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Beyond the billboard: A review of other external sources of driver distraction

Jane Hinton [a,*], Oscar Oviedo-Trespalacios [b], Barry Watson [a], Narelle Haworth [a]

[a] Queensland University of Technology (QUT), Australia
[b] Delft University of Technology, The Netherlands

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ABSTRACT

Road corridors contain countless sources of distraction, each carrying the potential to draw drivers' eyes and minds off roads, thus increasing the risk of a crash. While the impact of billboards on driver distraction has received considerable attention, empirical data for other types of roadside advertising signs is very limited. Furthermore, the existing research examining other potential external sources of distraction is fragmentary, which makes it difficult to develop evidence-based road safety policies to mitigate risk. Therefore, the aim of this study was to conduct an exploratory review to ascertain and synthesise the available distraction-related literature for various types of roadside advertising signs (excluding billboards) and other potential external sources of distraction in the road corridor. Based on distraction-related theory and existing literature, 58 predefined categories of potential distraction sources were developed to guide an exploratory literature search using the Scopus database. Fourteen documents relating to external distraction sources were identified in the database search with a further five studies found using a backwards citation chaining search (N=19). However, no studies for non-billboard types of roadside advertising signs were found. Studies included those that investigated driver distraction in relation to construction zones, commercial logos contained within official traffic management Dynamic Message Signs (DMS) and service (logo) signs, drones, murals, roadside memorials and wind turbines. While one study investigated whether an external source of distraction can have a positive effect on driver behaviour, the remainder focused on the potential negative impacts on road safety of these sources of distraction. A key finding of the review is that crash risk increases when drivers continue to visually and cognitively engage with a source of distraction. Overall, the studies provide insights into the types of distractions that can be encountered in road corridors and the impact they can have on driver behaviour. However, more research is required before the mechanisms and pathways involved in these types of distractions can be effectively conceptualised, and thereby mitigated to reduce the burden of distraction risk and road trauma.

1. Introduction

Driver distraction is a major contributing factor in road crashes. It has been estimated that 68.3 % of all crashes are associated with observable distractions. Additionally, prolonged glances towards objects outside the vehicle have been found to increase crash risk by an odds ratio of 7.1 (Dingus et al., 2016). Driver inattention has been implicated in most crashes involving serious injuries (Beanland et al., 2013) with distraction, along with driver-related error, impairment and fatigue, being responsible for nearly 90 % of crashes (Dingus et al., 2016). A commonly accepted definition of driver distraction is the "diversion of attention away from activities critical for safe driving toward a competing activity, which may result in insufficient or no attention to activities critical for safe driving" (Regan et al., 2011, p. 1776). This definition is useful as it draws on attention theory which acknowledges the interacting relationship between safety–critical and secondary (competing) tasks.

A competing activity exists when a driver's attention competes with the activities needed to perform safety–critical driving tasks, thereby increasing the risk of a crash (Dingus et al., 2016). These activities include driving-related (for example, attending to warning indicator lights) and non-driving related tasks (looking at a crash scene, reading a message on an advertising sign or thinking about a roadside memorial) (Regan & Oviedo-Trespalacios, 2022; Regan et al., 2009). Other

* Corresponding author.
E-mail address: jane.hinton74@gmail.com (J. Hinton).

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competing activities can take place involuntarily, be instigated by drivers, arise from unknown sources within a driver's mind, or be sourced from inside or outside the vehicle (Regan & Oviedo-Trespalacios, 2022). When a driver engages with one or more actions in response to a distraction source (for example, looking, reading or thinking) it becomes a safety concern as these secondary tasks may compete with activities needed for safe driving (Regan et al., 2009).

Although research indicates that distracted driving is a road safety concern (e.g., Beanland et al., 2013; Dingus et al., 2016; Qin et al., 2019), the available research does not provide a comprehensive set of guidelines which road agencies can apply to mitigate (or eliminate) the effects of distraction on driver behaviour (Horberry & Edquist, 2009; Qin et al., 2019; Regan & Oviedo-Trespalacios, 2022). The World Health Organisation's (2023) global road safety status report recently stated that while 162 countries have generally legislated against distracted driving, most of the legislation relates to the use of mobile phones within the vehicle. Thus, identifying and responding to research studies that have examined potential road safety impacts associated with external sources of distraction should be prioritised.

The impact of billboards on distraction and driver behaviour has predominated the research field for over 70 years (Marciano, 2020) with new studies continuing to emerge (Brome et al., 2021; Nouzovský et al., 2022; Zhang et al., 2020). In addition to roadside advertising signs, there are many other sources of distraction that can occur outside a vehicle, distracting a driver away from safety-critical driving tasks. Very few studies have focused on other types of roadside advertising signs. In a comprehensive systematic review of the literature, Oviedo-Trespalacios et al. (2019) found that most of the roadside distraction research had focused on static and digital billboards and that limited evidence for other types of roadside advertising signs was identified.

Billboards are not the only type of roadside advertising sign. Any sign within the road corridor that derives a profit or benefit from advertising a message may be considered a roadside advertising sign. Beyond the billboard, roadside advertising signs come in all shapes, sizes and formats ranging from stand-alone signs beside the road (such as inflatable advertising devices) to advertising panels attached to (non-official) street name signs (Hinton et al., 2022). Further, road agencies are co-opting the availability of devices traditionally used solely for road and traffic management to display non-driving related messages and, or commercial logos, such as those incorporated into Dynamic Message Signs (DMS) (Chrysler et al., 2017) and service centre (logo) signs (Zhang et al., 2013). Fig. 1 illustrates a selection of the different types of advertising signs that may be found in Australia; but may vary in look and style to those in other jurisdictions.

Coupled with an increasing growth in advertising sign technology, insufficient data about how different types of roadside advertising signs may have an impact on driver performance makes it hard to draw firm conclusions about how to regulate these types of signs (Oviedo-

Examples of different types of roadside advertising signs other than billboards found in Australia: (a) inflatable advertising sign, (b) dynamic message signs (DMS), (c) illuminated advertising panels (circled) above (non-official) street name signs and (d) service centre / logo sign (commercial logos on an official Manual of Uniform Traffic Control Device). Note: These signs may differ across jurisdictions. Photographs provided by the authors.

Fig. 1. Examples of different types of roadside advertising signs other than billboards found in Australia.

Trespalacios et al., 2019). Whatever their form, advertising messages seek to influence, by communicating to road users in order to derive a commercial, political, community or other benefit. This suggests that a key function of roadside advertising is to explicitly gain the attention of road users.

Along with roadside advertising signs, other objects, events or activities located outside the vehicle can encroach into the road corridor, increasing the risk of a crash. Examples of these include drones, roadside memorials, markets and stalls, wind farms, sporting events and public utilities (e.g., mobile phone towers). Together with roadside advertising signs, these ancillary uses of the road corridor may distract a driver away from safety-critical driving tasks. Road-related objects, events or activities may also distract a driver such as when viewing crash scenes and construction zones along with elements within the built and natural environments (Horberry & Edquist, 2009; Regan et al., 2009). Essentially, the number of potential external sources of driver distraction within the road corridor is conceivably vast (Regan & Oviedo-Trespalacios, 2022).

Sourced from previous literature, Regan et al. (2009) systematically identified approximately 60 potential sources of distraction, with the majority located within the vehicle. The potential distraction sources were characterised into six groups: "things brought into vehicle," "vehicle systems," "vehicle occupants," "moving object or animal in vehicle," "internalized activity," "external objects, events or activities," and "other sources of distraction" (Regan et al., 2009, pp. 252-253). Despite literature reliably reporting that approximately 30 % of distraction-related crashes are attributable to drivers' interaction with external distraction sources (objects, events or activities), the impact of external distraction sources on driver behaviour is under-investigated (Regan & Oviedo-Trespalacios, 2022).

Creating safer roadsides is not solely the mandate of the transport sector, but a broad and shared responsibility for all. As such, non-traditional stakeholders that utilise and gain benefit (commercial or otherwise) from being within the road corridor such as the outdoor advertising industry and mobile phone manufacturers, also have obligations (Regan & Oviedo-Trespalacios, 2022). This is particularly the case when the use of their technology may adversely influence driver behaviour by distracting drivers away from safety-critical tasks.

Roadside advertising signs are not the only means by which messages can be conveyed to the driver. Many potential distraction sources that communicate a message seen from a vehicle can be considered a messaging device. Messaging devices that communicate or convey a message may cognitively engage drivers which may increase opportunities for drivers to be distracted. Therefore, drivers may not just be visually distracted by an object, event or activity within the road corridor, but also cognitively engaged by the message it intentionally or inadvertently conveys. For example, paying attention to a roadside memorial might simply be a visual distraction for some whereas it may communicate a message to other drivers that the road they are travelling on is unsafe, trigger memories of past trauma, or act as a reminder to drive safely (Beanland and Wynne, 2019; Churchill & Tay, 2008).

As a further example, a plane flying overhead would not normally be considered a messaging device, but it may become so if it is engaged for example, in signwriting. That is, both roadside memorials and planes may be a visual distraction in one situation, but in another circumstance dependant on the context, may become a messaging device to drivers. In the signwriting context, this may result in a greater cognitive impact on drivers compared to objects or activities that primarily act as visual distractions (which would still have an associated cognitive dimension).

As there is a large body of evidence relating to the risks associated with internal-to-vehicle distractions, it is expected that external distractions may also pose a safety risk. Emerging research indicates digital billboards are a concern, which raises the possibility that other types of advertising signs and other external sources of distraction may also represent a safety problem (Oviedo-Trespalacios et al., 2019). A recent study by Han and Du (2024) conducted a broad and general overview of the gaps and challenges in roadside safety research. Amongst other aspects relating to roadside design, environment and management, the review found that most of the research to date for roadside features, such as signage, rumble strips and landscaping, focused on infrastructure, driver behaviour, weather events and road design which were the predominant factors affecting roadside safety. The study recommended that further research on driver behaviour, including research that examines driver fatigue, speeding and driver distraction was needed to improve strategies for roadside management and driver education (Han & Du, 2024). Further, the available evidence regarding other potential external-to-vehicle distraction sources appears fragmentary and inconclusive (Regan and Oviedo-Trespalacios, 2022). This study seeks to address a gap in knowledge by focusing solely on reviewing the literature in the context of external sources of distraction in the road corridor and their potential to distract, rather than a taking a broader approach to roadway safety as per the study by Han and Du (2024).Therefore, the aim of this study was to conduct an exploratory review to ascertain and synthesise the available distraction-related literature for various types of roadside advertising signs (excluding billboards) and other potential external sources of distraction in the road corridor.

The following Method section describes the choice of search methodology, the selection of search terms and the study's search procedure (Section 2). The subsequent section presents the results of the review (Section 3) before synthesising and discussing the main implications of the findings including the study's strengths and limitations (Section 4). Recommendations for future research are detailed in the concluding paragraph (Section 5). The nine types of information extracted from each study included in the review (consisting of: authors, year, country, document type, measures used, sample size and gender balance, analysis and findings for each document) is detailed in Appendix 1.

2. Method

2.1. Choice of search methodology

Careful consideration was given to determine the most appropriate search methodology for the review. While the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) requires the search strategy to encompass all websites, registers and databases (Page et al., 2021), this approach was not feasible for this study given the area under investigation is fragmented. Further, due to the large number of potential distraction sources, it was considered impracticable to generate a PRISMA procedure for each source. Creating broad search terms to cover every distraction source proved a challenge as the nomenclature used for some distraction sources can encompass a wide variety of terms (for example, drones can also be known as unmanned aerial systems (UAS) and a type of electric vertical take-off and landing aircraft).

Given the difficulties associated with selecting search terms and the limited and fragmentary nature of the available literature, an exploratory review grounded in distraction-related theory, previous literature and combined academic and professional experience was considered the most appropriate approach. The Scopus database was selected as it is comprehensive, multidisciplinary and the largest scientific database of its type in the world, covering a broad collection of subject areas within peer-reviewed journal articles, books and conference papers.

It was also necessary to omit searches for grey literature as a number of studies commissioned by the advertising industry has been shown to have significant methodological flaws (Friswell et al., 2011; Wachtel, 2009). Hence, the focus of this study was on sensitivity rather than specificity.

The overall conceptualisation of the study, along with the development of the search categories, search terms, and inclusion and exclusion criteria selected for the exploratory review were based on the:

- application of the theory and definitions for driver distraction and inattention as conceptualised by the "Taxonomy of driver

inattention" which has been widely accepted within the road safety literature (Regan et al., 2011, p. 1774);
- types of external sources of distraction previously identified in literature (external objects, events or activities) (Horberry & Edquist, 2009; Regan et al., 2009);
- consideration of the distraction mechanisms and potential additional pathways as conceived within the novel Driver Behaviour Roadside Advertising (DBRA) conceptual framework developed for roadside advertising signs (Hinton et al., 2022);
- reported lack of empirical evidence for mobile advertising and other types of roadside advertising signs (excluding billboards) (Hinton et al., 2022; Oviedo-Trespalacios et al., 2019);
- authors' experience with other external distraction sources likely found within the road corridor in Australia.

2.2. Search categories, search terms, selection criteria and outcome measures

All authors agreed on the 58 search categories of external distraction sources selected for the exploratory review. These categories comprised of objects, events and activities located outside the vehicle (external sources of distraction) and classified into the following two groups:

- types of roadside advertising signs (excluding billboards) including mobile advertising (n = 22);
- other potential external sources of driver distraction (n = 36).

Refer to Table 1 for the full list of the 58 search categories undertaken in the review.

The selection of mandatory search terms used for the exploratory review was based on distraction and road and traffic safety literature. "Driver distraction", "attention", and "inattention" and "road and traffic safety" (and their related search operators) were mandatory search terms. Each of the mandatory terms were combined with the search terms created for a single search category (as listed in Table 1) and a database search was performed. This database search was repeated for each of the 58 potential sources of driver distraction (for example, A-frame sign, fun runs, inflatable sign, monuments and public utilities). Details of the mandatory search terms are provided in Table 2 which shows the terms used for the "A-Frame sign / footway sign / footpath sign / sandwich board sign" search category as an example. Database searches were conducted between 23 April 2023 and 2 May 2023. To ensure the Scopus database search captured as much of the available literature, no date restrictions were applied, all document types were included, and no limitations were placed on the different aspects of driver distraction (such as eyes or minds off road) examined within the literature. Titles and abstracts were used to screen for relevant records and then verified by reviewing the full text documents. A backward citation chaining search was conducted on all the documents identified in the database search and included in the review if relevant.

For completeness, searches were also conducted for static, electronic, digital and video billboards and trivision signs (a type of billboard) to ascertain if any new billboard research had been conducted since the 2019 systematic review (Oviedo-Trespalacios et al., 2019). However, the results of these searches were not used as part of this review but were considered alongside those of Oviedo-Trespalacios et al. (2019) when writing the introduction to the paper.

Inclusion and exclusion selection criteria were used to screen each document identified in the 58 database searches. All authors were involved in the screening and verification process to ensure consensus around the inclusion of the final documents identified in the exploratory review.

Documents were included in the exploratory review if they met the following inclusion criteria:

- Studies were written in English, peer-reviewed and published in any year;
- Studies where the outcome measure(s) used directly compared the impact of an external distraction source on driver performance with a control condition where the distraction source was not present;
- Studies where the outcome measure(s) used directly compared the impact of the different types or degrees of external distraction source on driver performance;
- Studies where the outcome measure(s) used directly compared the impact of an external distraction source with an internal distraction source on driver performance;
- Studies where the outcome measure(s) used investigated the impact of an external distraction source on driver performance in real or simulated driving environments using crash data, observational data (e.g. video analysis, eye-tracking, lane-keeping) or self-report data.

Documents were excluded from the exploratory review if they met the following exclusion criterion:

- studies investigating the impact of digital and static, electronic, digital billboards and trivision signs on driver performance.

The database searches for each of the 58 categories of potential external sources of distraction returned a total of 441 documents. Four duplicates were removed. The title and abstracts of the remaining 437 documents were screened in accordance with the inclusion and exclusion criteria. Fourteen relevant documents were identified. In the interests of inclusivity and given the limited availably of the documents identified, a backward citation chaining search identified five additional documents. The final 19 documents formed the basis of the exploratory review. The document selection process is shown in Fig. 2.

3. Results

3.1. Overview of identified documents

Out of a total of 58 category searches, no documents were found for other types of roadside advertising signs including mobile advertising devices. One relevant document found in the static billboard search was allocated to the DMS category group. The 19 documents identified related to seven (of 58) categories of distraction sources. The seven category sources included: construction zone / construction equipment (n = 1), drones / model aircraft / eVTOL / electric vehicle take-off and landing (n = 3), dynamic message sign / DMS / variable message sign / VMS / traffic management sign / TMS / changeable message sign / CMS / matrix sign (n = 2), mural (n = 1), roadside memorial / ghost bike / white cross / memorial cross (n = 3), service centre sign / service center sign / logo sign (n = 8) and wind generator / wind farm (n = 1). Table 3 shows the results of the category and backward citation chaining searches (in brackets).

Upon consideration of the final selected documents, the 58 external distraction sources under investigation were categorised according to their proximity to the road – located on, besides, or above the road. Although most of the distraction sources are generally only present in one of these locations, some distraction sources can occur across locations such as drones operating above and beside the road. As a result, the 58 categories of external distraction sources were arranged in Table 1 according to their proximity to the road.

Two studies identified were from edited books, two from conference papers, one was a technical report and the remaining 14 were journal articles. The publication period spanned 34 years from 1989 to 2023. Research was conducted in Australia, Canada, China, India and the United States of America (U.S.) reaching across high- to lower middle-income countries. The majority of the studies were from the U.S. (13 studies ranging from 1989 to 2023), three studies were conducted in Canada from 2008 to 2011 with one study each from Australia, China

Table 1
Distraction sources selected for the database search and organised in relation to their proximity to the road.

Search category	Advertising sign	Other distraction source
On the road		
Animals on roads / stock movement / animal-vehicle		●
Art on traffic signal boxes / advertising on traffic signal boxes (or wraps on traffic signal boxes)	●	
Banners on light poles / vertical banners / banners on bridges / tear drop flags / banners on roads	●	
Construction zone / construction equipment		●
Crash scenes / crash incidents		●
Dynamic message sign / DMS / variable message sign / VMS / traffic management sign / TMS / changeable message sign / CMS / matrix sign		●
Fun runs / triathlons / marathons / sporting activities		●
Litter collection / rubbish collection		●
Marches / protests / public meetings		●
Mobile advertising / transport advertising / vehicle advertising	●	
Service centre sign / service center sign / logo sign		●
Town sign / city sign / welcome sign		●
Utility sign		●
Beside the road		
A-Frame sign / footway sign / footpath sign / sandwich board sign	●	
Animation display		●
Bee hive / apiary site		●
Bunting / streamers		●
Burning-off / fire reduction / fire management		●
Bus shelter / transit shelter		●
Christmas decorations on light poles / holiday decorations		●
Commercial sign	●	
Community sign / charity sign / event sign	●	
Corflute sign	●	
Display home sign	●	
Electric vehicle charging stations		●
Farm machinery		●
Fossicking		●
Free-standing advertising sign	●	
Graffiti		●
Holograms		●
Inflatable sign / wavy men / inflatable balloons / hot air balloons	●	
Landmarks		●
Mannequin / mechanical advertising device / sign wavers	●	
Mail box / post box		●
Mobile phone tower		●
Monument / statue		●
Murals		●
Off premise sign	●	
On premise sign	●	
Phone booth / telephone booth / payphone		●
Pole sign	●	
Political sign / election sign / electoral sign / candidate sign	●	
Public utilities		●
Pylon sign	●	
Real estate sign / property for sale sign / for sale sign	●	
Roadside memorial / ghost bike / white cross / memorial cross		●
Roadside stall / roadside shop / roadside market / roadside vending / footpath dining		●
Rotating advertising sign	●	
Rubbish bin / trash bin / garbage bin		●
School sign		●
Scrolling sign	●	
Service organisation sign	●	
Shopping centre sign / shopping center sign / mall sign / shopping mall sign / shopping complex / shopping plaza / plaza sign / market sign	●	
Street furniture		●
Street name sign / Identilite / IdentiLite[a]	●	
Urban art		●
Wind generator / wind farm		●
Above the road		
Drones / model aircraft / eVTOL / electric vehicle take-off and landing		●
Totals	22	36

[a] "Identilite" and "IdentiLite" are Australian trademarks of Claude Outdoor Pty Ltd. These devices are illuminated advertising panels above street name signs which may be found in Australia.

Table 2
Search terms used or the database search for each potential distraction source.

Search term	Mandatory operators
Driver distraction, attention and inattention	(diversion* OR divert* OR "divided attention" OR distract* OR attention* OR inattention*) AND
Road and traffic safety	(traffic* OR road* OR motorway* OR highway* OR freeway* AND "safety") AND
Potential distraction source	("A-Frame sign" OR "footway sign" OR "footpath sign" OR "sandwich board sign")
Outcome	(TITLE-ABS-KEY (traffic* OR road* OR motorway* OR highway* OR freeway* AND "safety")) AND (TITLE-ABS-KEY (diversion* OR divert* OR "divided attention" OR distract* OR attention* OR inattention*)) AND (TITLE-ABS-KEY ("A-Frame sign" OR "footway sign" OR "footpath sign" OR "sandwich board sign"))

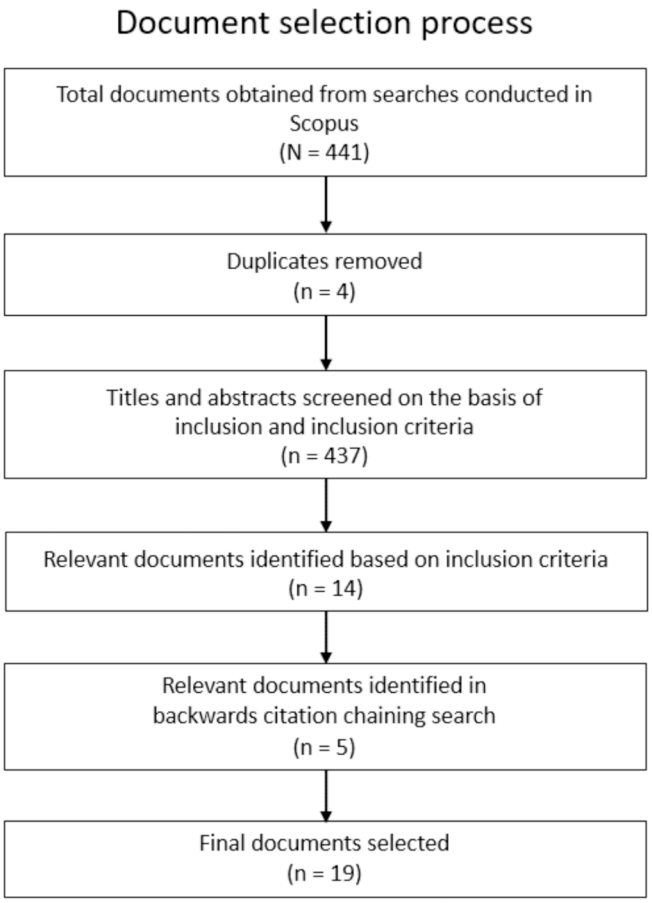

Fig. 2. Document selection process flow diagram.

and India. Two studies were solely questionnaire-based, three were on-road instrumented vehicle experiments, one was video-based and 13 were studies conducted in driving simulators. All but four studies used eye-tracking technology. Refer to Appendix 1 for information extracted from the studies identified and reported in this paper.

Some relevant studies known to the authors were not among the search results and as a result, placed constraints on our ability to identify and characterise all available research in this field. This may be due to the imprecise nature of key terms selected by the authors or the assigned index terms. For example, a study about unrelated traffic management messages on DMS (Harms et al., 2019) and research comparing advertising panels on bus shelters and elevated signs (Crundall et al., 2006), did not appear in the results of the database search. Additionally, although every effort was made to include multiple search terms where relevant (for instance, terms such as VMS, DMS, CMS, TMS and matrix signs), the lack of consistent terminology within literature may have also restricted the number of studies identified in this review. Further, the terminology used for different types of roadside advertising devices often varies across jurisdictions (Roberts et al., 2013).

3.2. *On the road – Sources of distraction*

3.2.1. *Construction zones*

One study investigated driver distraction patterns of highly experienced drivers at a *construction zone* under real-life driving conditions (Gupta et al., 2022). The authors argued that roadside hazards at construction zones would increase the likelihood of driver distraction. Six male drivers who drove routinely as part of their occupation were recruited to drive an unfamiliar route navigating around a construction zone on an arterial road near an intersection in Delhi, India. Using eye-tracking and heat map technology, drivers' eye fixation (distraction) patterns were assessed at three areas of interest at the "approach transition zone", "working zone" and "terminal transition zone" (Gupta et al., 2022, p.426). The approach transition zone was the length of road leading up to the working zone which was the construction site itself. Drivers entered the terminal transition zone after passing the working zone.

Compared to the terminal transition zones, drivers were less focused (as shown by more gaze points on the heap map) during the approach zone as they were collecting information about the new route and identifying potential hazards. The authors reasoned that if the construction site had used correct signage and road markings, drivers would rapidly understand the road environment and its potential hazards. Correct signage and markings would, therefore, result in reduced (or no) driver fixation points as more fixation points indicated that drivers were more distracted. The greater focus toward the forward roadway (less gaze points) in the terminal transition zone indicated that the drivers had become familiar with the route and its hazards after passing the site.

Table 3
Documents identified in the category and backward citation chaining searches (in brackets).

Category search	Documents identified (#)
Construction zone / construction equipment	1
Drones / model aircraft / eVTOL / electric vehicle take-off and landing	2(1)
Dynamic message sign / DMS / variable message sign / VMS / traffic management sign / TMS / changeable message sign / CMS / matrix sign	1(1)
Mural	1
Roadside memorial / ghost bike / white cross / memorial cross	2 (1)
Service centre sign / service center sign / logo sign	7 (1)
Wind generator / wind farm	(1)
Total	19

Within the construction working zone, five of the six drivers displayed fewer gaze fixations and gaze durations which the authors explained as being due to the drivers' extensive experience. Further, that the combined heat maps for all six drivers showed minimal impact on the drivers' performance across all zones. The study concluded that new and inexperienced drivers may be more at risk of distraction in similar situations compared to experienced drivers (Gupta et al., 2022).

While the drivers in this study were considered highly experienced, such drivers may still be distracted involuntarily if an unexpected competing activity (such as an insect or a food spill inside a vehicle) makes it hard, or unavoidable for drivers to ignore (Regan et al., 2011). In this regard, the safety audit conducted as part of the study identified a number of hazards at the construction site which placed the drivers (and pedestrians) under unsafe conditions. The hazards identified included the lack of a traffic management plan, poor road conditions, incomplete pedestrian crossings, missing road markings and improper or missing signage such as the absence of advance warning signs and hazard markers. However, as the focus of this study was on testing experienced drivers in situations where distraction sources (hazards) were elevated – rather than investigating the impact of construction zones on driving behaviour – it is difficult to compare the results of this study to other, relevant research.

3.2.2. *Dynamic message signs (DMS)*

Road agencies use *Dynamic Messages Signs* (DMS) to communicate traffic management information or road-related messages to drivers. DMS are also known as Variable Message Signs (VMS) and Changeable Message Signs (CMS). In a field experiment, 30 participants drove a test vehicle on a closed driving course during the day and at nighttime to examine the distraction potential of including sponsor acknowledgement logos on LED CMS (Chrysler et al., 2017). The research was conducted in response to the Texas Department of Transportation's (DOT) consideration of the establishment of public–private sponsorship agreements with businesses that provide highway-related services.

Legibility distance for target words or travel times on the CMS and detection distance of road hazard objects (for example, imitation deer, box and tire) were the measures used to investigate the impact of sponsor logos on drivers' cognitive workload (degree of mental effort or resources needed by drivers) and sign comprehension. To assess legibility distance, participants were asked to announce the point at which they could see the words (and travel times) on the DMS which may (or may) not have incorporated a sponsorship logo and when they detected a road hazard.

Sponsor logos were incorporated into travel time and safety messages normally displayed on CMS. The logos were approximately one third of the size of the overall CMS display and the font sizes were not altered. The variables under investigation included whether the logo was present, light versus dark background colors displayed with the logo, the blue or black background colour of the message sign displaying safety messages and the use of single-phase (nine types) and dual-phase (four types) safety message signs. More particularly, single-phase signs contain nine combinations of three kinds of logos with three kinds of background or sign colour while dual-phase signs were a combination of the presence or absence of changing text and changing logos.

Results showed that sponsor logos did not affect the legibility distance of safety message signs with a black background, but a small effect was found for those signs displayed on a blue background. No significant legibility effects were found for travel time signs. The use of sponsorship logos was initially found to affect object detection distances at nighttime when objects were positioned 100 ft (30.5 m) behind the CMS compared to objects placed at distances 1,500 ft (457.2 m) and 200 ft (60.9 m) in front of the sign. However, further analysis showed that this effect was only present for tires located behind the sign (Chrysler et al., 2017).

This paper extended the research of another article referenced in their study which found no significant effect on participants' workload due to recall of the message content when a logo was displayed (Pike et al., 2016). Measures used in this study included gaze duration, "last glance distance" (sign legibility), lane maintenance and compliance with speed limits. In conjunction with the findings of this study (and subject to a future on-road assessment), the authors of both papers concluded that as no appreciable cognitive distraction was found for drivers associated with the inclusion of sponsor acknowledgement logos, the use of logos on CMS was supported (Chrysler et al., 2017; Pike et al., 2016).

The results of this study indicated that participants were not cognitively distracted by the extra workload imposed by the additional sponsorship logos. However, one potential ecological limitation of this study is that as participants were told to actively search for the CMS (and, or its messages), their resultant driving performance may not reflect realistic driving conditions.

DMS can be used solely for the purpose of commercial advertising displayed using similar text formats to DMS when used for traffic management or by displaying messages that incorporate commercial images and pictures. However, DMS can act as a type of advertising sign as they communicate commercial messages to drivers which may prove a distraction risk. Both studies found no impact on driver performance due to the inclusion of commercial logos on DMS. However, as only two relevant studies were identified, it is difficult to effectively evaluate the risk of driver distraction due to the impact of logos incorporated into DMS.

3.2.3. *Service signs / logo signs*

The searches identified six driving simulator studies conducted in the U.S. that investigated the impact of *service or logo signs* – commercial logos on white-on-blue official traffic signs on driver performance under various conditions (Hummer, 1989; Kaber et al., 2015; Pankok et al., 2015; Zahabi et al., 2017a; Zahabi et al., 2017b; Zhang et al., 2013). White-on-blue logo signs are official traffic control signs regulated under the Manual on Uniform Traffic Control Devices (MUTCD) (administered by the U.S. Federal Highway Administration), that advise drivers of the upcoming availability of fuel, food, accommodation and other services located at highway interchanges.

One driving simulator study (with 24 participants) found no significant variations in driver performance when required to identify target commercial logos located with six-panel, nine-panel and overflow-combination logo signs (Zhang et al., (2013). Overflow-combination logo signs were comprised of two six-panel logo signs; one a typical logo sign with the other sign displaying two types of logos such as fuel and food. When identifying logos on the nine-panel sign, drivers altered their behaviour by reducing their speed in response to additional information being present on the sign compared to the driving behaviour associated with the six-panel signs, however, the extent of the changes were insignificant. Overall, the authors concluded that the results for the nine-panel and overflow-combination logo signs did not result in a significant change to driver performance measures (average speed, speeding percentages and lane keeping) due to the presence of logos signs and therefore, did not pose a road safety risk (Zhang et al., 2013).

The second driving simulator study examined the impact of MUTCD logo signs (six- and nine-panels) and mileage guide signs on driver performance (Pankok et al., 2015). The results found that compared to six- and nine-panel logo signs, off-road glance durations and fixation frequencies were appreciably less than those for mileage guide signs. No significant differences between the six- and nine-panel logo signs were associated with the frequency of off-road eye-fixations and length of glances. Although these results were significantly less for six-panel signs compared to those for the nine-panel logo signs, overall deficits in vehicle control were not identified indicating that the logo signs did not impact driver safety away from the driving task (Pankok et al., 2015).

The third study also examined the impact of MUTCD mileage guide signs and six- and nine-panels logo signs on driver behaviour with the addition of two conditions: difficult road environments (construction zones) and internal distraction sources (navigational systems) (Kaber

et al., 2015). All scenarios required 40 participants to drive through a construction zone – an area designed to increase driver difficulty but without logo or guide signs present – to investigate drivers' responses to logo signs that were in place before and after the zone. It was hypothesised that driving under difficult conditions through construction zones would improve driver performance, however, under this condition, drivers' deviation from speed limits worsened as shown by poor lane maintenance. Prior to driving, half of the participants were required to use their navigational system to request directions to the destination. Further, after commencing the drive, these same participants were required to change directions on the navigational system while driving. Although speed deviations were higher when the navigation device was switched on, compared to control conditions, this finding was only statistically significant in the construction zone (Kaber et al., 2015). The results for the mileage guide signs and the six- and nine-panels signs from the Pankok et al. (2015) study (without the constriction zone and navigation system conditions) were also reported in this third paper (Kaber et al., 2015). Neither study identified significant deficits in drivers' vehicle control that would indicate that logo signs were a visual distraction.

The fourth driving simulator investigated whether the number of sign panels (six versus nine), the familiarity or unfamiliarity of the logo, the textual versus pictographic format of the logo and the driver's age affected drivers' performance in terms of attentional allocation and the accuracy of target identification (Zahabi et al., 2017a). Sixty participants were equally divided across three age groups: young (18–22 y), middle-aged (23–64 y) and older (65 + y). The results showed that senior drivers, although using a more cautious driving style, performed worse than middle-aged and young drivers in respect to the number of misses for food and attraction related targets, which may potentially be due to declines in age-related cognitive processing. The number of panels, the familiarity of the logos and logo design had no discernible impact on driver behaviour or attentional allocation. When identifying targets, driver-accuracy was at its greatest for familiar logos or text (versus pictorial) format when they were presented in six-panel signs. The authors noted that the results of this study for drivers' target identification and attentional allocation could be applied to a wider population compared to the work conducted by Kaber et al. (2015) and Zhang et al. (2013) due to the inclusion of different age ranges and a larger sample size.

While the abovementioned driving simulator studies were conducted in highway conditions, the fifth study examined the impact of age and ramp sign format and content (number of panels, format and familiarity of logos) on driver's performance and attentional allocation on freeway exit ramps (Zahabi et al., 2017b). Participants' driving performance, detection accuracy and visual attention allocation were assessed. This study used the same participants (and age groups) as the fourth study. Compared to middle and younger aged drivers, the results showed that older drivers demonstrated poorer performance and more cautious driver control strategies when using the freeway exit ramps. Older drivers also showed reduced frequencies of off-road fixations and briefer durations of off-road glances in comparison to young and middle-aged drivers. Generally, a more cautious approach was adopted by drivers when nine-panel logo signs were visible (as evidenced by more decreases in drivers' speed) compared with fewer decreases in speed when observing six-panel logo signs. Target detection was better when participants searched six-panel logo signs compared to nine-panel signs and when identifying familiar (as opposed to unfamiliar) logo targets (Zahabi et al., 2017b).

The backward citation chaining search identified an earlier driving simulator study that investigated drivers' performance associated with two- and four-panel tourism and logo signs (Hummer, 1989). Thirty-six participants were asked to exit the freeway once they had identified a tourism or service logo they had been searching for. The dependent variables included drivers' lane maintenance, speed deviation, acceleration patterns and target detection distances. The results showed that compared to pictorial logos, driving performance significantly decreased when only the message or text was visible. Further, it was found that drivers' lane maintenance and acceleration control was poorer for four-panel signs compared to the two-panels signs, however, the average differences did not translate to changes in vehicle control.

In addition to the above-mentioned logo sign studies that investigated the impact on driver performance related to logo signs located external to the vehicle, a further two driving simulator studies were identified which adopted an internal-to-vehicle component for comparison purposes (Deng et al., 2020; Feng et al., 2023). Both studies noted that while the literature has examined the effects of road-safety related messages presented to drivers on in-vehicle display devices, limited research has been undertaken to investigate the impact of displaying non-road-safety information (such as logo signs comprised of commercial logos and related text) using the same in-vehicle format. Of concern, drivers may become distracted or experience information overload resulting in visual and cognitive distractions due to in-vehicle displays (Deng et al., 2020; Feng et al., 2023).

The objective of the first of the two studies was to investigate how drivers process non-safety related information displayed on logo signs and react to roadside hazards when the logos were displayed: i) on signs by the side of the road, ii) on an information device internal to the vehicle, or iii) using a combination of the external sign and internal information device (Deng et al., 2020).

Thirty-six participants, comprising older (65 – 85 y), middle aged (24 – 64y) and younger (18 – 23y) drivers, completed six simulated driving scenarios on a highway which included three interchanges (areas where the logo signs were visible). All drivers were provided with a trip destination and advised to leave the highway using the exit that corresponded with their destination. At the start of each trial, participants were given a "target logo" (relating to either food or accommodation service) and were asked to announce whether the target logo was present on the signs.

Drivers also had to negotiate unforeseen hazards (lead vehicle braking) in areas where the logo sign was missing (or in place) and shown on either the in-vehicle device or as a roadside sign. In every scenario, drivers were exposed to a mixture of the information (shown on either the on-road signs or in-vehicle displays) and logo formats (the logo or the logo including text). The roadside logo signs and sign displays within the vehicle were identical. Prior to each of the simulator scenarios, driver workloads were assessed against the NASA Task Load Index and participants completed a post-scenario survey at the end of each trial (Deng et al., 2020).

The results of the study found that across all presentation conditions, drivers were able to identify logos with a high degree of accuracy with minimal workload. While the number of collisions did not increase, drivers' responses to road hazards were slower when logos were presented. The results also showed that the impact on drivers' workload and performance were comparable for the external on-road signage and the in-vehicle logo sign displays. While identifying local service sign logos, drivers tended to effectively evade collisions and navigate driving hazards when using both the on-road and in-vehicle logo sign displays. When participants were interviewed after the experimental trials, most drivers reported to favour external on-road signs to that of the in-vehicle sign displays despite scenarios when both options were presented. In comparison to younger and middle-aged drivers, older drivers reported higher levels of workload and were not as accurate when identifying target logo signs. However, older drivers were found to be better at detecting hazards compared to middle-aged drivers and comparable to the performance of younger drivers. Overall, the findings supported the use of in-vehicle signs in combination with the standard use of on-road signs (Deng et al., 2020).

The second, simulator study (N=18) investigated the effects of information source (a measure of attention and distraction) and driver workload on driving performance, logo identification, visual (eye glance behaviour) behaviour and vehicle control (speed and lane deviations) among older (65 + y), middle-aged (23 − 64y) and younger drivers (19

– 22y) (Feng et al., 2023). Logos were displayed: i) on signs by the side of the road, ii) on an information device internal to the vehicle, or iii) using a combination of the external sign and internal information device with half of the scenarios presenting only the logo and the other scenarios showing the logo with the addition of text.

Participants completed six simulated driving scenarios on a highway which was comprised of three interchanges where logos signs were present. All drivers were allocated a trip destination and advised to take the highway exit that would allow the drivers to arrive at their destination. Participants were given a "target logo" (displaying either food or accommodation service) and were asked to state whether the target logo was present on the signs. Scenarios included those where only the logo signs were present or when the logo sign with additional text was displayed. Eye-tracking technology was used to establish the length of time that the signs were visible to drivers (glance duration) which was applied to two areas of interest: when the roadside sign and the display panel within the vehicle were presented. The images of the roadside logo signs and internal display panels were identical. Driver's workloads were also assessed against the NASA Task Load Index (Feng et al., 2023).

The findings of the study largely supported the use of logo signs when presented on in-vehicle display panels. No significant differences were found for either the external on-road logo sign, in-vehicle logo sign or the combination of external and internal information sources. Additionally, no significant impact was found for the logo-only signs and the signs displaying both the logo and additional text. Although not significant, drivers' glances were longer for on-road logo signs compared to glance durations for the in-vehicle logo signs for all age groups, which may indicate participants' preference for the conventional and more familiar on-road logo signage (Feng et al., 2023).

Logo signs when displayed on the in-vehicle device did not appear to visually distract the participants, nor did it result in an increase in driver-workload. When the external, on-road and in-vehicle displays were presented concurrently, drivers' speed control was marginally improved. Minimal negative impacts on driver behaviour were found for logo identification due to an increase in informational workload. With respect to age groups, older drivers did not perform as well on vehicle control and sign identification and glanced for longer at the logo signage. Aspects of signage design should be considered to account for individual differences such as driver's age (Feng et al., 2023).

Overall, the results of six of the eight studies identified provided support for the incorporation of commercial or sponsorship logos on MUTCD signs on highways and freeway ramps with the latter two studies supporting the use of in-vehicle logo signs displayed on information devices within a vehicle. However, to better understand the role distraction may play when comparing external and internal sources of distraction, further research should examine the reasons behind why drivers may glance for longer (length of eyes off road) at external, on-road logos signs compared to the same logo sign being displayed on an in-vehicle device. Similarly, as for logos incorporated into DMS, a distraction risk may also be relevant for service and tourism signs if the logos act as an advertising device, communicating messages to drivers.

3.3. Beside the road – Sources of distraction

3.3.1. Murals

One driving simulator study examined the impact of *murals* on driver distraction in tunnels to ascertain if appropriately designed murals could provide a road safety benefit. Tunnels can be problematic for drivers as they are long, narrow and enclosed areas, often have limited lighting and are associated with an increase in crash rates (Zhao et al., 2022). The study investigated the novel role decorations (murals) on the sidewalls of tunnels may have on driver performance. This is because murals or decorations may assist drivers to keep their attention focused on driving, and therefore, improve safety within tunnels.

Theories of colour psychology and optical illusion guided the design parameters created for the sidewall decorations in this study. In particular, it has been found that blue-coloured patterns may reduce driver fatigue and improve drivers' levels of comfort. Attentional theory posits that drivers' attentional resources are limited, so a visual-action-cognitive task was designed to determine the impact of the sidewall decorations on the drivers' attentional state. Driver performance was evaluated against measures of operational stability (acceleration and speed deviation), speed regulation (velocity, accelerator power) and levels of attention and distraction (lateral position and angle of steering wheel) in a driving simulator experiment which compared three different scenarios of sidewall decorations to the condition where no decorations were present. The sidewall decorations were based on the Beijing 2022 Winter Olympic Games icons. The four design schemes examined in the simulator scenarios included: no design elements present, a skier icon, a skier and ice ribbon, and an ice ribbon with a skier and snowflakes. Aside from the no design element, the other three schemes were each set against the background of a blue sidewall.

Thirty drivers undertook a pre-test (familiarisation with the simulator and briefings) and test condition drive (eight tunnel scenarios) and completed a follow-up questionnaire where drivers were asked to report how they felt physically and psychologically after each of the tunnel scenarios. Drivers psychological and physical characteristics are important as they can indicate uneasiness associated with entering and exiting the tunnel known as the "black hole effect" (an innate response that results in a driver suddenly reducing their speed including larger variations in their change of speed) (Zhao et al., 2022, p. 6.). Drivers were greatly affected by the design complexity of the decorations. Due to the multiple factors and attributes involved in assessing the impact of sidewall designs, the four tunnel decorations were investigated using a fuzzy comprehensive model grounded in the entropy weight method. The study found that the complexity of the elements used within the sidewall design had an effect on driver performance. They found that compared to no design schemes, the schemes that consisted of just the skier (scheme 2) and an ice ribbon with a skier and snowflakes (scheme 4) resulted in drivers maintaining lower speed levels with an overall improvement in driver performance.

From the drivers' reports of their physical and psychological states in the post-simulator questionnaire, the authors concluded that the drivers did not experience any negative effects associated with being in an enclosed space known as the "sidewall negative effect". Thus, the authors reported that drivers' negative physical and psychological states could be relieved by appropriately decorating tunnel walls (Zhao et al., 2022, p. 11).

Overall, the study found that appropriate sidewall decorations did not result in driver distraction as certain design elements on sidewall decorations can improve drivers' speed regulation, stability and their driving experience in tunnels. Further, the authors also argued that sidewall decorations in tunnels (murals) may be an innovative road safety feature as they have the potential to decrease driver boredom, impairments in vigilance, fatigue states and anxiety levels (Zhao et al., 2022).

While this study found that murals may have a road safety benefit for drivers in tunnels, this finding is a very specific application of murals. Hence, it is unclear how the findings of this study might generalise to other driving situations where murals may be encountered. In other contexts, murals can be artwork or used as advertising devices such as hand-painted billboards on walls or buildings located within road corridors. Further research is needed to better understand the wider application of murals and their impact on driver distraction and performance, particularly when they are used to convey messages to drivers.

3.3.2. Roadside memorials

Two studies that examined the relationship between *roadside memorials* and driver behaviour were found in the database search (Beanland & Wynne, 2019; Tay, 2009). The first study conducted an online survey that examined public and road agencies' opinions and

perceptions of roadside memorials. In addition, a short-term before and after experiment investigated drivers' red light running behaviours at four intersections where red-light cameras were in place: two at intersections with memorials and two without (Tay, 2009).

Of the 810 survey respondents more drivers reported that roadside memorials should be permitted (51 %) compared to those saying that they should not (38.4 %). Nearly half of the responses (46.8 %) indicated that roadside memorials would be "likely to distract them while they were driving". In general, 56.1 % of respondents agreed and strongly agreed that roadside memorials helped "people grieve for their loved ones" (Tay, 2009, p. 665). Although 46.4 % of participants generally disagreed (23.6 %) and strongly disagreed (22.8 %) that memorials "give the impression that the roads were unsafe", 36.9 % of respondents said they may be road safety hazard. Drivers also indicated that roadside memorials made participants "think about their driving" (39.1 %) and "drive more cautiously" (32.1 %) (Tay, 2009, p. 665). Regarding their own driving behaviour, 27.9 % said they were less likely drive through an intersection when the light was red and that they were more likely to stop in response to a yellow light (28.5 %).

The four selected intersections for both the treatment and comparison sites were all located on four-lane roads in urban environments with similar traffic volumes and comparable road environments and conditions. The two experimental sites were chosen due to their similarities in the amount of traffic infringements and traffic counts. The mock memorials in the treatment conditions were attached to utility and lighting poles on approach to the intersections with red-light cameras. The change in the number of traffic infringements identified by traffic cameras at the two experimental intersections with roadside memorials was found to be highly significant as infringements numbers decreased by 16.7 % (from 282 to 235). It was argued that this reduction of violations indicated that roadside memorials may provide a short-term safety benefit, rather than posing a distraction risk. In contrast, at the comparison intersections (without roadside memorials), infringement numbers increased from 250 to 292 (16.8 %). It was proposed that the unexpected increase in infringements in the comparison site could be explained by the riskier driving behaviours often associated with the improving (warmer) weather conditions in the area. Overall, the results indicated that roadside memorials should be permitted with some restrictions, however, further research was warranted to determine if memorials could provide a longer-term road safety benefit. (Tay, 2009).

The second study investigated whether roadside memorials captured a driver's attention and if any resultant changes in their driving performance had an impact on road safety (Beanland & Wynne, 2019). Based on the "threat superiority effect", the authors hypothesised that a threating stimulus such as a roadside memorial may preferentially capture a driver's attention as threat-related signals are often prioritised. Should this be the case, drivers would exhibit more and longer eye-fixations towards the roadside when the memorial is present, increasing the risk of a crash. Participants viewed 40 videos of road scenes with and without roadside memorials and orange traffic cones; a comparison object of comparable size which also signifies a road hazard. Drivers were asked a series of questions to examine their road safety behaviour which was determined by their self-reported ratings of perceived risk and choice of travel speed around roadside memorials.

The results indicated that roadside memorials visually captured a driver's attention as drivers fixated more (and displayed mostly shorter fixation times) on roadside memorials and the roadside area in comparison to the orange traffic cones. Participant's brief, total fixation times on roadside memorials (on average 400 ms) were not regarded as unsafe. However, one participant's comment indicated otherwise as they reported being emotionally affected after seeing a roadside memorial (Beanland & Wynne, 2019, p. 5):

> *Someone died back there. I hate those signs on the side of the road, I find that very traumatising and now I'm going to think about it for the whole rest of the drive down the highway, that someone died there. That's distracting to me.*

While two of the 40 participants said roadside memorials should not be permitted within road corridors as they may cause a distraction, 95 % reported that they should be permitted. No effects were for found for either perceived risk or preferred travel speed. Further, no evidence was found to indicate improvements in road safety were due to the presence of roadside memorials, nor were they indicative of driver distraction. Overall, the results did not support a case for prohibiting roadside memorials due to road safety concerns, and coupled with the lack of conclusive evidence more broadly, the authors proposed that the decision to ban roadside memorials may more likely be informed by other considerations such as aesthetics and public opinion.

The backward citation chaining search found an additional study that used a questionnaire to investigate drivers' and road agencies' views and opinions of roadside memorials and their feelings on whether road agencies should put policies into place to control their use (Churchill & Tay, 2008). Eleven (of 361) young drivers indicated that memorials would distract them. However, in contrast to road agencies' responses, most drivers indicated they would not be distracted and that memorials may reduce accidents as they are a warning to drive more carefully. Results indicated that only 10 % of Canadian road agencies had a policy in place, however, informal policies permitting roadside memorials were supported. On the whole, participants felt that memorials had a positive influence on drivers.

The results of the three studies identified in the review provide important contributions to the field, however together, they do not provide conclusive evidence on whether roadside memorials may distract a driver or potentially provide a road safety benefit.

3.3.3. *Wind generator/wind farm*

The backward citation chaining search identified a driving simulator study that examined the effect of *wind generators or wind farms* on driver performance, a relatively new structure in the road environment at the time (Milloy & Caird, 2011). The study used measures of speed maintenance, headway distances to a lead vehicle when hard braking (perception response times) and lane keeping, to investigate driver behaviour around wind turbines (wind generator or wind farm). Twenty-four drivers were presented with scenarios showing active wind turbines (using three different virtual wind speeds: off, slow and fast) extending 500 m along the side of a six-lane highway. Lane keeping, perception response times to the braking of a lead vehicle and the maintenance of speed were compared in the baseline and associated experimental wind turbines conditions.

No significant difference in drivers' response times to the lead vehicle hard braking was found. However, drivers' minimum headway distances from the lead braking vehicle were smaller when the turbines were visible to drivers in comparison to when they were not. The authors argued that this potentially indicated that drivers were following the lead vehicle too closely while watching the turbines. Drivers also lowered their speed around wind turbines which may be explained by drivers choosing to view the turbines due to their novelty factor.

No effect was found on lane keeping behaviour when the turbines were visible to the drivers. Using a collision algorithm to determine if drivers would have collided with the lead vehicle when hard braking, one crash was identified out of a possible 96 braking events. It was found that six seconds prior to the crash, the driver glanced back at the turbines in their rear vision mirror. However, the driver was looking at the speedometer inside the vehicle immediately prior to the crash. The authors argued that the wind turbines were only of interest to drivers due to the turbines' movement despite being visible for a longer period of time. Thus, future research was warranted to further investigate whether wind farms distract drivers or, if over time, drivers become accustomed to them as their novelty decreases.

3.4. Above the road – Sources of distraction

3.4.1. Drones (unmanned aerial systems)

Two driving simulator studies investigating *drones* (unmanned aerial systems) were identified in the database search (Barlow et al., 2019; Ryan et al., 2020). The study examined whether 30 drivers were visually distracted by drone operations near roadsides using three independent measures: the distance drone operations were located laterally offset from the edge of the road, the type of flight pattern (take-off and landing, racing and scanning) and the adjoining land use (urban versus rural locations) associated with the drone operations (Barlow et al., 2019). The study found that drivers' total amount of eye-glances away from the road (total fixation duration) were statistically significant when the drone was located at 0 m (and 0 ft); that is, directly beside the road's edge. Further, participant's fixation time was longer for the take-off pattern when the lateral offset from the road was 0 m (0 ft) compared to that for the 7.6 m (25 ft) and 15.2 m (50 ft) conditions. Participants looked for longer at the take-off and landing pattern of the drones compared to the racing and scanning flight patterns.

Overall, the nearer the drones and their operators came to the roadside, the more visually distracted drivers were. This was especially the case in rural (versus urban) locations, possibly due to drones and their operators being more conspicuous to drivers in less cluttered road environments. It was recommended that policies be developed to ensure drones and their operators are not located closer than 7.6 m (25 ft) laterally offset to the road's edge and for road agencies to consider extra offset restrictions in rural locations.

In the second study, 28 participants were recruited to undertake a driving simulator study that investigated the impact of drone height on driver performance when flying at 20 ft, 40 ft and 60 ft above ground level and the distractibility of drones and their operators when visible to drivers (Ryan et al., 2020). Measures included eye-glance behaviour and changes in speed and lateral position. The results found that continual two-second (or greater) eye-glances occurred 11 % of the time when the participant was looking at the operator or the drone, therefore, indicating that drivers were visually distracted. While it was hypothesised that drivers would change their lane position to avoid the drone when passing it, no significant effect was found. In addition, drivers did not reduce their speed in response to the different drone heights but were more visually distracted when the drone and their operators were visible compared to the drone only scenarios. Of particular interest, out of the 156 videos analysed, nine participants showed instances where drivers checked their rear-view mirrors to look back at either the drone and or its operator after passing them. Three (of the 28) participants engaged in this behaviour suggesting that these drivers were cognitively distracted by the drone.

A follow-up questionnaire found that 27 % of participants reported that they had seen drones operating beside the road prior to undertaking the experiment. When participants were asked if drones should be permitted near roads, 57 % of participants (n = 16) selected "No" with the remaining 43 % (n = 12) indicating "Yes". As drone use is increasing rapidly, it was recommended that road agencies introduce policies that align with the results of the study to better manage the distraction potential of drones when operating in the vicinity of roads (Ryan et al., 2020).

A third paper (identified through a backward citation chaining search) reported the results of a U.S. national survey investigating the use of drones around roadsides (Kim et al., 2017). The survey canvased opinions from 435 officers working in emergency services, transport and enforcement agencies across 98 cities. Six percent of the participants said they were aware of situations where drones had led to a crash and 17.66 % knew of near misses. Additionally, 45.9 % of respondents were aware of instances where drones had fallen on motor vehicles, with 92.5 % stating they are distraction risk. Further, 85 % said that the use of drones over roads should be regulated. The authors also cited other sources which detailed instances where drones had collided with vehicles in Australia, Belgium, France, Switzerland and a number of U.S. cities, raising serious concerns about drones and road safety (Kim et al., 2017). Road authorities often draw on public opinion (along with empirical data) to guide roadside safety policy development for external sources of distraction such as drones and roadside memorials (Barlow et al., 2019; Churchill & Tay, 2008; Tay, 2009).

Given advances in drone technology, the number and expanding use of drones (and other UAS devices) in road corridors, drones may present a distraction risk, warranting further investigation. This is particularly evident when a driver continues to visually and cognitively engage with a drone (and or it's operator) as they have the potential to distract a driver by taking drivers' eyes and minds away from safety-critical driving tasks.

4. Discussion

The aim of this study was to conduct an exploratory review to ascertain and synthesise the available distraction-related literature for various types of roadside advertising signs (excluding billboards) and other potential external sources of distraction in the road corridor. Excepting the two drone research articles that found evidence for driver distraction, the remaining 17 studies reported no appreciable impact on driver performance. While the aim of the study was achieved, the review yielded only a very small number of studies for other types of external distraction sources, corroborating the findings of previous research (Horberry & Edquist, 2009; Regan & Oviedo-Trespalacios, 2022; Regan et al., 2009). Similarly, no literature was found relating to the distraction impacts of other (non-billboard) types of roadside advertising devices, confirming that important knowledge gaps in this area remain (Hinton et al., 2022; Oviedo-Trespalacios et al., 2019).

Fourteen of the 19 studies that were identified in the review were conducted in a driving simulator and, therefore, it was difficult to compare the complexity of all road features such as whether the studies were located in urban or rural locations, located on entry or exit ramps or at intersections, for example. While simulator studies are of high-quality, there is an inherent absence of road complexity as they do not realistically reflect the road environment (Goodsell et al., 2019).

One of the key learnings from the review is that the studies adopted different approaches to investing the role distraction may play. One study explicitly examined whether a distraction source may provide a road safety benefit (murals on the sidewalls of tunnels) while the others focused on the extent to which a driver's attention may (or may not) be distracted away from safety-critical driving tasks. In addition, some sources of distraction (such as roadside memorials) may provide a road safety benefit in some circumstances. Further research is critical to address discrepancies across literature as a small number of studies does not necessarily indicate an absence of risk.

There are a range of factors that may influence the 'distractibility' of a distraction source. Whether a driver is distracted may be dependent on the context of that distraction. For example, drones flying without an operator were shown to be less distracting than when the drone and the operator were present (Ryan et al., 2020). Yet in another context, using sophisticated drone technology, a swarm of drones displaying commercial advertising may distract drivers through the message they convey to drivers. Novelty may also play a role in distraction. While wind turbines are relatively new objects found within road corridors their distraction potential may change as their novelty (and consequent impact on drivers' behaviour) decreases (or increases) over time (Milloy & Caird, 2011).

Therefore, distraction sources also have the potential to communicate messages to drivers. For some drivers, roadside memorials may evoke strong emotional reactions such as fear or alarm, which may influence the extent to which a driver is emotionally affected (or distracted), over and above the memorial itself (Lewis et al., 2016). Moreover, whether drivers are more likely to be affected by distraction sources may be dependent upon individual characteristics such as age,

gender and driving experience (Oviedo-Trespalacios et al., 2016; Taubman-Ben-Ari et al., 2004).

Additionally, commercial logos and symbols on DMS or MUTCD service signs may not be relevant for all drivers. While drivers may use them to navigate to upcoming businesses or services designated by the logo, it is possible that some drivers may be ambivalent to them. Conversely, commercial logos may actively communicate a message to drivers as opposed to their symbolic value alone. For example, food-related logos might trigger a driver's internal biological needs by making the driver feel hungry, initiating an internal distraction diverting their thoughts away from the road (Regan & Oviedo-Trespalacios, 2022).

The potential attentional pathways and mechanisms through which external sources of distraction (including roadside advertising signs) may contribute to road crashes is not well understood (Hinton et al., 2022). However, the DBRA conceptual framework can be used to conceptualise these mechanisms and pathways even though it was originally conceived to explain the impact of roadside advertising signs on driver behaviour. For example, the concept of "extended engagement" included within the DBRA can be used to explain how particular external sources of distraction can continue to distract drivers even after they are passed. This was evident in the drone and wind turbine studies where participants looked back in their rear-view mirrors, as they continued to visually and cognitively engage with the distraction source (Beanland & Wynne, 2019; Milloy & Caird, 2011). Similarly, one participant in the roadside memorial paper reported that as a result of seeing the memorial they continued to think about someone dying there for the remainder of their drive (Beanland & Wynne, 2019). It is proposed that while all three of these cases were experienced by a small number of participants, it may represent examples of extended engagement with a distraction source which has the potential to increase the risk of a crash or near miss (Hinton et al., 2022).

The DBRA conceptual framework considers that pre-existing, individual differences (human factors) may mediate drivers' performance around roadside advertising signs (Hinton et al., 2022). By extension, the DBRA conceptual framework has the capacity to account for the influence of potential individual differences that might impact on drivers' attentional capacity and susceptibility to be distracted due to other sources of external distraction. For example, these individual differences could include a driver's age, personality traits and states, and attention related disorders (such as an ADHD) (Arca et al., 2024; Oviedo-Trespalacios et al., 2016; Taubman-Ben-Ari et al., 2004).

Road corridors are a public asset but are increasingly becoming a contested space for commercial and other uses, all carrying the potential to distract. Reducing the impact of distracted driving is not the sole responsibility of government although it is traditionally mandated to do so. Consistent with the principles of the Safe System Approach, the safety of the road transport system is a shared responsibility among all stakeholders (International Transport Forum, 2016). Hence, all those involved in creating or managing objects, events or activities within the road corridor need to consider their potential impact on driver behaviour. On the whole, road users do not provide their consent to allowing potential distraction sources into the road corridor. That is, you can turn off a TV or radio advertisement, but you cannot switch off an interactive advertising sign transmitting bespoke messages to drivers. Nor can drivers necessarily avoid interacting with other potential external sources of distraction such as wind turbines or drones when they are located beside or above the road.

Given the fragmentary nature of the available research examining external-to-vehicle distraction sources, it is not currently possible to identify those that represent the greatest crash risk nor the feasibility of mitigating them through the use of existing countermeasure approaches. Without evidence-based data the practicalities of regulating and controlling the different types of potential distractions is challenging. Road agencies rely on evidence-based research to inform the development of road safety policy and without policies in place, the ability to mitigate particular sources of distraction through regulation or other types of countermeasures is constrained. The studies on drones (Barlow et al., 2019) and roadside memorials (Beanland & Wynne, 2019; Churchill & Tay, 2008; Tay, 2009) indicated that distraction related road safety policies were either limited or absent which was the main impetus for their research. For instance, Barlow et al. (2019) recommended that based on their study's results, road safety policies to regulate and mitigate the impact of driver distraction within road corridors should be developed to ensure drones and their operators are not located closer than 7.6 m (25 ft) laterally offset to the road's edge and for road agencies to consider offset restrictions in rural locations. Additionally, not all road agencies have the power to regulate particular sources of driver distraction within the road corridor and legislative controls may differ across jurisdictions.

As vehicle technology evolves including the refinement of autonomous vehicles, consideration should be given to how external sources of distractions may interact with internal to vehicle displays to influence driver behaviour, thereby informing future policy development in the area.

5. Conclusion

Driver distraction is a serious problem worldwide that can increase the risk of road crashes. This study focused on external sources of driver distraction and their potential impact on driver behaviour given that, with the exception of advertising billboards, these had not received as much attention in the literature as internal distraction sources. As such, it is important, original research that contributes to the existing body of literature. The results of 58 category searches for studies that address the different sources of external distractions provided context and highlight the research that is currently available. The exploratory review identified and synthesised the current state of knowledge and will assist regulatory bodies and academics when considering policy development and future research in the field.

Depending on the context, external sources of distraction in the road corridor have the potential to distract drivers' attention away from safety-critical driving tasks. However, the general state of the literature does not provide cohesive evidence regarding the extent to which they distract drivers (either in a positive or negative manner), making it difficult to formulate strong overarching conclusions. It is suggested that the mechanisms and pathways in the DBRA may provide a framework by which other external sources of distraction may be explored and better understood. The ability to characterise the relationship between external sources of distraction and their impact on driver performance has practical implications for policymakers when seeking to mitigate (or eliminate) any associated risks of death and injury. This exploratory review was limited in that it only captured literature written in English. In addition, a number of relevant studies known to the authors were not identified in the database search. Some potentially relevant studies may have been missed due to the inconsistent use of terminology used by researchers to identify different types of distraction sources. Therefore, the consistency of terminology used in publications to refer to different types of external distraction sources and types of roadside advertising devices other than billboards is essential to improve future search strategies to reduce the risk of driver distraction. Future billboard studies remain critical, however, the research focus also needs to extend beyond the billboard to include other types of advertising signs and external sources of distraction. Further research should consider the potential susceptibility of drivers to distraction based on a wide range of individual differences including age, personality states and attention related disorders. Moreover, future studies also need to examine the potential for different sources of distraction to impact on driving performance, both in a positive or negative way, not only when first encountered but also after they have been passed.

CRediT authorship contribution statement

Jane Hinton: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Oscar Oviedo-Trespalacios:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Barry Watson:** Writing – review & editing, Supervision, Conceptualization. **Narelle Haworth:** Writing – review & editing, Supervision.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

Appendix 1. . Information extracted from the studies identified in the exploratory search

Distraction source	Author/s	Year	Country	Document type	Data source	Measures	Sample size and gender balance	Analysis	Findings
On the road									
Construction zone / construction equipment	Gupta et al.	2022	India	Edited book	On-road instrumented vehicleEye-tracking	Gaze fixation and durationRoad safety audit	6 participantsM=6Age: 25-40y	Heat maps (gaze fixation and duration at Areas of Interest (AOI))Gaze sample percentages	Highly skilled drivers marginally effected by construction zone at AOI
Dynamic message sign / DMS / variable message sign / VMS / traffic management sign / TMS / changeable message sign / CMS / matrix sign	Pike et al.	2016	U.S.	Technical report	Driving simulatorEye-tracking	Message recallEye gaze patterns	43 participants in the open-ended data, and 42 in both the driving and eye tracking dataM=21F=22Age: 19-83y	Within-subjects non-parametric analysisANOVA	No significant effectof logos and message recallEye glance data found small numbers of glances of 2 s for logos
Dynamic message sign / DMS / variable message sign / VMS / traffic management sign / TMS / changeable message sign / CMS / matrix sign	Chrysler et al.	2017	U.S.	Journal	Closed driving courseEye-tracking	Legibility distances for target words on CMSRoad hazardobject detection distances	30 participants7 or 8 males and females in each groupYounger drivers group aged: 18-36yOlder drivers group aged: 57-85y	ANOVA	No significant effect for sponsor logos on legibility distances for travel time signs. Sponsor logos A small effect for legibility distances for safety message signs (blue background, but not with a black background)Sponsor logos showed a slight effect for object detection at some object locations
Service centre sign / service center sign / logo sign	Hummer	1989	U.S.	Journal	Driving simulatorPost experiment questionnaire	Lane maintenance, speed deviation, acceleration pattern and target identification	36 participants	ANOVA	Compared to pictorial logos, driving performance significantly decreased only when the message/ text was visible.Drivers' lane maintenance and acceleration control were poorer for four-panel signs compared to the two-panels, however, no functional changes in vehicle control were observed
Service centre sign / service center sign / logo sign	Zhang et al.	2013	U.S.	Journal	Driving simulatorEye-tracking	Signal detectionResponse time to target logo signsGaze direction and durationAverage speedLane deviationSpeeding percentage	24 participantsGender balanced Age: 18-58y	ANOVAMulti-way nonparametrictest	Drivers reduced speed when identifying logos on the nine-panels sign compared to the six-panel signsNo significant variations in drivers' attentional demands (off-road glance durations and fixation frequencies) were found when identifying logos with six-panel, nine-panel and overflow-combination signs
Service centre sign / service	Kaber et al.	2015	U.S.	Journal	Driving simulatorEye-tracking	Glance duration and frequency of	40 participants M=21F=19Age: 25-59y	Parametric and non-parametric ANOVA	Compared to six- and nine-panel logo signs, glance durations and fixation

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Distraction source	Author/s	Year	Country	Document type	Data source	Measures	Sample size and gender balance	Analysis	Findings
center sign / logo sign						fixationSpeed and lane deviation			frequencies were less than those for mileage guide signsNo significant differences between the six- and nine-panel logo signs in respect to the frequency of eye-fixations and length of glancesNo deficits in vehicle control were foundDrivers' speed and lane maintenance were most degraded at construction zones compared to conditions where signs were not present
Service centre sign / service center sign / logo sign	Pankok et al.	2015	U.S.	Journal	Driving simulatorEye-tracking	Glance duration and frequency of fixationSpeed and lane deviation	40 participants M=21F=19Age: 25-59y	Parametric and non-parametric ANOVA	Compared to six- and nine-panel logo signs, glance durations and fixation frequencies were less than those for mileage guide signsNo significant differences between the six- and nine-panel logo signs in respect to the frequency of eye-fixations and length of glancesNo deficits in vehicle control were found
Service centre sign / service center sign / logo sign	Zahabi et al.	2017a	U.S.	Journal	Driving simulatorEye-tracking	Accuracy of target identification, allocation of attentionand speed and lane deviation	60 participants Samplebalanced across three age groups:1: 18-22y2: 23-64y3: 65 + yGender balanced within age groups	Descriptive statisticsANOVA	Older drivers performed worse than middle-aged and younger drivers in respect to the number of misses for food and attraction targetsThe number of panels, the familiarity of the logos and the structure of the logo had no discernible impact on driving performance or attentional allocationWhen identifying targets, driver-accuracy was at its greatest for familiar logos or text panels when they were presented in six-panel signs
Service centre sign / service center sign / logo sign	Zahabi et al.	2017b	U.S.	Journal	Driving simulatorEye-tracking	Driving performance, detection accuracy and allocation of visual attention	60 participants Samplebalanced across three age groups:1: 18-22y2: 23-64y3: 65 + yGender balanced within age groups	ANOVA	Older drivers demonstrated poorer performance and more cautious driver control strategies on freeway exit ramps. Older drivers showed reduced frequencies of off-road fixations and briefer durations of off-road glancesA more cautious approach was used by drivers when nine-panel logo signs were visible compared with six-panel logo signsTarget detection was better for six-panel versus nine-panel logo signs and when identifying familiar (from unfamiliar) targets
Service centre sign / service center sign / logo sign	Deng et al.	2020	U.S.	Conference paper	Driving simulatorEye-tracking (data was collected but not reported)	Driving behaviour, logo identification, hazard negotiation, workload and post experiment questionnaire	36 participantsSample balance across three age groups1: 18-23y2: 24-64y3: 65-85yGender balance within age groups	ANOVAStatistical measures	Across all presentation conditions drivers were able to identify logos with a high degree of accuracy and minimal workloadWorkload and

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Distraction source	Author/s	Year	Country	Document type	Data source	Measures	Sample size and gender balance	Analysis	Findings
									performance were comparable for the external on-road signage and the in-vehicle logo sign displaysDrivers tended to effectively evade collisions and navigate driving hazards when using both the on-road and in-vehicle logo sign displaysOlder drivers reported higher levels of workload and not as accurate when identifying target logo signsOlder drivers were found to be better at navigating hazards compared to middle-aged drivers and comparable to the performance of younger drivers
Service centre sign / service center sign / logo sign	Feng et al.	2023	U.S.	Journal	Driving simulatorEye-tracking	A combination of driver performance, information processing, visual behaviour, hazard response and workload	18 participantsSample balance across three age groups1: 19-22y2: 23-64y3: 65 + yGender balance within age groups	Q-Q plotsANOVA	Logo signs displayed on an in-vehicle format did not indicate that drivers were visually distracted or result in an increase in driver-workload.When the on-road and in-vehicle displays were presented concurrently, drivers' speed control was marginally improvedMinimal negative impacts found for logo identification due to an increase in informational workloadOlder drivers did not perform as well on vehicle control and sign identification and glanced for longer at the logo signage.
Beside the road									
Murals	Zhao et al	2019	China	Journal	Driving simulatorEye-trackingFollow-up questionnaire	Speed regulation (velocity, accelerator power, Operation stability (velocity, accelerator power) Attention concentration levels (lateral position, steering angle)	30 participantsM=22F=8 (gender ratio generally aligned with attributes of Chinese drivers)	Repeated measures ANOVAComprehensive evaluation model based on the entropy method	Appropriate sidewall decorations did not result in driver distraction Suitable design elements on sidewall decorations can improve drivers' speed regulation, stability and their driving experience in tunnelsDecorated sidewall decorations in tunnels (murals) may be an innovative road safety feature
Roadside memorial / ghost bike / white cross / memorial cross	Churchill and Tay	2008	Canada	Journal	Questionnaires (x2)Students from a local universityRoad agencies in Canada.	Self-rated dataBefore and after comparison	414 respondentsM=302F=1111 = unclear~43,000 vehicles (treatment site)~39,000 (comparison site)	Descriptive statistics	Agreement that an informal policy should permit roadside memorials (with some safety restrictions put in place) Road agencies thought memorials were distracting while the students did not
Roadside memorial / ghost bike / white cross / memorial cross	Tay	2009	Canada	Journal	Online surveyOn road experiment	Self-rated dataRed light traffic violations at urban intersections (2 x treatment; 2 x control)	810 participants756 of the participants who indicated their gender: M=76F=480	Descriptive statisticsLikelihood ratio	Public opinion on policy and drivers' survey responses to roadside memorials were fairly dividedRed light traffic infringements numbers decreased by 16.7 % in the

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Distraction source	Author/s	Year	Country	Document type	Data source	Measures	Sample size and gender balance	Analysis	Findings
									6 weeks period after they were installed in comparison to the period of six week prior their installationInfringement numbers increased by 16.8 % at the non-treatment site for the same period both before and afterMemorials may have a short-term safety effect at intersections
Roadside memorial / ghost bike / white cross / memorial cross	Beanland and Wynne	2019	Australia	Journal	40 short video clips of daytime road scenes (from the perspective of the driver)Eye-tracking	Self-rated dataEye fixationsSafety related behaviours (perceived risk and preferred travel speed)	40 observersM=11F=29Age: 20-44y	Repeated measures designQuantitative variables used generalized estimating equations	The study found, that although roadside memorials capture a driver's attention, they are unlikely to have a negative (or positive) impact on road safety No effects were for found for both perceived risk and preferred travel speedOverall, most drivers supported memorials with only a few strongly against them as they were viewed as being distracting (and / or upsetting)
Wind generator / wind farm	Milloy and Caird	2011	Canada	Edited book	Driving simulatorEye-tracking	Speed maintenance, headway distances to a lead vehicle hard braking (perception response times)Lane keeping	24 participants Stratified into age groups of 18-25y (younger), 26-54y (middle-aged) and 55-77y (older) Gender balanced across all groups	Repeated measures ANOVA	While drivers briefly looked at the turbines, no significant difference to drivers' response times to the lead vehicle braking or for lane keeping behaviours was foundOverall, while drivers briefly looked at the turbines only minimal effects were found
Above the road									
Drones / model aircraft / eVTOL / electric vehicle take-off and landing	Kim et al.	2017	U.S.	Conference paper	Questionnaire	Self-rated data	435 participants	Descriptive statistics	The opinions of emergency services, transport and enforcement agencies across 98 cities in the U.S. were canvassed. The feedback indicated that drones have the potential to be a road and traffic hazard
Drones / model aircraft / eVTOL / electric vehicle take-off and landing	Barlow et al.	2019	U.S.	Journal	Literature review Driving simulatorEye-tracking	Eye-fixations for drone operations laterally offset to the road, landing patterns and land use	30 participantsAge: 18–70 yM=16F=14	ANOVALinear mixed model	The review found that while drones policies exist, no research was found specially for drones and driver distractionFixation time was longer for the drone take-off pattern when the lateral offset from the road was 0 m (0 ft) compared to that for the 7.6 m (25 feet) and 15.2 m (six feet) conditionsParticipants looked for longer at the take-off and landing pattern of the drones compared to racing and scanning flight patternsDrones are more conspicuous toin the rural (versus urban) environment due to less visual clutter
Drones / model	Ryan et al.	2020	US	Journal	Driving simulatorEye-	Speed changes, lateral position, eye	28 participantsGender balanced Age: 18-75y	Shapiro-Wilk testKruskal-Wallis	Drivers more visually distracted when operators

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Distraction source	Author/s	Year	Country	Document type	Data source	Measures	Sample size and gender balance	Analysis	Findings
aircraft / eVTOL / electric vehicle take-off and landing					trackingOnline post-experiment questionnaire	glance behaviour (visual attention) Demographic informationSelf-rated data		testWilcoxon signed-rank testMedian absolute deviation	and the drone were present (compared to the drone only scenarios)In 11 % of all scenarios, participants were found to be visually distracted as indicated by glances of two seconds or more towards drones or their operatorsNo significant difference was found for speed changes and lateral position27 % of participants reported seeing drones around roadsides and their opinions on whether drones should be permitted was fairly divided

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