjusting the radio [Burnett, 2023]. Counterintuitively, despite conversing with passengers being a source of distraction, research into the presence of passengers finds contradicting evidence, with some finding that passengers reduce the risk of an RTC whilst others finding the opposite [Vollrath et al., 2002; Chung et al., 2014; Huisingh et al., 2015; Caird et al., 2018; Charlton & Starkey, 2020; Green et al., 2022]. Exploring the interaction between passengers and the mechanisms that underpin distraction would therefore lead to deeper insights into what aspect of passengers being in the vehicle with drivers conveys either a safety or detrimental influence on RTC risk.

Given that most RTCs occur because of human error [Read et al., 2021], and distracted driving is the most prominent factor related to RTCs [Wundersitz, 2019; Cao et al., 2022], exploring how to minimise driver distraction would likely improve road safety. Indeed, focusing the exploration of distraction on passenger presence in greater detail could therefore lead to deeper insights in the field of road safety. In turn, this exploration could be used to influence road safety policy.

1.3. Research Aims

The research in this thesis aims to explore road safety in greater detail. This aim is based on the need outlined in this chapter for enhancing driver safety to meet national and intentional goals, complemented by both the impact on economics and human costs related to current RTC trends. A particular focus is on the interaction of distraction and passenger presence on driving performance associated with RTCs. Indeed, the research reported in this thesis has three main aims:

1) To identify the distraction task that is most detrimental to visual detection within an empirical experiment.
2) To explore the influence of passenger presence and distraction on RTC occurrences.
3) To explore the influence of distraction and passenger location on driving performance.

The importance of the first aim is that a distraction task that is the most detrimental to visual performance that can then be applied to the driving context will likely ensure that the driver is as distracted as possible when measuring driving performance. To further explore distraction, the second aim provides understanding about the interaction between a component of distraction (passenger presence) and distraction generally, related to RTC occurrences. The third aim explores passenger presence and distraction in greater detail by applying the findings from the first aim (most appropriate distraction task) and second aim (highest risk of driver and passenger age interaction related to RTCs) into an investigation of driving performance, which can be indirectly associated with RTC risk.

Addressing these aims is expected to further theoretical understanding about the influence of passenger presence and distraction on RTCs, whilst also providing guidance for policy makers related to administering the hazard perception test when assessing drivers for their licence.

1.4. Structure of this Thesis

From a review of the literature **(Chapter 2)**, it was determined that the influence of distraction has been explored in relation to hazard perception performance, but the distraction task is typically arbitrarily chosen. As such, this thesis aimed to provide a novel insight into driving safety by first comparing distraction tasks that differ in their difficulty to assess which distraction task is the most detrimental to visual detection in an abstract task **(Chapters 3 and 4)**. Following this, RTC data were analysed to assess occurrences of RTCs, comparing when the driver drove alone and when the driver was with passengers, in addition to various factors associated with the RTCs **(Chapter 5)**. A final study explored the most detrimental task from the abstract visual detection task, which was used as the basis for distraction and presented to driver participants in a hazard perception experiment whilst a passenger participant (the age of the driver and passenger interaction being determined by the examination of the RTC data) provided the distraction task to the driver **(Chapters 6 and 7)**. The findings of all studies are then used to address the research aims and relate what was found to previous literature and theory **(Chapter 8)**, before a summary of the research and its findings are presented **(Chapter 9)**.

Chapter 2: Literature Review

2.1 Introduction

The previous chapter introduced the rationale for this thesis, explaining why RTCs are an issue that can be mitigated if appropriate measures are considered. Providing deeper insights into this issue can provide guidance for road policy that leads towards safer roads.

Human error is a large area that researchers target for increasing road safety due to its contribution to RTCs [Salmon et al., 2010]. Of this, the risk of RTCs is known to increase when drivers are distracted [Klauer et al., 2014]. There are various types of distraction that a driver may experience, but one of these is passengers, for which the literature either suggests reduces or increases the risk of an RTC [Vollrath et al., 2002; Chung et al., 2014; Huisingh et al., 2015; Caird et al., 2018; Charlton & Starkey, 2020; Green et al., 2022]. The nature of distraction therefore appears important when considering how distraction influences road safety.

This chapter further explores the nature of distraction relating to road safety. First, the categorisation of how distraction is explored in relation to driving performance to understand why distraction is an important consideration for road safety researchers. The influence of how distraction influences visual performance will then be explored. Indeed, given that attention maintenance and hazard anticipation are related directly to RTCs [Taylor et al., 2013], understanding eye scanning behaviour is vital to gain a more comprehensive understanding of road safety. Following this, a critical examination into the distraction theories is presented to assess the state of knowledge of this field, complemented by a comprehensive critical analysis of road safety literature. Finally, how distraction interacts with age will be presented to explore why there is a higher prevalence of RTCs in younger, compared to older, drivers [Walshe et al., 2017]. Within this section, the interaction between passenger presence and age of both driver and passenger will be discussed to explore the influence of passengers on drivers' driving performance related to RTCs. A summary will then be provided to explain the main findings from this chapter and how it relates to the two experiments that will be presented in the forthcoming chapters.

2.2 Distraction Overview

Driver distraction occurs when drivers simultaneously engage in a secondary non-driving related task whilst conducting driving relevant manoeuvres [Regan et al., 2011]. Distraction can be divided into one of four categories: visual, auditory, physical, and cognitive **(Table 2.1)**.

Table 2.1 **Categories of distraction** when driving [Regan, 2007].

Category	Example
Visual	Looking at a route guidance map display instead of the road.
Auditory	Radio being played too loud that it masks other sounds.
Physical	If interacting with the in-car device influences steering of the vehicle.
Cognitive	Mentally disengaging from the task of driving to attend to another task.

Different categories of distraction have different outcomes on driving performance. Take visual and cognitive distraction as examples: visual distraction has been found to impair the driver's ability to maintain position within the road lane [Engström & Markkula, 2007], which contrasts the effect found for cognitive distraction that relates to an improved ability to maintain position within the road lane [Beede & Kass, 2006]. Furthermore, cognitive distraction has been found to impair the detection, recognition, and processing of an item in the visual scene as being hazardous [Engström & Markkula, 2007]. Depending on the distraction category, the influence on driving behaviour therefore differs.

Distraction categories can also combine. Liang & Lee (2010) suggest that, whilst distraction of any kind generally leads to worse driving performance than when the driver is fully engaged, visual distraction and cognitive distraction when combined moderate each other. Specifically, when both visual and cognitive distractions were combined, lane variance was greater than when visual distraction was presented alone [Liang & Lee, 2010]. Their study, complemented with the differing effects of distraction categories on driving performance, indicate that the modality and potentially combinations of distraction appear to be an important consideration to driver safety.

Furthermore, the way a driver's cognition adapts to compensate for the detrimental influences of distraction differs between the distraction categories. Examples include intentionally avoiding engaging in distraction, moderating speed to compensate for detriments caused by distraction, or choosing to cease driving altogether if the driver perceives themselves as being unable to avoid being distracted [Young & Michael, 2008]. Indeed, there is a greater degree of behavioural adaptation for visual, compared to cognitive, distraction, which includes the smoothness of steering actions (steering entropy) being bigger for visual, compared to cognitive, distraction [Zhang et al., 2014]. The detrimental influences of drivers that are engaged in distraction can be reduced if they cognitively attend to driving related information whilst driving, such as reflecting on driving speed and rules [Ojsteršek & Topolšek, 2019]. In other words, increasing the cognitive focus to the primary task of driving increases the ability of drivers to mitigate depreciations to driving performance that occur when drivers engage in distracting secondary tasks, although this does not specifically correspond to distraction given that a distraction is secondary tasks that are non-driving related. What these findings indicate is that the detrimental effects of distraction are not related to the increased mental workload of a secondary task, but that the nature of the secondary task is an important consideration in driving safety.

Working memory is a model for short-term memory, relating to the mechanisms that underpin mental workload [Khaksari et al., 2019; Radüntz, 2020]. This is a model that is divided into components including the central executive, which controls the flow of information and acts as a supervisory system to the phonological loop and the visuospatial sketchpad, respectively storing verbal and visuospatial information [Baddeley, 1992]. Working memory is important to consider for how distractions influence drivers' performance because it is associated with the concept of cognitive load, which relates to the amount of working memory resources used to execute tasks [Sweller, 1988]. Cognitive load is divided into three categories, which are the resources used in processing the information presented (intrinsic); the resources used in relation to the way the information is presented (extrinsic); and transferring the processed information into long-term memory as an automated item (germane) [Leppink et al., 2013].

All types of cognitive load (intrinsic, extrinsic, and germane) are implicated in driving, but how it influences driving is strongly selective and task dependent. For instance, manually operating the vehicle in terms leads to germane cognitive load, given that the working memory resources used to successfully execute tasks becomes automated for the driver with practice over time [Mitra et al., 2017]. In contrast, providing simultaneous tasks that increase the intrinsic cognitive load for drivers beyond the level found on automatised tasks conveys no detriments, and sometimes even improves performance [Miller et al., 2015; Engström et al., 2017].

If the cognitive load aspect of distractions was the cause of the increased risk of RTCs [Klauer et al., 2014], an increase of cognitive load would be expected to increase the risk of RTC as well. Given that this is not the case across all cognitive load domains, the benefit of providing a higher cognitive load to drivers in the instances where driving performance improves further supports that the risk increase emerges from the nature of the distraction itself rather than the cognitive load inherent to the distraction. What is not currently understood however is the threshold for which, if a driver surpasses a cognitive load level, their driving performance is impaired.

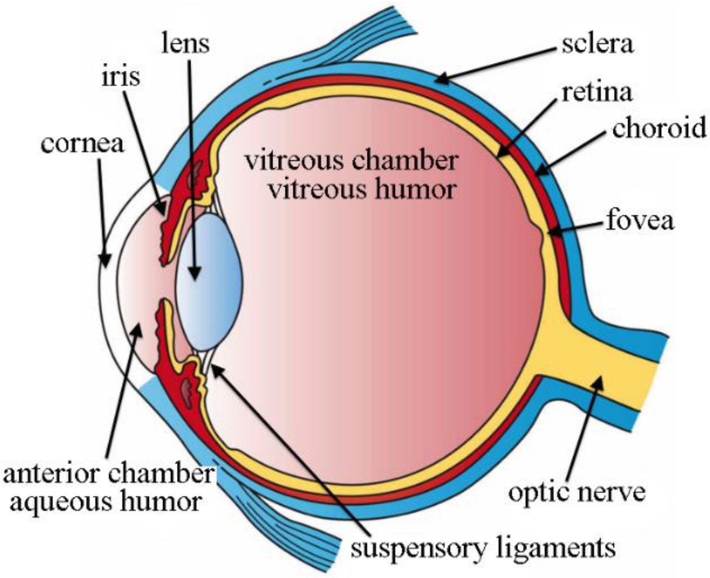
Additionally, the anticipation of distraction itself could cause the detrimental influence on driving performance. For instance, Savage et al. (2020) explored the influence of distraction on eye movements generally. They suggest that there are influences of both pre- and post-distraction, but not during the distraction period, on various eye movements. These include saccades and fixations, which respectively refer to rapid eye movements that bring objects of interest onto the central, highly sensitive part of the retina, and eye movements that remain relatively stable [Krekelberg, 2010; Holland & Komogortsev, 2013]. They further state that neurological evidence indicates an overall decrease in theta band output at occipital sites of the brain, which they interpret as evidence that distraction results in a reduction in visual processing. Supporting their interpretation is that visual short-term memory and visual perception is associated with theta band output [Demiralp et al., 2007; Liebe et al., 2012]. Consequently, vision and cognition appear highly interlinked. Examining how distraction influences vision could therefore lead to deeper insights into how distraction influences driving performance.

2.3 How Distraction Influences Vision

Vision is highly important to the task of driving, to the extent that visual processing accounts for 90% of driving information [Sivak, 1996]. An individual's visual system is responsible for visual perception, which facilitates the ability to receive, process, and interpret visual information to construct understanding of the surroundings. There are several parts to the visual system. These include the eye, retina, and fibres that relay visual information to the thalamus (sensory perception and movement) [Basso et al., 2005], the superior colliculus (sensory information with incorporation of cognition, and issuing motor commands) [Gandhi & Katnani, 2011], and parts of the brain stem (automatic processes, such as breathing and heart rate) [Hatfield & Epstein, 1985; Ogmen & Herzog, 2010; Snowden et al., 2012].

Of the components within the visual system, the eye is the primary agent that perceives and processes information, from which the remainder of the visual system can operate. The structure of the eye is shown in **Figure 2.1**. Different aspects of the eye facilitate certain functions, such as the cornea that moderates the amount of light that is processed [Spadea et al., 2016], or the choroid that supplies oxygen and nutrients [Shao et al., 2011].

Figure 2.1 Illustration of the **human eye**.



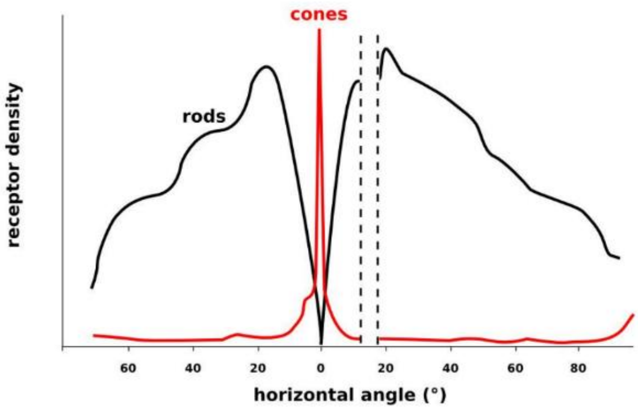
For producing the image that people perceive from the visual information received however, the fovea is arguably most important because it provides the photoreceptors that facilitates both high acuity and colour vision [Salles et al., 2016]. As visual acuity is implicated in RTC risk for older adults [Anstey et al., 2012], the fovea is of particular interest for driving safety. However, the influence of oxygen is understood to relate to how detrimental distraction is, whereby the drivers that are exposed to higher oxygen levels produce fewer errors in cognitive tasks [Scholey et al., 2020]. For distraction, the choroid may therefore be the most relevant part of the eye related to driver safety, which is supported by better cognition being related to thicker, rather than thinner, subfoveal choroidal thickness [Jonas et al., 2018].

An eye has two types of photoreceptors that facilitate vision: rods and cones, which respectively relate to vision in low and high light conditions [Stabell & Stabell, 2009]. In the retina, rods outnumber cones by a significant margin (91 million to 4.5 million) [Purves et al., 2001]. A cone is the only photoreceptor that contributes to vision at high light levels, but not at low light levels. A retina also lacks a uniform distribution of rods and cones.

In humans, nearly all cones are in the fovea, which is an area unique to primates that comprises 0.2% of the retina [Roska & Sahel, 2018] **(Figure 2.2)**. The visual information is provided by an area of only 2° visual angle. As such, foveal cones are extremely dense, with 150,000 per mm^2 of retina. Due to this and other anatomical features of the fovea, it can perceive detailed visual information with high spatial resolution. The importance of cones on visual acuity is further emphasised by the finding that, when measuring rod and cone degeneration together, only cone spacing is found to influence visual acuity [Bensinger et al., 2019].

The fovea typically comprises 1° of eccentricity, whereas the parafovea extends from 1° to about 4°–5°. Together, fovea and parafovea are commonly referred to as central vision. In contrast, peripheral vision, which is known to be associated with substantially degraded visual acuity as compared to central vision, encompasses the remainder of the visual field [Larson & Loschky, 2009]. In the horizontal plane, the visual field extends up to about 100°, and in the vertical plane, it extends to 60-75° [Boyce, 2014]. These structures are important for driver safety because the fovea is particularly implicated in safe driving, given that drivers with impaired foveal function, but otherwise functioning vision, are significantly slower than drivers with normal vision when measuring how fast they detect brake lights [Lamble et al., 2002a].

Figure 2.2 The **density of rod and cone photoreceptors** across the retina is represented by the horizontal angle (0° represents the centre of the fovea) [Osterberg, 1935].



Likewise, the useful field of view (UFV), which is the area of the visual scene that can processed effectively without moving the eyes or head, is associated with RTC risk; a 40% reduction of the UFV is linked to a twofold increase in RTC risk for older drivers [Thorslund & Strand, 2016]. However, due to the modest size of the fovea, most visual functions occur within the peripheral vision while driving: if an item in the driving scene is detected, the item is typically captured by peripheral vision and transferred to the fovea by eye and head movements [Fotios et al., 2016]. Such a mechanism is fortunate for road safety because hazards are processed differently depending on whether they are perceived in central or peripheral vision. Indeed, hazards are always processed better in central, compared to peripheral, vision, with later processing of highly hazardous situations being processed only within central vision [Li et al., 2022]. As such, both central and peripheral vision are important for driving safety, with the latter informing the former.

The presence of the visual system itself is implicated in driver safety, but how it functions is equally important. For instance, drivers' information processing of the visual scene could be related to the processing capacity of the driver, and where visual information is presented in the driving scene. Some distracting tasks cause the driver to divert their attention away from the road, which increases reliance on peripheral vision to detect driving-relevant events. Increasing drivers' reliance on their peripheral vision has implications for RTC risk.

An example is that Wolfe et al. (2019) conducted research where a space bar was instructed to be pressed whenever a vehicle in the participants' lane of travel applied the brakes, as indicated by its brake lights. Participants did this while maintaining fixation in the centre of the driving scene. A secondary task was presented where a collection of circles was presented above, to the left, below, and to the right of the central fixation point, making the shape of a plus sign. One of those circles would momentarily disappear and participants were required to either state which one had disappeared or state the direction of the circle that had disappeared previously in the sequence.

Wolfe et al. (2019) showed that brakes were detected at a greater rate and faster in foveal, compared to peripheral, vision when presented with distraction. However, whilst the distraction task varied in cognitive load, it was visual in nature. This meant that it did not necessarily explore the *fundamental* components of distraction for visual detection, but rather how visual detection was influenced by a specific modality (visual) of distraction task. The interaction between visual location and the amount of cognitive load drivers experience related to their driving performance is therefore not fully explored, given that other types of distraction may have had a different influence on their driving performance [Zhang et al., 2020a].

Driving research explores driving performance in various ways, but only the driver's ability to effectively perceive and respond appropriately to items in a driving that will lead to an RTC if the driver does not respond (meaning a change of speed or direction) is found to be related to RTC occurrences out of all other components of driving skill [Horswill & McKenna, 2004]. This ability is known as hazard perception. Moreover, the visual location of items that are precursors to hazards is particularly important in the driving scene. Roca et al. (2013) define precursors as items in the driving scene that provide cues to the hazard which might be more apparent to safe drivers with experience of similar situations. They suggest that there are two categories of precursors: behavioural and environmental. These refer to stimuli that are not hazardous earlier in the driving scene but then become hazardous, with the behaviour of the stimuli proving information that the hazard will emerge (behavioural), and stimuli where the hazard is not visible before the hazard emerges (environmental). The crucial difference is that the pre-cursor and hazard are the same stimuli for the former, differentiated temporally, whereas the pre-cursor and hazard are different stimuli for the latter, in which the pre-cursor is concealed by the general environment.

Crundall et al. (2012) suggest that central and peripheral vision are utilised qualitatively differently between the different categories of precursor, which leads to them being used differently between various types of hazards. For instance, they suggest that environmental precursors are less obviously connected to hazards than behavioural precursors, and this lower probability of fixating on environmental precursors may reflect some occasions where the precursor is monitored solely through peripheral vision. A higher cognitive load is anticipated to reduce the reaction time and detection rate of drivers to hazards whilst driving particularly in their periphery because drivers are known to scan the environment with less breadth. Indeed, one study noted that scanning the mirrors within the car (and wingmirrors) reduced by 3% whilst conducting cognitively loading tasks [Angell et al., 2015]. Peripheral targets are therefore implied to be more affected by a higher cognitive load than targets in foveal vision.

A further association between the type of vision used by a driver and cognitive load is related to gaze behaviour, which is a series of fixations and saccades. Higher velocities of saccadic intrusions (SIs) are observed in conditions where a task provides a higher cognitive load. SIs are conjugate, horizontal saccadic movements that tend to be three to four times larger than the physiological microsaccades and take the form of an initial fast eye movement away from the desired eye position, followed, after a variable duration, by either a return saccade or a drift [Abadi & Gowen, 2004].

Crucially for exploring how distractions influence driving performance, SIs are sensitive to the influence of cognitive load, whereas cognitive load is difficult to detect with microsaccades [Martinez-Conde et al., 2009; Korda et al., 2016]. Gowen et al. (2007) show that the cognitive load category modulates the magnitude of SIs. They showed that exogenous and endogenous attention, respectively meaning stimuli that have no meaning or have meaning related to the target that requires a participant response, provide different eye behaviours. Gaze response is facilitated if the exogenous target is presented at the cued location less than 200ms following the cue; impeded if the target is presented over 300ms later [Klein, 2000]. This late inhibitory effect is termed inhibition of return (IOR) and can last for up to 3s [Posner et al., 1985]. Facilitation towards the cue occurs from approximately 150ms and IOR is absent during manual response conditions unless the cue triggers a saccade to be prepared or executed [Müller and Rabbitt, 1989; Rafal et al., 1989; Fecteau et al., 2004].

SIs are directly implicated in drivers' cognitive load. Biswas & Prabhakar (2018) indicate that, whilst there are individual differences in baseline SIs whilst drivers are engaged with driving without distractions, SI velocities are observed as increasing when distractions are introduced. Crucially, drivers' instantaneous perception of a developing road hazard is accompanied by one or more high velocity saccadic intrusion, and SIs having velocities more than 3°/s can be used to detect change in cognitive load as well as developing road hazard. The issue however is that there were fundamental issues with the various iterations of study they contained within this research.

First, in one iteration, a task required participants to say aloud a letter they heard either two or three previously in the sequence, called the N-back task [Jaeggi et al., 2010], whilst the researchers recorded SI. The researchers did not record performance on this distraction task, so could not determine the locus of participants' focus as being either the distraction task or hazard perception. Another limitation is within a different study iteration they conducted, where the secondary task provided information that was directly linked (information about pressing a button) to the primary task (either pressing a button on a graphical interface in isolation to any other task, or whilst driving on different complexities of road in a simulated environment). As such, the secondary task was relevant to the primary task, rather than being presented as a distraction. These results provide tentative support regarding SIs for cognitive load generally, but whether the nature of the secondary task is important remains unanswered.

Likewise, the Index of Cognitive Activity (ICA) is a pupillometry measure that records the frequency of rapid pupil dilations; the ICA is a complementary measure to overall pupil size because it disentangles the pupil response to cognitive activity from effects of light input [Vogels et al., 2018]. Generally, more difficult problems evoke larger pupillary dilations, suggesting a relationship between problem difficulty and task-evoked activation [Duchowski et al., 2018]. Differences in the responses within the ICA are thought to reflect differences in central, rather than peripheral, brain processes; ICA is due to the psychosensory stimulus itself, facilitated by two muscle groups (dilator and sphincter) that causes a brief dilation related to both sympathetic as well as parasympathetic inputs, producing the observed pupillary dilation also known as the pupillary reflex [Beatty & Lucero-Wagoner, 2000]. These changes in the size of the pupil based on the dilation reflex are irregular and sharp, often exhibiting large jumps followed by rapid declines, regardless of lighting levels [Marshall, 2002].

ICA has been observed by Schwalm et al (2008) as being relevant for drivers for the task of lane changing and additional tasks, with varying levels of complexity leading to a stronger ICA response, although their study explicitly told participants not to prioritise either task. Given that they do not present the results of the performance for the non-driving related task, whether participants were sufficiently distracted in the experiment is not known. However, despite the limitations presented for SIs and ICAs, both support the idea that the cognitive factors relating to distractions are important to consider when exploring how distractions influence drivers' detection of items in the visual scene, particularly those in the periphery.

The automatic processes of the eye and distraction are useful to assess for its implication on road safety, but vision is not purely an unconscious process. Eye scanning behaviour is also important. Mackenzie & Harris (2017) found that performance on abstract tasks is correlated with effective eye movement strategies when driving, such as scanning the road. As such, strong cognitive performance results in more effective scanning behaviour, which leads to better driving performance.

In contrast, Harbluk et al. (2002) manipulated the complexity of mobile phone conversations whilst driving, which is a prevalent distraction [Prat et al., 2017]. They found that high complexity conversations lead to an increase in the percentage of time that drivers fixate on the centre of the road, scanning the road less extensively than when they are not engaged in conversation. The difference between the two findings could relate to the distraction task presented, which indicates the difficulty of effectively exploring distraction on driving performance. Understanding the fundamental aspect of distraction that leads to detriments could mitigate this limitation and provide guidance for future distraction research. Exploring how distraction influences drivers' cognitive processes could provide a solution.

2.4 Hazard Perception

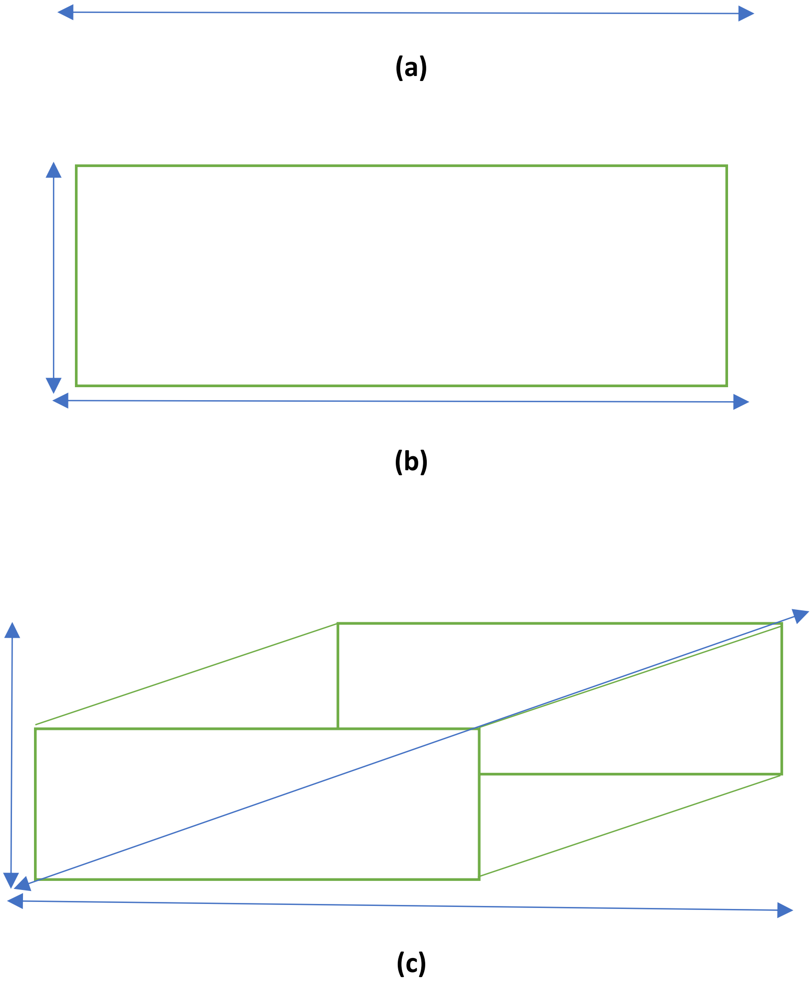
Of all driver related tasks, eye scanning behaviour is particularly important for detecting hazards, which can be trained and assessed. Introduced in 2002, UK driving licensure assessments have included a component that measures how effectively a learner driver is able to detect and respond to hazards called the hazard perception test [Driver and Vehicle Standards Agency, 2019]. Such training is understood to be effective at improving road safety: the introduction of the hazard perception test as part of the UK driving theory test to gain licensure has been estimated to reduce the rate of public-RTCs on non-low-speed roads by 11.3% [Horswill, 2016].

However, whilst hazard perceptions are thus useful for improving road safety, the nature of eye scanning behaviour could be influenced by the nature of the hazard perception test itself. For instance, Mackenzie & Harris (2015) explored visual search of participants when they conducted a visual detection experiment within the driving context either on a computer or based on a real road, finding that visual scanning became narrower (less spread) in a real driving context compared to passively watching videos on a computer. Their findings are associated with eye scanning behaviour between manual and automated driving, with the former having a narrower scanning pattern than the latter [Navarro et al., 2021].

In contrast, Boot et al. (2009) found that the same scanning patterns were used during different dynamic visual search tasks; there were individual difference effects between observers [Boot et al., 2006; Becic et al., 2007], but these tended to remain stable across all tasks. The difference between these findings could have arisen by the nature of the tasks they used in their research, with Mackenzie & Harris (2015) using driving scenes, whereas Boot et al. (2009) used abstract tasks that did not have a real-world context.

Screen-based experiments informed both research designs, which convey a two-dimensional (2D) image, with the driving scenes being 2D images of three-dimensional (3D) stimuli **(Figure 2.3)**. Driving scenes are implied by Deng et al. (2016) as relating to observers perceiving these 2D images as 3D representations, with observers mostly concentrating on the end of the road in front of the vehicle within the scene. They propose that the vanishing point of the road can be regarded as valuable top-down guidance in observers' search strategy. Li et al. (2016) found that eye scanning is understood as being comparable for both 2D and 3D items, but they used 2D images and actual 3D environments rather than 2D images that were perceived to be 3D. The mechanisms behind actual and perceived 3D items may differ. Whether results from abstract experiments would apply to the driving context thereby is uncertain, given that the images presented to observers are likely perceived as pure 2D items, whereby scanning behaviour is known to differ between these environments.

Figure 2.3 **Spatial dimensions** showing width (horizontal), height (vertical), and depth (diagonal) properties. One dimension (1D) showing width (*a*), 2D showing width and height (*b*), and 3D showing width, height, and depth (*c*). Note that 1D can either show width or height.



Li et al. (2016) also suggested that visual search patterns are more predicated on memory in 3D, compared to 2D, items. Their finding indicates that how these items are perceived may influence cognitive load of the task itself, with the 3D perception of driving scenes within hazard perception tests potentially leading to greater cognitive load in visual detection tasks compared to those found within the 2D abstract context. In turn, this may influence the additional cognitive load presented by distraction task on visual detection when presented between these contexts, suggesting that caution should be applied when considering findings from abstract experiments about driver safety.

For instance, Savage et al. (2013) found that observers who are preoccupied with a recent mobile telephone conversation whilst conducting a hazard perception test are slower to react than when they are fully focused, which occurs in 3D space. They also found that there were increases in blink frequencies, higher saccade peak velocities and a significant reduction in the spread of fixations along the horizontal axis. Such findings may not have been found in the 2D abstract visual detection experiments because a mental transformation based on objects is assumed (extrinsic to the person) in 2D, whereas depictions of human bodies or body parts within the 3D hazard perception test environment may be processed through a mental transformation based on the egocentric (intrinsic to the person) perspective [Zacks & Tversky, 2005].

Differences in cognitive mechanisms of mental rotation could explain why Bauer et al. (2022) found that for intrinsic rotations, participants had shorter reaction times and higher accuracy rates as a function of angular disparity. Similarly, pupil dilation changed in a similar manner, which indicated less cognitive load was required to complete the task for intrinsic, compared to extrinsic, mental rotations. Measuring the influence of the same distraction on visual detection between an abstract and driving specific context would provide further insights into this issue.

2.5 General Distraction Theories and Models

Further support for the implication of cognitive factors related to the influence of distractions on driving performance is provided by the way distraction itself is processed. One related theory is the Token Set Size Effect (TSSE). The TSSE presents a sequence of auditory objects that are irrelevant to the task a person is performing, in which performance to that task is disrupted if the set is increased from one (“AAAAA”) to two (“ABABABABAB”) [Tremblay & Jones, 1998]. The original iteration of TSSE implied that the effect was only present from one set to two sets of tokens, but not beyond two sets of tokens, suggesting that the effect arose from involuntary processing of the sound [Hughes, 2014]. However, recent research shows that the TSSE extends up to eight tokens and brief instrumental sounds, suggesting that the sound causes a disengagement of attention away from the prevailing task, regardless of the task processes involved [Bell et al., 2019]. The explanation of attention as being related to the TSSE further supports the idea of cognitive load being relevant to distraction, although the TSSE has not been directly researched in driving research. How the TSSE and its associated influence on cognitive load impacts visual detection for drivers is not currently known.

Another theory focused beyond the vehicle is the Theory of the Naked Street (TNS), in which road markings and other traffic signals are reduced to a bare minimum in shared spaces between pedestrians and drivers to cause ambiguity, in turn increasing drivers' responsiveness [Andrade, 2021]. Uncertainty that is inherent in ambiguity leads to higher cognitive load than if the ambiguity is not present and leads to more adherence to normative behaviours [Drolet & Frances Luce, 2004; Van Der Land et al., 2013]. The principle of the TNS is not specifically noted as being about distraction, but rather implies that street furniture relates to how attentive drivers are to the driving environment, in which the attention diminishes in relation in proportion to the greater number of street furniture pieces there are. This view is reflected in a remark from Andrade that "the greater the number of prescriptions, the more people's sense of personal responsibility dwindles" [Andrade, 2021].

The implementation of TNS has improved global road safety considerably since its inception, including a reduction of RTCs in Drachten (the city where it was first implemented) from 8.4 per year between 1994 to 2002, from which TNS was implemented and resulted in RTC numbers of 1 per year in 2005 [Senthilingam, 2014]. Likewise, this trend has been observed in Kensington High Street in London, where between 2000 and 2004, when the scheme had been started but not fully completed, pedestrian injuries from RTCs reduced by 43.7% [Marceau et al., 2007]. A caveat to note is that various improvements have been made in road safety across the years, so whether TNS fully accounts for the improvements reported here is not possible to state, but the short timeframe that the reductions have occurred in the areas where the schemes are implemented, compared to more modest national trends from the same years, are indicative of its influence. The impact of TNS shows that cognitive load can be increased whilst simultaneously decreasing distraction, in this case meaning the street furniture. Distractions inside the vehicle and intrinsic to the driver, such as emotions, feelings, desires, are not as easily adapted as urban design planning, but provides an indication that measuring and adapting the drivers' cognitive load could improve road safety.

Cognitive load is implied to be associated with distraction, in which the typical approach is to conduct research that aims to understand and potentially reduce distraction. However, a better approach would be to specify what drivers should pay attention to instead of defining distractions, as suggested by Hancock et al. (2009). Defining what drivers need to be "attracted" to will allow the focus to be directed toward when and where driver distraction occurs, compared to retrospectively deciding on what is considered distraction after the driving event has finished. Kircher & Ahlstrom (2017) further elaborate that approaching research with the focus being related to distraction rather than on specifying where attention should be leads to two separate statements:

1) A distracted driver is considered to pose a safety risk when his or her attention is shifted away from targets relevant to driving (specifically about safety risk).
2) Regardless of the outcome of the situation, distraction occurs when our attention is diverted to anything not relevant to driving (about diversion of attention, irrespective of consequence).

There are limitations with both statements. For instance, if drivers do not pose any risk by doing so, Statement 1 implicitly permits them to divert their attention from driving. However, the outcome of a situation can only be determined in hindsight when the outcome is known. In comparison, Statement 2 avoids hindsight bias, but sets an unduly strict and inflexible threshold by not allowing attention to be directed away from driving in any circumstance. The Minimum Required Attention (MiRA) theory is proposed to rectify the limitations of both statements [Kircher & Ahlstrom, 2017].

MiRA implies that the detrimental influence of secondary tasks on driving performance is not related specifically to distraction, but rather on whether there is sufficient attention to accrue sufficient information of the driving scene related to executing the driving task effectively. As such, whether a driver performs an additional task concurrently or not is irrelevant, given that inattentive driving will be defined as not receiving enough information to form a sufficient internal representation of the situation at hand when his or her information intake does not meet the minimum requirements.

The findings from Jarosch et al. (2017) contradict MiRA. When participants were presented with a monotonous task compared to an engaging task, whereby cognitive attention was anticipated as being diminished in the monotonous task that they defined as fatigue, no detrimental effects on driving performance were observed. They state a limitation was on the brief nature of the drive that was simulated (25 minutes), suggesting that a longer drive would have shown effects as previous research has demonstrated [Schmidt et al., 2009]. Further limitations that they did not acknowledge were that both types of tasks required manually interacting with a device that averted their visual attention from the driving scene, with the monotonous task (letter detection [shape identification and response]) requiring a shorter duration of gaze aversion compared to the engaging task (general knowledge [reading, comprehending, retrieval of the perceived accurate answer, and response]). Fatigue may have reduced the cognitive focus of the driver, but this potentially would have been moderated by the reduced gaze aversion compared to the engaging task. Their research did not effectively take this potential interaction into consideration.

The fundamental principle of MiRA is that retaining the capacity for drivers to be able to focus on the task of driving should improve driver safety. Fatigue is a relevant concern here, which is posited as either active or passive, respectively meaning that cognitive abilities are overloaded (resulting in a stress-like state), or that underload and monotony are produced (resulting in a loss of alertness and engagement with tasks) [Desmond & Hancock, 2000]. A relevant comment to the findings by Jarosch et al. (2017) is that asserting manual control after automated driving elicits a persistent loss of alertness as well as subjective symptoms of passive fatigue, which is counteracted by in-vehicle media [Matthews et al., 2019]. Given that fatigue impairs driving performance and increases the risk of an RTC [Schmidt et al., 2009; Simon et al., 2011], evidence supports the use of caffeine (a substance that counteracts fatigue) to improve attention, leading to faster reaction times and better accuracy to information processing tasks, and enhanced lateral and longitudinal control of the vehicle [Irwin et al., 2020]. These points suggest that distraction occurs when attention is diverted away from the task of driving, regardless of the outcome, aligning with the second statement postulated by Kircher & Ahlstrom (2017).

An alternative model to explain driver safety encapsulated driver awareness and comprehension of the driving scene, relating to the theory of situational awareness, which stipulates a taxonomy based on visual processing, mental comprehension, and projection of the information for future events [Endsley, 1999]. Situational awareness is also important within the Cognitive Simulation Model of the Driver (COSMODRIVE) [Bellet, 2007], although COSMODRIVE also follows from Allen et al. (1971), who suggest that automated skills (microperformance) and conscious planning of routes and adaptive navigation (macroperformance) are of equal performance. All these processes rely on processing information and responding appropriately, based on information received at the time and information built from mental models within the driver. In other words, perception is divided into two processes that process perceptual information simultaneously.

Bornard et al (2011) elaborate on the two simultaneous processes. The first of these is cognitive integration (i.e., bottom-up information processing), which encompasses the drivers' gaze on the road and items in front of the gaze. During the fixation time of a moving car, for example, if there is a pedestrian behind the car, the pedestrian's information will be processed. In the same way, an object passing in front of the driver's gaze will have the same effect. Second, perceptual exploration occurs. Using Neisser's perceptual cycle, which provides drivers with mental models (schemas) for how to effectively gain information whilst driving and focuses their attention on aspects of the environment to assess the schema [Neisser, 1976], and COSMODRIVE's driving schemas, this top-down approach allows drivers to focus on a particular area or item on the road.

As an example, when drivers arrive at a crossroad with traffic lights, their schemas retrieve the notion that they should watch the traffic lights based on previous experience; the information about their traffic light colour is an associated schema, but the driver behaviour is determined by the driver looking at the colour of the traffic light (bottom-up information processing). For road hazards, drivers perceive the hazard (bottom-up information processing) and use their schemas to understand that they are required to respond to the hazard to avoid an RTC. In other words, drivers use both bottom-up and top-down processing in the form of schemas for detecting hazards. Given that hazard perception training improves drivers' hazard perception performance [Arslanyilmaz, 2020], the interaction between bottom-up and top-down processing appears to be supported because their schemas are likely to be stronger whilst their driving performance is improved. Such training is understood to be effective at improving road safety. Indeed, the introduction of the hazard perception test as part of the UK driving theory test to gain licensure has been estimated to reduce the rate of public-RTCs on non-low-speed roads by 11.3% [Horswill, 2016]

Attention is required to adequately process information from the driving scene both from bottom-up and top-down processes, for which distraction impairs both. For instance, McCarley et al. (2004) demonstrate that the information encoded on the visual display can be degraded when talking on a hands-free phone, which can cause the driver to fail to detect changes more frequently. Additionally, McCarley et al. (2004) show that older adults have difficulty orienting their attention to knowledge-driven information when conversing. However, they found that there were no such effects observed for an attentive listening task. These findings suggest that actively engaging in the distraction task, rather than passively processing the information, causes detriments to driving performance.

Supporting the notion that active engagement in a distraction task conveys the detrimental influence on driving performance is McKnight & McKnight (1993), who requested responses from participants while they were conducting simulated drives on highways by use of simulated driving sequences. Within this simulation, they were required to control the vehicle they were within and tasked with reacting to various road hazards. Distractions were also presented, which varied in complexity. These included making a mobile phone call; conversing casually on the phone; conversing intensely on the phone; tuning a radio; and taking control in a no-distraction situation.

They found that drivers failed to respond to traffic situations under each of the four distraction conditions by anywhere between 34.3% to over 40%. Their finding was that the more an individual is required to engage with a distraction task, the more detrimental to driving performance the distraction task is, suggesting that top-down processes are impaired.

Complexity of distraction is one element to consider, but Multiple Resource Theory (MRT) states that the modality of both driving and distraction are also relevant. MRT suggests that there are three elements: the sensory modality through which information is input, the coding (such as spatial code for visual input, or verbal code for spoken input), and the response (such as vocal response). It is an essential tenet of MRT that the simultaneous tasks involve different modalities, codes, and responses to avoid interference [Wickens, 1980; Wickens, 2002; Horrey & Wilkens, 2004]. Indeed, when participants were asked questions whilst driving that either caused them to think of imagery or did not cause this, greater detriments to hazard perception performance was observed in the former compared to the latter [Briggs et al., 2016]. As driving is composed by a highly visual set of tasks [Johnson & Wilkinson, 2010; Navarro et al., 2021], these findings support MRT by suggesting that distractions that are highly visual in nature convey greater impairments to driving performance than those from other modalities.

Exploring how distractions influence detection rates to genuine hazards is understandably important to explore driver safety. Specifically, exploring how drivers determine what a hazard is must be considered to ensure that any test that measures driving performance against hazard perception is valid. To this, Swets (2012) suggests that the Signal Detection Theory (SDT) is one model that provide an explanation. Performance in SDT can be quantified by using probability-based theory, which assumes that there are two possible scenarios, whereby one is the signal (of interest) and the other is noise (absent). Additionally, SDT assumes that signal and noise distributions overlap, and that any specific hazard perception scenario can emerge from either state.

If the experimenter specifies the signals and responses of the phenomenon being explored by explicit instruction to experiments generally, the traditional conceptualisation of SDT works well. In contrast for hazard studies specifically, whilst the experimenter can specify what they mean by the term ‘hazard’, hazard perception tasks are considerably more challenging because they do not involve a binary state: whether a hazard was present or not. For instance, there are differences in hazard perception test performance related to cultural differences, but when participants are presented with a driving scenario that occludes the hazardous event, being preceded by a separate screen asking what happens next (hazard prediction test), there is no influence of culture on performance [Ventsislavova et al., 2019]. These results indicate that drivers from any culture understand what the items that the researcher considers hazards are, but drivers' perceptions of hazardousness differ based on culture to the extent that they may not see the items as hazards.

The lack of objective differentiation in the perceptions of hazards relates to the concept of fuzziness, which is a concept used in mathematics where boundaries are not precise [Klir & Yuan, 1995]. Using fuzzy logic is a good way to define scenarios that have fuzzy boundaries. The concept of fuzzy logic has been developed to deal with situations in which states do not fit into a strictly "yes" or "no" category [Zadeh, 1978]. Hence, fuzzy logic can be combined with SDT, namely Fuzzy Signal Detection Theory (FSDT), to analyse system detection performance when the definition of a signal or its response is not precise. In turn, this leads to the stimulus and response being on a continuum rather than categorical.

An example of the consequence FSDT has on hazard perception analysis, compared to SDT, is that the appearance of a pedestrian on the side of the road can vary in the potential of how hazardous they are to the driver, based on contextual cues (direction of travel, proximity to the road, etc). It is possible that SDT would constrain the range of possible responses by categorizing the pedestrian into either signal (present) or non-signal (not present), whereas FSDT utilises uncertainty as a powerful source of information by taking advantage of the "fuzziness" inherent in the stimulus itself [Stafford et al., 2003]. Another example is that when differing levels of distraction are measured in relation to differing levels of driving difficulty, more false positives (responding when participants should not) are recorded for higher, compared to lower, levels of distraction [Jamson & Merat, 2005].

For hazard perception, a deeper understanding can be gained about distraction related to the general context of the hazard, rather than the actual hazard itself, by using FSDT. With distractions of higher complexity, there are more errors of commission (participants incorrectly responding to a non-hazard) than in distractions of lower complexity [Savage et al., 2013]. Whether errors of commission arise because of drivers deliberately compensating for the detrimental influence of the distraction by being intentionally cautious, or their cognitive processes are depreciated meaning that drivers genuinely process the driving scene more inefficiently, is not known. However, the effect of distraction on SIs, mentioned in **Section 2.2** [Abadi & Gowen, 2004; Biswas & Prabhakar, 2018], suggests that the issue is likely related to the latter.

The theories and models outlined in this section provide an overview of the logic that is applied to not only research in this field, but also interpretation of results. Experiments within this thesis follow from the logic explained within this section, such that:

- TSSE suggests that all non-driving related tasks conducted simultaneously to driving will reduce attention to the task(s) of driving, regardless of complexity, with further research indicating that the cognitive load increases related to distraction is proportionate to the driving performance detriments.
- TNS suggests that higher cognitive load can, in some instances, lead to improved driving performance, indicating that the nature of tasks that cause cognitive load is important to consider.
- MiRA suggests that a minimum level of attention is required to facilitate effective driving performance.
- Situational Awareness and COSMODRIVE suggest that both distraction and driving performance relate to top-down (schemas) and bottom-up cognitive processes, that is influenced by the complexity of distraction.
- MRT suggests that different modalities of distraction task can lead to differing influences on driving performance.
- SDT and FSDT suggests that hazard perception is not binary, but rather a continuum based on the observer's understanding about what a hazard is.

These lead to the logic that distractions have been extensively explored in relation to driver safety, but these are specifically within the driving context. As such, they potentially influence the processing of both bottom-up and schemas from the drivers. Exploring how distractions influence visual detection in an abstract environment, negating the effect of schemas, may provide deeper insights into this matter. From such findings, the most detrimental distraction task could be applied to hazard detection within a driving context.

2.6 Distraction Literature

General distraction theories and models provide an understanding of how road safety is approached, but exploring literature that informed those theories and models within this field provides guidance about how to conduct further experiments. Distraction is consistently shown as being detrimental to driving performance [Di Stasi et al., 2010; Garrison & Williams, 2013; Lovell et al., 2022] **(Table 2.2)**. Empirical experiments [Liang & Yang, 2021; Miao et al., 2021], analysis of RTC data [Maasalo et al., 2019], and systematic reviews [Cao et al., 2022] informs these findings. Each of these study designs have provided useful insights into the field of driver safety, but there are associated limitations as well. These will be explored in this section.

Table 2.2 A selection of **driver distraction literature**.

Study	**Sample**	**Method**	**Findings**
Di Stasi et al. (2010)	49 (43 females)	Emotional content of distraction was manipulated as participants conducted a simulated drive.	The nature of the distraction has an influence on drivers' hazard perception performance.
Liang & Lee (2010)	16 (8 males)	Distractions were presented in either visual, cognitive, or a combination of visual and cognitive modalities to participants that conducted a simulated drive.	The modality of distraction influences the impact on driving performance.
Metz et al. (2011)	40 (22 males)	Participants conducted a simulated drive. Whilst doing so, participants either had no distraction (baseline), to read aloud numbers (visual) or a hierarchical menu navigation task (visual/manual).	Engagement with distraction is reduced when the situation is perceived as requiring extra focus on the primary task. When distraction occurs, visual behaviour is influenced, which is detrimental to driver safety.
Burge & Chaparro (2012)	20 (10 males)	60 driving scenarios were presented to participants, lasting 20-45 seconds. Participants were required to respond to discrete driving hazards whilst fully focused of distracted.	Texting has a detrimental influence on drivers' hazard perception performance.
Garrison & Williams (2013)	20 (12 males)	Participants were required to perform a simulated drive whilst either distracted or not distracted, responding to external items that were either distracting, relevant to the task of driving, and hazards.	Distraction is detrimental to cognitive processing of visual information in the driving scene and driving performance.
Holland & Rathod (2013)	27 (15 females)	Participants provided the researchers with their phone number to use in the experiment. They drove a simulated road and had three phone calls from the researchers throughout that participants were not permitted to answer.	The relevance of distraction to usual intention of the driver is an important factor for driver safety.
Hughes et al. (2013)	21 (20 females)	Participants completed three drives while responding to the peripheral detection task. The first drive was without any singing, whereas the other two were either listening or singing conditions. Participants then received a survey, exploring their opinions on their safety, anxiety, and level of distraction.	The level of engagement with a distraction task influences the impact on driving performance.
Carter et al. (2014)	403 parent-adolescent dyads	Various measures of driving attitudes, personality, and perceptions of distractions were measured using a telephone survey.	Adolescents are more likely to engage in distraction than their parents whilst driving, yet not have adequate self-awareness of this behaviour.
Jeon et al. (2015)	60 (34 males)	Participants had their emotional state manipulated before conducting a simulated drive.	Emotional states influence CL states, although drivers are not necessarily aware of the increase in CL.

Krishnan et al. (2015)	20 (14 males)	Participants were either placed on a training or a placebo programme. They then conducted a simulated drive, with their eyes being tracked.	Training reduces the impact of distraction on driver safety.
Briggs et al. (2016)	2 experiments: Exp 1: 60 (40 females) Exp 2: 46 (35 females)	Exp 1: Hazard reaction times were recorded from real driving videos, either whilst not being distracted, or distracted by questions they were required to respond to (split between statement verification tasks that induced imagery or did not). Exp 2: A hazard perception task, in which half of the participants were distracted by questions they were required to respond to. Eye movements were tracked.	Distraction impairs drivers' hazard perception performance. The nature of the distraction is important when considering the impact on RTCs.
Kaber et al. (2016)	16 (8 males)	Participants performed a simulated drive, with the goal being to reach the intended destination within 12 minutes. The driving task simulation was frozen at two points throughout the duration of the experiment, before and after hazard exposure and posing a set of situation awareness queries to drivers.	Distraction reduces situation awareness for drivers.
Kountouriotis et al. (2016)	2 experiments: Exp 1: 15 (8 males) Exp 2: 15 (8 females)	Exp 1: Gaze concentration was explored when a lead vehicle either was or was not present whilst the participant conducted a simulated drive. Participants conducted this with or without distraction (visual or non-visual). Exp 2: The same method was replicated for the second experiment, except the behaviour of the lead vehicle was altered (normal vs sinusoidal lead).	Distraction interacts with the visual information of the driving scene to influence participants' visual behaviour.
Biswas & Prabhakar (2018)	10 (7 males)	There were 4 experiments, using the same sample: -An exploration of whether cognitive load can be assessed by saccadic intrusion.	Saccadic intrusions can be used to detect drivers' distraction levels. They also are associated with drivers' hazard perception.

		-An exploration of dual task related to saccadic intrusion. -An exploration of dual task related to saccadic intrusion whilst driving on varying road geometries. -An exploration of saccadic intrusion for detecting drivers' mental state based on hazard perception.	
Brodsky (2018)	19 (13 males)	2 experiments exploring how singing and drumming to the beat distracts drivers whilst driving. Music: -11 songs were presented to participants that were rated for how well they were known. -Two days prior to the experiment session, participants received an email with the songs and lyrics, and were instructed to practice singing them. -Participants were required to sing two of those songs with no other task, and then the same design whilst being presented with a driving scene (low demand and high demand). Percussion: -Same as music design but measured tapping reactions to music rather than to notes.	Drivers moderate their conscious behaviours to distractions when driving to accommodate the detrimental influences to driving performance.
Harbeck & Glendon (2018)	554 (420 females)	An online survey was distributed, including many aspects of driver behaviour compared responses, between the sample related to length of licensure, driving experience, and driver sex.	The propensity for drivers to engage in distraction is influenced by perceived individual differences.
He & Donmez (2018)	32 (16 males)	Participants were either distracted or fully focused whilst being instructed to maintain a comfortable distance from lead vehicles and drive around the speed limit.	Distraction leads to impaired visual processing.

Hills et al. (2018)	82 (54 females)	Participants' eye movements were recorded. They were presented with a letter search task followed by the hazard identification task. Each letter search began with a fixation cross, before being shown strings of letters and were asked to count the number of vowels present and respond using the keyboard. Half the trials consisted of a road image being presented. Participants verbally identified the hazard. Half the trials consisted of a further two letter searches (in the same orientation as the first letter string) that were presented before the road picture was shown.	Eye behaviour is moderated by the CL level in the distraction task.
Keffane (2018)	300 (200 males)	Participants completed measures that assessed the Mini Mental State Examination, spatial ability, visual acuity, colour choice reaction time, working memory, and the Useful Field of View and Hazard Perception/Change Detection tests.	Distraction is important for driver risk of being involved in an RTC.
Castro Ramírez et al. (2019)	95 (60 males)	Participants first answered the 19-likert-scale response questions in the Attention-Related Driving Errors Scale, which is intended to measure the different consequences of distraction. They then viewed twenty-four video clips containing hazards. Just before the hazards occurred, the clip was suddenly stopped, a black screen appeared, and the participants were required to predict what would happen next in the driving scene (including the occurrence of a hazard).	Distractibility influences drivers' situational awareness for novice drivers, but greater experience leads to moderating influences.
D'Addario & Donmez (2019)	24 (13 females)	Participants were required to conduct a simulated drive with three emergency hazard events: left-turn across the path, pedestrian, right-incursion. Half conducted the drive fully focused whilst the other half were required to listen to several pre-recorded series of single-digit numbers and respond verbally with the digit that was presented one position previously from the current number.	Distraction influences the manner that hazards are processed, but not necessarily on behavioural adaptation.
Ebadi et al. (2019)	24	Participants were required to drive the same track twice whilst either distracted or fully focused, in a counterbalanced order.	Distraction reduces situational awareness.

Lacherez et al. (2019)	20 (11 males)	A hazard perception test was administered to participants whilst they were either distracted or not, and the level of visual blur varied.	Distraction is detrimental to hazard perception, which is not moderated by visual acuity of the driver.
Maasalo et al. (2019)	Fatality Analysis Reporting System data between 1996-2015.	An analysis was conducted for RTCs when drivers were categorised as either at-fault or not-at-fault.	Passenger characteristics can interact with driver behaviour to influence risk of RTC.
Arslanyilmaz (2020)	22	A computer simulated driving environment was presented. At various times on the journey, a distracting message would appear. The difference was assessed between participants that engaged with the warning online training application and those that did not.	Training reduces the influence of distraction on hazard reaction time and horizontal scanning of drivers.
Baldo et al. (2020)	78. Experimental condition: 30 males; 22 females. Control condition: 15 males; 11 females.	Participants were required to conduct the driving simulation. Some were required to recite a story via a mobile phone interaction, whilst others were fully focused.	Distraction influences drivers to moderate their driving behaviour but delay the onset of braking when required.
Moran et al. (2020)	79 (56 females)	Participants completed the 18-component line drawing task of the Rey-Osterreith Complex Figure Test, assessed their psychomotor skills using the Grooved Peg Board, assessed visual ability using the Trail Making Test, spatiotemporal perception using the visual object and space perception battery, Mini-Mental State Examination, and the stop-signal task. They then conducted a hazard perception test.	Various cognitive factors relate to hazard perception performance.

Ahlström et al. (2021)	16 (13 males)	Participants conducted a simulated drive, where they drove a bus with 10 stops. Between 2 pairs of stops, a distraction task was given.	Distractions lead to greater inattention to the task of driving.
Choi et al. (2021)	15 (all males)	Participants were required to drive on simulated roads in the simulator whilst simultaneously conducting a secondary task: simple addition. Brain activity was recorded for each participant when they were engaged in the experiment.	Neurological activity for exploring how driving is processed is the same related to addition as when people move their bodies.
Liang & Yang (2021)	7,962 safety critical events from the Strategic Highway Research Program (4,908 at fault)	Data from the 2nd Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS) were analysed. Event severity and fault were measured against secondary tasks, and seven control variables including weather, lighting, roadway surface, profile and curvature, presence of roadway junctions, and traffic density.	Distraction in the vehicle is more influential on RTC risk than out of vehicle but bears no influence on whether the driver is at fault or not.
Miao et al. (2021)	37 (23 males)	Baseline physiological data were recorded for each participant at the start of the experiment session. A hazard perception test was then randomly administered across two of four conditions: no music, slow, medium, or fast tempo).	Tempo of music influences the perceived CL and drivers' hazard perception performance.
Cao et al. (2022)	69 peer-reviewed articles	A systematic review was conducted.	Poorer hazard perception skills are associated with higher rates of RTCs.
Choudhary et al. (2022)	90 (83 males)	All participants participated in at least one distraction task and the baseline condition. Beyond this, participants decided how many distraction tasks they engaged in (up to five distraction conditions). Participants were required to complete a survey about their habits for distracted driving. They then had to conduct a simulated drive in which either a pedestrian crossed or there was sudden braking by the leading vehicle.	Drivers have different perceptions of risk related to different distraction activities, with a suggestion that they are not always able to accurately assess their actual risk whilst distracted.
Lovell et al. (2022)	24 (14 females)	Participants engaged in a visual task whilst engaged with distraction. Their visual behaviour was measured.	Distraction influences the physiology of the eye, which influences visual detection.

Conducting controlled laboratory experiments where primary data can be collected means that variables of interest can be manipulated, whilst intentionally omitting alternative factors that could confound the results. However, results could remain influenced by factors that researchers have not acknowledged as requiring omitting. An example is Di Stasi et al. (2010), who explored the consequences of unexpected emotional sounds on driving behaviour in risky situations. Their findings were that emotional sounds influence not only visual gaze, but also speed reductions, which reflects the findings by Jeon et al. (2015), who elicited emotional states by getting participants to write about an experience that was either emotive or neutral. Both studies indicate that emotions generally influence driving behaviour, given that Di Stasi et al. (2010) assessed the influence of happiness (baby laughing) and distress (woman screaming), and Jeon et al. (2015) assessed anger. However, the two studies differ in terms of happiness and distress being presented at the time of the simulated drive, whereas anger before the drive occurred. As the account within the study by Jeon et al. (2015) that induced anger was not verified, nor the magnitude of how distracted the participants were whilst driving, the lack of verification in either case could mean that there were differences between the studies in how distracting the conditions were. Conducting an experiment to explore different distraction tasks to discover which is most detrimental to visual detection, whilst measuring performance to the distraction task as well as driving performance, could rectify the concern raised here.

Whilst the degree of distraction may have been higher within the study designs of Di Stasi et al. (2010) compared to Jeon et al. (2015), participants in the former had held their licences for an average of 10 months compared to over two years in the latter. These respectively relate to novice and experienced drivers [UK Government, 2020]. Driving experience is important because it interacts with the influence of distraction for driving performance.

He & Donmez (2018) provide supporting evidence regarding driving experience being important on the influence of distraction and driving performance, given that their study explored the effects of distraction on anticipatory driving between novice and experienced drivers. They found that experienced drivers are 5 times more likely to engage in pre-event actions, compared to novices; distraction reduces the likelihood of exhibiting pre-actions; experienced drivers glanced more to the secondary task, but spent less duration within those glances, than novice drivers. A caveat to these findings is that participants were financially incentivised to prioritise the distraction task, which could be unrepresentative to genuine driving where drivers adapt their driving behaviour if they understand they are distracted [Castro Ramírez et al., 2019]. As such, the participants may have solely focused on the distraction task, thereby neglecting the driving task, and the results may relate to the higher degree of automatic skills (no conscious processing needed to execute skills) that experienced drivers have compared to novice drivers [Castro Ramírez et al., 2019]. Results from He & Donmez (2018) could therefore be confounded by the financial incentives presented by the researchers to participants.

A better approach may have been to require the drivers to pass a threshold in their distraction performance to be included in the subsequent analyses, with the drivers being instructed that the distraction task is the primary task they should focus their attention on. At the same time, drivers could then be incentivised to perform the driving task as a secondary measure by financial reward if they either reach a minimum threshold or surpass other participants in aspects of their performance. Applying the focus to the distraction task rather than the driving task will ensure that the driver is effectively distracted, whilst the incentive associated with the driving task would ensure their engagement with that task.

However, despite the limitations mentioned in relation to the study by He & Donmez (2018), neurological activity associated with both novice and experienced drivers supports their findings. For instance, Gharib et al. (2020) show that experienced drivers have faster reaction times and detect more hazards in tests, whilst concurrently having increased neurological activity in the areas related to visual attention and decision making. They suggest that these areas are implicated as being activated in the same way for both novices and experienced drivers, but that experienced drivers have stronger connections between the different neural areas. In particular, the researchers mention that the supramarginal gyrus, responsible for emotional processing and proprioception, which is the sense in which we detect the movement or motion of the body, is more connected to the other regions of the brain for experienced, compared to novice, drivers.

Beyond the automated processes that are beyond the drivers’ awareness, the experience, and subsequent consequences, of emotion on driving is predicated by the default mode network (DMN) in the brain [Xu et al., 2014]. The DMN is comprised of the medial brain structures: the ventral medial prefrontal cortex, the posterior cingulate/retrosplenial cortex, the inferior parietal lobe, the lateral temporal cortex, the dorsal medial prefrontal cortex, and the hippocampal formation [Buckner et al., 2008]. The neural activity of novice, compared to experienced, drivers is nuanced for the DMN: experienced drivers exhibited stronger correlations between the higher-order cognitive networks and lower-level sensory networks, whereas weaker correlations between the lower-level sensory networks, with these trends scaling with the driver experience level [Wang et al., 2015]. Thus, not only how much cognitive load is associated with a task, but the nature of the task itself, appears to thereby be an important consideration for how it influences performance.

Further neuroscientific evidence for the influence of distraction and hazard perception relates to the function of working memory, in which working memory capacity is essentially seen to be underpinned by an ability to focus on critical information whilst simultaneously resisting having one's attention captured by distraction [Shipstead et al., 2014]. For example, emotional distractions impact working memory because they impair the dorsal executive system, which is critical to active maintenance of goal-relevant information [Dolcos & McCarthy, 2006]. Regardless of the emotional content however, Louie & Mouloua (2019) demonstrate that the increased cognitive load inherent to distractions impacts working memory capacity in drivers, resulting in slower braking responses. For instance, Keffane (2018) suggests that a wide range of cognitive abilities are involved in safe driving, especially the UFV. Additionally, there are individual differences within working memory capacity of drivers, with those that have lower, compared to higher, working memory capacity performing worse in dual task conditions and reporting more instances of inattention when driving, with pupillary dilation appearing to discriminate between low- and high-capacity individuals [Wood et al., 2016].

Exploring the influence of visual acuity and distraction further is Lacherez et al. (2019), who explored the distracting influence of satellite navigation on hazard perception whilst participants conducted the experiment with varying levels of spatial frequency (level of blur) in a visual scene. They found that the influence of spatial frequency in a visual scene did not interact with distraction for hazard response time, indicating that distraction is detrimental to hazard perception, but is not moderated by visual acuity of the driver. In contrast, Lovell et al. (2022) conducted an experiment to explore visual behaviour to distraction caused by automobile displays, finding that distraction influenced the physiology of the eye, which consequently influences visual detection. Given that the study by Lacherez et al. (2019) is related to the driving context, whereas the study by Lovell et al. (2022) is about visual detection whilst not conducting a driving task, the difference in findings could relate to how visual behaviour influences the effect of distraction whilst driving.

The difference could also relate to specific limitations within each of the pieces of research. For instance, in the study by Lacherez et al. (2019), the distraction condition necessitated participants to listen and respond to the instructions, but this distraction condition was not representative of actual satellite navigation, which would be contextualised by relevance to the driver of the destination they wished to travel to (i.e., the driver's schema); the distraction was about listening to instructions without knowing where the destination was. This limitation did not apply to the study by Lovell et al. (2022), but a limitation with their study is that driving experience was not screened, so participants' behaviour within their study may not be representative to how actual drivers would respond. Indeed, Hills et al. (2018) indicate that whilst visual search is equivalent for novices and experienced drivers, detriments of visual carryover (eye movements that were relevant from a previous task but are not to the current task) related to hazard perception performance is less pronounced for experienced, compared to novice, drivers. Once again, the importance of driving experience is emphasised. Driving experience is thus an important consideration to explore within driving safety research.

Furthermore, Castro Ramírez et al. (2019) explored the influence of driving experience on distractibility and hazard prediction. They found that distractibility influences drivers' situational awareness for novice drivers, but greater experience leads to a moderating influence with regards to better discrimination and prediction of hazards, greater caution when driving, better situational awareness, and fewer errors in automatic actions (such as braking). The study is however limited because, whilst distractibility was assessed, the experiment did not assess performance whilst participants were distracted.

To rectify limitations with the study by Castro Ramírez et al. (2019), Ebadi et al (2019) explored the influence of distractions on drivers' anticipatory behaviour for hazards, finding that participants anticipated 44% of the hazards while performing the distraction task, compared with 72% within the control condition. The distractor task performance was not analysed though, so how focused participants were on that task was not effectively determined. As such, the comparison between distractor and control is limited by not accounting for whether all participants were distracted to the same magnitude within the relevant study condition. Likewise, responses were recorded for hazard anticipation, but no hazards appeared. As such, the study relates more to situational awareness rather than how distraction influences hazard processing and response specifically. Further research is required to assess the magnitude of distraction between participants within their performance for the distraction task and exploring this distraction task performance in relation to reaction times and accuracy of hazards that appear.

Whilst the study by Ebadi et al (2019) related more to hazard situational awareness rather than driver behaviour, situational awareness appears to be predicated by attentional capacity [Holland & Rathod, 2013; Jeon et al., 2015; Castro Ramírez et al., 2019], which is directly related to the how detrimental distraction is to driving performance [Taylor et al., 2013]. Indeed, Kahneman (1973) introduced the capacity model of attention, which assumes that there is a general limit on an individual's capacity to perform mental work, whilst also assuming that this limited capacity can be allocated with considerable freedom among concurrent activities. Applying the capacity model to the driving context, Kaber et al. (2016) explored the influence of cognitive abilities and distractions on hazard perception, providing further support of attentional capacity being relevant to driving performance. They found that driver awareness of the simulated roadway situation was 10–20% worse when exposed to the distraction, and that there was worse lane deviation with the distraction after hazard exposure. However, their study assessed cognitive abilities of the driver for general driving but did not assess performance directly for hazard detection and processing. As such, the results relate to understanding of distraction for general driving behaviours, but not necessarily hazard perception specifically.

Rectifying the limitation within the study by Kaber et al. (2016) is the findings from Kountouriotis et al. (2016), who explored situational awareness in relation to responding to lead vehicle actions. They found that participants looked lower down during the visual distraction, and their vertical gaze angle was higher for the non-visual distraction, when compared to control. Situational awareness thus appears to be important to hazard perception, although a limitation with both Kaber et al. (2016) and Kountouriotis et al. (2016) is that the sample size is low. A low sample size means that there is a greater likelihood that an effect was detected when there was no genuine effect, compared to if a larger sample were recruited [Lin, 2018], with error bars being wider for smaller, compared to larger, samples [Varoquaux, 2018]. Error bars are important to consider because they determine how much the data would vary if the same experiment was repeated, with a smaller error bar indicating more confidence that the current result is due to the phenomenon being investigated rather than chance [Krzywinski & Altman, 2013]. Consequently, the results from previous literature are indicative, but larger sample sizes are required to explore how distractions influence situational awareness, particularly in relation to drivers' hazard perception.

Contradicting the assumption within Kahneman's (1973) model that a threshold is required to be exceeded before degradation occurs is that degradation of attention and performance is observed in low-demand tasks. This is demonstrated by short duration tasks being completed slower by drivers that were stationary compared to actively driving [Tsimhoni & Green, 2001]. Likewise, Biswas & Prabhakar (2018) show that SIs are present even in low-demand tasks, in which increases in demand of cognitive load leads to the average velocity of saccadic intrusion increasing.

Young & Stanton (2002) introduced the Malleable Attentional Resource Theory (MART) to further explain how over- and under-loading attentional capacity is detrimental to driving performance. MART posits that the limit on attentional capacity may change in the relative short term, depending on task circumstances. Given that it is predicted that there will be over 400 million cars with increasing numbers of electrical devices inbuilt by 2025, up from 237 million in 2021 [Placek, 2018], principles from MART suggest that there will potentially be an increase in risk for drivers related to RTCs because there will be less capacity for drivers to observe relevant cues in the environment, which might be detrimental to driving [Schleicher & Gelau, 2011].

An experiment was conducted to explore how in-car devices influence driver' hazard perception by Metz et al. (2011), who compared two visual distraction tasks related to visual attention adaptation. They found that drivers rejected more secondary tasks in critical compared to uncritical situations; a longer duration of fixations was observed in distraction compared to baseline condition; there were more collisions reported in the distractions, compared to baseline condition. Their results suggest that even if drivers adapt how willing they are to attend to distraction tasks whilst driving based on the perception of driving difficulty, they remain less safe than if distractions were not presented, which is reflected in other research findings [Sarkin et al., 2013; Oviedo-Trespalacios, 2018; de Zwart et al., 2023].

There are also implications that the influence of cognitive load in drivers could be influenced by their baseline anxiety level to the task of driving. When applied to the context of test anxiety, individuals that experience greater anxiety have fewer fixations than low test-anxious individuals, with the interpretation that distraction in test anxiety is associated with unspecific hypervigilance and specific inhibition deficits, moderated by anxiety level [Hu et al., 2022]. Anxiety was explored by Hughes et al. (2013) within the field of driving safety by requiring participants to sing whilst driving and measuring their anxiety levels. They were specifically exploring the influence of singing on driving performance, with anxiety being recorded as supplementary information that was measured but not manipulated by the researchers. However, they found that singing was associated with higher anxiety than other conditions, which in turn led to it being perceived as more mentally exhaustive than the control condition.

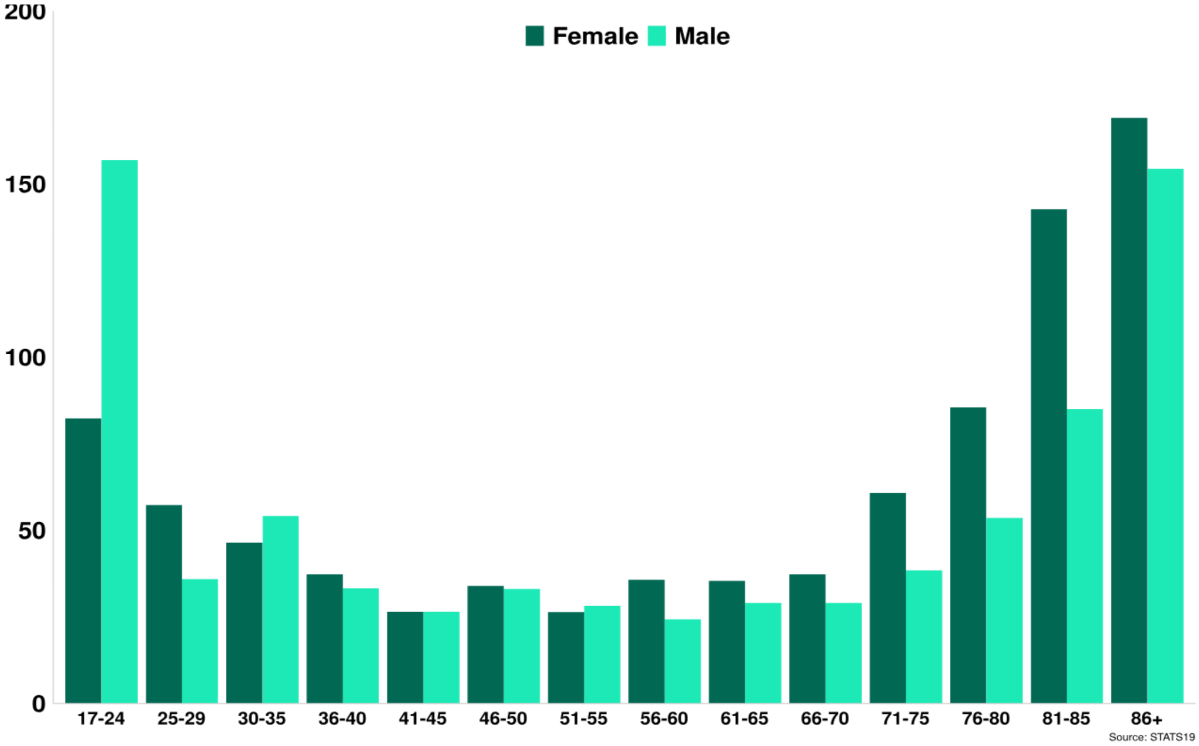
Limiting the findings by Hughes et al. (2013) is that singing whilst in an actual driving context is potentially different from singing whilst performing a simulated drive in a laboratory condition. This is due to the knowledge that participants have about their driving performance being measured. Consequently, this could have introduced additional anxiety that may affect some participants more than others, which is not typically present in a real driving scenario. A survey was used to capture views on how anxious they were, but as it is self-report data, this may not be accurate. Such limitations effectively represent the difficulty of introducing distraction to participants.

Anxiety is considered to relate to the perception of how risky a situation is, known as risk appraisal [Stöber, 1997; Milne et al., 2019; Scherer et al., 2022]. Mechanisms for underpinning risk appraisal is suggested in the Somatic Marker Hypothesis, which states that emotions relate to decision-making [Dunn et al., 2006]. The relevance of this hypothesis to driving is that experiencing traumatic/hazardous situations while driving, even when not resulting in injury, has been shown to be associated with negative emotional affect (i.e., lower moods) and increased concern for personal safety [Lucas, 2003]. This explains why RTCs are influenced by both conscious and unconscious processes, given that emotional processing appears to be important. Indeed, drivers' risk appraisal of a scene is an example, with novices and learners having similar, whilst experienced drivers having higher, skin conductance responses to emerging hazards [Kinnear et al., 2013].

Skin conductance is of particular concern to hazard perception, with Miao et al. (2021) showing that the speed of music relates to skin conductance that is higher for fast tempo music, which is associated with poorer hazard perception performance. Furthermore, Chirles et al. (2021) suggest that skin conductance can be used to as a marker of hazard anticipation, differing based on driver experience. They further state that interaction effects may illustrate situational awareness in licensed drivers, whilst illustrating deficiencies in sustained vigilance among learner drivers. Not only is skin conductance related to driver experience, with ~80% of novice drivers having a higher range of skin conductance than more experienced drivers [Seenivasan, 2023], but neurological activity differences are also associated with driver experience, especially related to cognitive processes [Megías et al., 2018].

Experience and the nature of distraction thereby appear to be important factors to explore in driving safety research. One difficulty with exploring driving experience in relation to road safety factors however is that drivers with more experience are of a higher age than those with less driving experience, by virtue of experience requiring time to acquire. Whilst the underpinnings that relate to these potentially conflated factors are difficult to parse in relation to their theoretical influence on RTCs, the UK actual RTC figures indicate that both younger and older drivers are high risk groups, suggesting that driving experience provides a reduction in the risk of an RTC only to a certain extent **(Figure 2.4)**. Indeed, both inexperienced and older drivers have a higher risk per km driven of being involved in a car accident than experienced drivers [Barbet et al., 2006]. Exploring differences between younger and older drivers in relation to their driving performance and associated RTC risk can provide guidance about how to investigate these highest risk demographics further.

Figure 2.4 **Number of car drivers that were killed or seriously injured (KSIs)** across all driver age groups, divided by sex, **per billion miles travelled**. Taken from **DfT (2022e)**.



2.7 Distraction and Ageing

Whilst neurological activity is related to driving experience, it is also related to driver age. For instance, older people have stronger theta (3.5-7.5Hz) and weaker gamma (30-60Hz) power than younger people [Tinga et al., 2023], which are types of brainwaves associated with neurological activity [Nigbur et al., 2011; Staresina et al., 2016]. Both theta and gamma power influence driving performance, with high activation of each respectively relating to a lack of awareness that corrective behaviours are required and implicated in sleep [Cox et al., 2000; Papadelis et al., 2006].

Within the ageing process, there are cognitive impairments that arise. For instance, processing of information in cluttered scenes associated with functioning UFV is known to depreciate with age, and the diminished efficiency among elderly observers is exacerbated when conditions require the division of attention between central and peripheral tasks [Sekuler et al., 2000]. Additionally, there is evidence that older drivers are at increased risk of being involved in an RTC per mile driven [DfT, 2018a]. This does not necessarily reflect any performance deficit associated with ageing, instead relating more to older drivers travelling a relatively low annual mileage [Langford et al., 2006], which is a considerable concern given that they are such a high-risk group, yet low mileage travelled compared to other driver age groups [DfT, 2022e]. The concern about the high-risk yet low mileage covered is accentuated further because visual difficulties in general cause older people to drive less or stop driving entirely [Ang et al., 2019]. This potentially indicates that the risk arises by causes other than visual deficits.

For hazard perception, changes in the visual system and changes in driving experience suggest age will have an impact on target detection. Visual performance declines throughout adulthood [Guirao et al., 1999], tending to remain stable up to the age of around 50–60 years and then undergoing a rapid decline [Harrison et al., 1992]. Optical performance of the eye therefore deteriorates with age. Boyce (2014) elaborates on the ageing process related to vision by stating that the range of maximum to minimum pupil size diminishes with age; elderly people are much less capable than young people to compensate for low light levels by having effective processes that dilates their pupils to retrieve more light. He also states that, with increasing age, the lens absorbs an increasing amount of light in the short wavelength region, reducing colour vision capabilities, and the degree of scatter within the eye also increases with age, progressively degrading the retinal image. Older drivers may engage in mitigation techniques to reduce their risk, such as choosing to drive less of stop driving entirely [Persson, 1993], but the unconscious processes that underlie their vision is therefore indicated to be inefficient compared to younger drivers.

Haegerstrom-Portnoy et al. (1999) provide supporting evidence. They suggest that there is a linear association between increasing age and impairments in visual acuity for near and distant targets, reduced contrast sensitivity and reduced ability to discriminate colours, all of which tends to start from the age of about 60 years. Furthermore, they demonstrated that the ability to detect targets in the peripheral visual field also deteriorates with age. Their study required participants to fixate towards a red LED. From this, detection of green LEDs in the peripheral field indicated a relatively modest decline in performance with age, with detection ranging from 100% at 60 years to about 90% at 90 years. When this task was accompanied by a parallel task, which involved counting the number of times the red fixation LED turned off, then the age-related decline in performance of the detection task was much greater, from about 98% at 60 years to 30% at 90 years. These results suggest that it is cognitive impairment (the distraction) rather than visual impairment that reduces peripheral detection with age. Furthermore, age-related impairments to task performance are expected to increase as the cognitive demand of the task increases [Vaportzis et al., 2013].

A limitation to the research by Haegerstrom-Portnoy et al. (1999) is that the distraction task they presented (requiring participants to count how many times the red fixation LED turned off) was performed silently, meaning that the distraction condition was not measured to understand the locus of participants' attention. Secondly, providing a distraction task that is related to the primary task could facilitate performance by causing participants to use more of their working memory than they otherwise would to the primary task rather than diminishing the division of cognitive load between one task and an alternative task that bears no relation to each other, although this effect is observed in people that have less experience [Runswick et al., 2018]; the study was exploring visual abilities, irrespective of driving experience, so how representative these results are in the driving context remains unanswered. Thirdly, the most prominent distraction found for drivers is auditory distraction from conversation with passengers [Robbins & Fotios, 2021], which is a different modality of distraction from that presented in the study. Whether the influence of distraction being presented in the same modality as the primary task (in this case, visual) related to visual performance is reflected in distractions that differ in modalities is thus not answered by their research.

The exploration of the ageing process related to vision that Haegerstrom-Portnoy et al. (1999) conducts is useful for understanding how older drivers' visual abilities are more impaired than younger drivers', and they provide evidence that increasing cognitive load provides further depreciation of performance, but their research does not underpin the nature of distraction itself. Indeed, Lee et al. (2008) examined the necessary components of distraction, suggesting that distractions can be visual, cognitive, biomechanical, or auditory, with supporting evidence that there is a difference between visual and cognitive distractions for older and younger drivers [Zhang et al., 2014; Cuenen et al., 2015]. However, Lee et al. (2008) also states that determining the type of distraction related to the distraction activity can be difficult. An example is passenger distraction, where the distraction could be visual (the driver turned to face their passenger and therefore was not observing the road), auditory (the driver was startled or taken by surprise by a comment from their passenger) or cognitive (the conversation was mentally taxing and impinged on the driver's concentration) [Zhang et al., 2014]. Unless all explanations are explored simultaneously in a study, the distracting task can be understood as being explored, but the fundamental mechanisms that underpin distraction are not.

Passengers causing distraction thus is considered to relate to an RTC risk that is moderated by age, in which younger drivers travelling with passengers are believed to have a higher risk [Theofilatos et al., 2018]. However, the type of distraction that passengers and drivers engage in alike is of equal importance. To understand the influence of distraction and driver age further, different distraction tasks must be considered. One type of distraction that is understood to be prevalent for drivers is mobile phone use, with research indicating that ~85% of American and ~66% Finnish drivers admit to using mobile phones whilst driving [Goodman, 1997; Lamble et al., 2002b].

Strayer & Drew (2004) explored the influence of driver age (younger or older) and the influence of mobile phone use whilst driving. Overton et al. (2015) provide further information of why this mobile phone use is detrimental to road safety by stating that drivers using their phones to text are 23 times more likely to be in an accident. They further state that, despite 97% of teenagers knowing the dangers of texting whilst driving, 43% reported that they still engaged in this behaviour. Additionally, they state that 77% of teenagers have observed their parents engage in texting and driving, and 75% say it is common among their friends.

Use of mobile phones is thus highly prevalent and high risk in the driving context but exploring mobile phones solely does not necessarily equate to a full account of cognitive load. For instance, even within the use of mobile phones whilst driving, there are multiple functions that a driver could perform that could relate to different types of distraction. An example is that focusing on texting means that the focus will be on physical distraction, whereas focusing on conversing will align with cognitive distraction. The focus of the investigation into either of these types of distraction could lead to different magnitudes of effect [Liang & Lee, 2010; Garrison & Williams, 2013; Kountouriotis et al., 2016]. An alternative approach that could provide more comprehensive insights into the nature of cognitive load itself is presented by Lees et al. (2010), who found that increasing the difficulty of tasks leads to increased cognitive load for older drivers, with associated detriments to driving performance. A limitation is that the ageing process is known to depreciate general cognitive functions [Renge et al., 2020], so whether the same influence (or magnitude of influence) on cognition is similar for younger drivers is not determined by their study. Ageing leads to a variety of cognition changes that affect driving performance. For instance, when considering emotional content, older people tend to focus on positive information whilst averting their attention from negative information, called a positivity bias [Scheibe & Carstensen, 2010].

Processing of emotional information is affected too, with verbal information being similar between older and younger people, but visual information being depreciated for older compared to younger people [Phillips et al., 2002]. The difference in processing abilities between these age groups provide a further limitation to the study by Chan & Singhal (2015), who used drivers aged 18-30, and provided only emotional information by audio. There is tentative evidence reported by Knight et al. (2007) to suggest that Chan & Singhal’s (2015) findings apply across all ages though, with older adults’ tendency to avoid negative stimuli being demonstrated to be reversed in younger adults whilst they are in a state of divided attention. This reversal of tendency between the different age groups occurs regardless of whether the simultaneous tasks are complementary in terms of being related to the primary task (divided attention) or not (distracted) [Mather & Knight, 2005].

There is an equivalent impact of distractions between younger and older drivers when considering reactions to road hazards (18% slower), following distance (12% greater), and recovery speed lost following braking (17% longer) [Strayer & Drew, 2004]. Distraction therefore affects all ages equally. In contrast, attentional capacity declines significantly as an individual ages [McAvinue et al., 2012]. This means that care must be taken when designing a study to investigate performance in a task in conjunction with performance to another task to ensure that the relevant cognitive process is being explored.

Related to attentional capacity is visual acuity, which appears to differ between younger and older drivers, although the impact of distractions on their driving performance appears to be similar between these age groups. Even without distraction, older, compared to younger, drivers have slower reaction times [Horswill et al., 2008], impaired ability to match the speed of the leading vehicle [Dastrup et al., 2009], and are found to initiate and execute movements more slowly and with less precision [Stelmach & Nahom, 1992]. Older drivers therefore perform worse on driving tasks than younger drivers when not distracted but appear to show equivalent detrimental driving performance from their respective differing baselines when engaging in distraction.

Additionally, when compared with younger drivers, older drivers have increased difficulty of simultaneously activating car controls, putting older drivers at risk when facing challenging and time pressure road events [Bélanger et al., 2010]. The difficulty that older drivers experience with this issue is potentially cognitive in nature rather than purely about their motor control. For instance, older drivers are found to have attentional deficits compared to younger drivers [Bakhtiyari et al., 2016], which mean they have impaired inhibitory control that leads to a high susceptibility to distraction because of being unable to divide their attention effectively [Healey et al., 2008]. In comparison, younger drivers actively choose to engage with distraction. This is because younger drivers are more prone to boredom than older people [Vodanovich et al., 2005], for which Malkovsky et al. (2012) divided the concept of boredom into categories of apathetic or agitated. These respectively mean the individual is unconcerned with their environment, or motivated to engage in meaningful activities, although attempts to do so fail to satisfy. They found that apathetic drivers are more likely to make errors on cognitive tasks; given that drivers attempt to alleviate feelings of boredom by seeking sensation, typically resulting in the engagement of distracting tasks

[Fuller, 2005], younger drivers are potentially more likely to align with boredom that is agitated rather than apathetic.

Further reasons why boredom could lead to impaired performance are that bored drivers are more impulsive [Mercer-Lynn et al., 2013], less attentive [Gordon et al., 1997], more aggressive and angrier [Dahlen et al., 2004]. Indeed, Clarke et al. (2006) found that RTCs in darkness are not merely a matter of visibility but were associated with how younger drivers are more likely to exceed the appropriate speed for a road at night, potentially relating to their attempt to relieve boredom. Furthermore, performance on tasks that require sustained attention [Sawin & Scerbo, 1995; Kass et al., 2001] and task engagement [Matthews & Desmond, 1998] is adversely affected, with these consequences being subsequently associated with driving offences [Furnham & Saipe, 1993]. Direct conclusions from these consequences to the risk of RTCs are difficult to provide, given that there are no reported statistics about how prevalent driver boredom is across all age groups. However, most journeys are well-practiced and familiar [Heslop, 2012], which leads to arousal decline associated with boredom [Csikszentmihalyi, 2002]. Boredom is consequently implied to be a common experience for all drivers, despite younger drivers suggested as being the most prone to distraction of all drivers. A threshold of mental stimulation beyond the primary driving task(s) is therefore posited as being advantageous to driver performance, but only when attention is toward the driving rather than divided to non-driving tasks. How these cognitive mechanisms between driver age groups influences the impact of cognitive load on visual detection is an area for further enquiry.

An increased propensity for younger drivers to engage in boredom is one element related to why they engage with distraction, but there are other equally important social influences. An example is the Multifactorial Model for Enabling Driving Safety, which explains how driving behaviour can be influenced both by the perceived and actual capacity to drive safely [Anstey et al., 2005]. When considering driving risk perception, defined as the perceived risk resulting from subjective judgments about severity and characteristics of the driving scene [Deery, 1999], drivers typically compare themselves with an imaginary person. The hypothesised other is often imagined as an unrealistic stereotype that engages in risky behaviour at a higher level than the self [Thornton et al., 2002].

Behavioural adaptations occur to compensate for self-perceived potential driving performance deficiencies [Charlton & Starkey, 2016]. A caveat is that a combination of depreciated self-awareness regarding driving performance and belief that other drivers are worse can potentially reduce the magnitude of how much behaviour is adapted. Hatfield & Fernandes (2009) provide supporting evidence by mentioning that statistics show younger drivers as being overrepresented in

RTCs. They further mention that younger drivers have a reduced aversion to risk, and are more likely to take accident risks, as well as having stronger motives for risky driving based on their desire for experience, excitement, sensation, social influence, prestige, confidence/familiarity, risk underestimation, and perceptions of risk irrelevance. Further support arises from younger drivers as being more likely to be distracted yet perceive their peers and parents as being more likely to be engaged in distraction tasks whilst driving [Carter et al., 2014].

It should be noted that all drivers are influenced by the misleading comparison of driving risk between themselves and an imaginary other, regardless of age [Horswill et al., 2004; Freund et al., 2005]. Such a comparison is thereby posited as a general tenet of driving behaviour, although driving adaptations in relation to self-perceived driving risk compared to others differs across age groups. Negative environmental conditions, such as inclement weather or night-time driving (both reducing visual acuity of the driver), reduces the likelihood that all drivers will commence a driving journey, but older drivers are more influenced by these conditions than younger drivers [Naumann et al., 2011]. These influences on driving are thereby about the magnitude of effect they have on the age group of the driver, not about one age group being influenced when another is not. Consequences of the comparison are thus arguably more concerning for younger, rather than older, drivers for two reasons.

Firstly, the increased risk of younger drivers in RTCs means that their lack of self-awareness and subsequent lack of intention to adapt their behaviour adequately leads to more road safety detriments for younger drivers compared to older drivers. Secondly, older drivers are more likely to adapt their behaviour more appropriately than younger drivers to mitigate driving risk. One explanation about why there is a difference in the ability for the drivers to adapt their behaviour, depending on whether they are young or old, is provided by the dual process theory of risky driving, which stipulates that there is an imbalance between the development of social-affective processes within the brain and the systems that underpin cognition for young drivers [Lambert et al., 2014; Cascio et al., 2015]. These systems are in a state of development until adulthood (25 years of age) [De Luca & Leventer, 2010; Bugg & Crump, 2012]. This has implications especially for the interaction between passengers and the driver on driving performance, in which the higher magnitude of risk that adolescents and young adults are willing to engage in compared to people of other ages are influenced by situations that are highly social-affective [Albert et al., 2013].

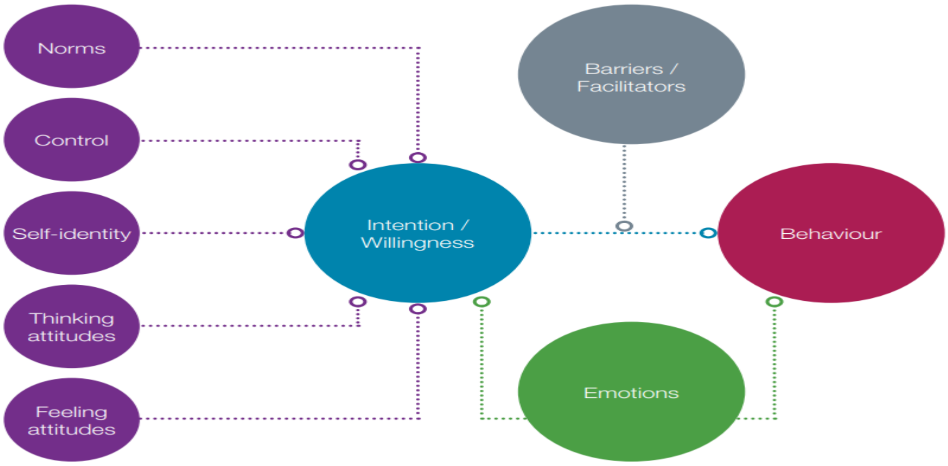
In those social situations, impulses associated with risk taking are not appropriately controlled by their immature cognitive control [Figner et al., 2009]. This theory explains why young drivers (18–25-year-olds) are found to be at a higher risk of an RTC when they are with a passenger that is around the same age [Toxopeus et al., 2011; Rhodes et al., 2015] and the RTC is typically of a higher severity than when it is with passengers of other ages, or the driver is driving alone [Villavicencio et al., 2022]. Whether these consequences relate to the immature cognitive processing or because of the desire to seek approval from people that are close to their own age, known as peer pressure [Wein & Hicklin, 2021], is yet not certain. Exploring the influence of distraction in relation to young drivers when they either are driving with passengers in their peer group (18-25-year-olds) or younger passengers (0-17-year-olds) will provide further insights into this issue.

Cognitive processing differences may explain why younger and older drivers differ in the way they approach mitigation strategies for reducing their risk of an RTC. Another explanation is the difference in sensitivity related to social influences, such as peer groups, in which younger drivers are more sensitive than older drivers [Todd et al., 2016]. Furthermore, the context of young driver behaviour is based on the principles contained with the Prototype Willingness Model (PWM) that, rather than unintentionally choosing to engage with maladaptive driving behaviour, risks are taken impulsively in response to risky situations, which facilitates young drivers' creation of their identity, opinions, and values [Cestac et al., 2011].

The Theory of Planned Behaviour (TPB) provides support for the PWM. TPB states that human behaviour is predicated by three principles: beliefs about the likely consequences (behavioural beliefs), normative beliefs about others' expectations (normative beliefs), and control beliefs about whether there are factors that may facilitate or impede the performance of the behaviour (control beliefs) [Bosnjak et al., 2020]. Mobile phone use in younger drivers is accounted by TPB, although normative beliefs influence drivers' willingness to engage with mobile phone use only when they are driving alone [Rozario et al., 2010]. In other words, when young drivers have passengers, they disregard beliefs about what others believe is pro-social behaviour, instead choosing behaviour that they feel is anticipated to enhance their own reputation amongst their peers [Shepherd et al., 2011; Simon et al., 2011; Centifanti et al., 2016]. Indeed, the motivations of young drivers for risky driving are stronger than those of older drivers [Hatfield & Fernandes, 2009], explaining why the social context is more influential for younger, rather than older, drivers.

TPB provides a framework for understanding the cognitive component of why drivers may engage in using their mobile phones, but Loewenstein et al. (2001) suggest that feelings of both how actions are anticipated to feel at the time of action and the subsequent consequence of those actions are also important factors to consider. The crucial distinction is that TPB is about a cognitive appraisal, whereas Loewenstein et al. (2001) elaborate upon an emotional appraisal. Of this separation, they further conclude that feelings are more of a prominent factor for drivers where they are confronted with a conflict between them and cognitive evaluations. These factors are shown in **Figure 2.5**.

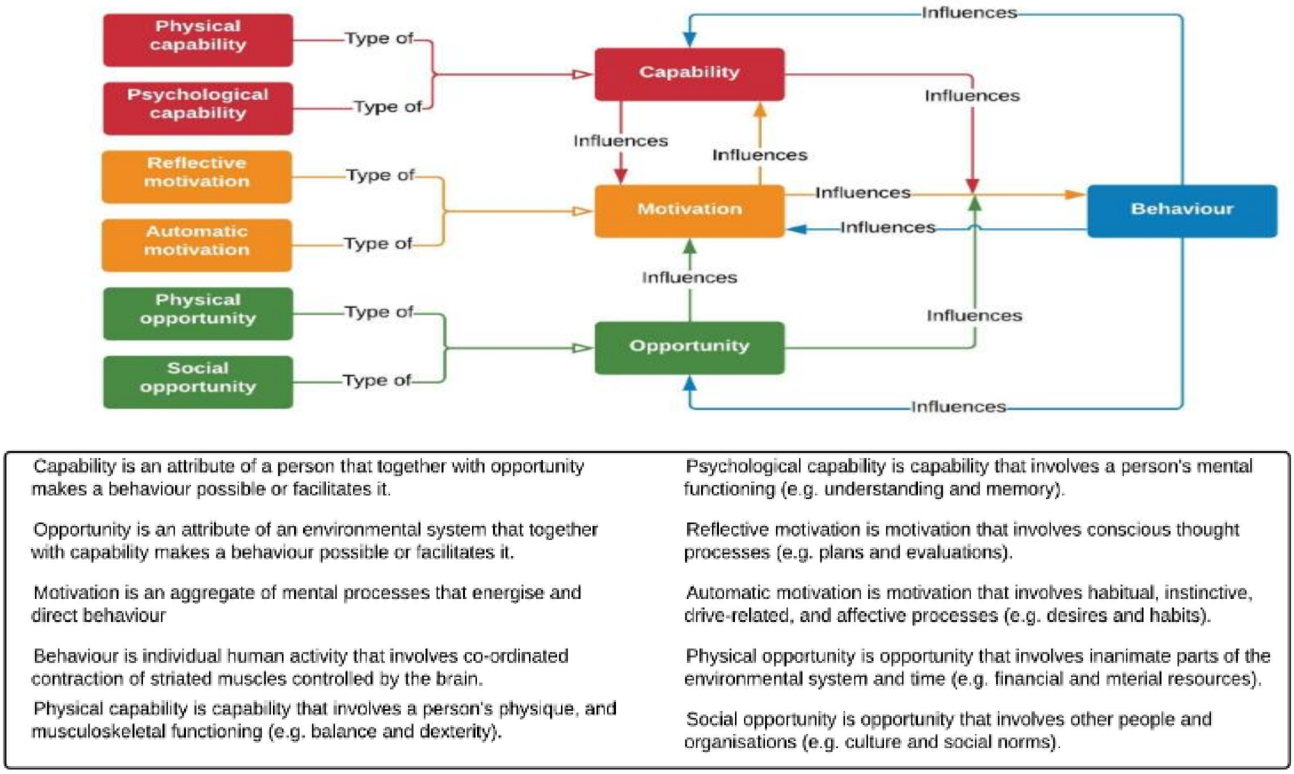
Figure 2.5 **The Theory of Planned Behaviour Model**, with an extension of anticipatory feelings of how the person will feel at the time of action (Thinking attitudes) and about the consequence (Feeling attitudes).



Whilst normative beliefs held by younger drivers is therefore indicated as facilitating riskier driving performance, normative beliefs for drivers facilitate less risky driving performance. For instance, drivers in their 50s are that they should retire from driving when they are in their 70s, although this increases to mid-80s when the same beliefs are assessed in drivers aged in their 70s [Rabbitt et al., 1996]. Additionally, older drivers are more capable at emotional regulation than younger drivers; poor emotional regulation leads to a maladaptive driving style, including engaging with distractions, which is associated with a higher risk of an RTC [Navon–Eyal & Taubman–Ben-Ari, 2020]. TPB consequently explains why younger drivers are more likely to engage in riskier driving compared to older drivers, when considering both social and cognitive influences.

Behaviour is seen as the consequence of various social and cognitive factors in TPB, but this model does not account for the converse interaction of behaviour influencing those antecedents. Michie et al. (2011) created the COM-B model, which provides a structure that this latter interaction can be mapped. COM-B alludes to Capability (C), Opportunity (O), and Motivation (M), which has a bi-directional connection with Behaviour (B), presented in **Figure 2.6**. Whilst TPB and the COM-B model may appear to be similar, there are differences. Placed in the driving context, this latter model is more precise. It comprises the ability of a driver, factors that influence the likelihood of engaging in riskier driving habits, and whether the driver has the potential of behaving in the manner they desire.

Figure 2.6 **The COM-B Model** [West & Michie, 2020]



Capability is an attribute of a person that together with opportunity makes a behaviour possible or facilitates it.

Opportunity is an attribute of an environmental system that together with capability makes a behaviour possible or facilitates it.

Motivation is an aggregate of mental processes that energise and direct behaviour

Behaviour is individual human activity that involves co-ordinated contraction of striated muscles controlled by the brain.

Physical capability is capability that involves a person's physique, and musculoskeletal functioning (e.g. balance and dexterity).

Psychological capability is capability that involves a person's mental functioning (e.g. understanding and memory).

Reflective motivation is motivation that involves conscious thought processes (e.g. plans and evaluations).

Automatic motivation is motivation that involves habitual, instinctive, drive-related, and affective processes (e.g. desires and habits).

Physical opportunity is opportunity that involves inanimate parts of the environmental system and time (e.g. financial and mterial resources).

Social opportunity is opportunity that involves other people and organisations (e.g. culture and social norms).

TPB mentions barriers and facilitators, but it is a category that is observed as solely influencing intention and willingness to engage in behaviour. This is a false conceptualisation because drivers that are cognitively impaired may not understand the extent of their impairment. Cognitive impairments themselves may lead to drivers underestimating risk, such as when drivers are intoxicated, but the depreciated cognitive processing potentially leads to intention and willingness for that driver to continue driving [Amlung et al., 2014].

The COM-B model better explains the decision process of drunk drivers than TPB because it explains how the capacity (both physical and psychological, respectively meaning the ability for the driver to manually control the vehicle and their beliefs of their ability) and motivation (conscious thoughts and unconscious habits) interact in relation to manifested behaviour. Another benefit of COM-B is that the elements that influence behaviour are more segmented than TPB, which potentially leads to interventions that are more focused for changing driver behaviour [Gunnell et al., 2019; Cociu et al., 2022].

Motivation of the driver is at the centre of COM-B, in which all factors lead into. As such, the principle of COM-B is that changing driver motivation will influence driver behaviour. Driver distraction does not appear to have been explored in relation to COM-B to the researcher's awareness, but research in an alternative field of enquiry that aims to reduce the amount of time staff are seated in a workplace to improve productivity shows that the model can identify areas that should be targeted to improve behaviour [Brierley et al., 2021].

Applying the Capability aspect of the COM-B model to driver distraction, older drivers have less capacity to control the vehicle with the precision that younger drivers can and have reduced cognitive capacity than younger drivers [Bélanger et al., 2010; Bakhtiyari et al., 2016]. Research that explores cognitive load could be associated with the mental functioning of a driver, related to the psychological capability of the driver. An associated point is that there is a greater perception of demand and frustration among both younger and older adults when under loss incentives (behaviour intended to avoid loss) [Jang et al., 2020].

Loss incentives could thereby increase cognitive load whilst driving. Such loss incentives for driving would be related to the penalty point system, which punishes drivers for breaking the driving rules presented by the UK government [The Highway Code, 2022]. When considering Opportunity, younger people typically earn less than older people [Office for National Statistics, 2021] so have less income to afford to spend on penalties if they violate the rules.

A general penalty point system appears to convey a road safety benefit, such as in Spain where there was a 10% reduction in the risk of driver-fatal collisions, and 2% of overall collisions, following the introduction of a penalty system [Novoa et al., 2010]. Translating the benefits from Spain to the UK would mean that the penalty system has prevented an estimated 2,559 extra collisions on UK roads in 2021. Whilst the penalty system clearly indicates not only the impact of loss incentives on driving behaviour but also the power of the COM-B, the relative lack of finances to pay for penalties would be anticipated to lead to younger drivers driving more cautiously than older drivers. However, younger drivers are not shown to be more cautious than older drivers [Navon–Eyal

& Taubman–Ben-Ari, 2020]. Given that conscious behaviour would perhaps influence younger drivers to not engage in distraction so as to reduce the risk of being penalised, the unconscious influences of cognitive load on their driving performance could explain why they are at a greater risk of an RTC.

Overall, cognitive load therefore appears to be a significant factor that underlies the detrimental nature of distracting tasks, regardless of what the distraction task is. Whilst distraction itself has been shown to be either intentional or unintentional [Vodanovich et al., 2005; Healey et al., 2008], cognitive load is posited as being beyond the conscious control of the driver, based on the evidence provided in this chapter.

2.8 Distraction and RTC Data

Empirical work provides a controlled way to measure distraction in relation to visual performance, both for driving and non-driving contexts. However, whether the cognitive load in these experiments would had led to an RTC is uncertain because the reported findings are associated with factors related to RTC risk (reaction time and detection accuracy) rather than an occurence of an RTC incident. The findings are thereby implicated in, but do not explicitly relate to, road safety. Exploring how distractions influence occurrences of RTCs will provide further understanding into this matter.

For an example of the issue of investigating distraction in an experiment environments rather than RTC occurrences, Metz et al. (2011) provided insights into the influence of distractions in different driving contexts (critical compared to uncritical situations), but the distraction was placed low in the central unit of the vehicle, which is also known as an in-vehicle infotainment system. An example of the in-vehicle infotainment system is presented in **Figure 2.7**.

Infotainment systems are common in vehicles, so represent comon driving. Indeed, the global market estimated to be worth \$20.8bn in 2021 and expected to reach \$38.4bn by 2027 [Markets and Markets Research, 2022]. However, information is not typically limited to the lower portion of these systems in a real driving context in the way that it is in the research by Metz et al. (2011) [Saxena, 2020]. Rather than peripheral vision, their participants may have fully averted their attention to the distraction task in their research. As such, participants would be required to avert their attention more in their research compared to an actual driving scene.

A similar limitation is found in the study by Brodsky (2018), who explored the influence of singing and tapping to music on driving performance. The songs presented were rated for familiarity, but their experiment did not assess whether participants would generally sing and tap along to those songs in an actual driving context. Consequently, there may have been less of an emotional connection to the song than in real driving, meaning that the participants could more easily dissociate from the task in this experiment, when necessary, compared to the actual driving context.

Figure 2.7 An example of an **in-vehicle infotainment unit in a vehicle**, placed in the centre of the car.

Empirical experiments that explore in relation to road safety therefore provide useful insights, but the artificial nature of these experiments means that genuine driver behaviour cannot be fully represented [Santos et al., 2005; Zöller et al., 2019]. To rectify these concerns, other measures have been devised to assess real driving without requiring controlled labaratory experiments.

For example, data collected from drivers' self-reported behaviour is an effective method of analysing driving behaviour, such as surveys or questionnaires, but self-report data is limited by the increased potential of social desirability that the respondent may feel about choosing an anwer that makes them appear favourably [Holden & Passey, 2009; Caputo, 2017; Holtgraves, 2017]. Additionally, the validity of this information is argued to be questionable [Harrison, 2010; Agramunt, 2018]. Indeed, a systematic review of 20 driving safety studies using self-report data validates the perception that information gained from this type of data is questionable, given that there are differences between self-reported and objective measures of driving behaviour when considering fatigue and vigilance states, although there are some similarities when measuring driving in stressful situations [Kaye et al., 2018]. These findings therefore provide some insights into driver behaviour, but are not sufficient to provide a comprehensive understanding when taken in isolation.

Another method is to use Naturalistic Driving Studies (NDSs), which utilise advanced instrumentation installed in vehicles to constantly collect driving information in real-world driving scenarios, without requiring specialised equipment inside the vehicle or researchers to be accompanying the drivers when collecting data [Guo, 2019]. The measures typically recorded are presented in **Table 2.3**. Whilst NDSs are resource intensive that require multiple sensors to detect information, with associated high costs involved, this method facilitates the possibility to analyse data repeatedly from a wide range of perspectives based on behavioural, vehicle, and environmental data. Furthermore, the data are automatically recorded and provide objective data, rather than trusting the results based on the driver or observer’s reporting, explaining why findings from NDS have been raised in policy discussions relating to advanced driver assistance systems [Fitch & Hanowski, 2012], distracted driving [Klauer et al., 2014], impaired driving [Dingus et al., 2016], and vulnerable road users [Ehsani et al., 2020].

Table 2.3 **Measures typically recorded** in instruments within vehicles associated **with NDSs** [Knoefel et al., 2018].

Driving Behaviour	Example
Characteristics	Frequency of driving
	Speed
	Position
	Type of road
Actions and Reactions	Lane changes
	Intersections
	Passing
	Merging
Destinations	Variety and distance
	Distance
	Route planning
Driving Conditions	Time of day
	Season

NDSs are useful for understanding typical driving behaviour. However, due to most RTCs reported in NDSs being low-severity, sufficient RTC assessments are difficult to perform. An additional limitation is that, due to diverse sensor types and variations, long-term NDSs (data collected over a longer period of time) are challenging to collect and process [Knoefel et al., 2018]. Likewise, radar has been used in several NDSs, but the data quality is often unreliable because of missing and erroneous information [Dingus et al., 2006; Bärgman, 2015].

In contrast, governmental databases that contain RTCs follow a similar structure between countries to report their national RTC incidents, known as RTC investigations. Whilst driver behaviour cannot be fully understood by RTC investigations, given that the driving information reported is based at the point of the RTC, there are a greater set of RTCs to explore within this method compared to NDSs. As such, the influence of factors directly related to the occurence and absence of an RTC can be more easily determined than in data collected by NDSs.

One topic that can be explored by RTC investigations is the influence of passengers. Exploring the influence of passengers on RTC risk can be achieved by NDSs, but the lack of standardised reporting may mean that the risk is exaggerated or underreported in some areas compared to others. Likewise, this risk can be explored by empirical experiments, but the artificial nature of the experiment, presence of the researcher and any recording tools may alter actual behaviour [Philip et al., 2005; Martens & Fox, 2007]. RTC investigations are thus a way to explore how passengers influence genuine driver behaviour and the subsequent contribution of this to RTC incidents.

Research has been conducted on the influence of passengers on RTC risk, in which findings have been mixed [Vollrath et al., 2002; Chung et al., 2014; Huisingh et al., 2015; Caird et al., 2018; Charlton & Starkey, 2020; Green et al., 2022]. The factors that have informed the focus of passengers and their influence on RTC has differed, with some focusing on distraction between driving alone and with passengers (increased risk) [Bingham et al., 2016], and age of both drivers and passengers (mixed risk, depending on the age in focus) [Lam et al., 2003].

Another factor to consider is the passenger seating positions (rear and front seating). Various studies have explored passenger seating on fatalities [Smith & Cummings, 2006; Mayrose & Priya, 2008; Górniak et al., 2022], but few have explored passenger seating in relation to the RTC risk. One study that has explored this issue is Smith & Cummings (2004), who found that passengers seated in the rear generally led to fewer RTCs than when passengers were seated in the front. However, their findings do not disentangle all factors related to RTCs, meaning that the results may not specifically relate to RTCs where distraction was the primary cause, which may differ in prevalence between when passengers are seated in the front or rear.

Distraction in relation to RTC risk and passenger seating may relate to how clear the view of the road ahead for drivers and passengers may be an important consideration. For drivers, the view of the road ahead makes sense becuase they require a clear view to ensure effective responses to hazards. Likewise, the view may be important for passengers because their view of the road ahead may moderate how engaged they are with causing distraction to the driver, potentially explaining why conversations whilst speaking on mobile phones (even handheld) are riskier than speaking to passengers in the car [Crundall et al., 2005; Charlton, 2009; Matthews et al., 2018]. Passengers in the front of the vehicle are better able to see approaching hazards and may therefore be more likely to reduce their distracting action (e.g. talking to the driver) than a passenger in the rear seat who has a restricted view of the road ahead. Put alternatively, passengers seated in the rear may engage more with distraction than those in the front, and this may subsequently lead to higher road traffic collision risk for the driver when the passenger is seated in the rear compared to when the passenger is seated in the front.

Despite the general mixed findings, younger passengers with younger drivers appear to increase the risk of an RTC, as mentioned earlier [Tefft et al., 2013], with teenage drivers being socialised into increased speeding behaviour based on peer pressure that becomes a structure to base justification on speeding behaviours when the driver becomes older; the drivers' own speeding was significantly different from friends' speeds when they drove [Møller & Haustein, 2014]. Indeed, despite recent improvements, young people continue to be most at risk in traffic within the US, with 18-20 and 21-24 year olds carrying mortality rates of 15.2 and 17.0 respectively, per 100 000 inhabitants of the same age group [International Transport Forum, 2021]. The age interaction between driver and passenger is therefore important to consider, especially the peer group for younger drivers. To date, no study has explored the interaction between all these factors (distraction, driver and passenger age, passenger seating position) mentioned.

2.9 Research Questions

The literature review provides evidence that cognitive load associated with distraction tasks influences driver safety. However, distraction is typically operationalised as the use of mobile phones [Brown et al., 2003; Burge & Chaparro, 2012; Burge & Chaparro, 2018; Kabir & Roy, 2021]. UK law states that it is illegal to hold and use an electronic device (phone, sat nav, tablet, or any device that can send or receive data) while driving or riding a motorcycle, meaning that a device must not be handled for any reason, whether online or offline [UK Government, 2022]. Thus, whilst the UK law does not prohibit hands-free use of mobile phones, the operationalisation of distraction as mobile phone use may not adequately represent a full account of distraction in driving. As such, relating the research to specific distractions may overlook how prevalent the cognitive load inherent to all distraction tasks generally is, potentially leading to insights about distractions with either high or low levels of prevalence that are associated with differing levels of RTC risk. Consequently, some of these investigations may explore distractions that are common but have a relatively small effect on the increase in RTC risk, or distractions that are rare but increase the RTC risk relatively more than other distractions. The focus of these experiments may therefore lead to erroneous conclusions if the findings are implied to represent cognitive load generally, rather than specific distractions.

Research has also been conducted that used abstract distraction tasks, such as requiring participant responses to visual targets, audible tones, and recalling items from lists [Tremblay & Jones, 1998; Bornard et al., 2011; Cuenen et al., 2015; D'Addario & Donmez, 2019]. These arguably supersede the modality specificity of specific distractions, given that those distractions relate to specific sensory functions such as using touch to interact with the radio and/or listening to the sound that arises from the activated radio.

In contrast, the assumption is made that findings from abstract detection tasks can be applied to any distracting activity, and are potentially more comprehensive than looking solely at one distracting task. An example is that activiting the radio and listening to the sound from the radio would not be considered collectively in the experiments, but cognitive load would relate to both elements that is not being effectively assessed in experiments that focus on specific distractions. Furthermore, distraction is typically explored in hazard perception experiments without understanding the distraction task that is most detrimental to visual detection in the first instance. This means that the results do not disentangle between whether the detrimental effects of distraction on visual performance within the driving scene is being mitigated by the drivers' schema (top-down processing). By isolating a visual detection task so that distraction is explored in relation to a visual detection task in an abstract environment that does not relate to the driver's schema, the distraction task with the largest decriments to visual performance can be understood without interacting with how the driver applies their schema.

Beyond the nature of the distractions being explored and the nature of how distractions influence drivers' hazard perception skills, a limitation with empirical experiments is that they are not possible to be associated with the presence of absence of an RTC because these never occur in controlled studies. Using RTC investigations could provide further insights into how distraction influences actual RTC rates, especially between driving alone and with passengers, and within cases where passengers are present. These investigations can also outline which driver and passenger age group combination(s) is the most at risk for an RTC, for which no research to date has explored distraction attributed to the passenger, driver and passenger age, and seating position on RTC risk, across cases where a passenger is present.

Findings from the abstract visual detection experiment and influence of passengers on RTC risk can then inform an exploration of the most detrimental distraction (from the abstract visual detection experiment) and most at risk driver and passenger age group (RTC investigation) to apply within a hazard perception experiment to explore how driving performance is influenced by these factors. In addition to driving performance, the number of false responses recorded can also be analysed related to the different conditions explored, given that more false positives are recorded for higher, compared to lower, levels of distraction [Jamson & Merat, 2005]. Results from this experiment can determine whether the distraction performance in the abstract environment applies to the driving context, related to how driver's schemas influence performance whilst the driver is distracted, whilst also exploring how such findings apply to the most at risk driver and passenger age group within the RTC database.

As such, this thesis aims to address these concerns by exploring three research questions using three studies:

1) Research Question 1: Does the degree of cognitive load within a distraction task influence visual detection performance within an abstract task?

    Hypothesis 1a: Higher cognitive load will be associated with lower accuracy and slower response rates when responding to a simultaneous task.

    Hypothesis 1b: Older people will be less accurate and slower than younger people when distracted and conducting a simultaneous task.

2) Research Question 2: Does the interaction of distraction, passenger and driver age, and passenger seating position influence the risk of a driver being involved in an RTC?

    Hypothesis 2a: RTC risk will be higher when driving alone compared to driving with passengers for all age groups, except for younger drivers travelling with younger passengers.

    Hypothesis 2b: In the presence of passengers, cognitive distraction will be associated with the higher risk of RTCs.

Hypothesis 2c: A passenger in the front seat will lead to lower RTC risk than a passenger in the rear seat.

3) Research Question 3: Does distraction presented by a passenger in either the front or rear passenger seat influence hazard perception performance in drivers' response to videos depicting hazards within driving scenes?

    Hypothesis 3a: Higher detection and faster reaction times in the hazard perception task will be associated with lower accuracy in the distraction task.

    Hypothesis 3b: Passengers seated in the rear will have higher accuracy reading the distraction task to the driver than passengers seated in the front.

    Hypothesis 3c: Passengers seated in the rear that are reading the distraction task will be associated with drivers' lower detection and slower reaction times in the hazard perception task.

    Hypothesis 3d: Fewer false positives will be recorded for drivers' hazard perception responses when passengers are seated in the front compared to the rear.

Findings from these studies will provide guidance for policy recommendations related to administering the driving hazard perception test in a way that will enhance identification within the driving licensure assessments of deficient hazard perception skills within the driving context. Additionally, these findings will provide further insights into the influence of passengers on RTC risk, which can be used to guide suggestions about whether drivers and passengers should be more cautious, and where passengers should ideally be seated to reduce the risk of an RTC. **Chapter 3** presents the method related to the first of the three studies.

Chapter 3: Distraction in relation to Visual Detection in an Abstract Environment – Method

3.1 Introduction

It was concluded in the literature review **(Chapter 2)** that distraction when driving increases the likelihood of an RTC [Kaber et al., 2012; Fernández et al., 2016; Lovell et al., 2022]. The fundamental element determining the influence of a particular distraction on driving performance is the cognitive load required to execute the distracting task [Reyes & Lee, 2008]. Cognitive load is already generated within the task of driving itself, one aspect of which is visual detection [Zagermann et al., 2016]. However, cognitive load can be increased further by drivers engaging in a secondary, non-driving task, known as distraction. Distraction leads to slower and less accurate performance on visual tasks such as detection and identification [Nilsson et al., 2018; Wolfe et al., 2019]. Distraction is thus recognised as impairing driving performance.

Previous research has explored the impact of specific distractions on driving performance, such as using mobile phones [Burge & Chaparro, 2018], conversing with passengers [Zhang et al., 2019], and medical conditions [Vaezipour et al., 2022]. However, as specific distraction tasks have varying degrees of prevalence [Robbins & Fotios, 2022] and RTC risk [Eid & Abu-Zidan, 2017], identifying the fundamental aspect of distraction that causes its detriments to driving performance is important. This is particularly important for distraction whilst driving because research in this field typically chooses a distraction task with the assumption of the cognitive load related to it, but the driving context itself could mean that any decrements distraction has on visual performance is moderated by the mental models already developed in the driver, known as a schema [Neisser, 1976].

To date, distraction hasn't been considered in relation to visual detection without real world context that may associate with schemas, meaning visual detection in an abstract environment. By exploring the influence of distraction on visual detection in an abstract environment, the impact of distraction on visual detection can be observed, before being applied to the driving context whereby distraction can be observed in relation to both visual detection and drivers' schemas.

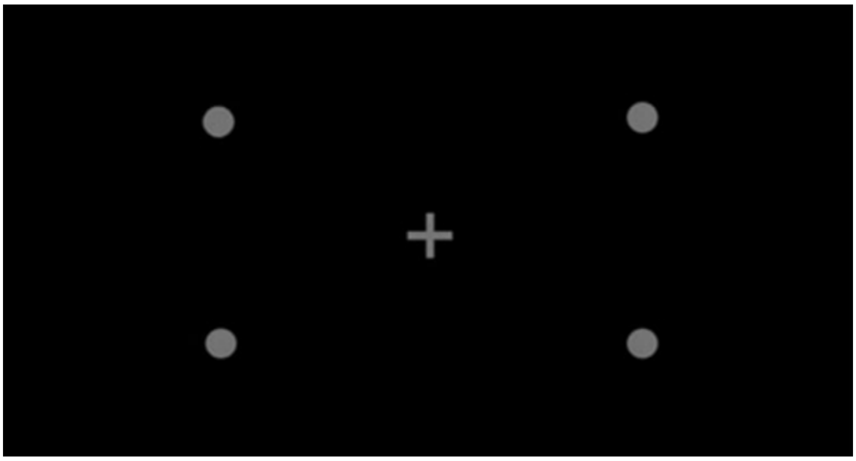
This chapter describes an experiment conducted to explore the effect of distraction on detection of targets in peripheral vision: several distraction tasks were used, with those tasks varying in cognitive load.

3.2 Stimuli and Apparatus

This experiment presented fixation and target stimuli on a screen. The screen on which the stimuli were presented measured 340mm x 190mm and had a resolution of 1366x768 pixels. At 780mm from the observer's eyes, the screen subtended an angle of 24.6° in width and 13.9° in height, a solid angle of 0.11sr.

There were four targets, and these appeared on the screen at a location towards each of the four corners for 250ms **(Figure 3.1)**. The target discs were eccentric to a central fixation mark, with the specific eccentricity for a given presentation varying between 15° and 18°. The distances were selected to ensure that the targets were in participants' peripheral vision when fixating toward the central cross [Fotios et al., 2016].

Figure 3.1 A screenshot showing **the visual detection task**. The discs are at an eccentricity of 18° from the fixation cross. In any given trial, a disc was presented at only one of these locations.



Participants had to fixate on the central cross whilst concurrently using their peripheral vision to attend to each of the circular targets that appeared in each of the four corners of the screen. 140 targets appeared (n=35 for each corner), over approximately 7 and a half minutes. The fixation cross was 18 mm in height and width and subtended an angle of 1.3° at the observer's eyes. Therefore, the fixation cross fell within the 2° foveal visual field. Target discs were 12 mm in diameter and subtended an angle of 0.88°. With the fixation cross being located at the centre of the screen, and with targets presented in each location at random, moving the fixation cross to one target location was considered to convey no benefit.

To represent an outdoor scene after dark, the luminance was manipulated, which is the measure of light that is emitted from a source [International Commission on Illumination (CIE), 2020]. The task presented on the screen for the experiment was a mean luminance of 0.23cd/m^2, which is the luminance presented in other driver safety research [Sturr et al., 1990; Strebel & Neumann, 2019]. To ensure the lowest luminance possible, the brightness of the screen was set to the lowest possible range from the internal settings of the laptop. The experiment was simulated in this context this experiment because the risk of RTCs is higher at night compared to daytime [Ackaah et al., 2020]. In addition to luminance, illuminance was also measured, which is the measure of light that is received by the receiver from a source [CIE, 2020]. This resulted in 0.76lux, which is close to the lux found in real night-time driving (1lux) [Ahlström et al., 2018]. The experiment therefore represented the lighting conditions at night appropriately.

3.3 Distraction Tasks

To examine the variation in cognitive demand, 6 distraction tasks were presented simultaneous to the visual detection task, varying in the complexity. The different tasks thus were considered to related to different magnitudes of cognitive load:

- N-back.

The n-back task aligned with the task provided by Jaeggi et al., (2010), in which a series of letters were presented, with a pause between each randomly chosen from the range of 2–4 s. Performance on this task was determined by the number of letters correctly reported. Participants were required to say the letter they had immediately heard (n-back=0), one previously in the sequence (n-back=1) or two previously in the sequence (n-back=2). Research shows that in comparison to the alternative n-back conditions, n-back=2 promotes a greater influence on heart rate, galvanic skin responses, respiration, horizontal gaze position variability, and pupil diameter, all of which indicates a high degree of cognitive load [He et al., 2019]. This experiment was therefore anticipated to be exploring different magnitudes of cognitive load, rather than specific distraction, whilst participants conducted the alternative simultaneous task: visual detection of targets in an abstract environment.

- Word Generation

Participants were required to listen to the word in a sequence and then respond by generating a word beginning with the letter that finished the word in the list that they had heard. A word generation task was chosen because novel word generation is understood to be a high cognitive load task [Silva et al., 2021]. Word generation is also understood to present different neurological activity to the n-back task [Shin et al., 2018]. Thus, comparing the impact on detection performance of these two types of distraction would indicate whether the difference in neurological activity within high cognitive load activities lead to differences in visual detection performance within the alternative simultaneous task.

- Number Fixation

A visual stimulus was used for the number fixation task. The fixation cross was replaced for 250ms by a single-digit integer (1–9) at randomised intervals between 2 and 3.5 seconds. Each number was presented in Ariel font and measured 2.8cm x 1.8cm, subtending a visual arc of 2.0° at the participants eyes. Participants were instructed to read aloud this sequence of numbers. Performance on this task was determined by the number of correctly reported digits. This number fixation task was included as a distraction condition to enable comparison with previous research [Fotios et al., 2018; Fotios et al., 2019], in which it was previously used to examine the degree to which fixation was maintained rather than being a purposeful distraction.

- Control

No distraction was presented simultaneously to the alternative simultaneous visual detection task.

Peripheral target detection is impaired by auditory distraction, [Kountouriotis & Merat; 2016; Bell et al., 2019] which is particularly prevalent on the road [Robbins & Fotios, 2021]. As a result, different types of auditory distraction tasks were predominantly used as the basis of distraction in the current experiment. However, number fixation (a task related to fixation maintenance) was included to explore the results in relation to results found in previous studies that the researcher was involved with [Fotios et al., 2018; Fotios et al., 2019].

A random sequence of English words was played over the computer speaker. After each word, participants were required to say aloud a word that began with the last letter of the word they had just heard. To illustrate the task, participants were given the example: "*If 'apple' is heard, you are required to generate a word beginning with 'e' as this is the final letter of apple*"; note that 'apple' was not used as a word in the experiment, instead being used purely for illustrative purposes to the participant. On each occasion, participants were instructed to come up with a new word instead of repeating one they had previously provided. Any duplicates were considered errors. A gap was presented between each word in the sequence, with the duration of this gap being from 4 to 6 seconds, chosen at random from the computer program.

The pool of words delivered in the word generation task are listed in **Table 3.1**. The pool of words was drawn from the commonly used English words used to test the phonetic abilities of children during primary education (up to the age of 11 years in the UK) [Department for Education, 2013]. Taking words from this list increased the chance that participants would be familiar with the words they would hear, especially if they were not native speakers. Correct responses were determined by participants providing words that were valid (a real word), novel (new), and appropriate (relevant to the word they had heard) related to the final letter of the stimuli word in the experiment list.

Table 3.1 **Words** that were presented to participants **in the Word Generation distraction task**.

King	Flat	Sit	Chef	Knife	Full	Fine
Yard	Book	Top	Fish	Came	Squat	Bait
Turn	Cup	Born	Hello	Leg	Cow	Joy
Hot	Cat	Chill	Shop	Again	Man	Friday
Went	Room	Hit	Yawn	Help	Photo	Quick
Both	Girl	Sing	Scheme	Beer	Intend	Zip
Vest	Zoo	Air	Day	Check	Flag	Wall
Bead	Need	Leap	Fruit	High	World	Mad
Father	Red	Road	Pleasure	Bag	Vet	School
Launch	Boat	Hard	Miss	View	Hill	Gum
Few	This	Say	Thought	Pie	Usual	Long
Village	Puss	Buzz	She	Blow	If	Pin
Nap	Gem	Chief	Cricket	Melt	Wine	Zigzag
When	Out	Dog	Head	Farmer	Watch	Send
Wet	Letter	Cell	Now	Rob	Jug	Hand
Blue	Tune	Key	Mind	Money	Cold	Boy
Pet	Law					

A summary of the distraction tasks is presented in **Table 3.2**. Trials were divided into six blocks. There were no changes in peripheral detection tasks between blocks, whereby the task was always for participants to press a button whenever they detected a visual target whilst they fixated on a central cross. However, the distraction tasks varied between experiment blocks, although not within them.

Table 3.2 Summary of **the distraction conditions** used in this experiment.

Distraction Condition	Modality	Interval
N-Back=0	Cognitive	2-4 seconds
N-Back=1	Cognitive	2-4 seconds
N-Back=2	Cognitive	2-4 seconds
Word Generation	Cognitive	4-6 seconds
Number Fixation	Visual	2-3.5 seconds
Control	N/A	N/A

Previous literature was consulted to inform the minimum level of accuracy required to determine that participants were engaging with the distraction task. Monk et al. (2011) explored n-back=2 performance in relation to three Naturalistic Actions Tests (NATs), which involving making toast and coffee simultaneously, wrapping a present, and packing a lunchbox and schoolbag. Performance on NATs indicated that 45% is the minimum accurate recall of letters to demonstrate sufficient n-back engagement.

As such, given that the n-back=2 was considered one of the highest cognitive load conditions, a minimum threshold of 45% was used to in this study, meaning that participants were required to attain at least 45% accuracy in each distraction condition to be considered as sufficiently attending to the distraction tasks whilst attending to the alternative concurrent task.

To play the audio recordings of letters (n-back task) and words from the experiment list of stimuli, laptop speakers were used, set to 37 in the internal settings. The test room was free of any other distractions, and no potential distractions that arose incidentally during the study session were recorded as having occurred.

3.4 Procedure

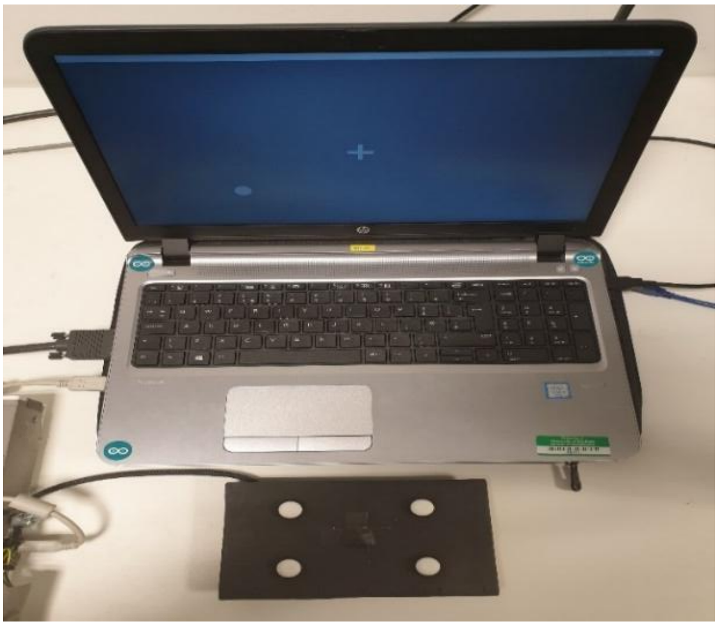
Participants arrived at the experiment room and were presented with the information sheet **(Appendix A.i.)**. They were permitted to read the information sheet before being presented with the consent form **(Appendix A.ii.)**. During this time, the researcher emphasised that the participant was permitted to ask any questions about the experiment if they wished to clarify any information. After signing the consent form, participants were then presented with the visual pre-screening tests.

One of these tests was to measure visual acuity, which determines how well a person can discriminate between two stimuli separated by a distance at a high level of contrast [Kniestedt & Stamper, 2003]. Visual acuity performance was measured by a Landolt Ring Chart to ensure that participants have adequate visual capabilities for the purpose of the study. The Landolt Ring Chart is a measure typically used in visual research to measure peripheral vision. Participants were required to have a visual acuity of 6/10 of better. This is the minimum standard for UK drivers [UK Government, n.d.]. The chart was 187cm away from participants under D65 light, which accurately simulates daylight [Lam & Xin, 2002; Xu et al., 2003]. Additionally, participants were screened for colour blindness and their auditory ability respectively using the Ishihara colour blindness test and asking participants if they were able to hear clearly.

Upon completion of the visual pre-screening tests, participants were sat before a laptop screen. The experiment was conducted in a laboratory with the lights switched off and the windows covered to exclude daylight, leading to the luminance and illuminance conditions mentioned in **Section 3.2**. Participants were informed that the primary experiment task required them to fixate on a central cross while also responding to peripheral targets that would appear intermittently throughout the experiment. Participants completed the experiment conditions in a counterbalanced order of distraction conditions, within which the sequence of numbers, letters or words were randomised for each participant.

Participants were instructed to look towards the fixation mark and to press a button as soon as possible upon detection of one of the peripheral targets. They were instructed that they could begin by informing the researcher they were ready. A button box was used to indicate target detection. Four individual buttons were displayed in a rectangular array to represent the locations of the targets on-screen **(Figure 3.2)**. For instance, if the target appeared in the top left of the screen, the top left button of the button box was required for the participant to be considered to have registered a valid response. Pressing a different button, or not pressing any button, was counted as a miss.

Figure 3.2 **Laptop and button box arrangement.** The experiment can be seen on the laptop monitor: in this instance, the participant would have to respond by pressing the bottom left button.



A distraction task was conducted simultaneously with the detection task. There were six blocks of trials, each using a different distraction task, with the block order being randomised. At the beginning of each block, participants received instructions on how to respond to each task. Participants were instructed to try their best for both the target detection and distraction tasks, rather than assuming one was more important than the other.

The complete experiment took 45 minutes, with each block taking 450s to complete, allowing 140 target detection trials. Before the next block of trials began, participants were reminded of the instructions for the next cognitive task during a short break, from which they were asked if they were ready to commence before the next trial began.

Results for the visual detection task to the peripheral discs were transcribed automatically to an Excel document. In contrast, the results for the distraction task performance were manually recorded by the researcher into an Excel document to determine if the participants were sufficiently distracted whilst they were engaged with the peripheral target task. From this, the results were transferred to IBM SPSS Statistics 29.0.1.1. to be further analysed.

3.5 Participants

Ethical approval was gained by the School of Architecture's Ethics Administrator (Application number 024441) **(Appendix A.iii)**. An a-priori power analysis was conducted using G*Power version 3.1 to determine the minimum sample size required to test the study hypothesis [Faul et al., 2007]. Results indicated the required sample size to achieve 99% power for detecting a medium effect was *N*=58 for a Mixed ANOVA (f = .2, 1 -ß = .99, p = .05). 59 participants were recruited and distributed amongst both younger (*n*=30, male=15) and older (*n*=29, female=20) participants.

If participants usually wore corrective lenses whilst driving, they were permitted to do so whilst conducting the experiment and conducted with habitual correction in place. Participants completed a consent form after reading the experimental information sheet and were paid £10 on completion of the experiment.

Specific ages were not reported by participants. Instead, they categorised themselves whether they were 18-25 years old or ≥60 years. These respectively related to the younger and older age groups. The range used to categorise young participants reflects that used by the UK Department for Transport to define young car drivers, for whom there is a high casualty rate when weighted by distance travelled [DfT, 2018b]. Similarly, ≥60 years was defined as the older age group because of the threshold presented by Haegerstrom-Portnoy et al. (1999), who show that this is the age related to the onset of significant impairment to spatial vision measures that are degraded under reduced contrast, luminance, or glare.

3.6 Research Design

The experiment used a 6×2 mixed design, with one within-subject factor of distraction condition (control, n-back=0, n-back=1, n-back=2, word generation, number fixation) and the between-subjects factor of age (young [≤25 years] vs. older [≥60 years]).

For target detection, there were two dependent measures: reaction time (measured in seconds) from onset of target to button press, and detection accuracy. Performance on the distraction tasks was characterised as the percentage of correct responses for each task.

3.7 Summary

This chapter presented the method used in an experiment exploring visual detection performance of participants to a visual detection task whilst simultaneously attending to distraction tasks entailing varying levels of cognitive load within an abstract environment. Tasks that have been recognised as associating with high cognitive load have been included here to compare with each other. An exploration into these factors could potentially inform future research designs. **Chapter 4** presents the results of this experiment.

Chapter 4: Distraction in relation to Visual Detection in an Abstract Environment – Results

4.1 Introduction

When driving, if a driver engages in non-driving related tasks at the same time, defined as distraction, their driving performance is impaired [Strayer & Drew, 2004]. However, previous research that has explored this issue typically presents the distraction task whilst participants are actively engaged with other driving related tasks, such as maintaining speed [Moran et al., 2020], maintaining headway (the distance between the car and lead vehicle) [Liang & Lee, 2010] and detecting driving related hazards [Burge & Chaparro, 2012]. These factors indicate that there are multiple aspects to driving that require cognitive, not just visual, effort [Briggs et al., 2016]. Consequently, the influence of distraction on visual detection generally is potentially influenced by the task of driving itself in previous research. A visual detection task devoid of real-world context could provide deeper insights into how distraction influences vision generally, which is the basis of this chapter. An experiment was conducted to explore distraction on visual detection, based on the method explained in the **Chapter 3**. There was 1 research question, with 2 associated hypotheses, of the data analysis within this experiment, explained in **Chapter 2, Section 2.9**:

Research Question 1: Does the degree of cognitive load within a distraction task influence visual detection performance within an abstract task?

- Hypothesis 1a: Higher cognitive load will be associated with lower accuracy and slower response rates when responding to a simultaneous task.
- Hypothesis 1b: Older people will be less accurate and slower than younger people when distracted and conducting a simultaneous task.

In addition to addressing the research aims, findings from this experiment were intended to inform the distraction task used in the second empirical experiment within this thesis **(Chapter 6 and 7)**: exploring how distraction and passengers influence driving performance. In doing so, the distraction task most detrimental to vision generally will be determined before the distraction is applied within the driving context to assess its influence of driving performance.

First, the data were assessed for any outliers. Normality was then assessed to determine which analytical test to use for the inferential statistics. Afterwards, the data were analysed to address the research aims before a discussion of the findings in relation to previous literature and theory are explored. Finally, the chapter is summarised for the key points raised.

4.2 Cleaning the Data

Data were screened for technical faults related to processing of responses. Afterwards, data were assessed between participants to screen if there were any outliers that should be removed from further analysis. Note that for reaction time data, any targets that were missed were considered missing data for reaction time too. Distraction performance was measured as a percentage of correct responses in relation to the sequence of items that were read aloud in each distraction condition.

4.2.1 Technical Faults

There were initially technical issues with some of the participants' registered responses. This included a system error that occurred within the younger group (n = 1) for n-back=0 and n-back=1. Likewise, in the older group there was a system error for all distraction conditions (n = 1) and for n-back=2 (n = 1).

Additionally, there was one participant that requested to not complete n-back=2 due to finding the task too difficult, whilst also using only one response button within the Number Fixation task, meaning that the participant did not register which location they observed the visual target within the Number Fixation distraction block of trials.

Such technical difficulties meant that the sample between each distraction conditions varied, with the valid sample to be assessed being shown in **Table 4.1**.

Table 4.1 **Sample size** for each distraction condition after assessing for valid responses **due to technical issues**.

Distraction Condition	Responses	
None	*Younger: 30*	*Older: 28*
N-back=0	*Younger: 29*	*Older: 28*
N-back=1	*Younger: 29*	*Older: 28*
N-back=2	*Younger: 30*	*Older: 26*
Word Generation	*Younger: 30*	*Older: 28*
Number Fixation	*Younger: 30*	*Older: 27*

4.2.2 Outlying Participants: Reaction Time

Following the process of cleaning data that were not valid, data were assessed for whether any outlying data were present. Outlying data is defined as values that differ by three times the standard deviation of the mean, which lead to an under- or overestimation of the resulting value when whole datasets are analysed [Kwak & Kim, 2017]. As such, identifying and correcting for outliers was essential. Data were thus assessed for outlying data between each participant, between each distraction condition.

When measuring reaction time, there was 1 participant (younger) that provided outlying data in 4 distraction conditions: None, n-back=0, n-back=2, and Central Number Task. Omitting this participant changed the normality distribution, leading to 1 participant (older) providing outlying data in the "None" distraction condition. Consequently, these outlying participants were omitted from further analysis when related to reaction times, with no further outliers being identified. This meant that data were analysed for 56 participants. Subsequent analyses were therefore distributed between younger (n = 29) and older (n = 27) participants.

4.2.3 Outlying Participants: Detection Accuracy

When measuring detection accuracy, there were 6 participants (older n=4) that provided outlying data in 3 distraction conditions: None (older n = 2), n-back=0 (older n = 2; younger n = 1), n-back=2 (younger n = 1). To avoid omitting so many datapoints, data were log-transformed to base 10 [lg_{10}]. Such a transformation uses the original distribution to then transform all the points equally so that the scale becomes narrower, potentially more likely to lead to a bell shape curve called a Gaussian distribution that relates to a normal distribution [Curran-Everett, 2018]. A normal distribution assumes that some values fall below 0 and some fall above, whereas a lognormal distribution for which the transformation relies upon assumes that all values will be positive integers [Gualandi & Toscani, 2019]. As participants are unable to detect less than 0 targets, this was considered an appropriate measure to take.

When a lg_{10} transformation was applied, there was 1 participant that provided outlying data (younger) for the n-back=1 distraction condition. Consequently, these outlying data were omitted from further analysis when related to detection accuracy, with no further outliers being identified. This meant that log transformed data were analysed for 58 participants. Subsequent analyses were therefore distributed between younger (n = 29) and older (n = 28) participants.

4.3 Normality

As there were >50 participants in this experiment, Kolmogorov–Smirnov tests were used to assess normality in these data [Razali & Wah, 2011] **(Table 4.2)**. Normality analyses were conducted on the reaction time data that were not transformed, but the information presented here relates to the lg_{10} detection accuracy data.

Table 4.2 **Normality** of data for **Reaction Time and Detection Accuracy**. An asterisk besides the figure indicates significance at the .05 level.

Measure	**Distraction Condition**	**Descriptives**			**Normality Test**
		Mean	Skewness	Kurtosis	Kolmogorov-Smirnov
Reaction Time	None	.60	.38	-.34	p = .200
	N-back=0	.61	.62	.21	p = .022*
	N-back=1	.68	.58	-.67	p = .180
	N-back=2	.77	.38	.02	p = .110
	Word Generation	.77	.47	-.30	p = .097
	Number Fixation	.60	.54	.30	p = .200
Detection Accuracy	None	.61	.03	-.77	p = .200
	N-back=0	.69	-.21	-.86	p = .031*
	N-back=1	.96	-.47	-.44	p = .200
	N-back=2	1.37	.04	-.44	p = .200
	Word Generation	1.27	.22	-1.64	p = .047*
	Number Fixation	.67	-.42	.00	p = .200

For both reaction time and detection accuracy data, normality is mostly assumed (*p* > .05). The exceptions are n-back=0 for reaction time and detection accuracy, and Word Generation for detection accuracy. Whilst non-normal data were therefore reported, parametric tests were considered permissible. This is because whether a parametric or non-parametric test is used influences the null hypothesis (that the independent variable has not had an influence on the dependent variable) as being rejected even though it is accurate and shouldn't be rejected, called a Type 1 error [de Gil et al., 2013]. Actual Type I error rates approximate nominal rates for parametric tests (t tests and OVA [variance type]-tests) that are not altered in a notable manner if the assumption of normality is not violated severely [Nimon, 2012]. Given that the *p* (significance) value is above .001 within this data for the non-normal conditions, parametric tests are appropriate to use across all measures [Greenland et al., 2016].

4.4 Inferential Statistics Analysis

A 6 (distraction condition [within]) x 2 (age [between]) mixed ANOVA was conducted with the participants' data to explore the influence of different distractions, with their associated different levels of cognitive load and modality, on abstract visual detection. First, this interaction was explored for abstract visual detection reaction time, and then was explored for abstract visual detection accuracy.

The following analyses will be divided into exploring the interaction between distraction conditions (n-back=0, n-back=1, n-back=2, Word Generation, Number Fixation, and None), between age group (younger and older), and any interaction effects between distraction condition and age.

4.4.1 Reaction Time

Homogeneity of variances was assessed in relation to reaction times across all 6 distraction conditions between age groups using Levene's Test. Results from Levene's Test indicates that the variances between the different age groups were not unequal across all distraction conditions, except n-back=2 **(Table 4.3)**. In much the same respect as normality not being altered in a notable manner if the assumption of normality is not violated severely, ANOVAs are robust to violations in homogeneity of variance, provided the sample sizes between conditions are similar [Vorapongsathorn et al., 2004; Schmider et al., 2010]. No corrections were therefore used for variances between the conditions for this analysis.

Table 4.3 Levene's Test statistic to indicate **homogeneity of variance of reaction times** across **all distraction conditions**. An asterisk besides the figure indicates significance at the .05 level.

Distraction Condition	**Levene's Test**
None	*F*(1,56) = .112, *p* = .740
N-back=0	*F*(1,53) = .031, *p* = .862
N-back=1	*F*(1,53) = .856, *p* = .362
N-back=2	*F*(1,52) = 4.636, *p* = .039*
Word Generation	*F*(1,54) = .230, *p* = .635
Number Fixation	*F*(1,53) = .061, *p* = .807

Another important consideration was to check whether the variances between all possible combinations of conditions in the ANOVA are equal. This is determined by Mauchley's Sphericity test [Hinton et al., 2004], which found that there were unequal variances between the different combinations ($W(14) = .227$, $p < .001$). Greenhouse-Geisser corrections were therefore used in the analysis, which corrects violations of sphericity: when the variances of differences between all combinations of groups are not equal [Hinton et al., 2014]. Sphericity is important to consider because if the variances of differences between conditions differ, the analyses may be unduly influenced by the research design rather than the variables being explored.

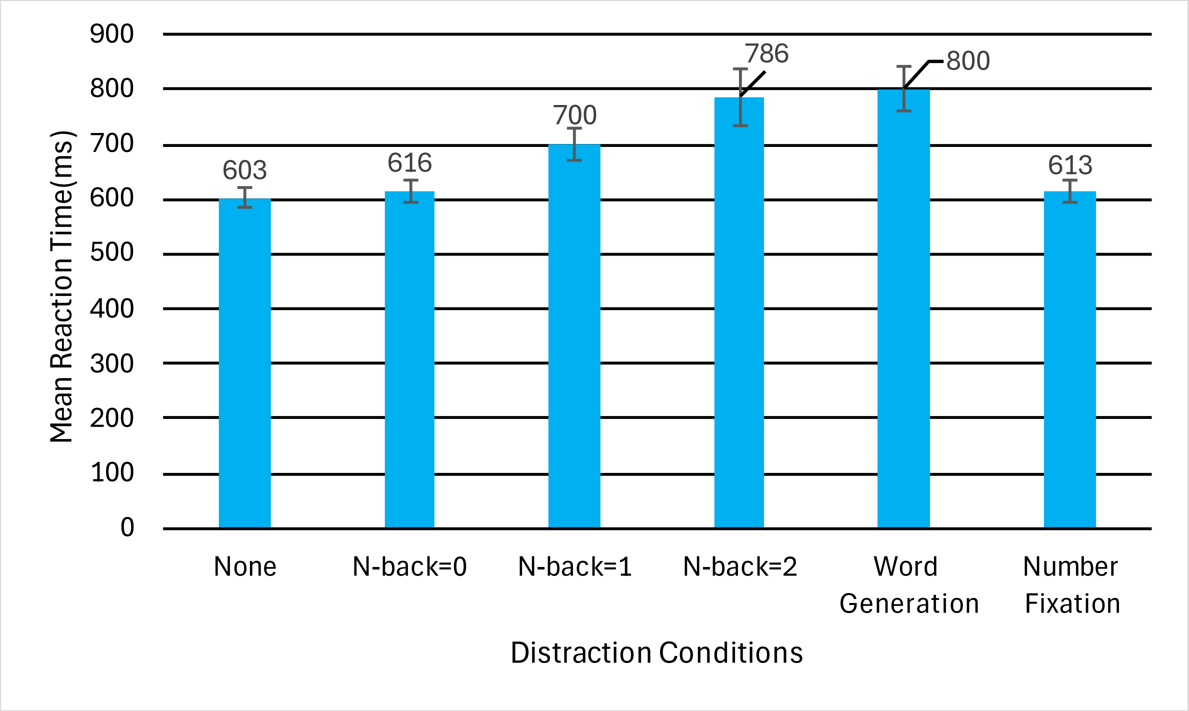
There was a significant difference between performance within the distraction conditions and visual detection speed within the peripheral target detection task ($F(3.229,96.871) = 41.059$, $p < .001$, $n_p^2 = .578$). Participants were fastest to respond to the targets when no distractions were presented (x = 603ms), and slowest when presented with the Word Generation condition (x = 800ms). Mean reaction time was close to Word Generation when participants were presented with the n-back=2 condition (x = 786ms). Similarly, mean reaction time was close between n-back=0 (x = 616ms) and Number Fixation (x = 613ms). Reaction time for n-back=1 was almost half-way between n-back=0 and n-back=2 (x = 700ms). All pairwise comparisons are shown in **Table 4.4**.

Table 4.4 **Pairwise comparison of reaction time between all distraction conditions.** Figures in parentheses indicate significance level. An asterisk besides the figure indicates significance at the .05 level.

Pairwise Comparison	**N-back=0**	**N-back=1**	**N-back=2**	**Word Generation**	**Number Fixation**
None	-.013(1.000)	-.097(<.001*)	-.183(<.001*)	-.197(<.001*)	-.010(1.000)
N-back=0		-.084(<.001*)	-.169(<.001*)	-.184(<.001*)	.003(1.000)
N-back=1	-.084(<.001*)		-.086(.003*)	-.100(<.001*)	.087(<.001*)
N-back=2	-.169(<.001*)	-.086(.003)		-.014(1.000)	.173(<.001*)
Word Generation	-.184(<.001*)	-.100(<.001*)	-.014(1.000)		.187(<.001*)

These results indicate distractions are more detrimental to visual detection speed in proportion to the amount of cognitive load presented in the distraction task **(Figure 4.1)**.

Figure 4.1 Mean **reaction time** of participants responding to visual targets **between the different distraction conditions**. Taller bars indicate slower reaction times.



Adjusted for the Bonferroni correction, there was a significant effect of age on visual detection speed within the peripheral target detection task (*F*(1,51) = 18.409, *p* < .001, n_p^2 = .380). A 110ms difference was found between younger and older participants, with younger participants having a faster reaction time (x = 631ms, CI = 600-662ms) than older participants (x = 741ms, CI = 699-784ms).

Additionally, there was a significant interaction between distraction conditions and age group within the peripheral target detection task (*F*(3.229,96.871) = 5.075, *p* < .002, n_p^2 = .145). Performance across distraction conditions was similar between age conditions in some respects. For instance, both age groups were fastest at responding when no distractions were presented compared to when any distraction was presented. Similarly, both younger and older showed a similar level of decrements to their visual detection when presented with n-back=2 compared to n-back=1 (younger: 99ms difference, older: 72ms difference), and Number Fixation being the condition that depreciated visual performance the least for both younger and older participants.

However, there were many differences. This includes the difference between n-back=0 compared to when no distractions were presented (younger: 5ms difference, older: 22ms difference), n-back=1 and n-back=0 (younger: 41ms difference, older: 127ms difference), and opposing trends between n-back=2 and Word Generation (younger: 31ms difference [slower for n-back=2], older: 60ms difference [slower for Word Generation]). The n-back task with the greatest cognitive load (n-back=2) was the most detrimental of all n-back tasks for both age groups, but the distraction task that was overall the most detrimental between the age groups differed **(Figure 4.2)**.

4.4.2 Detection Accuracy

Homogeneity of variances was assessed in relation to detection accuracy across all 6 distraction conditions between age groups using Levene's Test. Results from Levene's Test indicates that the variances between the different age groups were not unequal across all distraction conditions, except None **(Table 4.5)**. Following the logic presented in **Section 4.4.1**, no corrections were used for variances between the conditions for this analysis.

Figure 4.2 Mean **reaction time** of participants responding to a visual target, **compared between age and different distraction conditions**. Taller bars indicate slower reaction times.

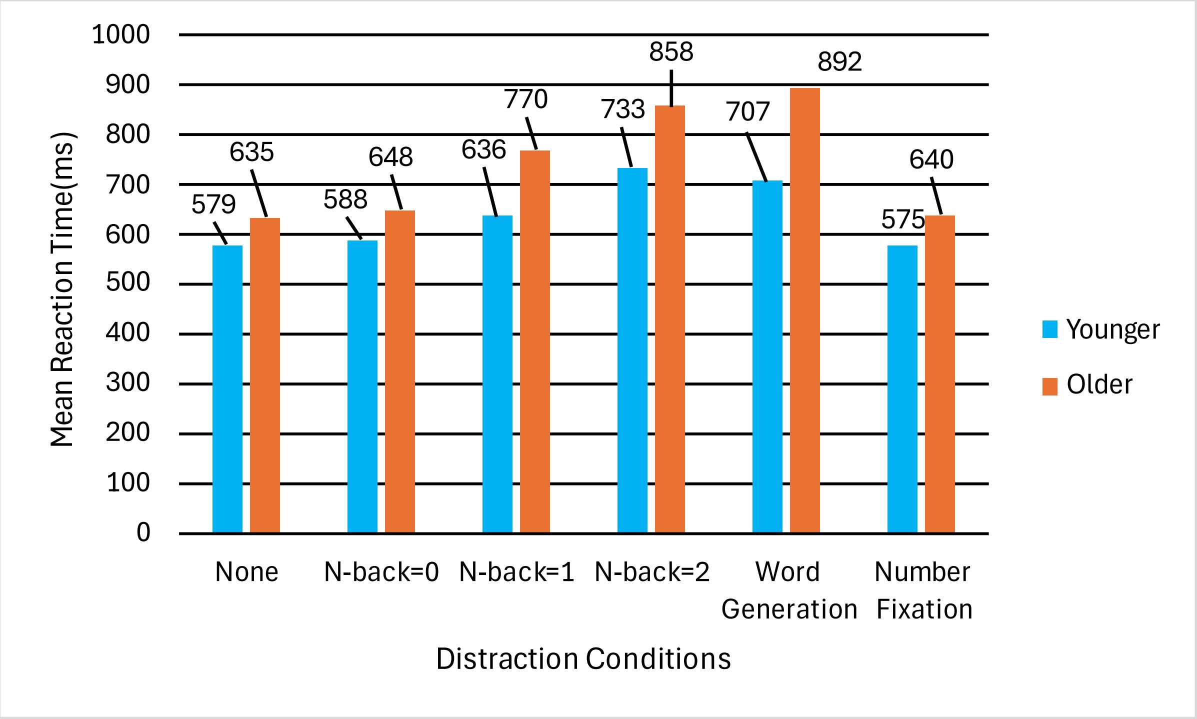


Table 4.5 Levene's Test statistic to indicate **homogeneity of variance of detection accuracy** across **all distraction conditions**. An asterisk besides the figure indicates significance at the .05 level.

Distraction Condition	**Levene's Test**
None	*F*(1,49) = 5.142, *p* = .032*
N-back=0	*F*(1,52) = 1.965, *p* = .171
N-back=1	*F*(1,55) = .001, *p* = .979
N-back=2	*F*(1,54) = 3.069, *p* = .089
Word Generation	*F*(1,55) = 2.014, *p* = .165
Number Fixation	*F*(1,51) = 3.483, *p* = .072

The data were also assessed using Mauchley's Sphericity test to determine whether the variances between all possible combinations of conditions in the ANOVA are equal. This found that there were unequal variances between the different combinations ($W(14) = .380$, $p < .001$). Greenhouse-Geisser corrections were therefore used in the analysis.

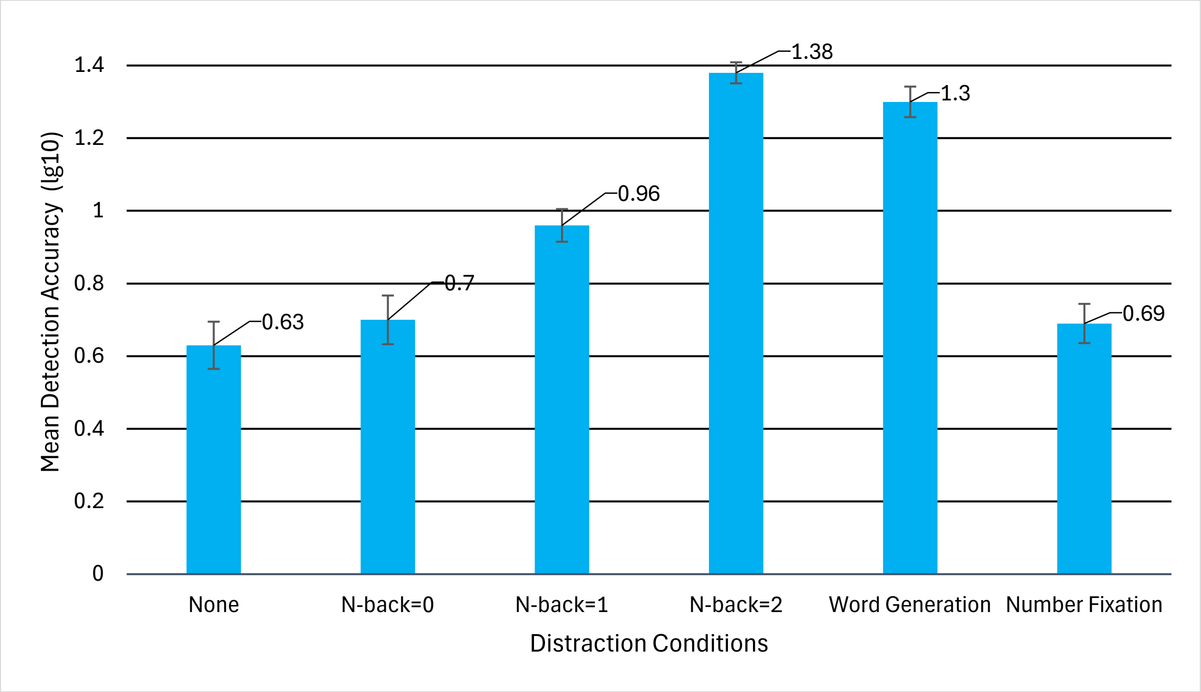
There was a significant difference between distraction conditions and abstract visual detection accuracy within the peripheral target detection task ($F(3.780,154.970) = 48.804$, $p < .001$, $n_p^2 = 1.00$). Note that the data were reported in terms of how many targets were missed, lower values indicate better accuracy. All pairwise comparisons are shown in **Table 4.6**.

Table 4.6 **Pairwise comparison of detection accuracy between all distraction conditions.** Figures in parentheses indicate significance level. An asterisk besides the figure indicates significance at the .05 level.

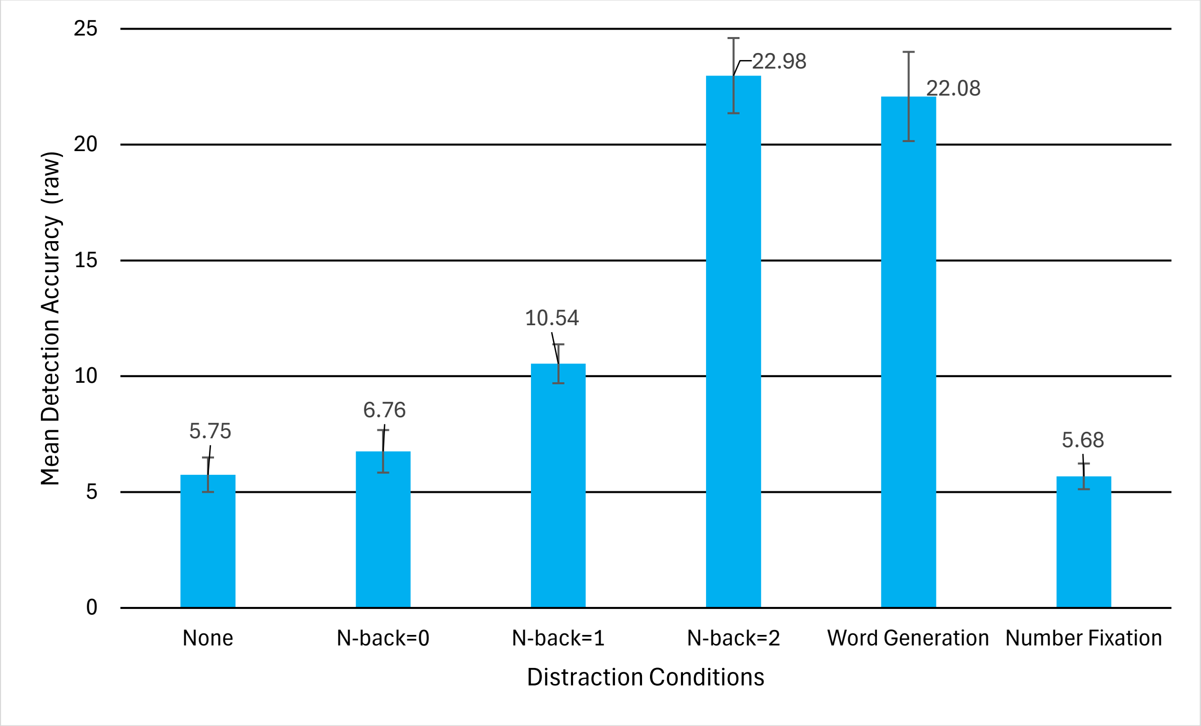
Pairwise Comparison	**N-back=0**	**N-back=1**	**N-back=2**	**Word Generation**	**Number Fixation**
None	-.064(1.000)	-.327(<.001*)	-.743(<.001*)	-.664(<.001*)	-.059(1.000)
N-back=0		-.263(.071)	-.680(<.001*)	-.601(<.001*)	.004(1.000)
N-back=1	-.263(.071)		-.417(<.001*)	-.338(<.001*)	.267(<.001*)
N-back=2	-.680(<.001*)	-.417(<.001*)		.079(1.000)	.684(<.001*)
Word Generation	-.601(<.001*)	-.338(<.001*)	.079(1.000)		.605(<.001*)

Accuracy was best when no distraction was presented ($lg_{10} x$ = .63; untransformed x = 5.75 targets missed) and least accurate when presented with the n-back=2 condition ($lg_{10} x$ = 1.38 untransformed x =22.98 targets missed), which is like Word Generation ($lg_{10} x$ = 1.30; untransformed x = 22.08 targets missed). Participants were of similar accuracy levels between n-back=0 ($lg_{10} x$ = .70; untransformed x = 6.76 targets missed) and Number Fixation ($lg_{10} x$ = .69; untransformed x = 5.68 targets missed). There was a larger difference in accuracy ($lg_{10} x$ difference = .42; untransformed x difference = 12.44) between n-back=2 ($lg_{10} x$ = 1.38; untransformed x =22.98 targets missed) and n-back=1 ($lg_{10} x$ = .96; untransformed x = 10.54 targets missed), and a large difference in accuracy (lg_{10} x difference = .26; untransformed x difference = 3.78) between n-back=1 ($lg_{10} x$ = .96; untransformed x = 10.54 targets missed) and n-back=0 ($lg_{10} x$ = .70; untransformed x = 6.76 targets missed). These results indicate distractions are more detrimental to visual detection accuracy in proportion to the amount of cognitive load presented in the distraction task **(Figure 4.3)**.

Figure 4.3 Mean lg_{10} (a) and untransformed [raw] (b) **detection accuracy** of participants responding to visual targets between the **different distraction conditions**. Taller bars indicate lower accuracy.



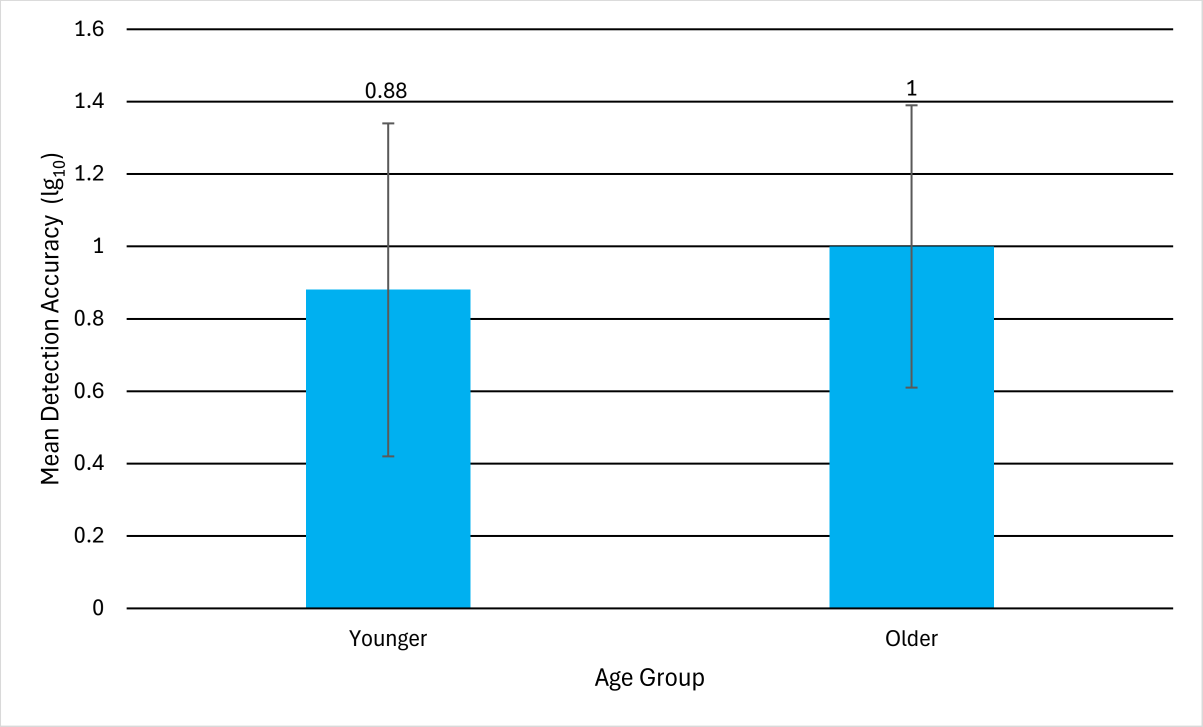
(a)



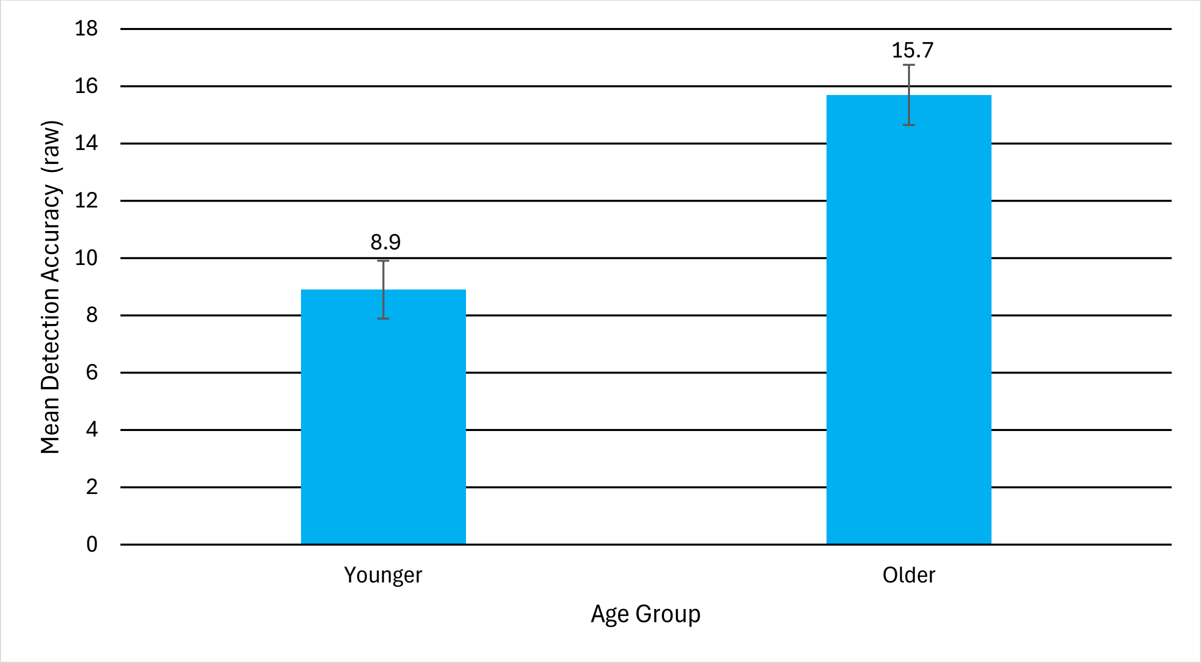
(b)

Adjusted for the Bonferroni correction, there was a marginal non-significant effect of age on visual detection accuracy within the peripheral target detection task (*F*(1,41) = 4.034, *p* = .051, n_p^2 = .501) **(Figure 4.4)**. Detection accuracy therefore is highly likely to be influenced by age in this experiment, but caution must be applied due to the p value being >0.05, with younger participants missing fewer targets (lg_{10} target misses *x* = .88; untransformed target misses *x* = 8.90) compared to older participants (lg_{10} target misses *x* = 1.00; untransformed target misses *x* = 15.70). In contrast, there was a non-significant interaction between distraction conditions and age group within the peripheral target detection task (*F*(3.780,154.970) = 1.386, *p* = .243), meaning that the influence of distraction was not moderated by age.

Figure 4.4 Mean lg_{10} (a) and untransformed [raw](b) **detection accuracy** of participants responding to visual targets, compared **between age**. Taller bars indicate lower accuracy.



(a)



(b)

4.5 Summary

This experiment was conducted to explore the influence of level of cognitive load on visual detection within an abstract environment. Results from this experiment demonstrated that distraction was detrimental to both reaction time and detection accuracy, causing reaction times to be slower and less accurate. Reaction time was moderated by age, in which performance differed between younger and older participants. Additionally, accuracy was influenced by age, but there was no interaction between age and distraction task on the number of peripheral targets missed within this experiment. The distraction tasks therefore are indicated as conveying a similar decrement to visual performance accuracy between conditions, irrespective of whether the participant is younger or older. These results will be further discussed in relation to wider theory and previous literature in **Chapter 8**, especially addressing the hypotheses outlined in **Section 4.1**.

This chapter aimed to provide an insight into the most detrimental distraction task to visual detection without the influence of drivers' mental models that they retain (schema). To further these findings, the results in this chapter will inform the distraction task that will be used in a hazard perception experiment, whereby visual detection will be contextualised in a driving scene. Such an investigation will provide insights into how drivers' schemas moderate the detrimental effects of distraction on visual performance.

To further inform the subsequent hazard perception experiment, **Chapter 5** will explore actual RTC data to assess various aspects of passenger presence in relation to drivers' risk of an RTC. The results of this exploration will be to inform the most at risk driver and passenger age groups to investigate in the hazard perception experiment.

Chapter 5: Interaction between Distraction, Driver-Passenger Age, and Passenger Seating on RTC Risk

5.1 Introduction

The previous experiment explored the influence of cognitive load due to distraction on visual detection in an abstract environment **(Chapters 3 and 4)**. That experiment explored how different levels of cognitive load contributes to visual detection performance on discs in the periphery of participants' visual field. Driving performance is considered to relate to RTC risk [Beede & Kass, 2006; Engström & Markkula, 2007], although the experiment conducted in the abstract environment did not directly observe the occurrence of RTCs. As such, the interaction between distraction and driving performance in the experiment is assumed to be associated with the risk of an RTC. In other words, whether distraction influences the risk of an RTC was not measured. Analysing RTC data will provide further insights into this matter.

There are various distractions that could be considered, but whilst many distractions relate to specific tasks, one environmental potential distraction whilst driving that can be concurrent to other distractions is the presence of passengers. Previous literature provides conflicting findings about the influence of passengers on RTC risk, whereby some research indicates that passengers reduce the likelihood of a driver being involved in an RTC [Vollrath et al., 2002; Chung et al., 2014; Charlton & Starkey, 2020], whereas others do not [Huisingh et al., 2015; Caird et al., 2018; Green et al., 2022]. The issue is that different studies that explore this topic focus on different factors, such as distraction [Laberge et al., 2004] and passenger age [Rueda-Domingo et al., 2004].

Additionally, seating position is an important consideration [Smith & Cummings. 2004], i.e. whether the passenger is seated adjacent to the driver in a front seat, or behind the driver in a rear seat. For instance, mobile phone conversations relate to the cognitive load that depreciates the drivers' ability to attend to the driving task. Whilst conversation generally is the most prominent distraction on minor roads [Robbins & Fotios, 2021] and mobile phone conversations are more prominent on major roads [Robbins & Fotios, 2022], the detriments in driving performance are more pronounced in mobile phone conversations compared to in-car passenger conversations [Charlton, 2009]. As such, there was 1 research question, with 3 associated hypotheses, of the data analysis within this study, explained in **Chapter 2, Section 2.9**:

Research Question 2: Does the interaction of distraction, passenger and driver age, and passenger seating position influence the risk of a driver being involved in an RTC?

- Hypothesis 2a: RTC risk will be higher when driving alone compared to driving with passengers for all age groups, except for younger drivers travelling with younger passengers.
- Hypothesis 2b: In the presence of passengers, cognitive distraction will be associated with the higher risk of RTCs.
- Hypothesis 2c: A passenger in the front seat will lead to lower RTC risk than a passenger in the rear seat.

A potential reason for mobile phone conversations being more detrimental to driving performance than in-car passenger conversation is that the person speaking on the phone is unable to see the driving scene, meaning that they do not moderate the conversation as effectively as if they were inside the vehicle with the driver **(Figure 5.1 and 5.2)** [Charlton, 2009]. As such, whether passengers have a clear view of the road ahead may be an important factor related to RTCs.

The seating position of passengers could consequently be important for drivers' being involved in an RTC. Indeed, passengers in the front seats have a clearer view of the road ahead compared to those in the rear seats, especially those immediately behind the front seats, meaning that the RTC risk could be lower when passengers are seated in the front compared to the rear. To the researcher's awareness, no study has explored how distraction, driver and passenger age interactions, and passenger seating position interact for RTC risk.

Figure 5.1 **Top-view of a car, showing the inside of the vehicle** [carbodydesign.com, 2008]. Note that this shows the layout of a car with the driving seat being the leftmost front seat, whereas the driver's seat in the UK car seat set-up is in the rightmost front seat.

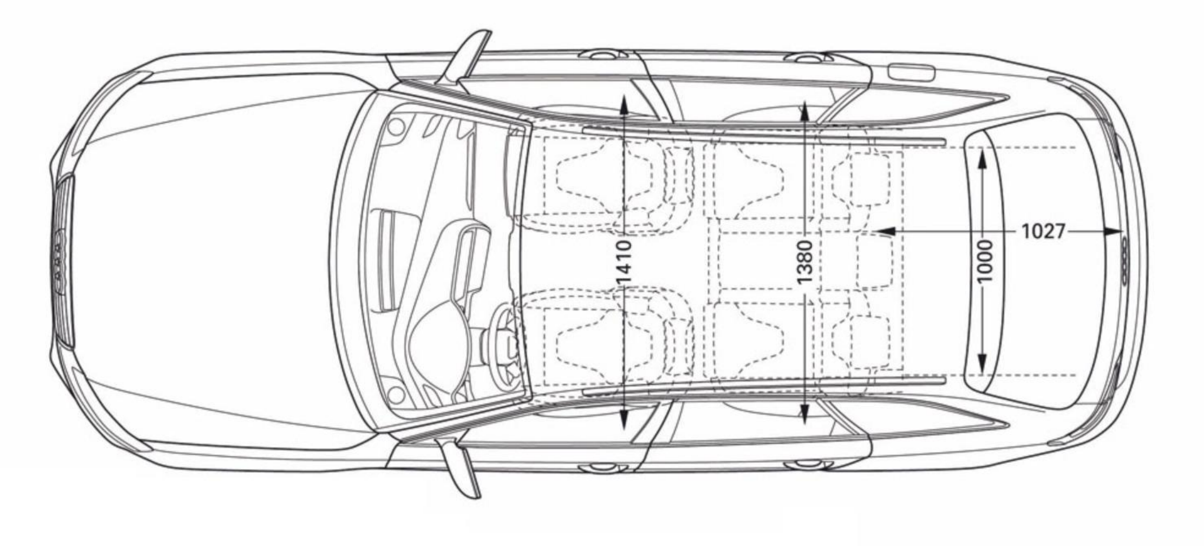
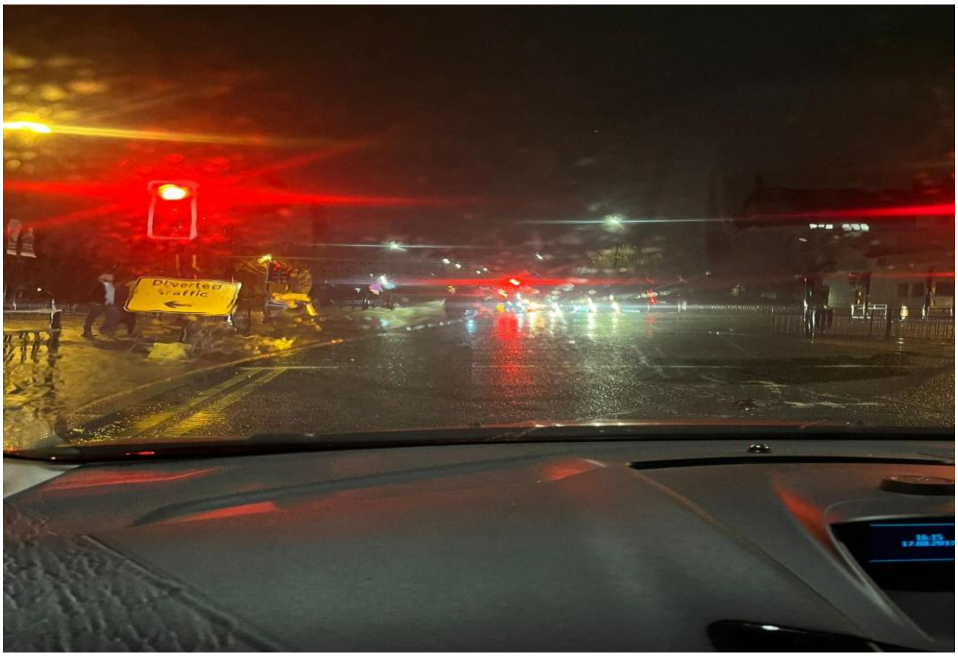


Figure 5.2 **Passenger view** when seated in the **front passenger seat (a)** or the **rear behind the driver seat (b)**. The specifications are based on a UK car set-up.



(a)

(b)

Police records of RTCs in Great Britain (England, Scotland, and Wales) are captured in STATS19 [DfT, 2023]. The STATS19 database provides information including contributory factors such as distraction when relevant, location, time, injury severity, number of vehicles, and passenger age and seating position. However, the presence of passengers and their associated information is only recorded when they are a casualty, meaning that they could be involved in an RTC but not be reported if they are not injured. Another limitation is that, whilst distraction inside the vehicle is reported, it does not define what type of distraction it was.

The Fatality Analysis Reporting System (FARS) is a record of all police reported RTCs in the USA which involved a fatality. Initiated in 1975 by the US Department of Transportation (DoT), FARS is a record of police reported RTCs that occur across all US States on a public highway in which a person dies within 30 days of the incident [DoT, 2010]. In contract with STATS19, FARS includes information relevant to an analysis of passenger distraction, including passengers involved in RTCs that both were and were not injured, as part of the wider suite of road safety measuring tools including the Crash Reporting Sampling System and the Crash Investigation Sampling System [DoT, 2010]. The principle that guides its use is that it provides an objective basis for evaluating motor vehicle safety standards and highway safety programs, measuring highway safety, and suggesting solutions [Koehler & Brown, 2009].

An analysis was conducted using the FARS data to explore the influence of passengers on drivers’ risk on an RTC, and whether their influence is moderated by seating position, i.e. whether passengers were seated in the front or rear. Insights will be provided into how distraction in real driving impacts driving safety by addressing 1 research question, with 5 associated hypotheses, of the data analysis within this study, explained in **Chapter 2, Section 2.9.**

5.2 Method

RTC information from 2010 to 2019 within FARS data were chosen to inform the passenger analysis. The data range started at 2010 because that is the year in which FARS commenced recording distractions: the range ends in 2019 to avoid any influence of travel restrictions associated with the COVID pandemic starting in 2020. That event may have affected, for example, the number of drivers travelling with passengers. Indeed, Ku et al. (2021) indicated that there were more passengers travelling with drivers compared to before the pandemic occurred.

The nature of distraction is recorded in one FARS spreadsheet (‘*Distraction*’), whereas a second spreadsheet reported information about the car occupant involved in the RTC (‘*Person*’). Within these, RTC incidents were reported over one row each for ‘*Distraction*’, but varied in *‘Person*’, depending upon how many people were affected by the RTC. This meant that the information from each spreadsheet was required to be merged before analysis could occur.

To merge these FARS spreadsheets, all information within *‘Distraction*’ was first transferred into a tab of a blank spreadsheet. Then, relevant columns from *‘Person*’ were transferred into a separate tab within this new spreadsheet. Of the 119 columns within *‘Person*’, five columns were transferred **(Table 5.1)**. Data from the National Center for Statistics and Analysis (2022) informs **Table 5.1,** which presents the columns incorporated from both original spreadsheets, and **Table 5.2**, which presents the categories within the columns containing nominal data.

Table 5.1 **Columns taken from** the ‘*Distraction*’ and ‘*Person*’ spreadsheets from **the FARS database**.

Spreadsheet		**Column Name**	**Description of Variable**	**Type of Data**
Distraction	Person	ST_CASE	RTC incident	Scale
Distraction	Person	VEH_NO	Vehicle number	Ordinal
Distraction		MDRDSTRD	Distraction category	Nominal
	Person	AGE	Age of car occupant	Scale
	Person	PER_TYP	Nature of car occupancy	Nominal
	Person	SEAT_POS	Seating position	Nominal

Within the distraction variable, the data were tidied so that only specific distractions, or the category ‘*No Distraction*’, would be included in the analysis, meaning that all categories from ‘*No Driver Present*’ downwards in **Table 5.2** were excluded. This decision was taken because if reporting of the presence of a distraction is vague, there may have been more uncertainty about whether distraction contributed to the RTC compared to when specific distractions are recorded. Within the passenger type variable, only drivers and passengers in transport were incorporated, meaning that drivers and passengers that were in the vehicle, but it was stationary were excluded. Including any other categories would have diverted the focus from analysing the influence of passengers on drivers’ RTC risk within typical driving. Finally, all first to fourth seats were included in the SEAT_POS column, whereas all other categories were excluded, because these seats represented typical seating positions for drivers and passengers, but the excluded categories did not.

Table 5.2 **Categories of nominal data included in the analysis.** Text in this table is presented here to show all categories available from FARS, but text in red is excluded from the current analysis.

Column Name		
MDRDSTRD	PER_TYP	SEAT_POS
Not Distracted	Driver of a Motor Vehicle in Transport	Not a Motor Vehicle Occupant
Looked but Did Not See	Passenger of a Motor Vehicle in Transport	Front Seat – Left Side (Driver's Side)
By Other Occupant(s)	Occupant of a Motor Vehicle Not in Transport	Front Seat – Middle
By A Moving Object in the Vehicle	Occupant of a Non-Motor Vehicle Transport Device	Front Seat – Right Side
Whilst Talking/Listening to a Mobile Phone	Pedestrian	Front Seat – Other
Whilst Manipulating a Mobile Phone	Bicyclist	Front Seat – Unknown
Whilst Adjusting Audio/Climate Controls	Other Cyclist	Second Seat – Left Side
Whilst using Integral Vehicle Components	Person on Personal Conveyances	Second Seat – Middle
Whilst Reaching for Device/Object in Vehicle	Unknown Occupant Type in a Motor Vehicle Transport	Second Seat – Right Side
Distracted by Outside Person/Object/Event	Persons in/on Buildings	Second Seat – Other
Eating or Drinking	Unknown Type of Non-Motorist	Second Seat – Unknown
Smoking		Third Seat – Left Side
Other Mobile Phone Related		Third Seat – Middle
No Driver Present		Third Seat – Right Side
Distraction/Inattention		Third Seat – Other
Distraction/Careless		Third Seat – Unknown
Careless/Inattentive		Fourth Seat – Left Side
Distraction (Distracted), Details Unknown		Fourth Seat – Middle
Inattention (Inattentive), Details Unknown		Fourth Seat – Right Side
Not Reported		Fourth Seat – Other
Lost in Thought/Daydreaming		Fourth Seat – Unknown
Other Distraction		Sleeper Section of Cab (Truck)
Unknown if Distracted		Other Passenger in Enclosed Passenger or Cargo Area
		Other Passenger in Unenclosed Passenger or Cargo Area
		Other Passenger in Passenger or Cargo Area, Unknown Whether or Not Enclosed
		Trailing Unit
		Riding on Vehicle Exterior
		Not Reported
		Unknown/Reported as Unknown

To enhance the ease of analysis, the RTC cases were checked to observe if they constituted one or multiple rows of data. Overall, the 793,826 individual rows of data for that date range related to 348,591 RTCs. There are more data rows than RTC events because there was variability in the number of both vehicles and casualties that were involved in each RTC.

For the current analysis, only drivers with or without passenger(s) in a single vehicle were included. These were referred to in the spreadsheet as two tabs: '*Unique Vehicle*' and '*Single Vehicle – Multiple Cases*' respectively. Any cases involving multiple vehicles were disregarded because needing to check all 793,286 rows of data manually would have been likely to cause the potential for human error to rise, complemented by the increased time that this task would have taken. Additionally, the influence of distraction on each vehicle involved may have been different but would not have been possible to determine from the way this data have been reported and tidied.

Data were filtered between the '*Unique Vehicle'* and '*Single Vehicle – Multiple Cases*' tabs to inform the analysis that explored distraction for each driver and passenger. Drivers when they were driving alone, or when they were with passengers, were respectively represented by these tabs. A new series of spreadsheets were then used to filter these data by age of driver, and the associated passengers they were transporting at the time of the RTC.

Drivers were then filtered for age in both tabs. For '*Unique Vehicle*', no further filtering work was required once the data were identified for whether the driver was younger (18-25), middle-aged (30-60), or older (65+). These age categories are informed by changes that occur with the ageing process, with younger drivers being more prone to boredom than older drivers [Dahlen et al., 2004] and older drivers having higher detriments to their vision than younger drivers [Anstey et al., 2005]. Additionally, these age categories are those identified in previous road safety literature [Waller, 1991; Shekari Soleimanloo et al., 2017; Shaaban et al., 2020; Zhao & Yamamoto, 2021]. In contrast, within the drivers that were filtered for age in '*Single Vehicle – Multiple Cases*', the data were screened so that all drivers between each age category would be identified, then the passengers associated with each driver age category would be identified. Finally, the data from the '*Unique Vehicle*' tab related to the relevant driver age category were transferred to the new spreadsheet, where the data could then be analysed for all drivers and all passengers.

A final point of consideration was about whether to include all ages of drivers. Individual States within the US vary in when they deem drivers to be of legal age to drive, although 18 is the minimum legal age in the most conservative ones [Governors Highways Safety Association, 2023]. As such, drivers involved with RTCs that were under 18 years of age were excluded, given that they would have not been the legal age to drive so would have not been associated with a typical driving situation. Next, to provide discrete age groups, the RTC cases were filtered into “younger” (18-25), “middle-aged” (30-60), and “older”. There were 229,398 data points included (28.92% of raw data) after cleaning the data (Driver *n* = 176,736; Passenger(s) *n* = 52,662). Finally, the data where passengers were present were assessed to include only those where one passenger was present rather than multiple passengers, reducing the RTC cases further by 60.6% from 52,662 to 20,754. **Table 5.3** presents how these figures are divided between different passenger age groups.

Table 5.3 RTC frequencies for drivers with one, and without, passenger.

Driver Age	No Passenger Frequencies	Passenger Age Group	With Passenger Frequencies
Younger	53,325	*Younger*	5,669
		Middle-Aged	808
		Older	57
Middle-Aged	95,041	*Younger*	3,150
		Middle-Aged	6,432
		Older	636
Older	28,370	*Younger*	252
		Middle-Aged	631
		Older	3,119

5.3 Results

Odds ratios (ORs) can be used to quantify the strength of the association between risk factors and outcomes. Odds and ORs relate to probabilities of binary outcomes across two levels of two variables [Norton et al., 2018]. An example is that ORs would be used when exploring the difference in risk between the risk of an RTC whilst a driver is driving alone and distracted instead of not distracted, compared to the risk of an RTC whilst a driver is driving with a passenger and distracted instead of not distracted.

Within single variables with multiple levels, relative risks (RRs) are used for calculating the risk of an outcome. The RR is a ratio of the probabilities of an outcome happening in one condition compared to the probability of an outcome happening in another condition [Tenny & Hoffman, 2022]. For the current work, RRs specifically relate to passengers when exploring their seating position on drivers’ RTC risk, such that the RTC occurs in all cases, but the analysis explores which seating condition is riskier compared to the alternative. As such, the influence of distraction when drivers were either with or without passengers was explored by both OR and RR analyses, using FARS data between 2010-2019. Equations **(1)** and **(2)** explain how the OR and RR analyses were calculated.

$$OR = (A/B)/(C/D) \tag{1}$$

where *'A'* and *'B'* refer to 2 levels in a condition, and *'C'* and *'D'* refer to 2 levels in another condition. For the current experiment, *'A'* and *'B'* could relate to distraction when the driver drives alone (*'A'*) or distraction when the driver is with a passenger; *'C'* and *'D'* could relate to no distraction when the driver drives alone (*'C'*) or no distraction when the driver is with a passenger (*'D'*).

$$RR = E/F \tag{2}$$

where *'E'* refers to the condition that is the focus of the relative risk and *'F'* refers to the alternative condition(s).

5.3.1 Interaction of Driver and One Passenger

OR and RR analyses were conducted to explore how driver and passenger age interacts for risk of an RTC, including the presence of distraction, seating position, and any interaction of risk. First, a RR analysis was conducted between passenger age groups within each driver age category to explore the risk of drivers travelling with certain ages of passengers **(Figure 5.3** and **Table 5.4).** The RR formula is presented in **(3)**.

$$RR = E/F \tag{3}$$

where *'E'* equals total RTCs of the passenger age group in focus, and '*F'* equals the cumulative total of all other RTCs involving passengers for the driver age category in focus.

Figure 5.3 **Relative Risks** for each **passenger group**, compared **within each driving age group**.

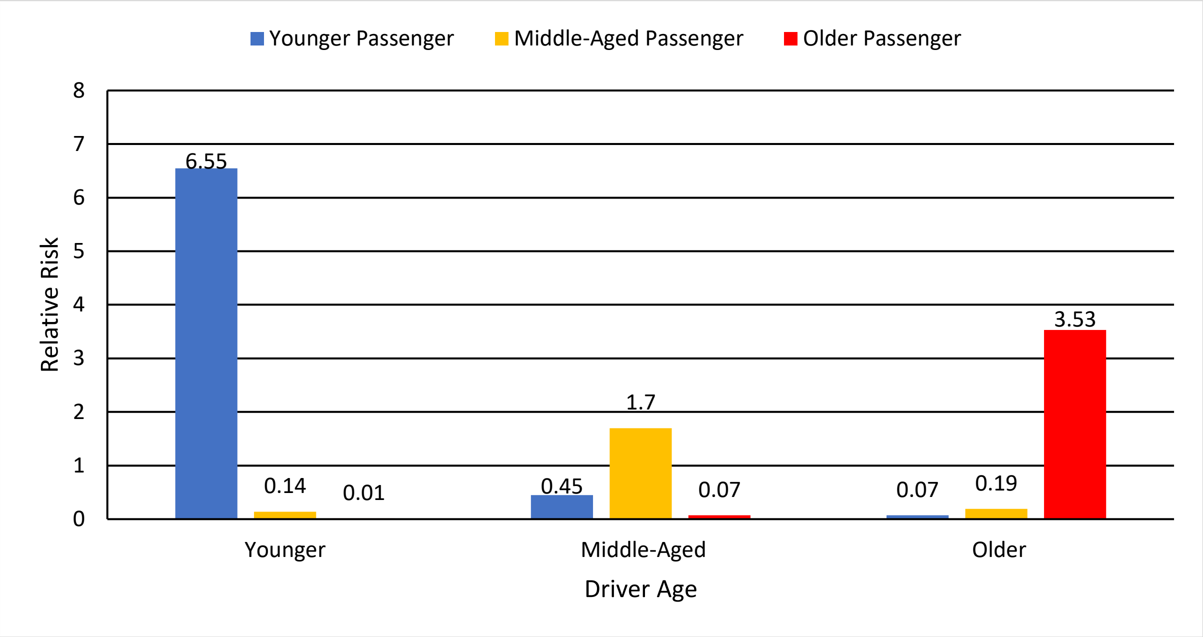


Table 5.4 **Confidence Intervals for each RR** for RTCs associated with passenger age groups compared to other passenger age groups within the same driver age category**.**

Driver Age	Passenger Age	Confidence Interval
Younger	*Younger*	5.00-8.58
	Middle-Aged	0.11-0.18
	Older	0.01-0.01
Middle-Aged	*Younger*	0.41-0.49
	Middle-Aged	1.56-1.86
	Older	0.06-0.08
Older	*Younger*	0.06-0.08
	Middle-Aged	0.16-0.22
	Older	3.04-4.10

These results indicate that the risk for an RTC when travelling with passengers is lower than travelling alone when drivers travel with passengers that are not the same age as themselves, but the inverse is true when the passengers are the same age, given that the RR is below 1 and above 1 respectively. Younger drivers travelling with younger passengers are at most risk compared to other same age pairings at almost 2x the risk of older drivers travelling with older passengers, which is the second riskiest pairing.

To explore the influence of passengers on RTC risk in further detail, an OR was used to assess the influence of passengers on RTC risk when distraction is involved. The results will provide deeper insights into the influence of distraction itself on RTC risk **(Table 5.5** and **5.6)**.

Table 5.5 RTC figures between drivers with one, or without, passengers across distraction condition and driver age.

Driver age	**Driving Conditions**							
	Passenger Age:		*Younger*		*Middle-Aged*		*Older*	
	Driver without Passenger(s)		Driver with 1 Passenger		Driver with 1 Passenger		Driver with 1 Passenger	
	Distraction	*None*	*Distraction*	*None*	*Distraction*	*None*	*Distraction*	*None*
Younger	3,321	50,004	360	5,309	48	760	5	52
Middle-Aged	5,230	89,811	232	2,918	356	6,076	45	591
Older	1,256	27,114	11	241	27	604	134	2,985

Table 5.6 OR of drivers' RTC risk based on the presence of distraction and their age related to the interaction between incidents involving drivers with one, or without, passengers. The formula to calculate the ORs is presented in formula **(4)**. Confidence Intervals at the 95% level are in parentheses.

Drivers	**Passengers**		
	Younger	**Middle-Aged**	**Older**
Younger	0.98 (0.88-1.10)	1.05 (0.78-1.41)	0.69 (0.28-1.73)
Middle-Aged	0.73 (0.64-0.84)	1.01 (0.90-1.13)	0.76 (0.56-1.03)
Older	1.01 (0.55-1.85)	1.04 (0.70-1.54)	1.03 (0.86-1.24)

$$OR = (A/B)/(C/D) \tag{4}$$

where *'A'* equals figures for the driver whilst they were alone and distracted, '*B'* equals figures for the driver travelling with a passenger and distracted, *'C'* equals figures for the driver whilst they were alone and not distracted, and *'D'* equals figures for the driver travelling with a passenger and not distracted.

The results indicate that when RTCs occur and distraction is a primary cause and passengers either are or are not present, middle-aged drivers travelling with younger passengers reduce the RTC risk compared to if the middle-aged driver was distracted and travelling alone. The confidence intervals of all other driver-passenger age pairings provide inconclusive information about whether passengers mitigate the influence of distraction on RTC risk, given that they all range from below 1 to above 1.

5.3.2 Passenger Seating Position

The previous analyses in **Section 5.3.1** explored cognitive load for passengers, regardless of where they were seated. A further RR analysis was therefore conducted to explore the influence of passenger seating, driver and passenger age, and presence of distraction on risk of RTC **(Tables 5.7** to **5.9)**. The formula for calculating the RR is presented in formula **(5)**.

$$RR = E/F \tag{5}$$

where *'E'* equals total figures for the passenger age of focus and distraction condition (either distracted or not distracted) within the driver age category, and '*F'* equals the cumulative total of all other passengers within the driver age category in focus and distraction condition (either distracted or not distracted). Note that this formula is applied separately for front and rear seating.

These analyses appear to show that passenger seating position has an influence on the risk of an RTC. For instance, the OR of younger drivers travelling with younger passengers are at an increased risk of an RTC generally compared to younger drivers travelling with any other age of passengers, but this risk is more pronounced in the rear when the driver is distracted. Moreover, the risk is more pronounced when younger passengers are seated in the rear and travelling with younger drivers. A caveat however is that the confidence intervals where the risk is higher than 1 are wider than all other confidence intervals. This means that the data that inform the results are not extensive enough to provide a conclusive finding.

Table 5.7 **RTC figures between drivers with one passenger, across driver-passenger age dyads and front and rear seating.** The first and second clause of the age dyads refer to the driver and passenger respectively.

		Distract Condition	Driver and Passenger Age Dyads								
			Young-Young	Young-Middle	Young-Older	Middle-Young	Middle-Middle	Middle-Older	Older-Young	Older-Middle	Older-Older
Seating	Front	None	4702	707	46	2033	5079	545	182	538	2873
		Distracted	309	46	5	168	304	45	9	23	130
	Rear	None	607	53	6	885	997	46	59	66	112
		Distracted	51	2	0	64	52	0	2	4	4

Table 5.8 **RR of RTC risk related to the interaction between driver and passenger age and passenger seating position when only one passenger is present.** The first and second clause of the age dyads refer to the driver and passenger respectively.

		Distract Condition	Driver and Passenger Age Dyads								
			Young-Young	Young-Middle	Young-Older	Middle-Young	Middle-Middle	Middle-Older	Older-Young	Older-Middle	Older-Older
Seating	Front	None	6.24	0.15	0.01	0.36	1.97	0.08	0.05	0.18	3.99
		Distracted	6.06	0.15	0.01	0.48	1.43	0.10	0.06	0.17	4.06
	Rear	None	10.29	0.09	0.01	0.85	1.07	0.02	0.85	1.07	0.02
		Distracted	25.5	0.04	0.00	1.23	0.81	0.00	0.25	0.67	0.67

Table 5.9 **RR confidence intervals of RTC risk related to the interaction between driver and passenger age and passenger seating position when only one passenger is present.** The first and second clause of the age dyads refer to the driver and passenger respectively. Note that figures with asterisks beside them could not be calculated as there were no cases in one of the conditions being calculated.

		Distract Condition	**Driver and Passenger Age Dyads**								
			Young-Young	Young-Middle	Young-Older	Middle-Young	Middle-Middle	Middle-Older	Older-Young	Older-Middle	Older-Older
Seating	Front	None	0.86-45.32	0.02-1.09	0.00-0.07	0.05-2.56	0.28-14.02	0.01-0.57	0.01-0.36	0.03-1.29	0.56-28.54
		Distracted	0.83-53.04	0.02-1.31	0.00-0.09	0.07-3.51	0.20-10.47	0.01-0.73	0.01-0.50	0.02-1.41	0.49-33.59
	Rear	None	1.22-87.07	0.01-0.76	0.00-0.08	0.01-6.17	0.15-7.78	0.00-0.15	0.12-6.28	0.14-7.90	0.00-0.15
		Distracted	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	0.02-4.00	0.04-10.71	0.04-10.71

5.4 Summary

Analysis of the FARS data was used to assess the effect of passenger presence on RTC risk, exploring the influence of distraction, driver and passenger age, and passenger seating position. The results suggest that passengers generally reduce the likelihood of an RTC. However, when distraction is a contributory factor to the RTC, there results are inconclusive.

Passenger seating was also explored. A RR found that if an RTC occurs and passengers are present, younger drivers are at a greater risk of RTCs when younger passengers are seated in both the front and rear compared to other passenger age groups. However, the confidence intervals are wide for all driver-passenger age pairings that suggest high risk, meaning that the results are inconclusive.

Further discussion of how the findings presented in this chapter relate to previous literature and wider theory will be presented in **Chapter 8**, especially addressing the hypotheses outlined in **Section 5.1**. The following chapter will combine the findings from the abstract experiment **(Chapters 3 and 4)** in terms of the most detrimental distraction task found related to visual performance with the findings from this RTC data analysis to explore the influence of passengers on RTC risk to inform an experiment exploring hazard perception performance whilst distracted.

Chapter 6 will present the method of an exploration into hazard perception performance whilst a passenger travels with, and distracts, a driver that conducts the hazard perception test. Younger passengers will be explored with younger drivers to assess whether the potential increased RTC risk of this driver-passenger age dyad compared to other dyads corresponds to driving performance risk differences.

Chapter 6*:* Passenger impairment to Hazard Perception - Method

6.1 Introduction

A previous experiment in this thesis explored the influence of distraction on visual detection when the items to be detected were abstract in nature, but the results were not related to the driving context **(Chapter 3 and 4)**. Road traffic collision data were then explored in relation to distraction and passenger presence on driver road traffic collision risk, but the mechanisms that underpin such risk was not effectively addressed **(Chapter 5)**. As such, this chapter explores distraction on visual detection within the driving context whilst the driver is distracted by a passenger, especially focusing on the influence of younger drivers travelling with younger passengers; younger is defined in **Chapter 5**.

6.2 Stimuli and Apparatus

Twenty hazards were presented within a series of 20 clips. These videoclips had a rate of 30 frames per second and a resolution of 1920 x 1080. The FPS and resolution in this experiment reflects properties found in previous studies, which determines how smooth and realistic the footage appears [Vlakveld, 2014; Mackenzie & Harris, 2015; Ibrahim & Ab Rashid, 2016]; a higher FPS and resolution leads to greater realism.

The clips either contained at least 1 hazard (12 videoclips; 10-44 seconds) or contained no hazards (8; 13-23 seconds) **(Table 6.1 and Figure 6.1)**. Discrete videoclips were presented instead of a continuous videoclip because providing brief mental breaks in vigilance for the visual task was anticipated to reduce habituation, which is the gradual decrease in responsiveness due to repeated presentations of the same stimulus [Rankin et al., 2009]. In turn, habituation is anticipated to reduce cognitive load [Ariga & Lleras, 2011]. Whilst driving requires continuous vigilance for hazards, the effect of distraction was intended to be measured against driving performance without incorporating the influence of habituation to observe drivers at their riskiest (i.e., highest rate of cognitive load).

Table 6.1 **Hazards presented to participants.** Video numbers correspond to those presented in **Appendix B.i**.

Hazard	Video	Description
1	7	Car pulling up to junction.
2	8	Car pulling up to junction.
3	11	Car is approaching a van with its left indicator on.
4	11	Person steps between two parked cars ahead of you.
5	12	Car pulling out of driveway.
6	12	Pedestrians crossing over in the car's path of travel.
7	13	Car pulling up to junction.
8	13	Car ahead braking.
9	14	A truck is parked ahead of you with its hazard lights on.
10	14	Car ahead of you crossing your side of the road to get to the opposing lane.
11	15	Ambulance crosses the lane into your path of travel.
12	16	Cyclist on the road in front of you.
13	17	Car ahead braking.
14	17	Car pulls up to a junction to the side of you and crosses into your path of travel.
15	18	Person in a supermarket car park is pushing a series of trolleys ahead of you, facing away from you.
16	18	People are at the boot of their cars, standing marginally in your path of travel.
17	18	A person is packing groceries into her car. She has left her trolley in your path of travel.
18	18	A van is approaching a junction that you are approaching.
19	19	Car pulls up to a junction to the side of you and crosses into your path of travel.
20	20	Pedestrians crossing over in the car's path of travel.

Figure 6.1 **Examples of hazards that were presented to participants.** Two pedestrians are crossing the path of participant's vehicle (a) and a cyclist is cycling in the path of the participant (b). All hazards are listed in **Appendix B.i**.

(a)

(b)

The participant that was required to respond to hazards as soon as they appeared in the videoclips. This task was conducted whilst the participant was in a seat that would have been the "UK driver's seat" in the seat configuration that represented a car seat setup within the experiment room. At the same time, another participant was required to present the distraction task to the participant that was conducting the hazard perception test, whilst they sat in either the "UK front passenger seat" or "UK rear seat" behind where a UK driver would be seated.

The participant that conducted the hazard perception test is referred to as the "driver", whereas the alternative participant is referred to as the "passenger" in this experiment. Each seat was 45cm from the floor to the seat, and 42cm x 42cm for the seat measurements themselves. The front passenger seat was 70cm away from the driver's seat when measured in the centre of the base of the seat, whereas the back of the driver's seat to the back of the rear passenger seat was 85cm **(Figure 6.2)**. The seating position of the passenger at the start of the experiment was randomised, but they would change to the alternative seat halfway through the trials **(Figure 6.3)**.

Figure 6.2 **UK Seating arrangement** of the driver (a), the front passenger (b) and rear passenger (c) **within this experiment**.

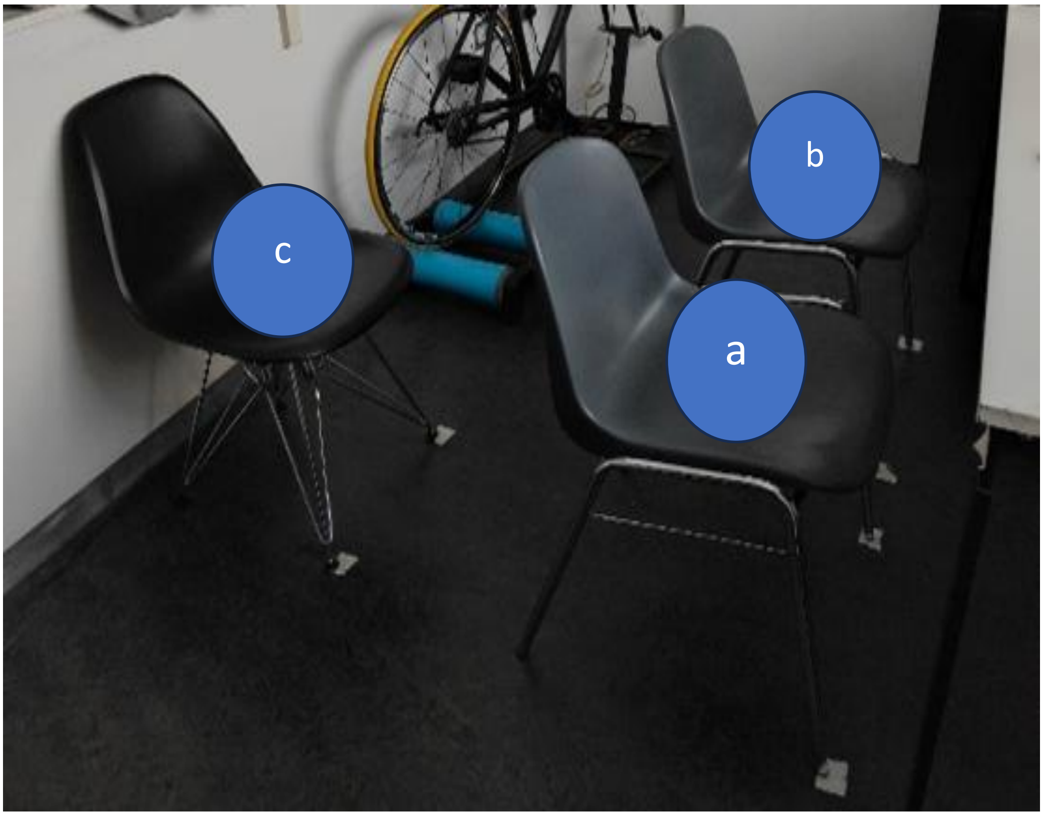
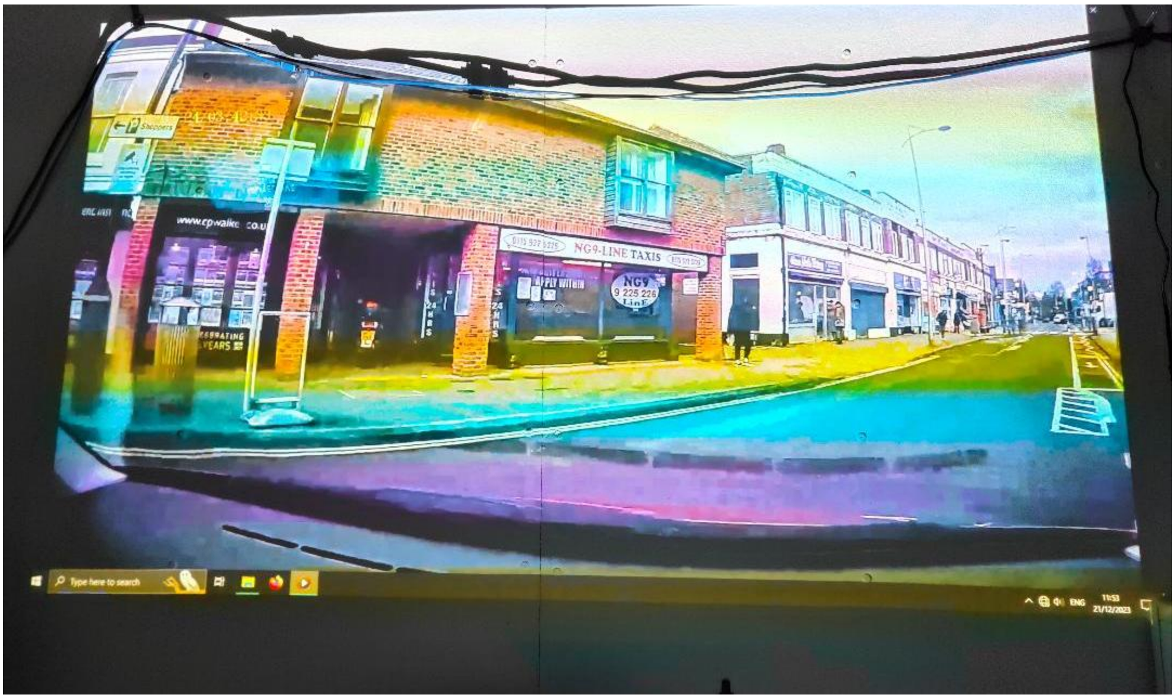


Figure 6.3 Passenger's view when they are seated in the front (a) and rear (b). Note that the driver's view is also represented in (a).



(a)

(b)

The hazard perception task was presented as a projection on a 97cm x 182cm wall ahead of the driver, at 155cm from the projection on the wall to the top back of the driver's seat. The screen therefore subtended a solid angle of 0.59sr based on the use of the inverse tan function (also known as atan (θ)): θ = (Opposite / Adjacent).

The projection was mirrored from a HP Probook laptop that ran a Python program of the hazard perception experiment **(Figure 6.4)**. Drivers were required to indicate by mouse button click immediately when they detected an item in the video that was defined to them as a hazard by the researcher (an item that would require them to change their speed or direction if they were the driver).

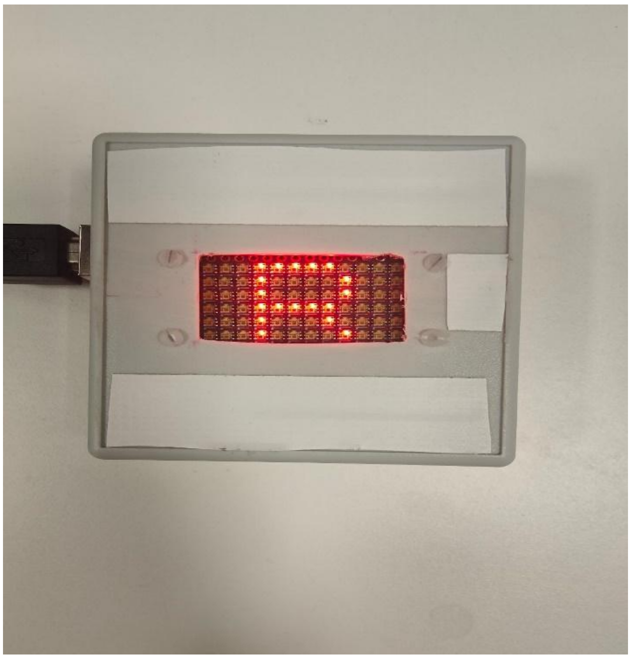
Whilst the driver conducted the hazard perception test, the passenger was required to read aloud a letter that appeared on an electronic device every 1-6 seconds **(Figure 6.5)**. The driver was required to listen to the letter that the passenger mentioned and respond with the letter that appeared 2 previously in the sequence that the passenger presented. An example would be if the passenger spoke a sequence of "A, J, H", the driver would be required to say the letter "A" when the passenger mentioned "H".

The videoclips presented in the experiment were from dashcam footage procured from the researcher and their acquaintances in a previous unpublished iteration of this experiment, which provided a repository of over 120 hours of unedited footage. A selection of 50 individual pieces of dashcam footage were selected at random to be inspected further from the repository, each clip ranging from 3 minutes to 10 minutes in length. To sort through the repository, the videoclips were manually categorised by the researcher into those that either had or did not have a hazard.

Additionally, 20 bespoke videoclips that contained an artificially generated overlay of wingmirrors and mirror above the driver and front passenger's seat were reviewed. Of these, 6 were selected to be included within the 20 videoclips presented in the hazard perception test, 2 of which were videos that contained 3 hazards (2 hazards in 1 video and 1 hazard in 1 video). There were no hazards that appeared in the artificial overlay within these videoclips.

Figure 6.4 **Seating arrangement in relation to the projection.** Note that the rear passenger seat is not shown.

Figure 6.5 **Device that the passenger holds**, which presents the letter sequence for the distraction task.



Within the research planning stages, a second person assisted with determining whether a hazard was presented in the videoclips. Ratings were reported as either 1 or 0, respectively referring to yes or no. There was an agreement of ϕ=.55, *p*<.001, which is implied to be a moderate degree of agreement [Hallgren, 2012].

From the previous step, 20 videoclips were chosen to be used for the experiment where there was agreement either that they contained or did not contain hazards (12 for hazards and 8 for control). Videoclips that had no identified hazards were decided to be presented alongside those with hazards to increase the unpredictability of whether a participant should respond or not, with the aim being to reduce habituation.

When drivers responded in the experiment to the hazards, each mouse click was translated to coordinates that were decoded using a Python language algorithm **(Appendix B.ii.)**, which showed where participants had clicked within the footage, presented as a small circle at the exact location that the participant clicked **(Figure 6.6)**.

Figure 6.6 **Example of driver hazard perception response.** In this example, the participant used the mouse to click in the location of the vehicle at the junction.

The small circle was within a larger circle, for which if the hazard was within, the response was considered accurate. The strength of this approach was that participant detection could be easily checked for where exactly they were responding to within the videoclip, compared to a method that required participants to respond without discriminating the location they were referring to. Furthermore, the smaller and larger circles that were presented at the location of where the participant clicked ensure that there was high enough sensitivity to conclude that the participant had accurately perceived the hazard, whilst not being too strict by only ensuring that the hazard had to be where the participant exactly clicked. This approach reduced any ambiguity that may have otherwise arisen. Mouse-clicks on specific locations within the scene was also used because this method is used in the hazard perception test within the UK official driving theory test, meaning that the results found could be related to the way that the actual hazard perception test is administered.

To encourage recruitment and active engagement with both the distraction and hazard perception tasks alike, £200 was offered for participation in relation to hazard perception task performance. The financial incentive was related to task performance, with £100 being split as £50 for the fastest reaction time compared to all other performances and £50 for the highest detection accuracy compared to all other performances for drivers, and £100 being split as £50 if the passenger managed to secure either of the £50 rewards.

The reason why payment in relation to task performance was considered imperative in this experiment is because the driver would be required to score a minimum level of accuracy in the n-back=2 score to ensure they were sufficiently focused, whilst this payment would incentivise drivers to also attend to the hazard perception task; without the financial incentive, the drivers may have prioritised one task over the other. Likewise, the passengers would be paid in relation to the drivers' task performance because they would therefore be wanting to ensure that the driver performs well, which reflects real driving. However, the lack of specific instruction to the passenger about what they should focus on means that if they did moderate their engagement with the distraction based on how well they could see the view of the road ahead, such effects would arise organically rather than because of the experiment design itself.

Whilst drivers were informed that they needed a certain level of accuracy in the n-back=2 task, the threshold was deliberately not explained because if the participants were informed, this may have meant they focused until they believed they had passed the threshold. The current approach ensured that they would likely remain vigilant throughout the entire experiment.

Following the approach within the abstract visual detection experiment stated in **Chapter 3**, a minimum threshold of 45%, meaning that participants were required to attain at least 45% accuracy in each distraction condition to be considered as sufficiently attending to the distraction tasks whilst attending to the alternative concurrent task.

The lighting within the hazard perception task was also measured to gauge how different the lighting was across all videoclips. Three measurements were taken of the illuminance (lux) from the researcher's eye level and averaged for each videoclip, with the video paused at the exact same point within the same video for all 3 measurements **(Table 6.2)**. Luminance measures were important for the driver because they were required to view the videoclips to conduct the hazard perception task, but was also important for the passengers, who may have moderated their engagement with the distraction task based on their view of the videoclips. The driver and passenger view when they were both seated in the front was considered to relate to the same illuminance of the videoclips.

To measure the illuminance when passengers were seated in the rear behind the driver, the researcher measured the illuminance whilst seated in the rear seat behind an obstacle that measured 137cm from the ground in a vague shape of the human form. This obstacle provided the equivalent effect of a driver partially blocking the participant's view **(Figure 6.3b)**.

Table 6.2 **Illuminance measurements** (lux) for the videoclips between front and rear participant seats.

Videoclip Number	Front Seat	Rear Seat
1	35	11
2	57	16
3	36	8
4	61	21
5	40	13
6	7	2
7	50	18
8	31	8
9	26	8
10	13	1
11	32	8
12	78	20
13	65	18
14	27	5
15	10	3
16	78	23
17	43	11
18	50	12
19	40	9
20	27	7

6.3 Procedure

The experiment took place in a laboratory with the room lights turned off and daylight occluded using window covers. Pairs of participants came to the experiment session. Upon arrival, both participants were asked to re-read the information sheet **(Appendix B.iii.)** and sign the consent form **(Appendix B.iv.)**.

Participants then proceeded to undertake the Landolt Ring and Ishihara tests to assess visual acuity and colour vision respectively, which was presented in the same manner as the previous study within the thesis (**Chapter 3**). These tests were used when deciding whether the participant was eligible for the study, given that the study requires participants to be able to see effectively.

The driver was seated before the screen where the experiment was to be presented. At the same time, the passenger was seated either beside or behind the driver, depending on which condition they were assigned at the start of the study.

The researcher read aloud instructions for the experiment from a pre-written script to standardise the information that all participants would receive. Information in the script was generated by the researcher, although contained information that was provided by researchers in other studies [Moran et al., 2019]:

"During this experiment, you will see a series of 20 clips from the perspective of a driver. The screen will go blank between each clip. Some clips will have hazards for you to respond to, whereas some may not; there may be more than one hazard in the clip. A hazard is anything in the clip that would change your speed or direction, if you were the driver (e.g. indicators, pedestrians crossing over in your path of travel, cars changing lanes, etc). I want you to click in the exact location of the hazard when you perceive one as fast as you detect it.

Whilst conducting the hazard perception task, you [directed toward the driver] *will be performing a distraction task, which should be your primary focus within this experiment. The distraction task will be presented by the passenger and will consist of a sequence of letters that you* [directed toward the passenger] *must read aloud, whilst at the same time, you* [directed toward the driver] *must say the letter that was presented two previously in the sequence. So, if the sequence was A and C before the first clip was presented, and then the first letter heard when the clip is playing is Z, you would say A because this was the letter presented to you two previously in the sequence. Then if the next letter you hear was X, you would say C for the same reason. This process continues throughout the whole experiment.*

Remember: your primary focus should be on the distraction task whilst you conduct the hazard perception test at the same time. If at any time you lose track of the sequence, try not to panic. Instead, just listen to the next letter in the sequence and try to keep track of the task once again.

To driver: *You will earn £50 if you have the fastest reaction time out of all participants and £50 if you have the highest detection to hazards out of all participants. You must have a certain level of accuracy in the distraction task for your hazard perception performance to be considered valid.*

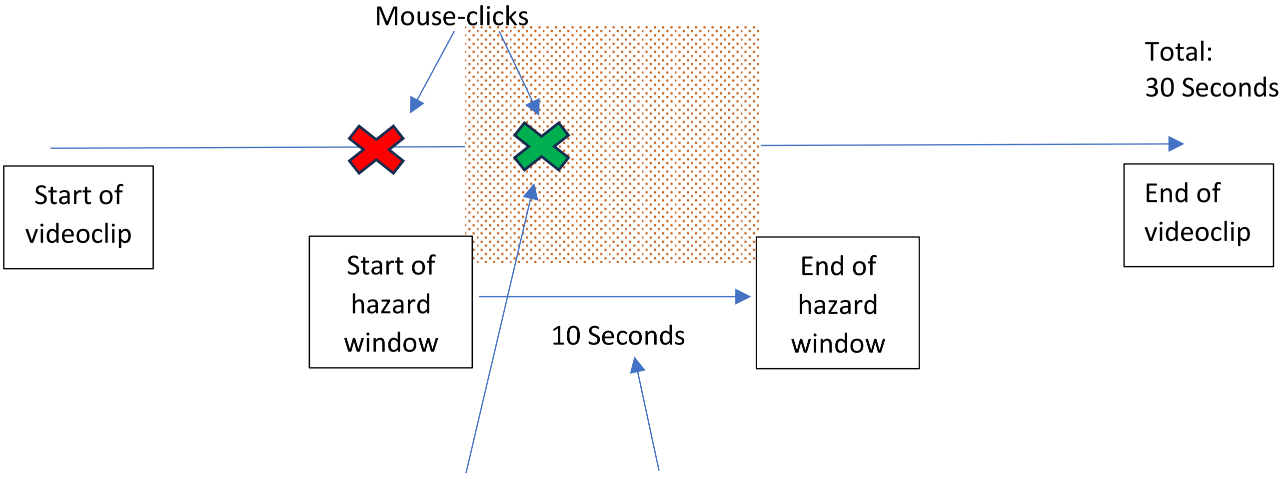
To passenger: *You will earn £50 if the driver manages to either get the fastest reaction time or highest detection rate to the hazards."*

Participants were asked if they understood or would like any further information, to which the researcher responded by providing additional tuition. If participants were happy to then proceed, the study began. The experiment presented a pseudo-randomised sequence of videoclips, with 6 videoclips containing at least 1 hazard and 4 videoclips containing no hazards (control) for the first passenger seating condition (front or rear), and then the alternative videoclips being used for the second passenger condition. During this experiment, the hazard perception data was automatically transferred to an Excel sheet whilst the researcher manually recorded the n-back performance of both the driver and passenger.

Once the experiment ended, participants were thanked before leaving the room. The n-back performance was analysed to determine the accuracy both when the passenger was seated in the front and rear. Additionally, the researcher translated the hazard perception task reaction time data so that it was based within the hazard window rather than the beginning of the video, divided by the whole duration of the hazard window. A scale between 0 (beginning of the hazard window) and 1 (end of the hazard window) was produced **(Figure 6.7)**. The videoclips varied in their duration, which subsequently led to a variation in the duration of the hazard windows **(Table 6.3)**. As such, this measure allowed all videoclips to be analysed using the same scale of data. If this measure was not adopted, there would have been the potential issue of drivers' detection rate confounding the reaction time data. For example, when calculating the range of durations between all videoclips that were detected by drivers and contained at least 1 hazard, there was a narrower range for the hazard windows than the videoclips between all participants (mode videoclip duration: 10-44 seconds; mode hazard window: 2-13 seconds). Additionally, there was a smaller difference between the overall mean hazard window duration compared to the mean videoclip duration of videoclips that were detected containing at least 1 hazard across all drivers (x videoclip duration = 22.05, SD = 1.25; x hazard window duration = 6.39 , SD = .39). This proposed scale provides a standardisation that can be applied to all videoclips to ensure that the analysis is equal, whereby analyses are not as influenced by variation in duration length across all hazard perception videoclips.

Once this data was collected, both the n-back=2 and hazard perception data were then transferred to IBM SPSS Statistics software.

Figure 6.7 **Accurate response to hazards**. In this example, the videoclip is 30 seconds in duration, with a hazard window with a duration of 10 seconds. The driver has clicked twice in the video. The red cross is an invalid response; the green cross is a valid response. The calculation used is at the bottom of this figure.



Calculation: Timestamp of valid mouse-click (e.g., 2 seconds)/Duration of hazard window (e.g.,10 seconds) = Scale Response between 0 and 1 (e.g.,0.2).

Table 6.3 **Videoclip and hazard window durations** in seconds.

Video #	Videoclip Duration	Hazard Window Duration	Hazard Number
7	15	5	1
8	44	5	2
11	30	13	3
11	30	11	4
12	20	4	5
12	20	6	6
13	20	4	7
13	20	2	8
14	10	10	9
14	10	3	10
15	22	8	11
16	27	5	12
17	19	7	13
17	19	8	14
18	29	5	15
18	29	2	16
18	29	8	17
18	29	3	18
19	13	8	19
20	13	8	20

Table 6.4 Combined **duration range in seconds of all videoclips with hazards and all hazard windows** where at least one hazard was detected for each participant. Figures in parentheses indicate the mean of each duration range in seconds.

Participant	Videoclip Duration	Hazard Window Duration
1	10-44 (21.87)	2-13 (6.33)
2	13-30 (20.89)	3-13 (7.33)
3	10-44 (22.13)	2-13 (6.00)
4	13-30 (21.70)	2-13 (7.00)
5	10-44 (21.87)	2-13 (6.33)
6	10-44 (22.81)	2-13 (6.10)
7	13-44 (23.34)	2-13 (6.00)
8	13-44 (24.23)	2-13 (6.11)
9	10-29 (20.35)	2-13 (6.60)
10	10-44 (21.87)	2-13 (6.33)
11	13-29 (22.05)	2-13 (6.25)
12	10-44 (22.48)	2-13 (6.45)
13	10-44 (21.87)	2-13 (6.33)
14	10-44 (22.08)	2-13 (5.91)
15	10-29 (20.49)	2-13 (6.22)
16	10-44 (24.20)	2-13 (7.00)
17	10-29 (19.98)	3-13 (6.90)
18	10-44 (22.01)	2-13 (6.55)
19	10-44 (24.70)	2-13 (6.38)
20	10-44 (22.13)	2-13 (6.00)
21	10-29 (19.29)	2-11 (5.38)
22	10-44 (22.81)	2-13 (6.10)
23	10-44 (22.81)	2-13 (6.10)
24	10-29 (20.35)	2-13 (6.60)
25	10-44 (22.68)	2-13 (6.70)
26	10-44 (22.89)	2-13 (6.40)
27	10-44 (22.22)	3-13 (6.60)
28	10-29 (20.57)	2-13 (6.30)
29	10-44 (22.01)	2-13 (6.55)
30	10-44 (22.68)	2-13 (6.70)

6.4 Participants

Ethical approval was gained by the School of Architecture's Ethics Administrator (Application number 056343) **(Appendix B.v.)**. An a-priori power analysis was conducted using G*Power version 3.1 to determine the minimum sample size required to test the study hypothesis [Faul et al., 2007]. Based on the results from the Passenger Analysis, which indicated an odds ratio of 1.73 between rear and front passenger seats for all RTCs involving young passengers for young drivers, the effect size is calculated by dividing the odds ratio by 1.81 [Chinn, 2000]. This means that the effect size estimated for this study is Cohen's dz = 0.956. The results indicated the required sample size to achieve 99% power for detecting the estimated effect for this experiment was *N*=30 (dz = 0.956, 1 - ß = .99, p = .01). As the dependent variable is hazard perception performance performed by drivers, but passengers were required to provide the independent variables of distraction between passenger seating position, there were 60 participants (30 drivers and 30 passengers) required across 30 sessions required.

To be eligible, participants were required to be aged between 18 and 25 for driver and passenger alike. All 60 participants (Male: N = 24, x = 23 years of age; Female: N = 36, x = 21 years of age) were recruited from the University of Sheffield. These were divided between driver (Male: N = 8, x = 21 years of age; Female: N = 22, x = 21 years of age) and passenger (Male: N = 15, x = 24 years of age; Female: N = 15, x = 20 years of age).

All participants had a visual acuity of at least 6/12, the minimum standard for UK drivers as tested at the start of the experiment; corrected vision was permitted, provided the experiment was conducted with habitual correction in place throughout. All participants had normal colour vision as tested using the Ishihara colour plates. Consequently, no participant was excluded based on these visual tests.

6.5 Research Design

The experiment used a 2 level within-subject design. This included the passenger seating position (front and rear) in relation to their presentation of the distraction task to the driver, measured against the drivers' hazard perception performance. Drivers' reaction time, detection accuracy, mouse-clicks to videoclips when no hazards were present, and the ratio between overall mouse-clicks and how many hazards were detected were used as dependent measures. Performance on the distraction task was also analysed as a separate measure, although the drivers' n-back=2 task performance was explored in relation to passenger seating positions, association with the previously mentioned dependent variables, and within a moderated regression to explore if there was an interaction between the n-back and seating position on the dependent variables. Passengers' engagement with the n-back=2 task was also explored separately. The n-back=2 performance is characterised as the percentage of correct responses for each task.

6.6 Summary

This chapter presented the method for an experiment that explored how distraction influences young drivers' hazard perception when the distraction task is presented by a passenger of a similar age in either the front or rear seat. **Chapter 7** will present the results of this experiment.

Chapter 7: Passenger impairment to Hazard Perception - Results

7.1 Introduction

Exploring the FARS RTC data in relation to driver distraction and both passenger presence and seating position indicated that passenger seating position (i.e. whether the passenger is seated adjacent to or behind the driver) affects RTC risk. The risk difference between passenger seating position is accentuated for younger drivers travelling with same age passengers, relative to carrying passengers of any other age.

To explore passenger seating in further detail, an experiment was conducted to assess young drivers' reaction time and detection rates within a hazard perception test whilst a young passenger is seated adjacent to or behind the driver and causing distraction to the driver. Differences in hazard perception test performance may arise between passenger seating positions as this may influence the extent of distraction. For instance, when seated in the front, passengers may engage with distraction tasks with more moderation as they can see the road more clearly and therefore allow their perception of road conditions to moderate their interactions with the driver compared to when passengers are seated in the rear. In turn, this potentially means that drivers are less distracted when passengers are seated in the front than the rear, which may subsequently mean that they are faster and more accurate when responding to hazards when passengers are seated in the front than the rear.

In response to passengers' view of the hazard clips in the experiment, they are expected to divert their attention to the screen from the n-back task more when seated in the rear compared to the front seat. This is due to the passenger not having as clear a view in the rear than if they were seated in the front, which subsequently means they will not be able to perceive the hazards in the videoclips as effectively in their periphery so may need to focus their attention more. As such, this means that passengers' n-back task performance is expected to be less accurate in the rear compared to the front seat. The potentially higher distraction of passengers' n-back task performance caused by the less predictable frequency of their responses may influence drivers' hazard perception task performance, such that when passengers are seated in the rear and are expected to have a more infrequent response than when they are seated in the front, drivers' hazard perception task performance will be worse. This is expected because drivers may find that passengers that read the n-back task at a more consistent rate may find that the distraction task is more predictable so require less conscious effort to process than when the rate of n-back being spoken is less consistent.

The distraction task used in this experiment was informed by an earlier experiment in this thesis that was conducted in an abstract environment, which determined that the n-back=2 task was the most detrimental to reaction time and accuracy. Visual detection performance was explored in relation to distraction in that experiment, but the detrimental effects of distraction on visual performance was not explored in relation to the mental model of driving (top-down processes) that drivers may use to mitigate impairments. Additionally, the n-back=2 task was used as the distraction task because this has been used extensively in road safety research [Conti et al., 2014; Melnicuk et al., 2021; Jannah et al., 2023].

Within this experiment, two participants conducted the experiment session at the same time. One participant (the driver) conducted a hazard perception task whilst being distracted, and the other participant (the passenger) presented the distraction task to the participant conducting the hazard perception experiment. This chapter presents data analysis of this hazard perception experiment. There was 1 research question, with 4 associated hypotheses, of the data analysis within this experiment:

Research Question 3: Does distraction presented by a passenger in either the front or rear passenger seat influence hazard perception performance in drivers’ response to videos depicting hazards within driving scenes?

- Hypothesis 3a: Higher detection and faster reaction times in the hazard perception task will be associated with lower accuracy in the distraction task.
- Hypothesis 3b: Passengers seated in the rear will have higher accuracy reading the distraction task to the driver than passengers seated in the front.
- Hypothesis 3c: Passengers seated in the rear that are reading the distraction task will be associated with drivers’ lower detection and slower reaction times in the hazard perception task.
- Hypothesis 3d: Fewer false positives will be recorded for drivers’ hazard perception responses when passengers are seated in the front compared to the rear.

7.2 Cleaning the Data

The data were first assessed for outliers. Normality was then assessed to determine which analytical test to use for the inferential statistics, complemented by a reliability analysis to test whether the hazards formed an internally consistent scale.

7.2.1 Accounting for Reaction Time in Missing Responses

Across the 30 drivers that conducted the hazard perception test, 20 hazards were presented each, equating to 600 hazards in total. Of these, there was no responses to 190 (32%). To account for reaction times to these missing targets when analysing the data, the technique suggested by Choi et al. (2015) was followed. This uses the participant average as a proxy for every missing value in their dataset. An alternative approach was to consider translating missing participant values to each hazard as the slowest possible reaction time. This is because replacing missing values with averages will overestimate performance at hazard detection, as missing a hazard is arguably the worst possible performance rather than average performance. These approaches will respectively be referred to here as average replacement and slowest replacement. Both approaches are reported here to consider how they influence results.

The k-nearest neighbour technique was also considered. This uses the missing datum as the reference point and searches for the most similar elements based on a distance function between the query element and the closest neighbour (i.e., the missing value is estimated based on the most similar recorded value in the categories specified by the researcher) [Batista, 2009]. However, given that the type of hazard presented across all video clips were not controlled so that there were equal amounts of similar hazards, the categories would have been imbalanced, leading to potentially erroneous correction of missing values.

7.2.2 Reliability Analysis

Target stimuli in the Hazard Perception experiment were based on information that varied between each videoclip, such as a car approaching a junction or a cyclist. A reliability analysis was conducted to explore whether detection accuracy was consistent across all hazards [George & Mallery, 2018].

Reliability was assessed using Cronbach’s Alpha (α), which describes the internal consistency between items in a test or scale, therefore relating to the interrelationships between those items; it ranges from 0 to 1 [Tavakol & Dennick, 2011]. The measurement error index is calculated by squaring the correlation and subtracting it from 1.00. For example, if a test has a reliability of 0.90, there is 0.19 error variance (random error) in the scores (0.90×0.90 = 0.81; 1.00 – 0.81 = 0.19) [Kline, 2014]. Consequently, test scores will be less vulnerable to error as reliability estimates increase.

For this test, each individual hazard was compared to other hazards across all individual participants' performance. The value for Cronbach's Alpha was α = .58. Based on a definition suggested by George & Mallery (2018), where >.9 is excellent, >.8 is good, >.7 is acceptable, >.6 is questionable, >.5 is poor, and <.5 is unacceptable, the α between hazards in this experiment are poor.

Omitting data from one of the hazards (Hazard #8: a car braking) increased the scale the most compared to all other items, raising the overall α to .63. The value could further be increased to .67 by removing another hazard (Hazard #7: a car pulling up to a junction), and then .70 by removing another hazard (Hazard #13: a car braking). Further omissions would result in negligible increases to α (the largest increase being by .01).

The reliability analysis indicates that seventeen hazards should have remained in the analysis, with Hazards #7, #8, and #13 being removed. This provided a hazard perception scale with a reliability between all hazards used within this experiment that was approaching "acceptable" according to Cohen's criteria [Cohen, 2013]. However, Wieland et al (2017) explored a meta-analysis of studies that removed items after a reliability analysis, with their suggestion to produce data analyses that have both the removed hazards and all hazards. Subsequent analyses will therefore present findings from hazards that were removed from the reliability analysis and all hazards. These will be referred to as reduced data and all data respectively.

In comparison, the value for Cronbach's Alpha using slowest replacement was α = .78. This rating equates to a figure that is considered acceptable, whilst being close to "good". No hazards were omitted for analyses with slowest replacement.

7.2.3 Outliers

Nevil (2013) provides an explanation about Z-scores, which are a statistical measurement that can outline when data points exceed a reasonable threshold of dissimilarity that it makes sense to correct or omit the data from further analysis, or risk confounding the conclusions with flawed data. Z-scores describe a value's relationship to the mean of a group of values. More specifically, Z-scores are measured in terms of standard deviations from the mean. If a Z-score is 0, it indicates that the data point's score is identical to the mean score. In contrast, a Z-score of 1.0 would indicate a value that is one standard deviation from the mean. Similarly, Z-scores may be positive or negative, with a positive value indicating the score is above the mean and a negative score indicating it is below the mean.

As such, Z-scores were used in this experiment to provide an indication of how much detection rate to each hazard deviates from the mean, guiding whether the data should be omitted from further analysis. An absolute value of ± 3.0 is typically used to identify outliers [Tabachnick et al., 2013], much in line with how outliers were calculated for the Abstract Detection experiment, which is the logic adopted within this experiment when considering whether values were outliers.

7.2.3.1 Individual Hazards

Detection of each hazard was analysed to assess whether any specific hazard should be omitted from further analysis. Whether the data were assessed across both or between passenger seating positions (front and rear) whilst the driver conducted the hazard perception test*,* no hazards exceeded a value of ± 3.0. Similarly, the same findings were made for both Reduced and All data. Consequently, all hazards remained within the subsequent analyses for both the reduced and all datasets.

7.2.3.2 Participant Hazard Perception Performance

Rather than basing the reaction time calculation on how long after the video had started, reaction times to each hazard within the hazard perception videoclips were based on hazard windows, which related to when the hazard first appeared and ended within the videoclip. Participant responses provided automated details about their reaction time. The hazard perception scores were standardised based on the process mentioned in **Chapter 6**.

The reason why this hazard window scale was produced rather than using the raw data was that the videoclips varied in length; given that the videoclips were randomised between each passenger seating position, analysis based on an unstandardised scale may have confounded the results. From this, the reaction times of each participant was averaged across all hazards, meaning that the analysis is based on one reaction time data point for each participant for each passenger seating position (front or rear). Subsequently, z-scores were produced, which indicated that there were no z-scores that exceeded ± 3.0 across all averaged reaction time data either for all hazards or for all hazards except those removed based on the reliability analysis for average replacement data. The same was found for analyses using slowest replacement data

Detection rate was defined as proportion of trials in which a response was given. This was established separately for the passenger seated either in the front or the rear. All z-scores for detection rate did not exceed a value of ± 3.0, except for one participant whilst the passenger was seated in the rear for Reduced Data (10% of hazards; z-score: - 3.52) and All Data (13% of hazards; z-score: -3.67). Likewise, given that participants were permitted to click the mouse as many times as they desired, one participant clicked over three times the standard deviation value more than other participants across all videoclips when no hazards were present whilst a passenger was seated in the front (7.17 mouse-clicks; z-score: 3.85) and rear (8.33 mouse-clicks; z-score: 4.61) for All Data.

There were fewer mouse-clicks for the same participant for the driver when the passenger was seated in the front for the Reduced compared to All Data (6.20 mouse-clicks; z-score: 3.47), but the same number of mouse-clicks when the passenger was seated in the rear across both Reduced and All Data (8.33 mouse-clicks; z-score: 4.94).

An excess of clicks could be an issue because it means that they have more opportunity to respond to hazards by chance rather than by genuine detection. Performance was thus examined to assess how many hazards were detected by the driver compared against all clicks for each passenger seating condition. All z-score values did not exceed ± 3.0.

To address the variables in which participants had z-scores exceeding a value of ± 3.0, the data within the overall detection rate per passenger seating condition and mouse-clicks for videoclips that contained either hazards or no hazards were transformed using log to base 10. This relates to the method explained in the Abstract Detection experiment **(Chapter 3)**.

Transforming the data reduced the z-scores of mouse-clicks to videoclips when no hazards were present where passengers were seated in both front and rear seats to < 3 for Reduced and All data alike. However, there was an increase for the participant that detected 17% of the Reduced Data (z-score -3.52 increased to -5.02) and 10% of All Data (z-score -3.67 increased to -5.43). Log transformations were therefore not considered appropriate for correcting outliers in this experiment.

The Winsorizing method was used to rectify outlying data, where an outlier is replaced with either the next highest or lowest case within the normal distribution of data, depending on which extremity is intended to be reduced [Field et al., 2012; Tabachnick et al., 2013; Mowbray et al., 2019] **(Table 7.1)**. The scale of the data being analysed thus becomes reduced. Winsorizing is considered a conservative approach because it permits a case that would otherwise be considered an outlier to contribute to the calculation of the estimate [Mowbray et al., 2019].

Table 7.1 Original and Winsorized **values for outlying** detection and mouse-click **data**.

Measure	Dataset	Extremity	Original Data	Z-Score	New Data	Z-Score
Detection	All	Lowest	10%	-3.67	30%	-2.48
	Reduced	Lowest	17%	-3.52	38%	-2.23
Mouse-Clicks	All	Highest	6.20	3.47	3.67	1.72
			8.33	4.94		
	Reduced	Highest	7.17	3.85	3.67	1.56
			8.33	4.61		

The Winsorized transformations meant that there were now no data that exceeded 3 standard deviations from the mean, subsequently meaning that all data were included for subsequent analyses.

As detection rate was not influenced by how the missing data were treated, the z-score analysis of detection rate was equal between average replacement and slowest replacement analyses.

7.2.3.3 Participant Distraction Task Performance

To assess whether the drivers were distracted whilst they conducted the hazard perception task, their distraction task performance whilst they conducted the hazard perception test was analysed. Z-scores were measured for their distraction task data, finding that no performance in the n-back=2 task exceeded ± 3.0 beyond the standard deviation of the mean between all participants. All participant data were therefore retained on this basis.

Whilst drivers' distraction performance did not align with the statistical definition of an outlier, a further concern was about whether they were sufficiently distracted because variations in this measure may have confounded results by comparing hazard perception test performance between drivers that were or were not distracted.

Indeed, most drivers were sufficiently engaged in the n-back task, 6 drivers achieved < 45% accuracy. This includes 2 drivers where the passenger was seated in the front (40% and 41%), 2 drivers where the passenger was seated in the rear (34% and 42%), and 2 drivers with both passenger seating conditions (front and rear respectively: driver 1 [27% and 9%] and driver 2 [27% and 38%]). However, for drivers that achieved <45% in the distraction task in relation to only one passenger seating position, their overall n-back=2 performance when combining both front and rear passenger seating indicated that they were sufficiently engaged (45-60%). In all these cases, the reaction time and detection rate within the hazard perception test was similar to data provided by other participants. As such, all data were retained for subsequent analyses.

Passenger engagement with the n-back task was also explored, with the logic that they would moderate their engagement more with a clearer view of the driving scene whilst sat in the front seat compared to the rear seat. In contrast to driver performance on the n-back=2 task, passenger engagement with this task remained consistently high, with 28 passengers providing 100% accuracy when seated in the both the front and rear.

Two participants were slightly less accurate (96% in the front seat for one participant, and 91% in the rear seat for one participant; respective z-scores of -2.99 and -6.95). There is not enough difference between passenger performance in each seating position or between passengers to inform a meaningful analysis. Consequently, the passenger engagement with the n-back task was not analysed any further.

7.3 Normality

Shapiro-Wilk tests were used to assess normality in these data by standardising each item to have a mean of 0 and standard deviation of 1 because the sample is <50 [Razali & Wah, 2011]. Normality was assessed for data when participant performance was averaged across all videoclips, separately by passenger seating position. The Shapiro-Wilk Test of Significance indicated that there were some variables that violated assumptions of normality, whilst some did not **(Table 7.2 and 7.3)**.

Table 7.2 **Descriptive statistics** of drivers' hazard perception performance and distraction task performance for **Reduced Data**. Figures in brackets for "Descriptives" relate to Standard Error. An asterisk besides the figure indicates significance at the .05 level.

Passenger Seat	**Measure**	**Descriptives**			**Normality Test**
		Mean	Skewness	Kurtosis	Shapiro-Wilk
Front	RT	.513(.020)	-.241(.427)	-.952(.833)	W(30)=.951, p=.183
	Detection Rate	.768(.026)	-1.18(.427)	1.053(.833)	W(30)=.844, p<.001*
	Mouse-clicks	1.301(.266)	2.606(.427)	8.527(.833)	W(30)=.718, p<.001*
	Detection/mouse-clicks	.365(.037)	.637(.427)	-.199(.833)	W(30)=.939, p=.084
	N-back Accuracy	.701(.035)	-.890(.427)	-.128(.833)	W(30)=.904, p=.010*
Rear	RT	.467(.017)	.105(.427)	.219(.833)	W(30)=.978, p=.759
	Detection Rate	.720(.027)	-.702(.427)	.091(.833)	W(30)=.933, p=.058
	Mouse-clicks	1.263(.296)	3.14(.427)	12.258(.833)	W(30)=.656, p<.001*
	Detection/mouse-clicks	.373(.032)	.029(.427)	-.903(.833)	W(30)=.964, p=.395
	N-back Accuracy	.687(.038)	-1.097(.427)	.815(.833)	W(30)=.886, p=.004*

Table 7.3 **Descriptive statistics** of drivers' hazard perception performance and distraction task performance for **All Data**. Figures in brackets for "Descriptives" relate to Standard Error. An asterisk besides the figure indicates significance at the .05 level.

Passenger Seat	**Measure**	**Descriptives**			**Normality Test**
		Mean	Skewness	Kurtosis	Shapiro-Wilk
Front	RT (Average Replacement)	.511(.020)	-.209(.427)	-.939(.833)	W(30)=.957, p=.263
	RT (Slowest Replacement)	.580 (.024)	.192(.427)	-.353(.833)	W(30)=.982, p=.868
	Detection Rate	.764(.026)	-.715(.427)	.574(.833)	W(30)=.921, p=.028*
	Mouse-clicks	1.078(.190)	1.545(.427)	1.543(.833)	W(30)=.780, p<.001*
	Detection/mouse-clicks	.394(.039)	.559(.427)	-.250(.833)	W(30)=.950, p=.174
	N-back Accuracy	.701(.035)	-.890(.427)	-.128(.833)	W(30)=.904, p=.010*
Rear	RT (Average Replacement)	.452(.015)	.492(.427)	1.472(.833)	W(30)=.943, p=.112
	RT (Slowest Replacement)	.542(.027)	.594(.427)	-.128(.833)	W(30)=.951, p=.180
	Detection Rate	.726(.029)	-.616(.427)	.164(.833)	W(30)=.937, p=.076
	Mouse-clicks	1.029(.177)	1.348(.427)	1.014(.833)	W(30)=.837, p<.001*
	Detection/mouse-clicks	.400(.033)	-.067(.427)	-1.078(.833)	W(30)=.952, p=.186
	N-back Accuracy	.687(.038)	-1.097(.427)	.815(.833)	W(30)=.886, p=.004*

The data conditions that violated the assumption of normality were transformed to log base 10 **(Table 7.4 and 7.5)**. Whilst the log(10) transformations rectified the violations for mouse-clicks, they did not resolve the violation arising from detection rate, with the transformation extending the violation to detection rate in both passenger seating conditions. Likewise, the p value was reduced for both passenger seating positions for drivers' n-back=2 accuracy, meaning that these data remained violating the assumption of normality. As such, parametric analyses were used for reaction time and the transformed detection in relation to all click data, but non-parametric analyses were conducted on untransformed data related to detection accuracy and drivers' n-back=2 accuracy.

Table 7.4 **Log(10) transformed descriptive statistics** of all driver participants for conditions that violated assumptions of normality when the data were not transformed for **Reduced Data**. Figures in brackets for "Descriptives" relate to Standard Error. An asterisk besides the figure indicates significance at the .05 level.

Passenger Seat	**Measure**	**Descriptives**			**Normality Test**
		Mean	Skewness	Kurtosis	Shapiro-Wilk
Front	Detection Rate	-.123(.017)	-1.715(.427)	3.037(.833)	W(30)=.785, p<.001*
	Mouse-clicks	-.106(.086)	-.277(.427)	-.188(.833)	W(30)=.962, p=.351
	N-back Accuracy	-.176(.027)	-1.455(.427)	-1.506(.833)	W(30)=.824, p<.001*
Rear	Detection Rate	-.144(.016)	-1.214(.434)	2.067(.845)	W(29)=.903, p=.012*
	Mouse-clicks	-.112(.085)	.036(.434)	-.112(.845)	W(29)=.987, p=.971
	N-back Accuracy	-.191(.038)	-2.903(.434)	10.692(.845)	W(29)= .679, p<.001*

Table 7.5 **Log(10) transformed descriptive statistics** of all driver participants for conditions that violated assumptions of normality when the data were not transformed for **All Data**. Figures in brackets for "Descriptives" relate to Standard Error. An asterisk besides the figure indicates significance at the .05 level.

Passenger Seat	**Measure**	**Descriptives**			**Normality Test**
		Mean	Skewness	Kurtosis	Shapiro-Wilk Test
Front	Detection Rate	-.126(.017)	-1.397(.427)	2.580(.833)	W(30)=.857, p<.001*
	Mouse-clicks	-.168(.083)	-.293(.427)	-.560(.833)	W(30)=.937, p=.075
	N-back Accuracy	-.176(.027)	-1.455(.427)	-1.506(.833)	W(30)=.824, p<.001*
Rear	Detection Rate	-.141(.018)	-1.229(.434)	1.964(.845)	W(29)=.888, p=.005*
	Mouse-clicks	-.152(.079)	.283(.434)	-.295(.845)	W(29)=.975, p=.697
	N-back Accuracy	-.191(.038)	-2.903(.434)	10.692(.845)	W(29)= .679, p<.001*

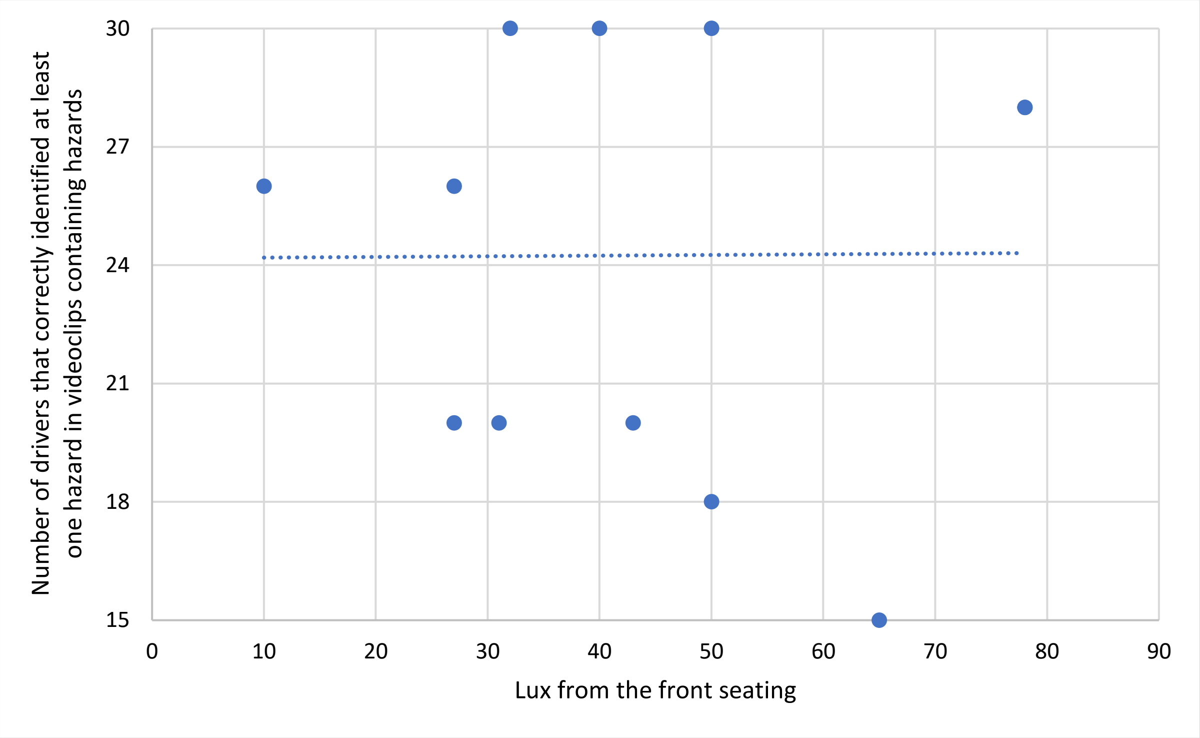
7.4 Lighting related to Visual Detection

The lighting of each videoclip that contained at least one hazard was assessed against visual detection accuracy. This is because there was variation between the videoclips in the lighting level, which may have influenced hazard perception performance because low lighting levels cause greater decrements to driving performance than higher lighting levels [Zhou et al., 2024]. There was a variation in the number of hazards in videoclips where hazards were presented. As such, assessing lux against the number of hazards detected by drivers would have been confounded by this variation.

Lux was therefore measured against the number of drivers that identified at least one hazard in videoclips containing hazards using Pearson's Correlation, whereby one response would constitute the driver having sufficiently observed the associated videoclip appropriately; any further accurate responses within the videoclip were not valid for this analysis **(Figure 7.1)**. Note that lux from the front seat was used for this analysis, given that this is the light levels that would have been relevant to the driver when they conducted the hazard perception task.

There was no relationship between lux and the number of participants that correctly identified at least one hazard in videoclips where hazards were presented (R^2 = .007, p= .984). This suggests that the variation in lighting did not influence whether drivers detected at least one hazard in videoclips where hazards were presented. As such, lighting variation between videoclips was not a confounding factor to the analyses inferential statistical analyses that were conducted.

Figure 7.1 **Correlation** between **illuminance (x-axis)** in the driver's/passenger **front seat** and **the number of participants that correctly identified at least one hazard** in each videoclip where hazards were presented **(y-axis)**.



7.5 Inferential Statistics Analysis

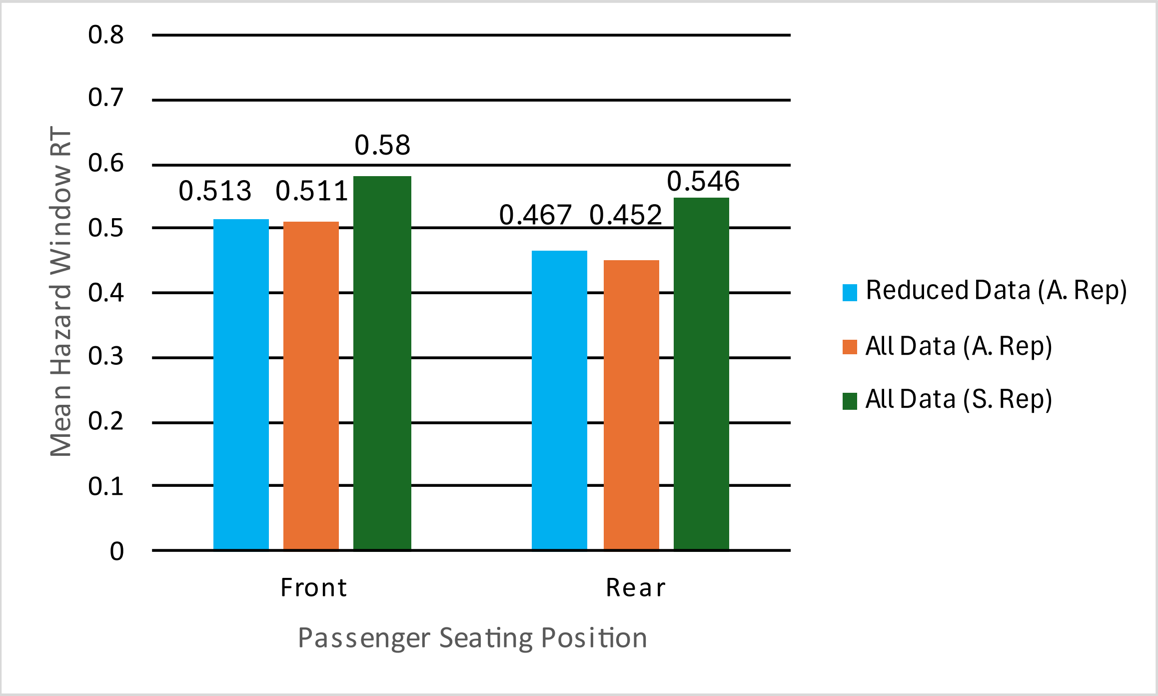
The influence of distraction was explored in relation to drivers' hazard perception performance when distraction is caused by passengers that are present. There was one variable with two levels (passenger seating position: front and rear), for which the same participant conducted both levels.

A Paired-Samples t-test was first used to explored reaction time, followed by a Wilcoxon-Signed Rank Test to explore detection rate, then Paired-Samples T-Tests to explore average mouse-clicks on videoclips that contain no hazards and detection to hazards in comparison to all mouse-clicks, before finally conducting a Wilcoxon-Signed Rank Test to explore distraction task performance for drivers when passengers were seated in either the front or rear.

7.5.1 Reaction Time

A Paired-Samples T-Test was used to explore reaction time of the drivers' performance in the hazard perception test whilst the passenger was seated either beside or behind the driver presenting the n-back=2 task. For analyses using average replacement, there was a significant difference in the reaction times of drivers to hazards presented within videoclips related to whether passengers were seated in the front or rear, although the effect size was small for Reduced Data (t(29)=1.941, p =.031, d=.354) and All Data (t(29)=2.367, p =.025, d=.432). Reaction time was slower when passengers were seated in the front (M=.513 [Reduced Data] and M=.511 [All Data], SD=.111 and SD=.108 respectively) compared to the rear (M=.467 [Reduced Data] and M=.452 [All Data], SD=.092 and SD=.083 respectively). Likewise, the trends were in the same direction for analyses using slowest replacement (t(29)=2.045, p <.001, d=.249), with reaction time being slower when passengers were seated in the front (M=.580, SD=.134) compared to when they were seated in the rear (M=.546, SD=.146). These results indicate that when passengers are distracting the driver, there is a greater detriment to driver' hazard perception reaction time when the passengers are seated in the front compared to the rear **(Figure 7.2)**.

Figure 7.2 Drivers' **reaction time** to detecting hazards when passengers are seated either in the front or rear causing distraction. The higher the bar, the slower the speed. Note that "A. Rep" and "S. Rep" refer to average and slowest replacement respectively.



To assess whether there was an association between drivers' n-back=2 performance and their reaction times to hazards within this experiment, their association between these measures was analysed by Pearson correlations for average replacement. This indicated that there was a weak association when passengers were seated in the front for Reduced Data (*r* = .035, p= .855) and for All Data (*r* = .030, p = .873) seats. However, drivers were affected more by their performance in the distraction task whilst the passenger was seated in the rear compared to the front seat for both Reduced (*r* = .318, p= .087) and All Data (*r* = -.318, p = .087), with these values being closer to statistical significance than for passengers seated in the front. These same trends were found when analysing slowest replacement for front (*r* = -.182, p = .335) and for rear seating (*r* = -.340, p = .066) **(Figure 7.2** and **7.3)**. These results indicate that the drivers' RT to hazards was potentially influenced by where the passenger was seated when the passenger distracted the driver, but within this experiment the difference did not reach statistical significance for either average or slowest replacement.

Figure 7.3 **Correlation** between driver hazard **reaction time (x axis)** against **driver distraction performance (y axis)** when **passengers were seated in the front**. Note that "A. Rep" and "S. Rep" refer to average and slowest replacement respectively.

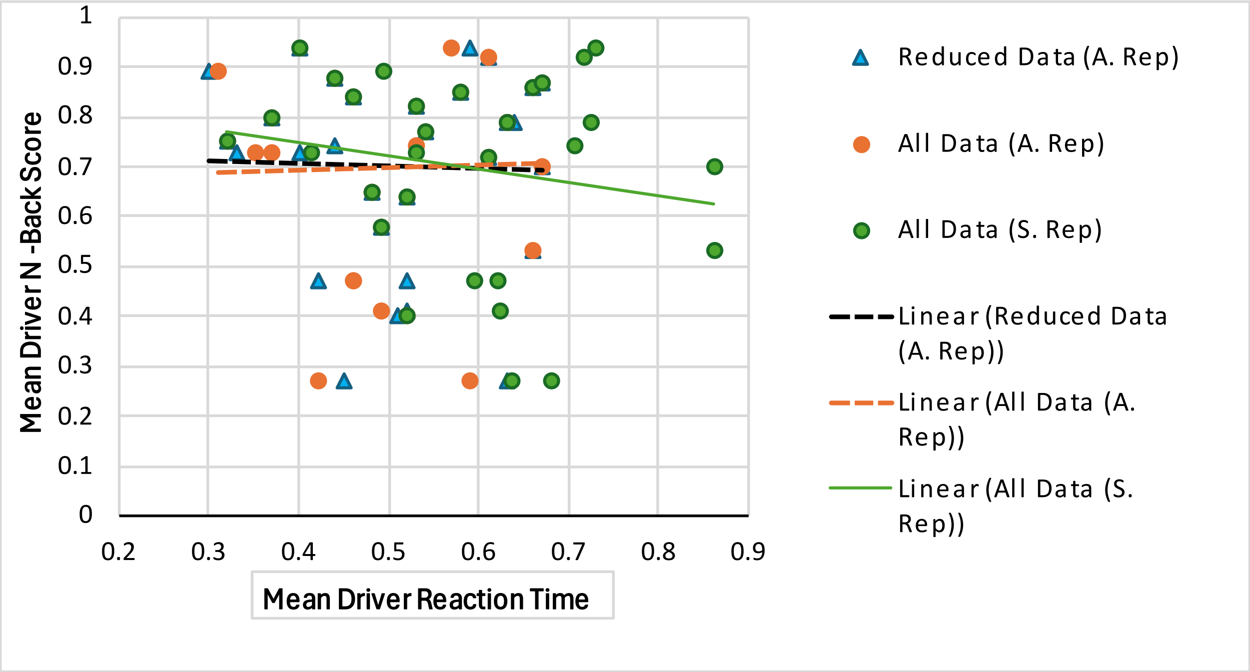
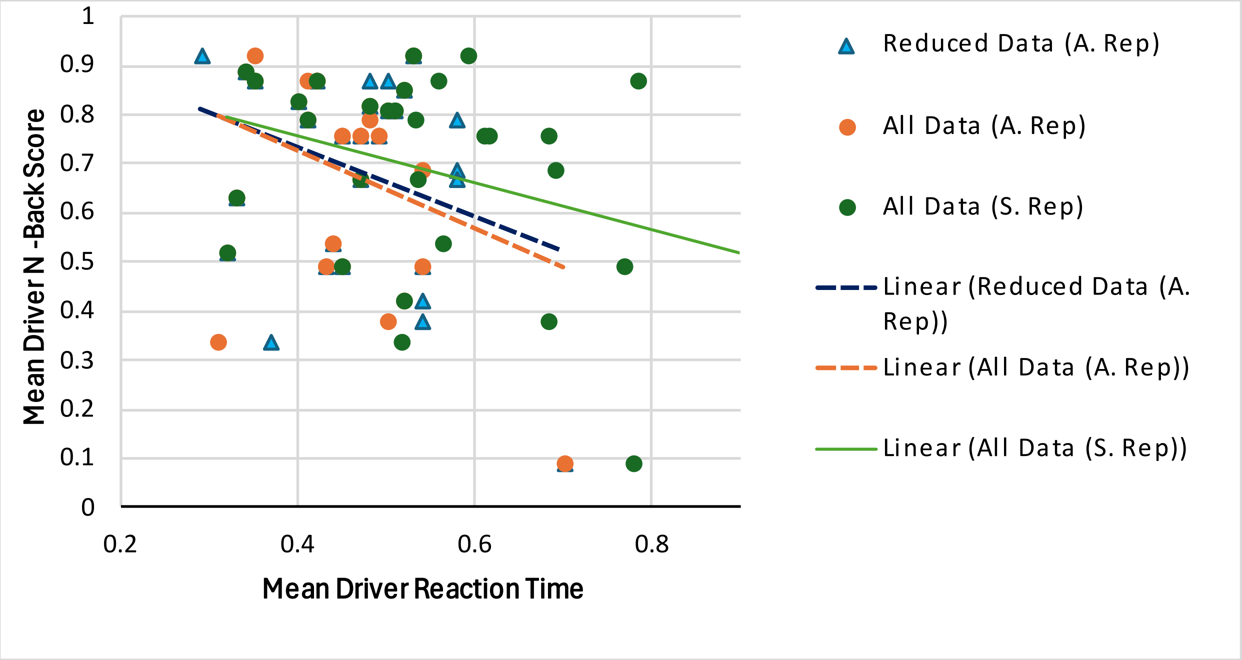


Figure 7.4 **Correlation** between driver hazard **reaction time (x axis)** against **driver distraction performance (y axis)** when **passengers were seated in the rear**. Note that "A. Rep" and "S. Rep" refer to average and slowest replacement respectively.



To assess the interaction between seating position and n-back task performance of the driver's RT, a moderated regression was performed for average performance. N-back task performance was the predictor, in which the data were centralised to the mean; RT to the hazard perception task was the dependant variable; and passenger seating position was a moderator. There was a non-significant interaction found on n-back task performance and RT of the drivers when passengers were seated in the front for Reduced Data (b = -.003, t = -.029, p = .977) and All Data (b = .023, t = .237, p = .814), and when passengers were seated in the rear for Reduced Data (b = -.138, t = -1.478, p = .145) and All Data (b = -.123, t = -1.365, p = .178). The same trend was found for slowest replacement for front (b = -.049, t = -.177, p = .763) and rear (b = -.266, t = -1.321, p = .655) seating. These results indicate that the passenger seating position did not influence the association between the drivers' n-back task performance and RT to the hazard perception task.

I

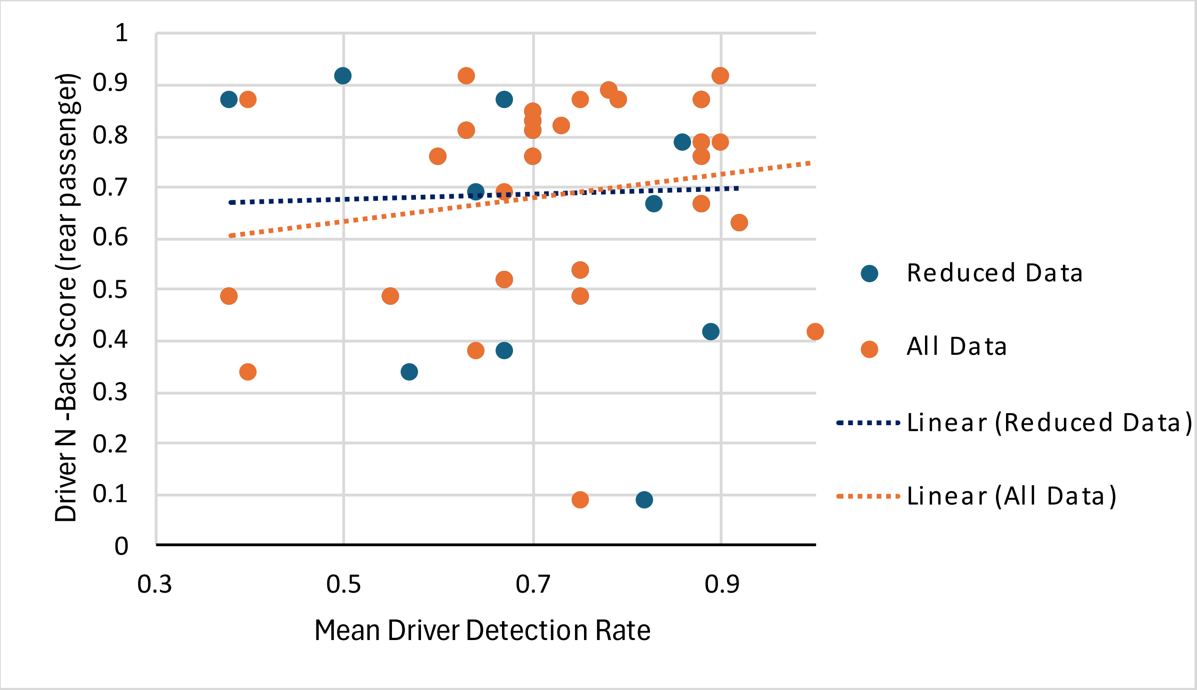
7.5.2 Detection Accuracy

A Wilcoxon-Signed Rank Test was used to explore the accuracy of the driver to the hazards within the hazard perception test whilst the passenger was seated either beside or behind the driver presenting the n-back=2 task. The difference in detection rate for drivers conducting the hazard perception test was non-significant between when passengers were in the front (M = .768 [Reduced Data] and M = .764 [All Data], SD = .142 and SD = .144 respectively) or rear (M = .720 [Reduced Data] and M = .726 [All Data], SD = .147 and SD = .157 respectively) seat for Reduced Data (Z = -1.879, p = .060) and All Data (Z = -1.427, p = .154). This means that drivers' accuracy in detecting hazards was not influenced by where passengers were seated when causing distraction.

To assess whether there was an association between drivers' n-back=2 performance and their detection rate to hazards within this experiment, the association between these measures was analysed by Pearson correlations, which does not require the data to be normal [Chakrabarty, 2018]. This indicated that there was a weak association when passengers were seated in the front seats for Reduced Data ($R^2 = .039$, p = .839) and for All Data ($R^2 = .087$, p = .649), and rear seats for Reduced ($R^2 = .037$, p = .847) and All Data ($R^2 = .176$, p = .353) **(Figure 7.5 and 7.6)**. These results indicate that the accuracy of drivers' detection to hazards was similar between passenger seating positions when the passenger distracted the driver, although there was a difference between Reduced and All Data for rear seating.

Figure 7.5 **Correlation** between driver **detection to hazards (x axis)** against **driver distraction performance (y axis)** when **passengers were seated in the front**.

Figure 7.6 **Correlation** between driver **detection to hazards (x axis)** against **driver distraction performance (y axis)** when **passengers were seated in the rear**.



To assess the interaction between seating position and n-back task performance of the driver’s detection accuracy, a moderated regression was performed. To account for the non-normal detection data, bootstrapping of 1000 samples from a simple sampling method was used. Unwin (2013) explains that bootstrapping involves a sample of size n that is drawn from the population (S). Rather than using theory to determine all possible estimates, the sampling distribution is created by resampling observations with replacement from S with the number of times that the researcher specified, with each resampled set having the original n observations. If sampled appropriately, S should be representative of the population. Therefore, by resampling S m times with replacement, it would be as if m samples were drawn from the original population, and the estimates derived would be representative of the theoretical distribution under the traditional approach.

N-back task performance was the predictor, in which the data were centralised to the mean; detection accuracy within the hazard perception task was the dependant variable; and passenger seating position was a moderator. There was a non-significant interaction found on n-back task performance and detection accuracy of the drivers when passengers were seated in the front for Reduced Data (b = .034, t = .213, p = .832 [non-bootstrapped], p = .782 [bootstrapped]) and All Data (b = .068, t = .467, p = .642 [non-bootstrapped], p = .568 [bootstrapped]), and when passengers were seated in the rear for Reduced Data (b = .031, t = .212, p = .833 [non-bootstrapped), p = .859 [bootstrapped]) and All Data (b = .137, t = 1.003, p = .320 [non-bootstrapped], p = .393

[bootstrapped]). These results indicate that the passenger seating position did not influence the association between the drivers' n-back task performance and accuracy to the detection of hazards within the hazard perception task.

7.5.3 False Positives in Videoclips with no Hazards

A Paired-Samples T-Test to explore the number of times drivers' provided mouse-clicks to videoclips where no hazards were present within the hazard perception test whilst the passenger was seated either beside or behind the driver presenting the n-back=2 task. For Reduced Data analysis, there was a non-significant difference (t(28)=-.113, p =.911) in the overall mouse-clicks from drivers when they were responding to hazards in this experiment between passengers that were in the front (M=-.099 [lg$_{10}$] and M=1.30 [untransformed]; SD=.477 [lg$_{10}$] and SD=1.456 [untransformed]) or rear (M=-.112 [lg$_{10}$] and M=1.263 [untransformed]; SD=.455 [lg$_{10}$] and SD=1.624 [untransformed]) seating positions. Likewise, for All Data, there was a non-significant difference (t(28)=-.017, p =.987) between when passengers were in the front (M=-.150 [lg$_{10}$] and M=1.078 [untransformed]; SD=.451 [lg$_{10}$] and SD=1.042 [untransformed]) or the rear (M=-.152 [lg$_{10}$] and M=1.029 [untransformed]; SD=.425 [lg$_{10}$] and SD=.968 [untransformed]) seats. This means that drivers provided a similar number of overall mouse-clicks, regardless of the passenger seating position.

To assess whether there was an association between drivers' n-back=2 performance and mouse-clicks across all videoclips where no hazards were present, the association between these measures was analysed by Pearson correlations. This indicated that there was a weak association when passengers were seated in the front seats for Reduced Data (R^2 = -.021, p = .912) and for All Data (R^2 = .083, p = .663), and rear seats for Reduced (R^2 = -.016, p = .934) and All Data (R^2 = .013, p = .947). These results indicate that there was minimal influence of passenger seating position related to the association between distraction performance of the drivers and the number of times that drivers provided false positives (responses when no hazards were present).

To assess the interaction between seating position and n-back task performance of the number of times that drivers provided responses to videoclips with no hazards present, a moderated regression was performed. N-back task performance was the predictor, in which the data were centralised to the mean; number of mouse-clicks to the videoclips that contained no hazards within the hazard perception task was the dependant variable; and passenger seating position was a moderator. There was a non-significant interaction found on n-back task performance and the number of mouse-clicks when passengers were seated in the front for Reduced Data (b = .295, t =

.197, p = .844) and All Data (b = .453, t = .464, p = .644), and when passengers were seated in the rear for Reduced Data (b = -.835, t = -.596, p = .553) and All Data (b = .064, t = .070, p = .945). These results indicate that the passenger seating position did not influence the association between the drivers' n-back task performance and the number of false positives in videoclips where no hazards were present within the hazard perception task.

7.5.4 False Positives across all Videoclips

A Paired-Samples T-Test to explore the number of times drivers' correctly identified hazards in relation to all mouse-clicks they provided within the hazard perception test whilst the passenger was seated either beside or behind the driver causing distraction. There was a non-significant difference in the ratio of how many hazards drivers accurately detected compared to overall mouse-clicks between front (M = .365 [Reduced Data] and M = .394 [All Data], SD = .205 and SD = .212 respectively) or rear (M = .373 [Reduced Data] and M = .400 [All Data], SD = .174 and SD = .179 respectively) passenger seating conditions for Reduced Data (t(29) = -.194, p = .847) and All Data (t(29) = -.128, p = .449). These results indicate that the passenger seating position has no influence in the ratio of how many mouse-clicks the driver chooses to make in relation to hazards presented throughout the duration of the hazard perception experiment.

To assess whether there was an association between drivers' n-back=2 performance and the ratio of how many hazards drivers accurately detected compared to overall mouse-clicks, the association between these measures was analysed by Pearson correlations. This indicated that there was a weak association when passengers were seated in both the front seat for Reduced Data (R^2 = .193, p = .307) and for All Data (R^2 = .162, p = .393), and rear seat for Reduced (R^2 = -.136, p = .473) and All Data (R^2 = -.058, p = .759). These results indicate that there was minimal influence of passenger seating position related to the interaction between distraction performance of the drivers and the ratio between overall mouse-clicks and detection accuracy.

To assess the interaction between seating position and n-back task performance of the ratio between the number of times that drivers provided responses to videoclips compared against the number of hazards presented, a moderated regression was performed. N-back task performance was the predictor, in which the data were centralised to the mean; the ratio between the number of mouse-clicks to the videoclips compared to the hazards presented within the hazard perception task was the dependant variable; and passenger seating position was a moderator. There was a non-significant interaction found on n-back task performance and the ratio of number of mouse-clicks against hazards presented when passengers were seated in the front for Reduced Data (b = .204, t =

1.122, p = .266) and All Data (b = .178, t = .940, p = .351), and when passengers were seated in the rear for Reduced Data (b = -.116, t = -.680, p = .499) and All Data (b = -.051, t = -.289, p = .774). These results indicate that the passenger seating position did not influence the association between the drivers' n-back task performance and the number of false positives in videoclips across all videoclips within the hazard perception task.

7.5.5 N-back Performance

A Wilcoxon-Signed Rank Test was used to explore the n-back=2 performance of the driver whilst the passenger was seated either beside or behind the driver presenting the n-back=2 task. There was a non-significant difference in n-back=2 performance of drivers between conditions where passengers were seated in the front (M=.701; SD=.193) or rear (M=.687; SD=.206) seating positions (Z=-.260, p =.795). This means that there was a non-significant difference in drivers' accuracy in the distraction task between passenger seating positions.

7.6 Summary

This experiment was conducted to explore the influence of passenger seating position on drivers' hazard perception performance when passengers are distracting the driver, for which the most detrimental distraction task found in relation to abstract visual detection was used as the distraction task. The trends did not change depending on how the missing hazards were processed.

Results from this experiment found that passenger seating position has an influence on drivers' reaction time, but the influence is small (either d=.354 or d=.432, related to Reduced and All Data respectively, or d=.249 when the data were treated for slowest replacement). There was also an association of drivers' n-back=2 performance and their RT between when passengers were seated in the front and rear, although this difference was close to, but did not reach, statistical significance. No other influences on drivers' hazard perception task performance related to passenger seating position were presented in the results.

Additionally, the results were mostly the same between Reduced and All Data, except for the association between n-back performance and detection accuracy where there was a stronger positive association between the n-back=2 performance and detection accuracy for All Data compared to Reduced Data. However, that association did not reach statistical significance in this experiment, meaning that the results could be related to chance.

Chapter 8 will further explore all the experiment’s findings from this thesis, including the findings presented in this chapter, in relation to previous literature and theory, addressing the aims and hypotheses presented in **Chapter 2: Section 2.7**. The thesis will then be concluded, with suggestions of future research that arises in relation to the findings in this thesis.

Chapter 8: Discussion

8.1 Introduction

This thesis aimed to explore the interaction of distraction and passenger presence on drivers' hazard perception and RTC risk. A core issue that is central to the thesis is that, whilst distraction has been explored in relation to both driving performance [Briggs et al., 2016; Bell et al., 2019; Baldo et al., 2020] and RTC risk [Dingus et al., 2006; Bärgman, 2015; Ackaah et al., 2020], results from the influence of distraction does not separate its influence either on bottom-up processing in terms of visual detection or top-down processing in terms of mental models of driving (schemas).

The first study in this thesis aimed to address how distraction influences visual detection without exploring the influence of distraction on driver's schemas by exploring how distractions affect visual detection performance in an abstract environment. The purpose of separating how distraction influences the cognitive processing of the driver (bottom-up and top-down processes) is to provide guidance for the most detrimental distraction task on visual performance specifically. Given that driver age influences how attention is diverted to a secondary task [McAvinue et al., 2012], both older and younger drivers were recruited to explore how driver age interacts with distraction task complexity in relation to visual detection performance.

Results from the first study provided an indication about driving performance, which is associated with RTC risk, but an issue that remains is that those results do not relate directly to RTC occurrences. As such, the second study in this thesis aimed to explore RTC data, exploring the differences in RTC risk between drivers driving alone or with passengers, including distraction, driver and passenger age, and passenger seating position. Passengers were chosen as a focus in this study because previous literature has provided contradictory findings about their influence on drivers' RTC risk, but this could relate to the differing focus of how passengers are being explored in relation to driver's RTC risk [Vollrath et al., 2002; Chung et al., 2014; Huisingh et al., 2015; Caird et al., 2018; Charlton & Starkey, 2020; Green et al., 2022]. This study is the first of its kind to explore distraction, driver and passenger age, and passenger seating position in relation to drivers' RTC risk.

Finally, the results from the abstract visual detection experiment and analysis of distraction and passengers on drivers' RTC risk were incorporated into a hazard perception experiment. In this experiment, passengers caused distraction to drivers as the driver conducted a visual detection task contextualised within videoclips based in a driving context. Passengers were either in the front passenger (beside the driver) or rear passenger (behind the driver) seat, conducting half the experiment in either seat. The distraction task used within the hazard perception experiment was informed by the abstract detection experiment (n-back=2) whereas the driver and passenger age group that was most at risk was informed by the analysis of distraction and passengers on drivers' RTC risk, primarily focusing on passenger seating (younger driver with younger passenger).

There were 3 research questions, with 9 hypotheses in total, across all investigations: the These were presented in **Chapter 2, Section 2.9.** These will be covered in turn, including addressing each hypothesis within the respective aim. Finally, a discussion of how the findings from this thesis relate to theory will be presented.

8.2 Cognitive Load within an Abstract Visual Detection Task

All hypotheses for the first experiment were supported by the results found in the abstract visual detection experiment. However, the third hypothesis, relating to the interaction between participant age and distraction on visual performance, was only partially supported. This is because there was an interaction found for reaction time performance, but not detection accuracy performance. The sub-sections below address these hypotheses in further detail.

8.2.1 Hypothesis 1a: Higher cognitive load leads to more detriments to visual performance

Reaction times were slower and detection accuracy was lower in relation to visual detection targets as the cognitive load in the distraction task increased. These align with previous literature [Lamble et al., 1999; Lavie et al., 2004; Keffane , 2018]. The results therefore indicate that the detrimental effects arise not solely due to allocating attention in another task whilst engaging with a visual detection task, but also the extent of the cognitive load within the distraction task itself.

However, there were exceptions to the experiment's results in relation to the overall trends, including visual performance in relation to the n-back=0 and the Number Fixation distraction task, which had non-significant differences in reaction times or missed targets compared to when no distraction was presented. Distraction in and of itself is thus indicated as having a nuanced influence on visual detection, whereby the task must exceed an attentional threshold before the distraction is detrimental to visual performance. Such findings provide validation to the MiRA theory, although the extent to which MiRA corresponds to driving performance in this experiment is limited due to the deliberate attempt to explore distraction in relation to visual detection without exploring the influence of distraction on drivers' schemas.

An explanation for the current results relates to the findings by Guerreiro et al. (2010), who suggest that distractions are especially related to neurological activity. The current experiment did not explore neurological activity whilst participants conducted the experiment, but the neurological literature provides further explanation for the mechanisms that underpin distraction processing, which could have led to the current results.

Neural oscillations (brain waves) are one such concept, which are oscillations of voltage in the brain that measure just a few millionths of a volt recorded in hertz (Hz) [Balduzzi et al., 2008]. Fronto-central theta band (4–7 Hz) are associated with cognitive load, especially in visual attention and memory, but activity is suggested to be independent of short-term memory load [Keller et al., 2017]. In contrast, alpha brain waves (8-12 Hz) [Foster et al., 2017] are associated with idling, default mode activity, and inhibition of cortical activity; decreased alpha power is associated with increased levels of arousal, resource allocation and workload [Kozlovskiy & Rogachev, 2021].

Activity in one is perceived to be inversely related to the other, but both are involved in important processes that underlie effective driving: a hippocampo-cortical feedback loop reflects theta oscillations during encoding of new information, while thalamo-cortical feedback loops reflect upper alpha oscillations during search and retrieval [Klimesch, 1999]. Activity of both types of brain wave differ depending on how difficult participants subjectively rate the task [Brouwer et al., 2012]. Given that the present results indicate that n-back=0 did not differ with the control condition, the current results suggest that there could be a threshold for which the additional presence of cognitive load is detrimental to a visual detection task.

According to Berti & Schröger (2001), they suggest that during early sensory processing, event-related potentials occur, which are brain responses directly related to sensory, cognitive, or motor experiences [Luck, 2014]. A similar series of neurological behaviours occur for both auditory and visual distraction, with an exception being related to the presence of absence of re-orientation negativity (RON), which is an activity that reflects attentional reorientation [Higuchi et al., 2014]. RON occurs in all modalities but was not observed in visual distractions when they were presented for 600ms, although were when they were presented for 200ms [Berti & Schröger, 2001].

Returning to the logic that the subjective rating of task difficulty influences neurological activity related to cognitive load, a reason for Berti & Schröger’s (2001) finding could be that participants found the long-duration visual stimuli easier so perhaps did not feel the need to re-orientate themselves to the task. In much the same way, the results from the abstract visual detection experiment could have arisen because of the subjective rating of the task itself. Such measurements were not conducted, so whether participants found the task generally easy or difficult is not possible to establish.

If this experiment were to be conducted again, either subjective ratings of how difficult participants found the tasks or neurological activity measurements would be useful additions to ensure that the tasks provided equal cognitive levels of cognitive load between age groups.

8.2.2 Hypothesis 1b: Difference in the age of participant and cognitive load on visual performance

Participant age influenced visual detection performance reaction time and the number of targets that were missed within the abstract visual detection experiment. Specifically, older participants performed slower and less accurate, compared to younger participants. There was also an interaction between distraction conditions and participant age on visual detection reaction time; the distraction effect was significantly different between n-back=1 between both participant age groups (faster for younger and slower for older), and the most distracting task was n-back=2 for younger participants but Word Generation for older participants.

An explanation for the age difference in the most detrimental visual performance related to distraction tasks is that, rather than an age difference being presented in completing long sentences once they or their clauses have been accessed, the ageing deficit is observed as relating to the individual being unable to retain multiple unrelated units [Gilchrist et al., 2008]. The former relates to attaining information, whereas the latter relates to retention of information. In essence, older people retain the ability to understand the gist of information to the same level as younger people but listening to discrete words and responding to them becomes slower, with this effect accentuated by distraction tasks with higher cognitive load.

Furthermore, the current results of the abstract visual detection experiment potentially arise because the Word Generation task presented a series of discrete words to participants and required them to generate a word from the final letter of the stimulus item. As such, the difficulty of the task may have inherently differed between the age groups, which would have corresponded to differences in neurological activity as mentioned in **Section 8.2.1** [Brouwer et al., 2012]. Accentuating the results is that ageing is associated with a decline in the ability to inhibit irrelevant information, explaining why such age-related influences of reaction times are likely to occur [Cuenen et al., 2005].

Similarly, the ability to inhibit irrelevant information is associated with working memory capacity, with individuals that have high working memory capacity being more adept at inhibiting irrelevant information compared to those with low working memory capacity [Rajan et al., 2019]. Whilst older drivers are less able to inhibit irrelevant information, younger drivers are less able to regulate their emotions in focused driving, which in turn leads to a greater prevalence of reckless behaviours for younger, compared to older, drivers [Navon–Eyal & Taubman–Ben-Ari, 2020]. In turn, this leads to older drivers having more efficient scanning patterns than younger drivers [Lee, 2010]. However, distraction is suggested to interact with age by focusing older drivers' attention on negative stimuli compared to younger drivers, who are not shown to focus their attention on such stimuli to the same extent [Knight et al., 2007].

The results of the abstract visual detection experiment showed marginal non-significant differences between older and younger participants for the number of targets missed. As such, the current results indicate that the ability to inhibit irrelevant information is still present, but slower due to the interaction effect between participant age and reaction time found in this experiment, but caution should be applied when interpreting the impact on overall accuracy of responses between age groups. Instead, the results in the current experiment potentially reflect the interaction between age and distraction on attentional focus, with older participants being slower than younger participants in distraction conditions with higher cognitive loads. This is explained in relation to the higher cognitive load conditions potentially causing frustration, which may have increased older, compared to younger, participants' attention to the distraction task.

8.3 Influence of Passenger(s) on RTC Risk

The first hypothesis was partially supported by the results, although the RTC risk when drivers of any age travel with passengers of the same age as themselves lead to an increased risk, whereas the inverse is true when drivers are travelling with passengers that are not in the same age category. The second and third hypotheses appeared to be supported by the results, although the confidence intervals around the figures mean that the results are inconclusive. The sub-sections below address these hypotheses in further detail.

8.3.1 Hypothesis 2a: Influence of passengers on overall RTCs

Drivers that were travelling with passengers that were similar in age to themselves had an increased risk of an RTC for any cause, whereas all other age interactions between driver and passenger showed that passengers reduced the risk of an RTC for any cause. These results supported previous findings that the presence of passengers reduces the risk of an RTC [Rueda-Domingo et al., 2004; Chung et al., 2014], with effect being reversed for drivers when travelling with passengers of a similar age [Lam et al., 2003; Bingham et al., 2016]. However, research typically explores the influence of passengers on younger (17-25-year-old) and older (65+ year-old) drivers [Strayer & Drew, 2004; Dastrup et al., 2009; Jang et al., 2020], with fewer studies into the interaction between middle-aged drivers (30-60-year-old) and passengers of the same age. How passengers influence middle-aged drivers is therefore not sufficiently explored in previous research, for which the current results indicate could be useful to explore for further insights into the field of driver safety.

8.3.2 Hypothesis 2b: Influence of passengers on RTCs related to distraction

When exploring the influence of passengers on drivers' RTC risk, moderated by distraction (either distracted and driving alone or distracted and travelling with a passenger), the results were more nuanced. The risk of an RTC is either increased or decreased compared to when the driver is distracted and travelling with a passenger, depending on the driver and passenger age.

For the period of 2010-2019, younger drivers had the same risk when travelling with a young passenger and distracted, compared to travelling alone when RTCs in either case involved distraction. In comparison, younger drivers travelling with middle-aged passengers had a higher relative risk, whereas with older passengers had a lower relative risk, compared to younger drivers travelling alone when distraction is involved in either case. For middle-aged drivers and older drivers alike, they were safest when travelling with younger passengers and most at risk when travelling with middle-aged passengers. An explanation for the influence of younger passengers travelling with either middle-aged or older drivers is that they may emphasise the caution they have when travelling with a younger, compared to all other ages of, passengers. This is because older drivers have a higher competency in risk appraisal [Kinnear et al., 2013], meaning they may appraise young drivers as being at a higher risk when driving.

The nature of how distraction influences both younger and older drivers, and any interaction between the two and how they moderate any deficiencies are also important to consider. An example is that older adults have difficulty orienting their attention to knowledge-driven information when conversing, but not when actively listening [McCarley et al., 2004]. The current results indicate that distraction influences the risk of an RTC between driving alone or with passengers but does not explore the way in which distraction occurred. Older passengers may adapt their approach to engaging with drivers, based on age and the risk level they determine in relation to the driver. Indeed, due to their higher competency in risk appraisal, older passengers may be more likely than passengers younger than themselves to appraise young drivers as being at a higher risk when driving [Kinnear et al., 2013]. Future research could explore how passengers attempt to mitigate risk based on driver and passenger age.

Whilst there is a wealth of research that has explored driver and passenger interaction on RTC risk [Ouimet et al., 2015], research that has explored young drivers specifically explores young drivers with young passengers usually [Toxopeus et al., 2011; Rhodes et al., 2015; Bingham et al., 2016]. One aspect that is not explained by these passenger analyses results however is why middle-aged passengers convey the greatest risk in each driver age category. Further research is required to deepen understanding that the influence of middle-aged passengers have on drivers’ RTC risk when distraction is involved.

Additionally, whilst these results were relevant to the period analysed, the confidence intervals ranged from under 1 to over 1 for those that were suggested to have higher risk in current period. This means that the results are inconclusive about whether RTC risk differs between different driver-passenger age pairings when distraction is the cause across all periods of time.

8.3.2 Hypothesis 2c: Passenger seating on RTC risk

For the period of 2010-2019, in cases where RTCs occurred and passengers were present, the location of where the passenger was seated had differing effects depending on the driver and passenger age. This means that passenger seating therefore did not have the same effect for all driver and passenger age interactions. The differences between driver and passenger age related to the influence of passenger seating on RTC risk included the risk being higher when passengers were seated in the rear compared to the front for younger drivers travelling with younger passengers, and to a lesser extent older drivers travelling with younger passengers. Conversely, the risk was higher when passengers were seated in the front compared to the rear for middle-aged drivers travelling with middle-aged passengers, and older drivers travelling with older passengers. There was a more nuanced result for the risk of an RTC related to passenger seating position for middle-aged drivers and younger passengers, where if no distraction was present, the risk was higher when passengers were seated in the front, but if distraction was present, the risk was higher when passengers were seated in the rear.

The results partially provide support to Smith & Cummings (2004), who found that passengers seated in the rear are associated with fewer RTCs compared to when passengers are seated in the front. However, the lack of consistency in this finding between all driver and passenger age interactions means that there are likely different mechanisms behind the differences in risk between passenger seating positions.

Younger drivers were consistently at a higher risk of an RTC when travelling with younger passengers for both front and rear passenger seating positions compared to either younger drivers travelling with other passenger age groups or other driver and passenger age interactions, regardless of whether distraction was involved or not. These findings align with previous research [Toxopeus et al., 2011; Rhodes et al., 2015] and supports the PWM by indicating that younger drivers choose to take risks to facilitate the creation of their identity, opinions, and values [Cestac et al., 2011], further supported by young driver's higher sensitivity to social approval [Todd et al., 2016]; if young drivers were cognitively incapable of driving effectively due to their depreciated cognitive processing [Figner et al., 2009], the influence of all passengers would be detrimental to young drivers in the same way, rather than the detrimental influence explained above being specifically related to younger driver and younger passengers' seating position. Indeed, the influence of all other passengers related to young driver's risk of an RTC across both passenger seating position was considerably lower compared to young drivers travelling with young passengers. These results therefore suggest that passenger seating position is an important consideration for road safety, with this factor being especially important when considering younger drivers travelling with younger passengers.

However, whilst these results were relevant to the period analysed, the confidence intervals were wide for many of the figures, including those where the risk in the current period was considered notably higher than all others. This means that the results are inconclusive across all periods of time about whether RTC risk differs between different driver-passenger age pairings related to passenger seating position, involving either distraction or when no distraction is the cause.

8.4 Influence of Distraction and Passengers on Driving Performance

None of the hypotheses for this research question were supported by the current hazard perception experiment. However, there are caveats to this finding. All hypotheses will be explored further in the sub-sections below.

8.4.1 Hypothesis 3a: Performance on the distraction task related to performance on the hazard perception task

Given that the attentional focus is reduced on relevant elements in the environment when individuals perform tasks requiring high cognitive load [Lavie et al., 2004], the expectation would be that the results from this experiment would show a scaling effect between hazard perception and distraction task performance. In other words, the anticipated effect would be that participants that performed better in the distraction task would perform worse in the hazard perception task. The results from this experiment does not support this conclusion.

There was a weak association between drivers' distraction task performance and their hazard perception performance in all cases. Separating the hazard perception measures between where the passenger was seated indicates that there was a stronger association found when the passenger was seated in the rear for the drivers' reaction times to the hazard perception task. However, the stronger association was close to, but not, statistically significant, possibly indicating that reaction time is a measure to further explore in this matter.

The current results contradict MiRA, whilst supporting the findings from Jarosch et al. (2017). They found that there were no detriments to driving performance as the distraction task continued, whereby fatigue (a higher cognitive load) was considered to occur [Schmidt et al., 2009; Simon et al., 2011]. However, a caveat to the current findings is that only one distraction task was explored. This is because replicating the abstract visual detection experiment from this thesis in this current experiment by exploring differences in drivers' hazard perception performance across multiple distraction tasks whilst also altering passenger seating would have extended the time required to collect data within the session, meaning it was impractical based on the researcher's resources.

An explanation for this experiment's conclusion is that all participants could have found the videoclips boring whereas the distraction task engaging, or the inverse. Neurological evidence suggests that if boredom is experienced, the default mode network (DMN: responsible for self-referential activities and contains brain regions that perform various cognitive functions) is implicated [Spreng et al., 2009]. If in a state of boredom, the DMN is activated and participants are more likely to seek stimulation from elsewhere, either by internal thoughts or the environment [Danckert & Merrifield, 2018]. In the case of this experiment, participants could be more focused on the distraction task compared to the hazard perception task, regardless of how they performed.

However, a limitation with this explanation is that the distraction task was known to be difficult, with a common participant comment being that the task was frustrating; frustration is considered to cause task-switching in dual task situations [Bowman et al., 2021]. Additionally, frustration is considered to impair driving performance [Lee, 2010]. As such, participants that performed badly on the distraction task would be anticipated to perform badly in proportion for the hazard perception task due to the impairments to driving performance or show improvements due to task-switching. This explanation therefore does not account for the current results of this experiment. Instead, the results indicate that the high cognitive load of the distraction task influences driving performance, regardless of how accurately they perform the distraction task.

Additionally, these results differ from the abstract visual detection experiment potentially because participants were instructed to focus primarily on the distraction task, meaning that all participants were equally as focused. Indeed, the abstract distraction experiment supported MiRA. Whilst participants were assessed to consider their distraction task performance whilst conducting the abstract visual detection task and were found to be above the threshold for being considered distracted whilst attentive to the alternative task [Monk et al., 2011], participants were not told which task to prioritise in the abstract visual detection experiment. Consequently, the focus on the distraction task could have varied more in the abstract visual detection experiment compared to the hazard perception experiment.

The assumption was that participants would prioritise the distraction task in both experiments, but the current results suggest that participants' task prioritisation may have been different from what was expected in the abstract visual detection experiment. Indeed, in a real driving context, compensatory behaviour is implemented by drivers when they are engaged in distractions [Baldo et al., 2020]. In contrast, participants were instructed to prioritise the distraction task over the driving task in this experiment. The results may reflect participants obeying the instruction rather than adopting typical behaviour whilst driving. Ensuring that participants are explicitly instructed in the way they were for the hazard perception experiment will ensure that this ambiguity does not arise in the future.

8.4.2 Hypothesis 3b: Passenger seating in relation to their engagement with the distraction task

Most passengers engaged with the distraction task with complete accuracy across both passenger seating position. There were exceptions to this, whereby accuracy was still high (>90%) but given that these exceptions were inaccurate at the start of the experiment, their error likely arises because of misunderstanding the task rather than being influenced by the seating position. An attempt was made by the researcher to ensure that passengers would be equally incentivised to behave in a way that would improve the drivers' ability to perform well on the hazard perception task by informing the passenger that they would receive a cash prize if the driver achieved the highest accuracy or fastest reaction time. This was intended to encourage the passenger to moderate their engagement with the distraction task based on their view of the road scene in the videoclips. This measure did not have an effect in the current study.

An issue with the current findings however is that the task may have been low cognitive load for passengers, despite being presented as high cognitive load for drivers. This would explain why the current results do not reflect the assumption of passengers' view of the road ahead based on the increased risk between mobile phone conversations (not able to see the road ahead) and passenger conversations (able to see the road ahead) [Crundall et al., 2005; Charlton, 2009; Matthews et al., 2018].

Passengers were required to read aloud a sequence of letters as they appeared, but drivers were required to say the letter that appeared two previously in the sequence. As such, the driver was anticipated as having a high cognitive load from the task, but the passenger may not have reached a threshold where the task caused them sufficient cognitive load that they felt they were required to moderate their performance. Given that the passenger analysis from the RTC data indicated that younger drivers travelling with younger passengers were most at risk when the passenger was seated in the rear, future research could explore whether passengers moderate their engagement with different distraction tasks whilst they are seated in the rear, rather than simply presenting them with one distraction task.

8.4.3 Hypothesis 3c: Passenger seating position on driver's hazard perception performance

Passenger seating in relation to drivers' performance on the hazard perception task was disrupted for reaction time only, with reaction time being slower when passengers were seated in the front rather than the rear. Detection accuracy, responses to stimuli that were not hazards (false positives), and the ratio between accurate detection to false positives across the whole videoclips were not found to be significantly influenced. Findings from this study therefore did not support the hypothesis that predicted that reaction time would be faster when passengers were seated in the rear rather than the front. There were no differences in the accuracy of passengers in relation to their performance whilst reading the distraction task aloud between when they were seated in the front or rear. As such, the current results do not show that passenger seating influences how much they engage with the distraction task. It was proposed that passengers seated in the front would moderate their engagement with the distraction task more than when they were seated in the rear because of the clearer view they have of the road ahead meaning they are able to detect hazards faster and more accurately. In turn, this leads to the driver being less distracted by the passenger when they are seated in the front than when they are seated in the rear. The results of this experiment therefore suggest that this reasoning was not correct.

An alternative reason for the result may be that the visible presence of a passenger could have influenced reaction time, given that the driver was exposed to the same level of distraction task from the passenger regardless of where the passenger was seated; the only difference between passenger seating position that emerged in this study was whether the passenger was visible to the driver, with the passenger being potentially visible in the drivers' peripheral vision whilst the passenger was seated in the front, but not visible when they were seated in the rear. However, to the researcher's awareness, passenger visibility to the driver whilst they are driving has not specifically been explored in relation to RTC risk. More research is therefore required to understand why visibility of passenger may influence results when the exposure to distraction is presented at equivalent levels between when passengers are seated in either the front or rear.

8.4.4 Hypothesis 3d: False positives to hazard perception performance

All mouse-clicks from passengers were analysed to assess whether seating position had an influence on the number of mouse-clicks passengers performed in instances where no hazards were present, across all videoclips in the hazard perception task. These include videoclips that did not have any hazards, and mouse-clicks to all videoclips. Passenger seating did not influence the number of false positives of hazards in either case.

These findings contradict FSDT, which suggests that "hazardousness" would be on a continuum rather than categorical [Zadeh, 1978; Klir & Yuan, 1995; Stafford et al., 2003]. Indeed, these findings specifically contradict the finding by {Jamson & Merat, 2005), who show that higher cognitive load leads to increased false positives. However, the cognitive load is assumed to differ based on passenger seating, but this is based on implied mechanisms behind risk differences between the two [Smith & Cummings, 2004; Smith & Cummings, 2006; Górniak et al., 2022], rather than certainty in passenger seating positions differing in their cognitive load. As such, exploring false positives in relation to different distraction tasks between seating positions, rather than on a single distraction task, would provide further insights into this matter.

8.5 How the Thesis Findings Relate to Previous Theory

The findings in this thesis partially support the Token Set Size Effect (TSSE), showing that distraction influences abstract visual detection for both reaction time and missed targets, but only reaction time for hazard perception. The TSSE presents a sequence of auditory objects that are irrelevant to the primary task a person is performing, in which performance to the primary task is disrupted if the set is increased from one ("AAAAA") to two ("ABABABABAB") [Tremblay & Jones, 1998]. TSSE implies that distraction influences performance on an alternative task, whilst also suggesting that performance on the alternative task would scale in proportion to the distractor condition. For instance, when passively processing auditory items, performance degrades in proportion to the number of sets presented [Campbell, 2003]. The current results do not support this conclusion, although there is a potential suggestion that distraction performance in relation to reaction times within the hazard perception task between passenger seating positions should be explored further.

A reason for this difference is that Horrey et al. (2017) found that when participants are presented with either no or boring audio conditions, these resulted in fewer variations regarding lane keeping and headway maintenance. In contrast, longer response times to critical braking events were recorded when participants were presented with an interesting audio condition. The nature of the distraction audio is thus an important consideration, in which the boring distraction task presented in this experiment potentially differs from distractions drivers choose to engage in to alleviate boredom in the real driving context. Relating this to the experiments in this thesis, there were no measures of how interesting participants found the distraction tasks. Whist Horrey et al. (2017) relate their findings specifically to driving behaviours, their results could be applicable if participants found the distraction tasks presented to them throughout the thesis experiments as boring.

How hazards are determined by each driver is also an important consideration for the results found in the experiments within this thesis. Swets (2012) suggests that the Signal Detection Theory (SDT) is one model for drivers determining what a target is or is not. Performance in SDT can be quantified by using probability-based theory; it assumes that there are two possible scenarios, whereby one is the signal, and the other is noise, either of interest or absent respectively. Relating this to the experiments within this thesis, there was only one type of target, devoid of real-world context, to detect in the abstract detection experiment, so all participants would likely have understood to respond in the same way to the targets. However, there were multiple types of targets that were presented as hazards in the hazard perception experiment, which participants may have differed in their understanding of the items being hazards [Ventsislavova et al., 2019]. The hazard perception experiment thus may have been influenced by individual differences of participants' conceptualisation of the term 'hazard', which could have caused participants to vary in their distraction level more for the hazard perception, compared to the abstract visual detection, experiment. Likewise, distracted drivers perform riskier behaviours [Brodsky, 2018]. The extent to which participants not only were, but also felt, distracted is therefore important as that may have influenced their performance to the primary task in both experiments.

Additionally, the differing perception of danger related to driving scene is more problematic to younger drivers than older drivers because when driving at a younger age, they tend to focus on the danger rather than the difficulty related to when certain manoeuvres can be performed. They subsequently under-estimate what dangers may occur during certain manoeuvres [Groeger & Chapman, 1996]. As all drivers in the current hazard perception experiment were younger drivers, their responses would likely have been related to the perceived danger of the scene. Results are therefore potentially representative for younger drivers only, rather than for all drivers, although this is indeed the highest risk group in relation to driver and passengers.

Additionally, the type of road used in clips is an important aspect to consider for the influence of distraction on hazard perception. Burge & Chaparro (2018) used FSDT to explore different conditions of mobile phone texting whilst participants were driving in city and highway environments, corresponding to more and less visually cluttered environments respectively. They found that there was a difference between texting, but not environmental, conditions. The videoclips within the experiment presented in the hazard perception experiment used driving scenes within cities only, so did not assess the impact of driving environment to hazard perception performance. However, as Burge & Chaparro (2018) solely explored texting on driving performance, which is a specific distraction, a future direction of their research could be to consider cognitive load rather than a specific distraction, where the former obviates the modality specificity of individual distraction tasks.

8.6 Thesis Limitations

Distraction performance in the abstract experiment was measured to ensure that participants were above the specified threshold (>45%) to ensure they were sufficiently distracted whilst attending to the visual detection task. However, they were not analysed in relation to visual detection performance, which could have provided direct comparisons with the hazard perception experiment. Such an analysis was not conducted because the researcher had participant’s distraction performance data on their personal laptop that was secure with password protection and the files were anonymised with a participant code identifying them, but the laptop was misplaced. Unfortunately, the researcher had no access to the distraction data to complete this analysis. The researcher would ensure that this did not happen again by ensuring regular back-ups to cloud based servers that were approved by the research institution and carefully managed by appropriate authorities within those authorities.

Another limitation that prevented direct comparison between the abstract visual detection and hazard perception experiment was that a passenger was not present in the abstract visual detection, but was in the hazard perception, experiment. The PhD originally was intended to explore the interaction between lighting and distraction on driving performance. This means that the scope of the PhD did not originally relate to the influence of passengers, only changing during the COVID period. By this time, the first experiment had been completed. This is a limitation that would be hard to prevent in the future, given that COVID and its influence on the course of this PhD was unpredicted. Given that research can stand alone when not in a thesis, unless externally funded as part of a wider project, this is a limitation that should likely not apply to any other scenario, although if it is in a wider project context, the researcher will consider alternative ideas to progress at the point of their original idea placed within the wider context of the whole project.

The number of targets in either the abstract visual detection or hazard perception experiment also provided a limitation regarding comparing the data. For instance, there were 140 targets across approximately 7 and a half minutes in the abstract visual detection experiment, whereas there were 12 hazards across almost 7 minutes of videoclip footage in total. This meant that there would be less certainty with analysing false positives for the abstract visual detection experiment compared to the hazard perception experiment; what may be observed as a false positive may be a late response to a genuine target in the former, whereas the latency of targets in the latter increases confidence in assessing the mouse-click as a false positive. As such, false positives were not assessed in the abstract visual detection experiment. This means that whether distraction influences false positives for visual detection alone, rather than when drivers' schemas are present, could not be determined.

In a similar manner, missing reaction time data in relation to missing targets in either the abstract visual detection or hazard perception experiment were treated differently. Missing reaction time data was left as missing in the abstract visual detection experiment, whereas was transformed to the average of the participant for the targets they detected in the hazard perception experiment. The reason for this is because there were a larger sample of targets to detect in the former, but a smaller sample in the latter. In turn, this means more misses would be required for the abstract visual detection experiment before the data were affected to the same magnitude as the hazard perception experiment. Retaining the missing reaction time data as being associated with missing target data was therefore considered to convey accurate representation of participant's performance for the abstract visual detection experiment. If the same approach was applied to the hazard perception experiment, the researcher's concern was that the analysis would be underpowered by the sample of hazards that were detected. As such, the current approach means that there are limitations with comparing results between the two experiments, but if they were treated the same way, there would equally be limitations. The decision therefore is not in relation to comparison of results between the two experiments, but rather the optimal approach to explore the variables within the study. In this regard, the decision was taken to approach data treatment in the way that it was approached.

Two further limitations were found in the passenger analysis study. First, the RTC data analyses for the passenger analysis study may have been influenced by the base rate of both the driver and passenger age profiles in terms of how many journeys are made for each pairing. Secondly, a limitation is that the base rate of where passengers are seated in the vehicle could not be found. For instance, if there are differences in prevalence of one passenger age group being seated in either the front or rear, whilst other passenger age groups are seated in the alternative seating position, the comparison between the passenger age groups may be misleading. Reference information about the frequencies of journeys made for driver-passenger age pairings and the frequency of where passengers are seated could provide a reference to facilitate further insights into the results from the current RTC data analyses. To the researcher’s awareness, there are no sources that provide this information. Future research exploring the role of passengers and distractions in RTC occurrences could seek to enquire directly with data providers to observe if this data is collected, or if not, there could be discussions about how to capture this data. A further benefit of such discussions is that they may provide guidance to RTC data collectors so that they are capturing comprehensive information about road users and how they engage with the roads, which may lead to deeper insights that can facilitate more effective policy recommendations.

There were also limitations with the hazard perception experiment. This included the possibility that, whilst the distraction task presented to drivers was of sufficient cognitive load, the distraction task was not sufficient to require passengers to moderate their engagement in the way that would be potentially implied in real driving. Similarly, only one distraction task was used. The distraction task was informed by the abstract visual detection experiment, so based on previous findings. However, the novel inclusion of passengers in this experiment means comparison between different distraction tasks whilst passengers were seated in either the front or rear and presenting the distraction task to the driver, between abstract and driving specific contexts, could not be determined. This analysis would have provided deeper insights into the influence of passengers and distraction on driver’s driving performance. Different distraction conditions were not explored in this manner within the hazard perception experiment because of the researcher’s time constraints, given that this would have required more hazards to attain, a larger sample to recruit, and an increased amount of time to conduct each session; an increase in time would have likely reduced how desirable the study was to participate in. As such, a further consequence is that a comparison between the abstract visual detection and hazard perception experiment could not determine the influence of distraction on visual detection alone (bottom-up processes) and drivers' schemas (top-down processes).

A similar limitation is also that no control conditions were explored (drivers' performance to the hazard perception task whilst they were not distracted), which was not conducted because of the lack of researcher's time. Without a control condition, the results of the hazard perception task, the influence of distraction in relation to passenger seating cannot be understood (distraction across different passenger seating positions), only the influence of passenger seating positions whilst distraction occurs.

The videoclips themselves that informed the hazard perception test also provided a limitation. Some videoclips showed standard dash-camera footage, whereas others showed dash-camera footage with an overlay of wingmirrors and an interior central mirror above the driver and front passenger seat. There were no hazards that appeared in any of the mirrors in the latter type of videoclips, so were comparative for the location of where hazards appeared. However, the introduction of the mirror overlay could have diverted drivers' attention away from the road, which may have been accentuated by the distraction task. The reason why these videoclips were used was because these were videoclips sourced for a previous iteration of the hazard perception experiment. The researched did not have access to any new footage for the current study. Future studies should explore videoclips that present the footage in the same way across all videoclips.

Illuminance differences between the videoclips may have provided a further limitation. Lighting is found to relate to driving performance in previous research, although the variation in illuminances was not found to affect hazard perception performance in the hazard perception experiment. As such, lighting could potentially influence other measures of car occupant behaviour, including those exhibited by passengers such as their engagement with distraction. Passengers' view of the road ahead may therefore be an important consideration in road safety. The lack of variation in passenger n-back=2 performance and the lack of alternative measure that could be correlated with lux meant that the illuminance level could only be assessed for drivers and how it influences their hazard perception performance, rather than in relation to whether it influenced passengers' moderation of their engagement with the distraction task. Future research could explore illuminance in relation to passenger distraction further.

The way the hazards were analysed was also a novel approach that was generated and adopted by the researcher. A " hazard window" was manually created within each videoclip, which related to the duration between when the hazard first appeared until the hazard was no longer present within the whole duration of the videoclip. Analyses were then conducted by when the mouse-click occurred within the hazard window, divided by the whole duration of the hazard window. This provided a scale between 0 and 1, with these respectively referring to the earliest and latest possible instance the driver could have provided a valid response to the hazard. This approach was chosen instead of raw millisecond time analyses, either within the whole duration of the videoclips or hazard windows, because both varied considerably between videoclips. This means that the analyses may have been influenced by drivers detecting hazards that had certain durations compared to others. If these were then compared against drivers that detected hazards within durations that were not similar, the raw millisecond time analyses would have not been comparable. As such, the scale analyses chosen obviated this confound by standardising all videoclip durations. However, a caveat is that this is an analysis technique that has not been verified by previous research. The implementation of this analysis technique thus allows comparison between participants in their responses but is limited by the unvalidated technique employed. Further research could explore this technique in greater detail to deepen understanding of its merits and limitations.

8.7 Summary

This chapter explored how the findings from the abstract detection experiment, passenger analysis, and hazard perception experiment relate to the research questions, hypotheses, and wider theory. The results largely supported most hypotheses within the research questions (**Table 8.1)**. **Chapter 9** considers how these findings relate to the wider thesis questions, whilst also elaborating on the future directions of this research.

Table 8.1 **Summary of findings** in relation to the thesis hypotheses**.**

Research Q.	Hypothesis	Decision
1	The higher the cognitive load in a distraction task, the more detrimental to visual performance the distraction will be.	Supported.
	Older people will be less accurate and slower than younger people when distracted and conducting a simultaneous task.	Supported.
2	RTC risk will be higher when driving alone compared to driving with passengers for all age groups, except for younger drivers travelling with younger passengers.	Supported.
	In the presence of passengers, cognitive distraction will be associated with the higher risk of RTCs.	Inconclusive.
	A passenger in the front seat will lead to lower RTC risk than a passenger in the rear seat.	Inconclusive.
3	Higher detection and faster reaction times in the hazard perception task will be associated with lower accuracy in the distraction task.	Not supported.
	Passengers seated in the front will have higher accuracy reading the distraction task to the driver than passengers seated in the rear.	Not supported.
	Passengers seated in the front reading the distraction task will be associated with drivers’ lower detection and slower reaction times in the hazard perception task.	Not supported.
	Fewer false positives will be recorded for drivers’ hazard perception responses when passengers are seated in the front compared to the rear.	Not supported.

Chapter 9: Conclusions

9.1 Introduction

The focus of this thesis was about the interaction between cognitive load associated with driver distraction and passenger presence on road safety. Results from this thesis indicate that as the cognitive load increases, the larger the decrements to visual detection reaction time and accuracy, which subsequently possibly relates. A further finding is that cognitive load, passenger presence, driver and passenger age, and seating position are important considerations for drivers' RTC risk. Finally, whilst the visual detection task whilst distracted was conducted in an abstract environment, whereby both reaction time and accuracy were influenced, distraction is only potentially associated with reaction time differences between passenger seating position within a visual detection study that is contextualised by real driving videoclips. These findings have implications for administration of the hazard perception test related to licensure of driving, driving safety guidance for drivers, and for future driving safety research design.

Distraction was the chosen as the focus because 94% of RTCs are attributable to human error, whereby distraction is the predominant associated factor [Wundersitz, 2019; Read et al., 2021; Cao et al., 2022]. In particular, the thesis aimed to provide deeper understanding of how distraction influences visual detection performance in a driving context to provide administration guidance of the hazard perception test, given that distraction is common for drivers but is not assessed within the hazard perception test that forms part of the official driving theory test. Another focus was about exploring how distraction influences RTC risk, particularly where passengers are present. The first study related to assessing visual performance related to cognitive load, devoid of real-world context to negate the influence of drivers' schemas, which was considered to potentially depreciate any visual decrements from the distraction [Neisser, 1976]. The second study assessed which various elements of distraction and passenger interactions associated with RTC risk. The third study compiled the most detrimental distraction task to visual performance in an abstract setting, and the highest risk driver and passenger combination in relation to risk differences between front and rear setting, to conduct a hazard perception experiment whilst a passenger was seated either beside or behind the driver and providing the distraction task.

Whilst previous literature has explored the topic of distraction within hazard perception tests, the exploration is typically in relation to specific distractions, such as mobile phones and music [Harbluk et al., 2002; Brodsky, 2018; Baldo et al., 2020]. Alternatively, arbitrary tasks are chosen, such as playing auditory tones, responding to abstract pictograms, and digit recall [Berti & Schröger, 2001; Bornard et al., 2011; D'Addario & Donmez, 2019]. Of the arbitrary tasks, the researchers either present with differing levels of difficulty that they associate with differing levels of cognitive load, or between different modalities [Metz et al., 2011]. The novelty of the research presented in this thesis is that the distraction task presented in the hazard perception experiment was chosen after empirical work conducted to assess visual detection of an abstract target in the first experiment. The abstract nature of the experiment meant that it was devoid of real-world context, subsequently meaning that attention could be explored related to the intended distractions, rather than introducing potential confounds of alternative visual items in traffic scenes that may have unintentionally diverted participants' attention.

As such, the strength of this approach is that the abstract visual detection experiment is purely related to visual identification, which provided greater insights into visual behaviour than if the distractions were compared in a driving context. Indeed, if alternative visual items diverted attention, this would have not only complicated the influence of the intended distraction on attention, but potentially vary in its compounded effect between participants as some may have been more distracted than others. Another complication if distractions were initially compared in a driving context would have related to the location of hazards in the driving scene; hazards that are visually detected would have been more varied than in an abstract visual detection experiment, in which the visual targets were presented in the same location to ensure that the results could be comparable.

By conducting an experiment to assess which distraction impairs visual detection performance the most without any real-world context first, the focus was solely related to cognitive load being presented in the distraction task rather than assessing distraction with the cognitive load inherent in a driving task. From this, impairments of the distraction task used in the hazard perception experiment would be comparable between both experiments, with findings potentially related to how cognitive load in both tasks interact for visual detection performance in a driving context.

Analyses were also conducted on RTC data to supplement the earlier findings, where the empirical studies exploring the nature of distraction on drivers' skills was complemented by exploring how distraction influenced RTC risk. The presence or absence of passengers was an important factor within these analyses because the focus was on exploring the distraction either from the passengers directly, and how the presence of passengers moderated the detrimental effects of distraction on the occurrence of RTCs, especially regarding passenger seating positions. As such, US rather than UK data were used because the US database had passenger information recorded, regardless of whether they were casualties or not, whereas the UK database only recorded passenger information if they were casualties.

9.2 Research Objectives

This thesis addressed three objectives about distraction and passenger presence in relation to RTC risk and driving performance. These are as follows:

1) *To identify the distraction task that is most detrimental to visual detection within distraction tasks that are compared in an empirical experiment.*

This aim was explored using an abstract visual detection experiment, with the main purpose to compare different distraction tasks with varying levels of cognitive load to explore the task that was most detrimental to visual detection. It was found that visual detection performance is influenced by the degree of cognitive load. Indeed, distraction was detrimental to reaction time and the number of targets missed in the abstract visual detection experiment. Trends showed that the higher the cognitive load, the slower the performance, which aligned with findings from previous experiments. In contrast, the number of targets missed between each distraction conditions were similar, except for those that had the highest level of cognitive load (n-back=2 and Word Generation), which had a non-significant difference in numbers missed between each other but a significant difference from all other distraction conditions. Such a finding perhaps indicates that there is a threshold for cognitive load and accuracy of visual detection performance.

Exploring the data further indicated that the trend differed between older and younger participants. Across all distraction conditions, older participants were slower than younger participants, although were equal in the number of targets missed. All distraction conditions provided similar levels of decrements to visual detection reaction time performance for younger participants, but the conditions with the higher cognitive loads were more detrimental to visual detection reaction time performance for older participants. Additionally, the distraction condition that provided the slowest average reaction times differed between the age groups (n-back=2 for younger; Word Generation for older). In comparison, there were no interaction effects between age and distraction conditions for the number of missed targets.

A caveat to the study however is that it did not compare an exhaustive list of distractions against visual detection performance. Comparing all possible distractions would not be possible because there is no certain way to ensure that all distractions are captured, plus conducting such a study would be too time intensive. As such, the decision was to compare distraction tasks that are typically used in studies already without the context of the driving scene. The abstract context of the visual detection task allowed results to be considered in relation to visual detection performance without the influence of drivers' mental models of driving that was anticipated to mitigate decrements to performance. In this regard, the study was different than previous research, which explored distraction within the driving context yet did not interpret the results in relation to bottom-up (visual detection) and top-down (mental models) processes.

2) *To explore the influence of passenger presence and distraction on RTC occurrences.*

RTC analyses were conducted with the US RTC database to address this aim. These indicate that passengers generally reduce the risk of a driver being involved in an RTC, although older drivers travelling with older passengers are at the greatest risk in relation to all driver risk, and younger drivers travelling with younger passengers are at the greatest risk in relation to all other passenger age groups within the same driver age category. The confidence intervals ranged below 1 to above 1 in risk for RTCs when distraction was the primary cause and passengers were present compared to drivers travelling alone and distracted. Similarly, the confidence intervals had a wide range for some driver-passenger age pairings, but especially younger drivers travelling with younger passengers across either front or rear passenger seating. Whilst the risk was always above 1 in each case, the wide confidence intervals mean that the results are not robust.

3) *To explore the influence of distraction and passenger location on driving performance.*

To explore this aim, a hazard perception experiment was conducted with young driver participants whilst young passenger participants were seated either beside or behind the driver, based on the most at-risk driver-passenger age interaction from the passenger analyses that were conducted on RTC data. The passenger presented the driver with the n-back=2 distraction task, based on the distraction task that conveyed the greatest decrements to reaction time performance for younger participants in the abstract visual detection experiment.

There was an influence of the distraction condition on reaction time performance in drivers' reaction time performance on the hazard perception task between when passengers were seated in the front or rear, whereby drivers' reaction time to hazards was slower when passengers were seated in the front than the rear. This finding contradicts the logic that passengers seated in the front would moderate their engagement with the distraction task more than when they are seated in the rear. However, the results of the experiment indicated that passenger seating does not influence the accuracy of the driver relating to hazard detection. Additionally, there was no influence of passenger seating position and passenger distraction on any other driving performance measurements, such as false positives from participants.

Other measures that were assessed include the illuminance levels in relation to detection of at least one hazard in videoclips that contained hazards. This showed that there was no association between the two, suggesting that the lighting levels did not have an influence on the results that were found. Likewise, a reliability analysis was conducted to explore whether some hazards were better detected than others, given that they differed in nature and videoclip duration within the study. Analyses were produced that compared "Reduced Data" (with hazards removed based on the reliability analysis) or "All Data" (with all hazards included). In much the same way, missing data were analysed with either the average of all collected data for the participant or imputed with the slowest possible time for the missing hazards related to each participant. These analyses suggested that removal of hazards based on the reliability compared to when all hazards were included had an influence on drivers' hazard detection accuracy comparisons between when passengers were seated in the front or rear. No other influence of the reliability analysis was found for other driving performance measurements.

9.3 Further Work

There are various elements that could be pursued further from the research in this thesis. Some suggestions arise from points made in **Chapter 8** and earlier in this chapter, which are condensed in **Table 9.1**.

Table 9.1 **Future research** based on earlier points raised.

Point	Future research
Either subjective ratings of how difficult participants found the tasks or neurological activity measurements would be useful additions.	Repeat the abstract visual detection experiment whilst measuring subjective ratings of task difficulty and/or neurological activity.
How passengers influence middle-aged drivers is…not sufficiently explored in previous research.	Explore further driver and passenger interactions in relation to middle-aged (30-60) drivers.
Future research could explore how passengers attempt to mitigate risk based on driver and passenger age.	Explore not just RTCs, but also passenger behaviour whilst they are travelling with drivers.
Further research is required to deepen understanding that the influence of middle-aged passengers have on drivers' RTC risk when distraction is involved.	Explore further driver and passenger interactions in relation to middle-aged (30-60) passengers, when distraction is the primary contributory factor to the RTC.
Future studies could further provide insights into the influence of peers/non-peers and road view by assessing driving performance in a laboratory setting.	Conduct laboratory studies for young drivers (18-25) travelling either with young passengers in their peer group (18-25) or younger passengers (0-17).
Conducting a study where interviews are conducted across multiple years and RTC analyses are conducted concurrently to the interviews will provide deeper insights into understanding .	Conduct qualitative (interviews) and quantitative (RTC occurrences) together to explore both perceptions and actual RTC risks. The interviews can be conducted over multiple years to provide trends over time.
Alternative passengers [to the passenger of primary focus] were not differentiated in age.	Conduct further passenger-passenger analyses, focusing on age interactions and other factors.
Future research could explore whether passengers moderate their engagement with different distraction tasks whilst they are seated in the rear.	Rather than exploring whether passengers moderate their engagement with the distraction task by exploring this with one distraction task, compare their engagement with distraction when presented with different distraction tasks.
Reaction time is a measure to further explore in [terms of the association between distraction performance and hazard perception performance].	Explore the association between different distraction tasks on reaction time performance to the hazard perception task.
Exploring false positives in relation to different distraction tasks between seating positions, rather	Explore false positives between different distraction tasks rather than one distraction task.

than on a single distraction task, would provide further insights into [whether FSDT is supported].	
A future direction of their research could be to consider cognitive load rather than a specific distraction.	Compare different types of driving distraction that provide equivalent detriments to visual detection performance, and then compare these in a hazard perception test context.
The intention of the study was to explore a breadth, rather than depth, of aspects related to distraction and passenger presence.	Focus on specific aspects of distraction and passenger presence rather than across multiple factors.
A comparison between the abstract visual detection and hazard perception experiment could not determine the influence of distraction on visual detection alone (bottom-up processes) and drivers' schemas (top-down processes).	Across an abstract environment and driving related context, compare different types of driving distraction that provide equivalent detriments to visual detection performance that are the same in both contexts.
No control conditions were explored (drivers' performance to the hazard perception task whilst they were not distracted [with passengers that were present]).	Conduct an experiment to explore the influence of both distraction and passenger presence in a hazard perception experiment, with distraction conditions and no distraction conditions.
Future studies should explore videoclips that present the footage in the same way across all videoclips.	Conduct a hazard perception experiment where all hazard videoclips have the same layout of footage. Alternatively, conduct an experiment with the same footage, either with or without a wingmirror overlay to assess whether this has an influence on performance.
Future research could explore illuminance in relation to passenger distraction further.	Explore different passenger distraction tasks whilst drivers conduct the hazard perception task, in relation to different lighting conditions of the videoclips.
Further research could explore this [hazard window] technique in greater detail to deepen understanding of its merits and limitations.	Conduct hazard window scale analyses in a hazard perception experiment where the hazard clips and hazard window durations are similar or divided in an intentional way to explore differences between duration types. This will allow the researcher to compare raw millisecond and hazard window analyses.

One factor to consider is whether the distraction is engaged with intentionally or not. A related point to raise is to explore whether drivers and passengers choose to suppress distraction. This is because in a real driving situation, there is an indication that older drivers suppress distraction to mitigate their cognitive impairments [Persson, 1993]. This may be potentially true of other driver age groups. The current experiments presented distractions that participants were required to respond to, but Hughes (2014) states that there are different cognitive processes for intentional engagement with distraction or not. If there is intention for the driver to engage with distraction, individual differences could also be important, such as if drivers would normally intend to answer mobile phones whilst driving when presented with a mobile phone distraction in the experiment [Holland & Rathod, 2013]. Repeating the abstract visual detection experiment with additional manipulations of whether distractions are intentional or not for participants would provide further insights that have not been addressed in this thesis.

Additionally, both the abstract visual detection and hazard perception experiments were conducted in laboratory conditions. The laboratory conditions may have not reflected the appropriate level of risk that drivers have when they drive, meaning that the artificial nature of the laboratory conditions may not accurately represent how drivers would behave in a real situation. Exploring variables that could increase risk would be ethically impractical to implement in an actual driving context. An alternative measure to explore whether the methodological limitations influence results could be to explore the same experiments between laboratory conditions in the way they were presented within this thesis, whilst also presenting them virtually. Given the greater immersion of the participant into perceived reality that virtual reality has compared to standard laboratory settings, this may lead to differences in results. However, if they present similar results, the suggestion would be that the laboratory results represent actual driving performance with a reasonable level of accuracy.

A further research lead is in relation to the passenger analysis. The database did not collect all RTC information, just incidents where at least one occupant in the vehicle was killed within 30 days of the occurrence. Likewise, a comparison of years before and after 2010 could have assessed this issue of passenger presence on RTC risk but was not conducted in this thesis because distraction was only recorded from 2010 onwards. Two measures to address these issues is to source a database with a comprehensive set of passenger data that can be analysed and/or source data from other countries that have sufficient data and introduced road safety policy changes. An analysis of data before and after policy change could provide insights into the success of the new policy in relation to road safety.

9.4 Impact

By employing measures that could improve the hazard perception test, the practical consequences are that RTCs should be reduced. Within the context of this thesis, the findings highlight the influence of passengers and distraction interact in relation to RTC risk and visual perception performance in both an abstract and driving environment. The practical impact arising from the abstract experiment in this thesis is to alter the hazard perception test to include distraction in the driving test because the results found that higher cognitive load reduces accuracy and increases reaction times to hazards. Seating was found to influence RTC risk generally, with the assumption that seating may interact with distraction for hazard perception performance. This was not found, indicating that passenger distraction is not influenced by where they are seated whilst the driver is driving.

Passenger distraction is an important consideration, especially with the recent discussions in public discourse of introducing the graduated driver licencing (GDL) that will influence the extent to which new drivers are able to perform certain actions whilst driving, such as carrying passengers. However, given the limitation of the distraction presented by the passenger perhaps not being as distracting to the passenger to represent how they realistically distract in vehicles, there is further work to be considered in this matter to understand whether passenger seating should be considered when introducing any GDL policies or recommendations.

Appendix A: Abstract Detection Materials

A.i. Information Sheet

This study is part of a programme of research exploring how distraction and lighting interact to influence visual reaction times in drivers. This experiment tests the effect of different distractions. You have been given this information sheet because you have expressed interest to take part. Should you decide to participate after reading this information sheet, it would be helpful if you could contact the lead researcher; a time can be set aside for you to participate. Finally, regardless of your decision, thank you for your interest in this study.

What is the study's purpose?

The purpose of the study is to compare visual detection with three different distraction conditions. The results will inform the choice of distraction task used in future studies.

Why have you been approached to take part?

The research requires human participants so that we can measure how changes in lighting affect the ability to detect targets under different levels of distraction. To participate in this experiment, it is required that you have good hearing and vision. For vision, this means having a visual acuity of 6/12 or better, wearing your normal glasses if you would usually do so for driving. For hearing, this means being able to hear sounds of 40 decibels or higher, and between 20 and 20k Hz. We require participants who are aged either 18-25 years or older than 65 years.

Your visual acuity and hearing will be assessed once you come to the experiment room. It is therefore acceptable if you would like to take part but are not sure if you are eligible.

Do you have to take part?

Participation in this study is voluntary. Should you decide to proceed with participation, you will be asked to sign a consent form. You are able to withdraw without giving a reason at any point before, during or after your data has been collected. There will be no adverse consequences if you choose to withdraw.

What will be required of you if you take part?

This experiment requires that you are seated facing a display screen, looking towards a cross-mark at the centre of the screen. At random intervals, a second target will appear on the screen and if you see this you are asked to press a response button. In parallel, you will be asked to do one of three things: say aloud a number appearing on the screen, repeat a series of numbers or digits read out by the experimenter, or say a word starting with the last letter of a word stated by the experimenter. With the visual acuity and hearing measures, this task is expected to take approximately one hour.

How will your data be recorded and used?

You will be assigned a participant code that will be used to identify your data in the study rather than associating your data with your name. Using a participant code means that your identity in the study remains

anonymous. The researcher will input your experiment data onto a computer and associate it with your participant code. Your verbal responses to the some of the tasks will be recorded so that the experimenter can check your responses. All files and outputs will be accessible to the wider research team. Once the data have been analysed and the report written for this study, the audio files will be deleted. This is expected to occur around the PhD submission time in September 2021 at the very latest.

Should you decide to participate, your age, gender, and experiment data will be recorded. These data will be used in the research analyses and will be retained for future use. Future uses include our further analyses of the data and sharing the results with other researchers. You will be asked to add your name and sign the "Consent to Participate" form: this is to enable the researcher to confirm that we did seek informed consent to participate. Your name will not be included in the records of results; all data that you provide will be anonymised and it will not be possible to identify you from the data collected.

What are the possible disadvantages of taking part?

No disadvantages have been identified.

What are the possible advantages of taking part?

This research is investigating how we might improve the use of lighting and other visual aids to enhance road safety. This particular experiment is investigating how distractions affect the ability to detect hazards. The results will be used to design a second experiment using a driving simulator where changes in road lighting will be investigated.

You will receive £10 to cover your expenses in participating in the experiment.

If you take part, will your identity be kept confidential?

Yes. Any information relating to your identity will be kept strictly confidential. Only your participant code will be associated with data. To ensure confidentiality, your personal information and experiment data will be stored on a password protected computer within a locked room accessible by the research team only. No third party will be permitted to access either your personal information or your experiment data.

What is the legal basis for processing your personal data?

The legal basis for collecting and using your personal data is stipulated in Article 6(1)e Governance and Management:

- Processing is necessary for the performance of a task carried out in the public interest or in the exercise of the official authority vested in the controller.

Article 6(1)e comes from https://www.sheffield.ac.uk/govern/data-protection/privacy/general where the full document can be read.

Who is funding this research?

This research is funded by the Economic and Social Research Council (ESRC), and the Engineering and Physical Sciences Research Council (EPSRC) via the Hazards, Road Lighting and Driving (HAROLD) grant.

Who is the data controller?

The University of Sheffield will act as the data controller for this study. This means that they are responsible for retaining your information and using it in an appropriate manner.

Who has ethically reviewed this project?

This study has been ethically approved by the University of Sheffield's Ethics Review Procedure, as administered by the School of Architecture at the University of Sheffield.

How do you complain about this research if necessary?

In the first instance, contact the lead researcher who will endeavour to rectify your concern. If the response given is not satisfactory, please contact the supervisor or the head of school. All these contact details are provided at the end of this document. If your complaint relates to how your personal data has been handled, please visit: https://www.sheffield.ac.uk/govern/data-protection/privacy/general.

Lead researcher:
Scott Fox (srfox1@sheffield.ac.uk), Western Bank, Sheffield, S10 2TN.

Supervisors:
Professor Steve Fotios (steve.fotios@sheffield.ac.uk), Western Bank, Sheffield, S10 2TN.
Professor Richard Rowe (r.rowe@sheffield.ac.uk), 1 Vicar Lane, Sheffield, S1 2LT.

Head of School:
Professor Karim Hadjri (k.hadjri@sheffield.ac.uk), Western Bank, Sheffield, S10 2TN.

A.ii. Consent Form

Please tick the appropriate boxes	**Yes**	**No**
Taking Part in the Project		
I have read and understood the project information sheet dated 10/12/2018or the project has been fully explained to me. (If you will answer No to this question please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)	☐	☐
I have been given the opportunity to ask questions about the project.	☐	☐
I agree to take part in the project. I understand that taking part in the project will include an on-screen experiment, with verbal and visual detection responses required.	☐	☐
I understand that my participation is voluntary and that I can withdraw from the study at any point within two weeks of my data being collected; I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw.	☐	☐
How my information will be used during and after the project		
I understand my personal details such as name, age and gender will not be revealed to people outside the project.	☐	☐
I understand and agree that other authorised researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I understand and agree that other authorised researchers may use my data in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I give permission for the recorded responses from the computer experiment that I provide to be deposited in ORDA and the White Rose eTheses repository, respectively referring to repositories found at The University of Sheffield and the White Rose (partnership between University of Sheffield, Sheffield Hallam University, University of York, University of Leeds, and Manchester Metropolitan University), so it can be used for future research and learning.	☐	☐
So that the information you provide can be used legally by the researchers		
I agree to assign the copyright I hold in any materials generated as part of this project to The University of Sheffield.	☐	☐

Name of participant [printed]	Signature	Date

Name of Lead researcher [printed]	Signature	Date

A.iii. Ethics Application

Section A: Applicant details

Date application started:
Wed 16 January 2019 at 12:30

First name:
Scott

Last name:
Fox

Email:
srfox1@sheffield.ac.uk

Programme name:
PhD

Module name:
N/A

Last updated:
24/01/2019

Department:
School of Architecture

Applying as:
Postgraduate research

Research project title:
Exploring the Influence of Distraction on Visual Detection

Has your research project undergone academic review, in accordance with the appropriate process?
Yes

Similar applications:
N/A

Section B: Basic information

Supervisor

Name	Email
Steve Fotios	steve.fotios@sheffield.ac.uk

Proposed project duration

Start date (of data collection):
Fri 1 February 2019

Anticipated end date (of project)
Fri 31 January 2020

3: Project code (where applicable)

Project externally funded?
- not entered –

Project code
N/A

Suitability

Takes place outside UK?
No

Involves NHS?
No

Health and/or social care human-interventional study?
No

ESRC funded?
Yes

Likely to lead to publication in a peer-reviewed journal?
Yes

Led by another UK institution?
No

Involves human tissue?

No

Clinical trial or a medical device study?

No

Involves social care services provided by a local authority?

No

Involves adults who lack the capacity to consent?

No

Involves research on groups that are on the Home Office list of ‘Proscribed terrorist groups or organisations?

No

Indicators of risk

Involves potentially vulnerable participants?

No

Involves potentially highly sensitive topics?

No

Section C: Summary of research

4. Aims & Objectives

Safe driving requires that the driver detects potential hazards in sufficient time to take avoiding action. After dark, road lighting and head lighting are used to offset the impairment to visual detection from lower levels of ambient light. Cognitive distractions (such as talking with passengers, tuning the radio, looking at advertising boards) also impair driving. The aim of this research is to investigate the interaction between distractions, lighting and visual detection. There are three key objectives:

- Investigate types of distraction and hence determine a suitable proxy for use in experimental research of driving and detection.
- Investigate the manner in which lighting and distraction interact to influence drivers’ hazard perception.
- Investigate the influence of driver age on the interaction between lighting and distraction on detection.

This application is for the first experiment. This is a pilot study to investigate the parameters of standard distraction tasks, hence to select one for use in subsequent studies of driving and detection.

2. Methodology

A screen-based visual detection task will be conducted in the presence of different types of distraction. Participants will be instructed to fixate on a cross in the centre of the screen and press a response button when they detect a target appearing around the fixation mark. The targets to be detected are circular discs of low contrast, appearing 15 degrees from the line of sight to simulate hazards in peripheral vision. Whilst conducting this detection task participants will be simultaneously presented with one of four distraction conditions. These will be presented in individual blocks to participants, each lasting for five minutes. The distraction conditions are:

* n-back: a sequence of letters is read aloud to participants. There is an interval of one second between the letters being presented. The participant's task is to repeat the letters in the sequence back to the researcher. For n=0, the participant states the immediately heard letter. For n=1, they state one letter before that, and for n=2, two letters before that.

* word generation: a sequence of words is read aloud to participants. There is an interval of between four and six seconds between words. The participant's task is to listen to the word, and generate their own word which must start with the final letter of the word they have heard.

* number detection: the fixation mark changes to a single-digit number every two to five seconds, being presented for ~one second before reverting to the cross. The participant's task is to focus their visual attention on the cross and accurately announce the number they have seen to the researcher immediately after they have observed the cross change to a number.

*no distraction: the fixation target is presented without a distraction. This provides a benchmark condition.

All sequences will be randomised for each participant. Each distraction condition will last five minutes, with 25 visual detection events occurring within that time. Given that visual detection is significantly influenced by the amount of light within an environment, the room light will be switched off; the ambient lighting within the room whilst the light is switched off will be measured, in addition to the light emitted by the computer screen.

Experiment data will be automatically recorded into a Microsoft Excel file. These data are detection responses and reaction times to the visual detection event. Data from the output files will be exported to IBM SPSS Statistics 22 software, which will be used to analyse the data. A mixed-design ANOVA model is expected to be used to analyse the data, given the dependent variables are continuous, that age is being treated as a categorical (between-subjects)factor(younger or older) and the distraction conditions are a within-subjects design (no distraction, n-back=0, n-back=1, n-back =2, word generation, number detection).

3. Personal Safety

Have you completed your departmental risk assessment procedures, if appropriate?

Yes

Raises personal safety issues?

No

The researcher is working within the university premises, within typical working hours. There will therefore always be other people around if the researcher or participant feels uncomfortable being alone with one another. Participants are recruited from within the university, and are thus expected to behave in a professional manner. Additionally, there are no hazardous materials handled by either the researcher or participants in this current project.

Section D: About the participants

4. Potential Participants

Participants are required to have normal vision and hearing. Vision will be tested using standard tests (acuity chart and Ishihara plates) administered when they arrive into the experiment room. Participants will be asked if they have any hearing difficulties. If participants do not satisfy the criteria for vision and hearing by these screening tests, they will be excluded from participation.

This experiment will seek to recruit 84 test participants. This sample was determined by G*Power software to provide sufficient statistical power, with an effect size of 0.8 and achieved power of 0.95. Experiment conditions will be divided to contain participants aged 18-25, and 65+, respectively categorised as younger and older participants. This is to account for known effects of age on vision, driving experience and distraction. An equal number of males and females will be recruited. Details of gender are collected to account for fair representation in the study.

2. Recruiting Potential Participants

An opportunistic sampling frame will be employed to recruit participants for this study. Potential participants will be approached online by the use of emailing lists within the university. An email will be sent with a summary of the research project, the required task within participation, and £10 to compensate their time if they decide to participate. From this, people that directly reply to the researcher will be sent a document by email that provides information about the research (the Information Sheet), including the legal basis of their data collection and storage, and how the research is being funded. Participants will book a testing session via Doodle poll, which is an online platform for organising appointments in which participants will be given their participation code to enter so that their identity remains anonymous to other participants using the platform. Selection of an option within this platform will act as their requested time-slot to participate. Following this, the researcher will send a final email to the participant to confirm the details of their appointment to participate. Once enough participants are recruited for either age condition, any further participant that is categorised within that age group will be added to the waiting list in case any participant withdraws. Participants from the waiting list will be selected by the order they were added, meaning that the first person that is added to the waiting list will substitute the first person to withdraw.

2.1. Advertising methods

Will the study be advertised using the volunteer lists for staff or students maintained by IT Services? Yes

The volunteer list aligns well with the desired sample criteria: a large sample of specific age groups from the general population that are likely to be on the volunteer list. Other methods were considered, but these would not provide access to an appropriate sample in an economical way. For instance, snowball sampling as a strategy is better suited for identifying participants that are difficult to access; the criteria for this project is such that the population of interest is expected to be easily accessible. Additionally, an alternative opportunistic sampling method was also considered: approaching people on the street to take part. Given that the researcher does not physically encounter the people that receive the information by email, and the emailing list is not linked to any specific person, the participants’ identity remains anonymous. Sending an advert for the study to an emailing list means that people that respond are doing so because they take an active interest in participating rather than feeling obliged, whereas there is the potential for participants to be responding out of the notion of obligation if they were approached in person. Other sampling methods, such as probabilistic or random sampling, would take too much time and resources compared to an opportunistic sampling frame, so were disregarded.

3. Consent

Will informed consent be obtained from the participants? (i.e. the proposed process) Yes

Prior to data collection, all participants will be required to sign a consent form that outlines the terms of their participation, their right to withdraw, and their acknowledgement of how their data will be stored and used. The researcher and participant will each hold a copy of the signed document.

4. Payment

Will financial/in kind payments be offered to participants? Yes

This study is part of the Hazards, Road Lighting and Driving (HAROLD) grant from the Engineering and Physical Sciences Research Council (EPSRC). A financial incentive of £10 is provided by the grant to participants to compensate them for their time participating in the project. This is appropriate given that the study will take approximately one hour to complete.

5. Potential Harm to Participants

What is the potential for physical and/or psychological harm/distress to the participants?

The procedure is not anticipated to cause the participants psychological or physical distress. Should the participant wish to terminate their participation in the study, they will be able to do so without giving a reason. Participants' right to withdraw will be emphasised verbally by the researcher before the participants begin their experiment session.

How will this be managed to ensure appropriate protection and well-being of the participants?

Participation in this experiment requires observation of a screen and button pressing in response to images. The screen brightness is not sufficiently high to cause visual discomfort. The test period (one hour maximum) is not expected to cause discomfort from either observing the screen or for sitting still.

The experimenter has completed the University's out of hours and fire training courses.

Section E: About the data

4. Data Processing

Will you be processing (i.e. collecting, recording, storing, or otherwise using) personal data as part of this project? (Personal data is any information relating to an identified or identifiable living person).

Yes

Which organisation(s) will act as Data Controller?

University of Sheffield only

2. Legal basis for processing of personal data

The University considers that for the vast majority of research, ‘a task in the public interest’ (6(1)I) will be the most appropriate legal basis. If, following discussion with the UREC, you wish to use an alternative legal basis, please provide details of the legal basis, and the reasons for applying it, below:

N/A

Will you be processing (i.e. collecting, recording, storing, or otherwise using) ‘Special Category’ personal data?

No

3. Data Confidentiality

What measures will be put in place to ensure confidentiality of personal data, where appropriate?

Participants’ names will not be included in the records of results; all data that is provided will be anonymised and it will not be possible to identify participants from the data collected. Participants will be asked to add their name and sign the “Consent to Participate” form: this is to enable the researcher to confirm that informed consent to participate was sought. It will not be possible to link the consent form to the recorded experimental data. The consent forms will be kept within a file within a limited access space of the Arts Tower at the University of Sheffield. Once the research has been completed, the researcher will record the participant’s name on the Consent to Participate form and add an identification number. This will be a simple integer to record the order in which participants were recruited, but will not include their initials or other linked identification. When results are recorded, the number will be used to reference participants’ data, not their names.

4. Data Storage and Security

In general terms, who will have access to the data generated at each stage of the research, and in what form

The researchers will have access to both personal and experiment data from participants. All data will be anonymised using a numeric identification number. It will therefore not be possible to identify participants from recorded data. Only the consent form will include the participants’ name and identification number. During the experimental period the consent forms will be kept in the laboratory, locked in the filing cabinet, with that room being locked when not in use. On completion of the experiment, the collated consent forms will be scanned, with the scanned versions then stored only on the university approved secure file store and the paper copies destroyed.

What steps will be taken to ensure the security of data processed during the project, including any identifiable personal data, other than those already described earlier in this form?

Participants will be identifiable only on the signed consent forms. During the experimental period the consent forms will be kept in the laboratory, locked in the filing cabinet, with that room being locked when not in use. On completion of the experiment, the collated consent forms will be scanned, with the scanned versions then stored only on the university approved secure file store and the paper copies destroyed.

Will all identifiable personal data be destroyed once the project has ended?

Yes

Please outline when this will take place (this should take into account regulatory and funder requirements).

During the experimental period the consent forms will be kept in the laboratory, locked in the filing cabinet, with that room being locked when not in use. General Data Protection Regulation guidelines stipulate that personal details are only retained for as long as necessary; on completion of the experiment, the collated consent forms will be scanned, with the scanned versions then stored only on the university approved secure file store and the paper copies destroyed (estimated September 2021). However, the UK Data Service stipulates that electronic copies of the consent form should be made available for as long as the anonymised data is retained. Given that digitised, anonymised data is required to be uploaded to the funding body's data repository (White Rose eTheses Online), electronic copies of the consent form will be retained onto a university approved secure file store. This will contain only participants' names and signatures, not their participation code.

Section F: Supporting documentation

Information & Consent

Participant information sheets relevant to project?

Yes

Document 1055298 Add new version

- Version1 (Information_Sheet_v3.docx)

Click to add a participant information sheet

Consent forms relevant to project?

Yes

Document 1055299 Add new version

- Version1 (Consent_Form_v2.docx)

Section G: Declaration

Signed by:

Scott Ryan Fox

Date signed:

Wed 16 January 2019 at 12:37

Final Decision on Application

Approved

Appendix B: Hazard Perception Materials

B.i. Videoclips

No hazards:

Video 1:
https://www.youtube.com/watch?v=VMWaDyfAM8g&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=9

Video 2:

https://www.youtube.com/watch?v=iz7o7TtdA1Y&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=17

Video 3:

https://www.youtube.com/watch?v=iHSU2Sfb2JU&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=15

Video 4:

https://www.youtube.com/watch?v=HQ1lqWrnmZw&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=4

Video 5:

https://www.youtube.com/watch?v=Vc2jE8AKPXM&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=10

Video 6:

https://www.youtube.com/watch?v=MAeOBOGmNDA&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=7

Video 9:

https://www.youtube.com/watch?v=Zn9t_apFIAc&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=11

Video 10

https://www.youtube.com/watch?v=nJ1Cw77ack0&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=18

Hazards:

Video 7.

https://www.youtube.com/watch?v=CPBbxhhHrN8&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=3

Hazard: junction; note that there is audio in this video, but the audio was muted for the experiment.

Timestamp: 5 to 11 seconds.

Video 8

https://www.youtube.com/watch?v=Lkh7SSC7XEQ&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=6

Hazard: junction.

Timestamp: Start of the clip to 5 seconds.

Video 11.

https://www.youtube.com/watch?v=id62rTrhKmo&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=17&ab_channel=ScottRFox

Hazards: indicator and pedestrian.

Timestamp: 8 to 21 seconds.

Timestamp: 17 to 23 seconds.

Video 12.

https://www.youtube.com/watch?v=h94WTpTr35k&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=14

Hazards: car and pedestrian.

Timestamp: Start of the clip to 3 seconds.

Timestamp: 5 to 11 seconds. If participants responded to both pedestrians, the earliest response would be valid whilst any other responses would be discounted.

Video 13.

https://www.youtube.com/watch?v=HaZZrm1YWlI&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=7&ab_channel=ScottRFox

Hazard: junction and brake.

Timestamp: 5 to 9 seconds.

Timestamp: 15 to 16 seconds.

Video 14.

https://www.youtube.com/watch?v=bVzXp05D3jw&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=12

Hazards: hazard lights and car.

Timestamp: Start of the clip to the end for hazard lights; 4 to 8 seconds for the oncoming car.

Video 15.

https://www.youtube.com/watch?v=ArImx2uRq_c&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=2

Hazard: vehicle crossing.

Timestamp: 5 to 11 seconds.

Video 16.

https://www.youtube.com/watch?v=en_1aXA0724&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=13

Hazard: bike.

Timestamp: 20 to 25 seconds.

Video 17.

https://www.youtube.com/watch?v=3XMjaHyC-Qc&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=1

Hazards: brake and vehicle crossing.

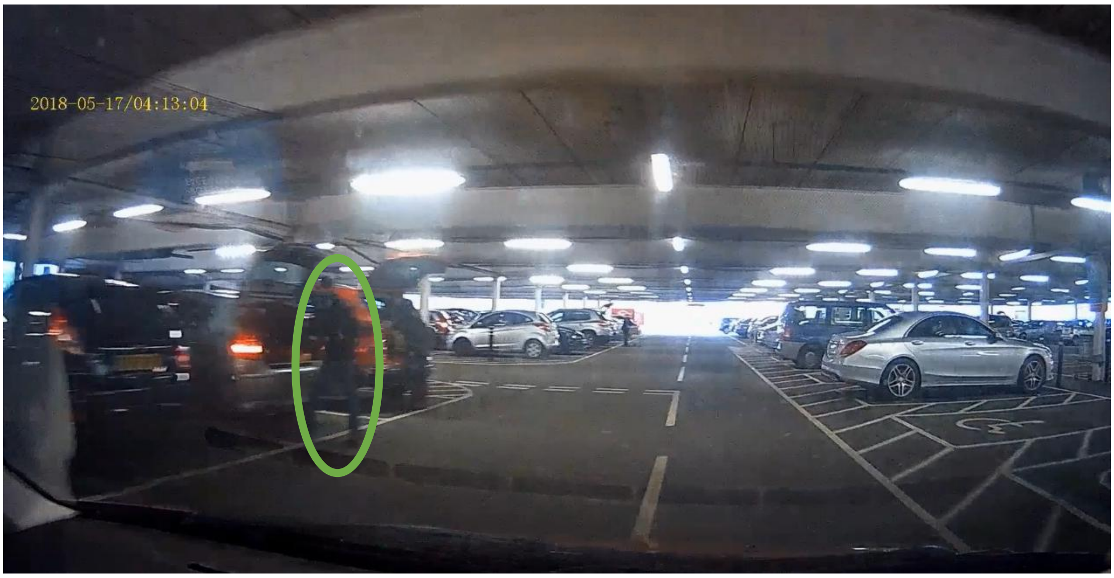
Timestamp: 2 to 13 seconds.

Video 18.

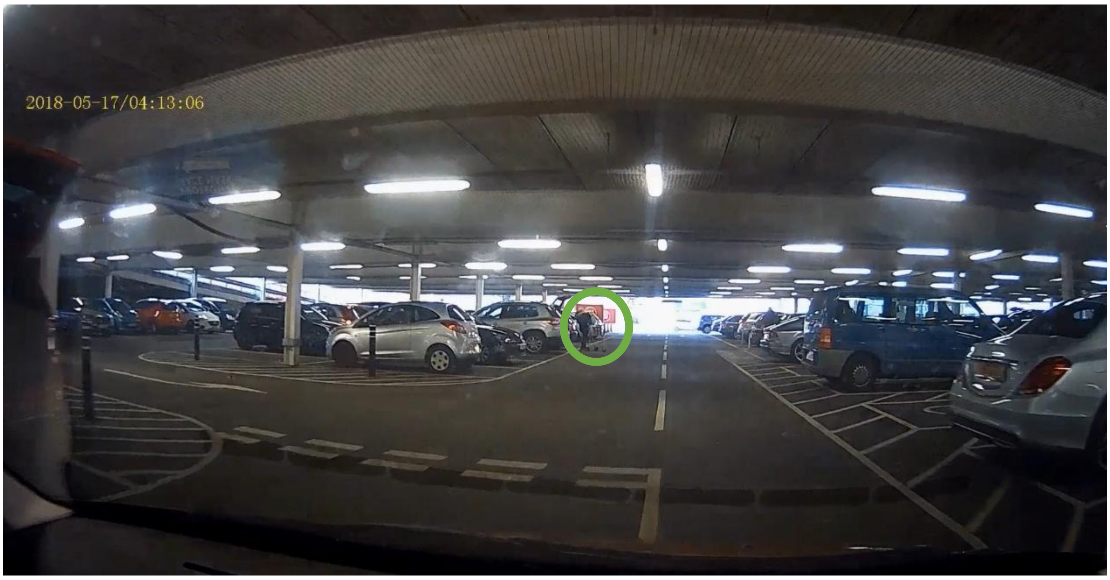
https://www.youtube.com/watch?v=Txxe5CB4bQI&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=8

Hazards: pedestrian, pedestrian, trolley, and junction.

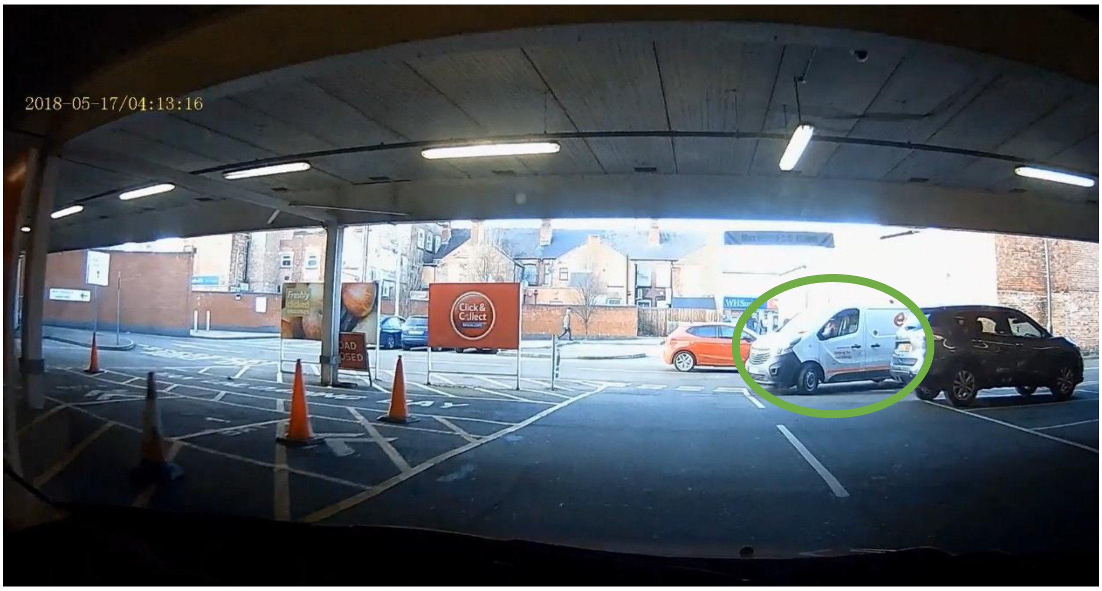
Timestamp: Start of the clip to 4 seconds.



Timestamp: 6 to 8 seconds.



Timestamp: 7 to 16 seconds.



Timestamp: 18 to 21 seconds.

Video 19.

https://www.youtube.com/watch?v=IM9CtXW19OM&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=20

Hazard: junction.

Timestamp: 1 to 9 seconds.

Video 20.

https://www.youtube.com/watch?v=mOeEML7l5r8&list=PL1MtPeIksK0oKNg5KSdBlG05Klg1PIQp0&index=19

Hazard: pedestrian crossing.

Timestamp: 3 to 8 seconds.

B.ii. Python Code for Retrieving Mouse Click Locations

```
import cv2
from media_files_ import path_list


#---------------------------------------------------------------
def settings():

    global display_images, save_images

    display_images = False # True or False

    save_images = True # True or False

#---------------------------------------------------------------
def main():

    # apply settings from function
    settings()

    log_list = path_list(‘analyse_this’, ‘csv’)

    for log in log_list:
        log_contents = read_log_file(log)
        clicks = []
        for line in log_contents:
            if len(line) > 3 and type(line[2]) == str and ‘—' in line[2] and int(line[6]) != 0:
                clicks.append([log, line[1], line[3], line[4], line[6]])
                # append with file name, x, y, frame number
        if clicks != []:
            for click in clicks:
                save_frame_click(click)
        print(‘end of this log’)

#---------------------------------------------------------------
def save_frame_click(click):

    video_frame_size = (1600, 900)

    #------------------------------------
    # data from log file
    log_file_name = click[0].rpartition(‘\\’)
    log_file_name = log_file_name[2].rstrip(‘.csv’)
    log_file_name = log_file_name.replace(‘log’, ‘L_’)
    video_filename = click[1].rstrip(‘.avi’)
    # mouse-click coordinates from top-left of frame
    x, y = int(click[2]), int(click[3])
    frame_number = int(click[4])
```

```
   #------------------------------------

   window_name = ‘window’

   print(f’video file: Videos/{video_filename}.avi’)

   frame_click_folder = ‘frame_click_images’

   stream = cv2.VideoCapture(f’Videos/{video_filename}.avi’)

   print(int(stream.get(5)))
   print(int(stream.get(3)))
   print(int(stream.get(4)))
   print(click)

   stream.set(1, frame_number) # 1, specifies zero-based frame number

   grabbed, frame = stream.read()

   # (image, centre_coordinates, radius, color, thickness)
   # thickness -1 fills the circle
   cv2.circle(frame,(x,y),28,(0,0,0),1)
   cv2.circle(frame,(x,y),30,(255,255,255),2)
   cv2.circle(frame,(x,y),32,(0,0,0),1)

##    cv2.circle(frame,(x,y),88,(0,0,0),1)
##    cv2.circle(frame,(x,y),90,(255,255,255),2)
##    cv2.circle(frame,(x,y),92,(0,0,0),1)

   cv2.circle(frame,(x,y),198,(0,0,0),1)
   cv2.circle(frame,(x,y),200,(255,255,255),2)
   cv2.circle(frame,(x,y),202,(0,0,0),1)

   # review frame scale, e.g. 0.5 for half original size
   scale = 0.5

   review_frame_size = (int(video_frame_size[0] * scale + 0.5), int(video_frame_size[1] * scale + 0.5))
   frame = cv2.resize(frame, review_frame_size)

   image_title = f’{log_file_name}_V_{video_filename}_F_{frame_number}_C_{int(x * scale +
0.5)}_{int(y * scale + 0.5)}’

   if save_images:
      cv2.imwrite(f’{frame_click_folder}/{image_title}_.jpg’, frame)
      print(f’new image saved: {image_title}_.jpg’)

   if display_images:
      cv2.setWindowTitle(window_name, image_title)
      cv2.imshow(window_name, frame)
      # might not be necessary to wait for window like this
      while cv2.getWindowProperty(window_name, cv2.WND_PROP_VISIBLE) == 0:
```

```
        # window is not open and visible
        cv2.waitKey(50)
      print(‘close image window to continue’)
      while cv2.getWindowProperty(window_name, cv2.WND_PROP_VISIBLE) == 1:
        # window is open and visible
        cv2.waitKey(500)

  stream.release()
  cv2.destroyAllWindows()

#-----------------------------------------------------------------
def read_log_file(196ilename):

  contents = []

  try:
    with open(196ilename, ‘r’) as f:
      contents = []

      for line in f:
        row = []
        for cell in line.split(‘,’):
          if ‘\n’ in cell: # deals with rows shorter than header
            if cell == ‘\n’:
              cell = ‘0\n’
            cell = cell[:-1] # remove ‘\n’
          row.append(cell)

        contents.append(row)
    print(‘’)
    print (f’log file read: {196ilename}’)

  except:
    eLog(f’log file not read: {196ilename}’)

  return contents # either [contents of input file] or []

#-----------------------------------------------------------------

if __name__ == “__main__”:

main()
```

B.iii. Information Sheet

Exploring the Interaction of Passengers and Distraction within the Hazard Perception Test Information Sheet

You have been invited to participate in a PhD research project that will be conducted in room 19.6 at The University of Sheffield. Before deciding whether to take part it is important you understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Don't hesitate to ask if there is anything that is not clear or if you would like more information – please see contact details provided at the end. Take your time to decide whether you would wish to participate.

What is the project's purpose?

The results of this experiment will help contribute to knowledge about how passengers influence driver safety. There is a lack of consensus about whether passengers increase or reduce the risk of Road Traffic Collisions, which are when a vehicle collides with either other road users and/or property. Given that conversation is considered one of the most prevalent driving distractions (an activity that averts attention from a primary goal to a secondary nonrelevant goal), the logic is the lack of consensus in the literature may arise from whether the passengers are conversing with the driver or not. This study aims to assess this logic.

Why have I been chosen?

The study is exploring the influence of passengers on younger drivers (18-25). You will be randomly assigned to either role, although you may only be a driver if you have a valid driver's licence (which will need to be seen by the researcher).

Regardless of whether you are designated a driver or passenger in this experiment, you must have adequate vision for driving regulations, whether corrected by glasses/contact lenses or not, and have full colour vision. These will be assessed upon arrival in the room.

You will be informed by email about whether you are a driver or passenger.

Do I have to participate?

It is your decision about whether you would like to take part. You can withdraw at any time without any negative consequences, and you do not have to give a reason.

What do I have to do if I participate?

Both driver and passenger will come to the experiment room at the same time and be required to complete a consent form. The information sheet will be present for you to remind yourself of any details at this point, and you will be encouraged to ask any questions if you require further clarity about anything. You will be assigned different tasks, depending on your designated role in the experiment.

Drivers:

You will be required to sit in the "driving seat" of the seating arrangement the researcher has set up. The wall ahead will have a projection of dash camera footage that you will be required to view. Throughout the footage, there will be items that appear where the speed and/or direction would need to be amended to avoid a collision from the drivers' perspective. This is called a hazard. You will be required to use the mouse in front of you that will be associated with a cursor on the screen, and move it to the location of the hazard, where you will be required to click the left mouse button. Please conduct this task as fast as you can. At the same time, you will be required to conduct an n-back=2 task (details below).

Passengers:

You will be required to sit in either the "front seat" or "rear seat" of the seating arrangement the researcher has set up. You will be told which seat to sit in first, although both seats will be used within the session. You will be responsible for providing the n-back=2 task (details below).

N-back=2 task:

A sequence of letters will be heard by the "driver". For every letter heard by the "driver", they must respond with the letter that appeared two previously in the sequence. This means that if the sequence was "*A*, *K*, *Q*", when the "driver" hears "*Q*", they must respond with "*A*". The nback=2 task will either be presented by the laptop speakers, or by the passenger, and should be prioritised over the hazard detection task mentioned in the driver section above.

Other information:

- Participants will be entered into a prize draw consisting of:
    - £50 for highest accuracy to hazard detection (driver).
    - £50 for fastest reaction time to hazard detection (driver).
    - £100 from a randomly selected participant (passenger).

- The session should last approximately 30 minutes in total.

What are the possible disadvantages and risks of taking part?

There are no disadvantages identified with taking part in the experiment. There are however risks about the experiment being conducted in a room that will have low lighting, which will be mitigated by only turning the lights off once participants are seated. Similarly, there may also be risks about eye strain, especially for the "passenger" reading the sequence of letters in low lighting. Eye strain will be mitigated by providing the "passenger" with the sequence to read on a device that is well-lit.

What are the possible benefits of taking part?

Participation in this experiment will assist in furthering understanding about the interaction between passenger presence, seating position, and distraction on drivers' hazard perception performance. Results may influence future policy for driving assessments.

Will my taking part in this project be kept confidential?

Yes.

- For this research, your age, gender, and use of corrective lenses will be written, but kept on a password protected laptop that only the researcher will have access to.
- The written information will be used for analysis purposes only and will be deleted at the end of 2025 to give time to write the experiment up into an academic journal article.
- A participant code will be ascribed to you at the start of the research session, which will be associated with any data analysed. These codes will be connected to your name and email address on one document contained within a password protected laptop. It is recommended that you keep a note of the code assigned to you in case you wish to discuss your participation later as this will be the only way you can be associated with the experiment data.
- You will also write your name and signature onto a consent form. These will only be accessible by the researcher and potentially the wider research team, but no other parties. These will be kept on a password protected laptop and destroyed at the end of the PhD (latest at the end of April 2024).

What is the legal basis for processing my personal data?

You will be asked to record your name, email address, and phone number to arrange and conduct the experiment/contact you in case of an emergency. Your age and gender will also be recorded to demonstrate how well the data collected is representative to the population. The use of corrective lenses is to report that you have normal vision at the time of the experiment. Also, you will be asked to write your name on the consent form; this is to enable the researcher to confirm that informed consent was sought to participate. Your name will not be included in the questionnaire and any subsequent data analysis or work, as a participant code will be used instead to ensure anonymity.

Who is organising and funding the research?

This research is not externally funded. It is carried out by Scott R. Fox at The University of Sheffield, School of Architecture, under the supervision of Professor Steve Fotios and Professor Richard Rowe.

Who is the Data Controller?

The University of Sheffield will act as the Data Controller for this study. This means that the University of Sheffield is responsible for looking after your information and using it properly.

Who has ethically reviewed the project?

This project has been ethically approved via the University of Sheffield's Ethics Committee (UREC), as administered by School of Architecture (ref number 056343). The University's Research Ethics Committee monitors the application and delivery of the University's Ethics Review Procedure across the University.

What if something goes wrong and I wish to complain about the research?

If there are any complaints about the research, please contact the researcher or his supervisors (contact details below). If your complaint has not been handled to your satisfaction, please contact the head of the School of Architecture, Professor Renata Tyszczuk.

Contact for further information

Researcher:

Name: Scott Fox
Email: srfox1@sheffield.ac.uk

Supervisors:
Name: Professor Steve Fotios
Email: steve.fotios@sheffield.ac.uk

Name: Professor Richard Rowe
Email: r.rowe@sheffield.ac.uk

Head of School: Professor Renata Tyszczuk

Office Address: School of Architecture, The Arts Tower, Western Bank, Sheffield S10 2TN.

Email:

r.tyszczuk@sheffield.ac.uk

Telephone: 0114 222 0313

B.iv. Consent Form

Please tick the appropriate boxes	**Yes**	**No**
Taking Part in the Project		
I have read and understood the project information sheet and the project has been fully explained to me. (If you will answer "No" to this question, please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)		
I have been given the opportunity to ask questions about the project.		
I understand that by choosing to participate as a volunteer in this research, this does not create a legally binding agreement nor is it intended to create an employment relationship with the University of Sheffield.		
I confirm that I have not have symptoms of COVID-19 for 14 days		
I understand that my taking part is voluntary and that I can withdraw from the study any time before the end of January 2024. I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw.		
How my information will be used during and after the project		
I understand my personal details such as name, phone number, address and email address etc. will not be revealed to people outside the project.		
I understand and agree that my data will be kept confidential and only permitted to be seen by those mentioned in the terms within the information sheet.		
I understand and agree that other authorised researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.		
I understand and agree that other authorised researchers may use my data in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.		
I give permission for the information that I provide to be deposited in University of Sheffield so it can be used for future research and learning.		
So that the information you provide can be used legally by the researchers		
I agree to assign the copyright I hold in any materials generated as part of this project to The University of Sheffield.		

Name of participant [printed] Signature Date

Name of Researcher [printed] Signature Date

Exploring the Interaction of Passengers and Distraction within the Hazard Perception Test Consent Form

Project contact details for further information:

Researcher:

Scott Fox, PhD Researcher

srfox1@sheffield.ac.uk

Supervisors:

Professor Steve Fotios, Professor of Lighting and Visual Perception

steve.fotios@sheffield.ac.uk

Professor Richard Rowe, Postgraduate Taught Programmes (PGT) Director (Psychological Research Methods)

r.rowe@sheffield.ac.uk

Head of School:

Renata A Tyszczuk, Head of school of Architecture and contact person in case of any complaints

regarding the experiment

r.tyszczuk@sheffield.ac.uk; 0114 222 0313

Gender:

Please indicate your age:

If you are wearing glasses or contact lenses during this research, then please indicate if they are for near-sighted or far-sighted vision

a) near-sighted

b) far-sighted

How long have you held a full driving licence for?

Does your licence allow you to drive in the UK?

Are you more used to driving on the left-hand side of the road (in the UK) or on the right-hand side?

B.v. Ethics Application

Section A: Applicant details

Date application started:
Tue 18 July 2023 at 12:04

First name:
Scott

Last name:
Fox

Email:
srfox1@sheffield.ac.uk

Programme name:
PhD

Module name:
N/A

Last updated:
10/10/2023

Department:
School of Architecture

Applying as:
Postgraduate research

Research project title:
Exploring the Interaction of Passengers and Distraction within the Hazard Perception Test

Has your research project undergone academic review, in accordance with the appropriate process?
Yes

Similar applications:
Exploring the Influence of Distraction on Visual Detection / Exploring the Influence of Distraction within the Hazard Perception Test

Section B: Basic information

Supervisor Name/Email:
Steve Fotios/steve.fotios@sheffield.ac.uk

Proposed project duration:
3: Project code (where applicable)

Start date (of data collection):
Mon 16 October 2023

Anticipated end date (of project)
Fri 1 December 2023

Project externally funded?
No

Suitability
Indicators of risk
Project code
N/A

Takes place outside UK?
No

Involves NHS?
No

Health and/or social care human-interventional study?
No

ESRC funded?
No

Likely to lead to publication in a peer-reviewed journal?
Yes

Led by another UK institution?
No

Involves human tissue?
No

Clinical trial or a medical device study?
No

Involves social care services provided by a local authority?
No

Is social care research requiring review via the University Research Ethics Procedure
No

Involves adults who lack the capacity to consent?
No

Involves research on groups that are on the Home Office list of 'Proscribed terrorist groups or organisations?
No

Involves potentially vulnerable participants?
No

Involves potentially highly sensitive topics?
No

Section C: Summary of research

1. Aims & Objectives

Safe driving requires that the driver detects potential hazards in sufficient time to take avoiding action. Cognitive distractions (such as talking with passengers, tuning the radio, looking at advertising boards) impair driving. Some literature suggests that the presence of passengers also impairs driving, whereas other literature suggests that they reduce the risk of road traffic collisions. The difference between these findings could relate to whether passengers are distracting the driver or not. One hypothesis in particular is based on the idea that if passengers moderate their engagement with a distraction task that influences a drivers' risk of a road traffic collision based on their visibility of the road scene, the seating position of passengers could influence the interaction between passengers and drivers' hazard perception performance.

The aim of this research is to investigate the interaction between passengers and distractions and visual detection in a hazard perception test context.

There are three key objectives:

1. To investigate the difference in hazard detection performance (reaction time and detection rate) whilst participants are distracted compared to not being distracted.

2. To investigate whether there is an interaction effect between distraction and passengers on drivers' reaction time and detection rate to hazards.
3. To investigate whether seating position influences whether passengers moderate their engagement with a distraction task, and its influence on drivers' reaction time and detection rate to hazards.

The results of this experiment and others within the project will be used to guide future research and provide guidance for road safety policy.

2. Methodology

Two test participants will arrive to the experiment session, with one being designated the "driver" and the other being designated the "passenger". The driver will conduct all trials, whereas the passenger will be sat in either the seat next to or behind the driver for experiment conditions and either be silent or actively facilitate the distraction task.

The driver will sit facing a screen on which will be shown a series of videos of road scenes as if they were driving a vehicle along these roads. Whilst watching these videos, drivers are required to press a button if they detect a hazard. The definition of "hazard" will be specified as an event that would demand anticipatory action such as slowing down. 14 clips will be footage taken from dash cam footage that shows the view only ahead. Five additional videos will be included that do not have hazards, acting as controls.

The distraction task will be an auditory n-back=2 task, which will either be presented by the laptop speakers or by the passenger, relating to whether the driver is being measured as driving alone or with a passenger respectively. The n-back=2 task is where a sequence of letters is heard by the driver, whereby they are required to say aloud these letter, but repeating the letter two back in the sequence. There will be a unique string of letters heard for each driver, with the sequence being presented at a randomised rate between 3-5 seconds from the laptop, and the passenger being instructed to attempt to read the sequence at a rate of one letter every 3 seconds when they present the task to the driver.

Hazard perception data (time at which a hazard was indicated by pressing the button) will be automatically recorded into a Microsoft Excel file, whilst the distraction task responses will be recorded manually by the researcher. When the passenger reads aloud the n-back=2 task, the sound will be recorded by the researcher's password-protected phone if both participants consent to the recording. All sound recordings will be deleted after the analysis has been completed. If participants do not consent to the sound being recorded, the researcher will use how many letters in the sequence they spoke as a proxy measure of how distracted they were when presenting the nback=2 task.

Subsequently, these will be exported to SPSS Statistics 22 software for statistical analysis. A 3 (distraction: no distraction, n-back=2 when driving alone, n-back=2 when driving with a passenger) x 2 (seating position of passenger: front seat or rear seat) Repeated Measures ANOVA model is expected to be used to analyse the data.

3. Personal Safety

Have you completed your departmental risk assessment procedures, if appropriate?
Yes

Raises personal safety issues?
No

The researcher will be working within the university premises, although will be working predominately at the weekend. Whilst there may not be others around, there will be CCTV recording the premises, and the researcher understands how to contact staff if required based on the out of hours training he completed on the 18/01/2022.

Participants will be recruited from within the university, thus are expected to behave in a professional manner.

The experiment does not require handling of hazardous materials by either the researcher or participants.

Additionally, the researcher has recently completed a fire safety training course (29/04/2023).

Section D: About the participants

1. Potential Participants

This experiment will be open to all if they have a full driving licence and normal vision and hearing. Normal vision and hearing include those people who might correct their hearing and vision using aids such as glasses.

2. Recruiting Potential Participants

An opportunistic sampling frame will be employed to recruit participants for this study. Potential participants will be approached online using emailing lists within the university. An email will be sent with a summary of the research project, the required task within participation. From this, people replying to the researcher will be sent the Information Sheet which provides information about the research, including the legal basis of the data collection and storage.

Participants will book a testing session via Doodle poll, which is an online platform for organising appointments in which participants will be given their participation code to enter so that their identity remains anonymous to other participants using the platform. Selection of an option within this platform will act as their requested timeslot to participate. Following this, the researcher will send a final email to the participant to confirm the details of their appointment to participate. Once enough participants are recruited, any further respondents will be added to the waiting list in case any participant withdraws. Participants from the waiting list will be selected by the order they were added, meaning that the first person that is added to the waiting list will substitute the first person to withdraw.

At the end of their data collection, participants will be asked if they want to be entered into a cash-prize draw.

2.1. Advertising methods

Will the study be advertised using the volunteer lists for staff or students maintained by IT Services?
Yes

The volunteer list provides an economical way to recruit compared to other methods. Other methods would not provide access to an appropriate sample in an economical way. For instance, snowball sampling as a strategy is better suited for identifying participants that are difficult to access; the criteria for this project is such that the population of interest is expected to be easily accessible.

Additionally, an alternative opportunistic sampling method was also considered: approaching people on the street to take part. Given that the researcher does not physically encounter the people that receive the information by email, and the emailing list is not linked to any specific person, the participants' identity remains anonymous. Sending an advert for the study to an emailing list means that people that respond are doing so because they take an active interest in participating rather than feeling obliged, whereas there is the potential for participants to be responding out of the notion of obligation if they were approached in person.

Other sampling methods, such as probabilistic or random sampling, would take too much time and resources compared to an opportunistic sampling frame, so were disregarded.

3. Consent

Will informed consent be obtained from the participants? (i.e. the proposed process):
Yes

At the start of each experimental session, each participant will be asked to sign a consent form that outlines the terms of their participation, their right to withdraw, and their acknowledgement of how their data will be stored and used. The researcher and participant will each hold a copy of the signed document.

4. Payment

Will financial/in kind payments be offered to participants?
Yes

Participants will have the opportunity to enter a cash-draw where they may receive up to £200 if they perform the best across three different tasks (£50 each): accuracy of hazard perception (driver), quickest reaction time of hazard perception (driver), and maintaining an appropriate speed of reading the n-back=2 task in the front (passenger) or rear seat (passenger). This is so that the main focus can be the hazard perception task itself, but for the distraction task to still be a priority. Without any incentive, participants may fully focus on the hazard perception task, without engaging appropriately with the distraction task, so an incentive was believed to be necessary for this study.

The cash-draw will be funded by the researcher directly.

5. Potential Harm to Participants

What is the potential for physical and/or psychological harm/distress to the participants?
The procedure is not anticipated to cause the participants psychological or physical distress. They will be seated, watching a video, and either occasionally pressing a button (driver), remaining silent or facilitating a task (passenger).

Should the participant wish to terminate their participation in the study, they will be able to do so without giving a reason. Participants' right to withdraw will be emphasised verbally by the researcher before the participants begin their experiment session. If one participant chooses to withdraw, both participants will terminate the experiment session together.
How will this be managed to ensure appropriate protection and well-being of the participants?
Participation in this experiment requires observation of a screen and button pressing in response to videos. The screen brightness is not sufficiently high to cause visual discomfort. The videos are typical road scenes: while they present potential hazards (e.g. a pedestrian waiting to cross a road), they do not show any road traffic collisions.

The test period (one hour maximum) is not expected to cause discomfort from either observing the screen or for sitting still. The experimenter has completed the University’s out of hours and fire training courses. The videos will last between 20 to 30 seconds each, and contain no flashing imagery, so is not expected to cause any distress to the participants.

6. Potential harm to others who may be affected by the research activities

Which other people, if any, may be affected by the research activities, beyond the participants and the research team?
No other people are expected to be affected.

What is the potential for harm to these people?
N/A

How will this be managed to ensure appropriate safeguarding of these people?
N/A

7. Reporting of safeguarding concerns or incidents

What arrangements will be in place for participants, and any other people external to the University who are involved in, or affected by, the research, to enable reporting of incidents or concerns?
The contact details for the head of department, who is not associated with the project, will be written on the consent form that the participants will hold in case they wish to contact somebody about issues related to the research and/or project.

Who will be the Designated Safeguarding Contact(s)?
The primary supervisor: Professor Steve Fotios

How will reported incidents or concerns be handled and escalated?
Within the university.

Section E: Personal data

1. Use of personal data

Will any personal data be processed or accessed as part of the project?
Yes

Will any 'special category' personal data be processed or accessed as part of the project?
No

Provide the number of people whose personal data you expect to process or access.
24

2. Managing personal data

Which organisation(s) will act as data controller(s) of the personal data?
University of Sheffield only

Who will have access to the personal data?
Just the researcher.

What measures, processes and/or agreements will be put in place to manage the personal data?
Participants' names will not be included in the records of results; all data that is provided will be anonymised and it will not be possible to identify participants from the data collected. Participants will be asked to add their name and sign the "Consent to Participate" form: this is to enable the researcher to confirm that informed consent to participate was sought. It will not be possible to link the consent form to the recorded experimental data. The consent forms will be kept within a file within a limited access space of the Arts Tower at the University of Sheffield. Once the research has been completed, the researcher will record the participant's name on the Consent to Participate form and add an identification number. This will be a simple integer to record the order in which participants were recruited but will not include their initials or other linked identification. When results are recorded, the number will be used to reference participants' data, not their names.

Will all identifiable personal data in digital or physical format be destroyed within a defined period after the project has ended?
Yes

When will the identifiable personal data be destroyed?
After data have been analysed and the research has been written up into the thesis chapter(s) and potentially academic article to be published, the data will be destroyed. This will occur at the end of the PhD programme, which will occur at the end of April 2024.

3. Third-party services

Will any external third-party services not provided by the University be used to process or access personal data during the project?
Yes

Provide details of each external third-party service
Doodle.com. This is to organise the time of participants for the study. Participants will be given a number to write into the software that relates to their choice of timing to ensure that their details remain anonymous from other participants. The researcher will keep a record of the participant and the number they have been given. These details will be deleted at the end of April 2024 at the latest. No personal information from participants will be recorded in the software.

Has the University's Information Security team approved the external third-party services you intend to use?
No

Has the University's Data Protection team approved any contracts and/or terms and conditions related to the external third-party services?
No

4. Security of computers, devices and software
Will personal data be processed or accessed on any computers or devices that are not managed by the University of Sheffield?
Yes

Will all computers and devices that are not managed by the University of Sheffield be secured in accordance with the IT Code of Connection?
Yes

Will any software not approved by the University of Sheffield be used to process or access data?
No

Will any software be written or developed in order to process or access the personal data?
No

Section F: Supporting documentation

Information & Consent
All versions
Participant information sheets relevant to project?
Yes

Document 1128024 (Version 1)
All versions
Consent forms relevant to project?
Yes

Document 1128025 (Version 1)
All versions
Additional Documentation
Document 1128026 (Version 1)
The risk assessment of the experiment

External Documentation
This follows the same set up as a previous hazard perception study (Ref # 041351) I conducted that gained ethical approval. Other than a second participant being included in the session, there are no significant changes to this experiment compared to the previous experiment mentioned.

Section G: Declaration
Signed by:
Scott Ryan Fox
Date signed:
Sat 23 September 2023 at 11:23

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