



# The effects of auditory satellite navigation instructions and visual blur on road hazard perception



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## ABSTRACT

The distracting effects of mobile telephone use while driving are well known, however the effects of other sources of distraction, such as auditory navigation devices, are less well understood. Whether the effects of auditory distraction might interact with other sensory impairments, such as vision impairment, is of interest given that visual impairment is relatively common within the population, particularly as a result of uncorrected refractive error. In this experiment, 20 current drivers (mean age of  $29.4 \pm 3.2$  years), binocularly viewed video recordings of traffic scenes presented as part of the Hazard Perception Test and responded to potential hazards within the traffic scenes. Half of the presented scenes included auditory navigation instructions as an auditory distractor. Additionally, some of the scenes were viewed through optical lenses to induce different levels of refractive blur (+0.50 DS, +1.00 DS and +2.00 DS). Hazard perception response times increased significantly ( $p < 0.05$ ) with increasing blur. Participants were significantly slower in reacting to hazards for the +1.00 DS and +2.00 DS blur conditions compared to the control condition (with no blur). There was also a significant increase in response times to hazards in the presence of the auditory navigation instructions. The combined effect of blur and auditory instructions was additive, with the worst performance being in the presence of both blur and auditory instructions. These results suggest that the delivery of auditory navigation guidance for those with visual impairments, such as blur, which are relatively common in the population, should be further investigated.

## 1. Introduction

Driver distraction has been highlighted as a major cause of motor vehicle crashes, reportedly being responsible for up to 80% of all collisions (Malaterre, 1990; NHSTSA, 2006; Rumar, 1990; Young et al., 2008; Young and Regan, 2007), and is likely to become more problematic in the future as the in-vehicle environment becomes more complex. Drivers who are engaged in a secondary auditory task show poorer vehicle control (Horrey and Wickens, 2006; Ranney et al., 2005), are less likely to detect peripheral targets (Amado and Ulupinar, 2005; Recarte and Nunes, 2003), and are poorer at identifying hazards and slower to respond to them (Brookhuis et al., 1994) than drivers who are not distracted. The detrimental impact of multi-tasking while driving is further corroborated by findings that driving performance is significantly impaired for drivers who are conversing on a mobile phone (Lamble et al., 1999; Strayer and Drews, 2007; Treffner and Barret, 2004; WHO, 2011), with crash risk being increased by a factor of four (McEvoy et al., 2007; Redelmeier and Tibshirani, 1997). Indeed,

Redelmeier and Tibshirani (1997) noted that the increase in crash risk associated with mobile phone use is comparable to the effect of driving while under the influence of alcohol. Importantly, these authors found that the distracting effect of mobile phone use was not reduced when a hands-free display was adopted. Importantly, not all investigators concur with these findings (Ferdinand and Menachemi, 2014), with some studies demonstrating an improvement in certain driving behaviours while participants are engaged in conversing on a mobile phone (Atchley and Chan, 2011; Haigney et al., 2000; Janssen and Brumby, 2010; Liu, 2003).

Being able to interact effectively with in-vehicle devices is likely to depend on the ability of the driver to divide their attention, and previous research has shown that there are large individual differences in the ability of drivers on divided attention tasks (Ball and Owsley, 1991; Ball and Rebok, 1994; Clay et al., 2005). One group of drivers who are likely to have the most difficulty with divided attention are those with visual impairment. Visual impairment is relatively common within the population, with uncorrected refractive error (optical blur) being the

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leading cause of reversible visual impairment in older adults (VanNewkirk et al., 2001), and large numbers of individuals with uncorrected refractive error continue to drive (Keeffe et al., 2002). Importantly, both the effect of visual blur alone and the effects of visual blur in complex, attention-demanding driving situations are unknown. Our previous studies have demonstrated that low level sensory changes (e.g., changing visual contrast, and hearing) are associated with reduced performance on cognitive tests and with cognitive aspects of driving (Hickson et al., 2010; Wood et al., 2010, 2009). A critical question is whether degraded vision due to refractive blur influences attentional allocation in complex environments such as driving, and whether such attentional changes influence multi-tasking in real-world driving situations.

One form of technology which has become very prevalent in current vehicle designs is auditory navigation instruction, either from a devoted device, or using a mobile phone app. However the potential impact of distraction from such devices remains under-researched (Ferdinand and Menachemi, 2014). A small number of studies have suggested that both music and synthesized speech of the kind used in navigation devices may cause some adverse changes in simulated driving behavior (Dalton and Behm, 2007; Dalton et al., 2007; Tsimhoni et al., 2001), and there have been calls for more thorough research into this area (Ho and Spence, 2008). Some previous studies have examined advanced traveler information systems (which involve navigation instructions in addition to driver warnings and other information) most often in combination with visual displays, and showed that auditory and multi-modal displays are less distracting while driving than visual displays alone (Dingus et al., 1997; Kim and Son, 2011; Liu, 2001). In a separate study (Lee et al., 2016) we examined the influence of blur and simulated navigation instructions on eye movements for a single level of visual blur.

In the present study we presented visually and cognitively normal young adults with the Hazard Perception Test (HPT) (in which participants are required to identify hazards in videos of real driving scenes), either with or without simulated auditory navigation instructions and with four different levels of visual blur. Performance on the HPT has been shown to be significantly associated with retrospective and prospective crash involvement in studies involving cross-age samples (Darby et al., 2009; McKenna and Horswill, 1999), as well as self-reported retrospective crashes in older adults (Horswill et al., 2010; Wells, 2008) and prospective state-based crash risk in younger drivers (Horswill et al., 2015). To establish whether auditory distractors might have greater effects on those with visual impairment, we also introduced visual blur alone or in combination with simulated auditory navigation instructions. We hypothesized that increasing levels of blur would lead to increasing response latencies to hazards when participants were exposed to blur, which would be further slowed when participants were simultaneously exposed to both visual blur and auditory distractors.

## 2. Methods

### 2.1. Participants

Participants were 20 young drivers (mean age of  $29.4 \pm 3.2$  years; range 18–35 years) including 11 males and 9 females. All participants were licensed drivers, had previous driving experience, and satisfied the minimum Australian drivers' licensing criteria for binocular visual acuity of 20/40. The study followed the tenets of the Declaration of Helsinki and was approved by the Queensland University of Technology Human Research Ethics Committee. Participants were given a full explanation regarding the nature of the study, experimental protocols and possible consequences of the study, and written informed consent was obtained, with the option to withdraw at any time.

An eye examination was performed for each participant to ensure that they had no ocular disease and to determine their optimal



**Fig. 1.** Example images from a Hazard Perception Test trial. Each trial is a continuous video in which participants must identify a potential hazard as quickly as possible. The circle is inserted here to indicate the correct location that the participant should click to indicate the hazard.

refractive correction, which was determined using retinoscopy followed by subjective Jackson cross-cylinder and blur-back techniques using a phoropter head. Binocular visual acuity was assessed with the optimum refractive correction using a 4 m ETDRS chart at a luminance of  $100 \text{ cd/m}^2$ .

### 2.2. Materials

#### 2.2.1. Hazard perception test

The Hazard Perception Test (HPT) consists of a series of video presentations of traffic scenes recorded from the driver's perspective (Horswill and McKenna, 2004). Participants are required to view the videos and identify the presence of any potential hazards by manually tapping the hazard on the touch-screen monitor (Fig. 1). In the experiment, a hazard was defined as a situation in which a collision or near collision with another road user (including stationary vehicles, cyclists, or pedestrians) would occur unless the driver were to take some type of evasive action (slowing, steering, etc.) (Wallis and Horswill, 2007). The primary outcome measure was the response time of the participant to respond to the hazard.

The HPT in the present study comprised 80 video clips of different driving scenes with one driving event in each clip that was considered to be a hazard. The videos were presented on a LCD touch-screen monitor ( $30.2 \text{ cm} \times 22.6 \text{ cm}$ ) with screen resolution of  $1024 \times 768$ , refresh rate of 60 Hz, at a working distance of approximately 50 cm. Eighty traffic conflicts (across 80 video clips of approximately 30 s duration) were selected on the basis that (1) there were anticipatory cues available and (2) the conflict became unambiguous such that most participants would respond to the hazard at some point. The software recorded participants' response time for each potential conflict (starting from the first moment that the potential conflict was detectable), and these were averaged to obtain an overall hazard perception response latency. The response time in seconds and the accuracy of response were recorded for each scene. A response was coded as correct (a true hit) only if the participant correctly tapped the relevant hazard while it was still present on the screen. A tap on any part of the screen that did not contain the hazard (e.g., another vehicle or object not representing a hazard) was counted as a false alarm. All videos were filmed during the day. For a given video, the hazard could appear at any time. As there was no objective metric to define when the hazard would become apparent as a hazard to an ideal observer, response times (measured as

the time of the first correct tap on the target) were normalized by calculating the participant’s deviation from the mean response time of the group for each of the individual hazards in seconds. This deviation score was then added to the mean response time for the group to determine the participant’s response time score (Horswill et al., 2010).

For each video clip, simulated navigation audio instructions were also recorded and played during the video (similar to audio instructions from a commercial navigation device). The video clips were divided into 40 with audio instructions that were possible to follow (e.g., turn left at the next intersection where there was clearly an intersection in the road ahead), and 40 video clips with instructions that were not possible to follow according to the driving scene (e.g., take the 2<sup>nd</sup> exit at the roundabout ahead, when there was no roundabout in the traffic scene ahead). This ensured that the participants maintained concentration on the audio instructions while simultaneously performing the HPT. Both the possible and impossible instructions were relevant given the scene, and required the participant to attend to a section of roadway ahead to determine whether the instruction was possible to follow or not. Participants were instructed to state at the end of each video whether the auditory instructions were possible or not possible to follow. The video clips were randomized into eight sets (with 10 different driving video clips in each set), which were then presented in a random order between participants.

In the no-distractor condition the videos did not have any sound, and participants simply had to indicate the presence of a hazard by tapping the hazard on the touch-screen monitor. In the audio distractor condition the participants were required to respond to the hazard while simultaneously listening to the navigational audio instructions. Each video clip had one or more navigational audio instruction, with at least one of the audio instructions synchronized with that point in time when the hazard should first become apparent to the participant. At the end of each HPT video clip, a one second gap was allowed for the participant to indicate whether or not they felt that it was possible to follow the navigation instructions provided during the video. A ‘yes’ response would indicate that the participant believed it was possible to follow the entire sequence of instructions contained within the video, whereas a ‘no’ response would indicate that at least one of the instructions given in the previous video was impossible to follow. Apart from the navigation instructions, there was no additional sound (e.g., background noise, traffic noise) contained in the videos. A practice session was conducted before the actual testing, to ensure that participants understood the testing procedure.

2.3. Procedure

The study was a 2 (auditory distractor vs no-distractor) \* 4 (0.00 DS (baseline optimal refractive correction), +0.50 DS, +1.00 DS and, +2.00 DS blur) repeated-measures design (ie. 8 conditions in total). The experiment was conducted under normal room lighting conditions (approximately 500 lx). The HPT test was conducted for all participants in the no distractor condition first for all visual conditions, followed by the audio distractor condition. In each of the 8 conditions a different set of 10 videos was presented.

For the HPT testing participants wore their optimal refractive correction and an additional +2.00 DS working distance correction for the 50 cm testing distance (i.e., distance to the touch-screen), plus a myopic (plus-power) blur lens (depending on the visual condition being tested) in a trial frame before both eyes. Fig. 2 presents a simulation of the effect of the +2.00D plus power lens on the visual images seen by the participant. Previous research (Cufflin et al., 2007; George and Rosenfield, 2004; Mon-Williams et al., 1998; Rosenfield et al., 2004) has demonstrated that the eye partly adapts to blur (i.e., visual acuity improves) in the initial minutes following exposure to blur. Thus a 14 min adaptation time was allowed prior to administration of the HPT after the introduction of blurring lenses, in an attempt to minimize these blur adaptation effects. In addition, the visual blur conditions were



Fig. 2. Simulation of the blurring effect of a +2.00 DS plus-power lens added to the appropriate optical correction for the working distance of the test.

ordered from low to high levels of blur (i.e., 0.50 DS to +1.00 DS to +2.00 DS) so that the impact of each level of blur was not reduced by adaptation to the previous level (for instance a reduced effect of +0.50 DS after exposure to +2.00 DS). During the adaptation period the participant watched a movie on the same touch-screen monitor at a distance of 50 cm to maintain constant accommodation throughout the experiment. An adaptation period of 14 min was also used for the control (no blur) condition to allow participants to adapt to the room lighting conditions and to maintain constant levels of accommodation between trials. The total testing time for all four conditions took approximately 84 min, with the measurement time for each blur condition being approximately 21 min (14 min of blur adaptation and 7 min of testing).

2.4. Analysis

A two-way repeated measures ANOVA was conducted for the effects of blur and distractor conditions on response time and accuracy on the HPT (including both true hits and false alarms). As for previous studies, the response times were normalized by calculating the participant’s deviation from the mean response time of the whole group for each hazard regardless of visual or distractor condition, given that there is no objective way to define exactly when the hazard might become visible to an observer viewing the video clip. The group mean response time across all incidents was then added to the mean deviation scores (this last step was used to assist in interpretation of outcomes) (Horswill et al., 2011).

3. Results

Table 1 shows the group mean response times to hazards in each of the vision and distractor conditions explored in the study.

There was no significant interaction between the factors of blur and auditory distractor, indicating that the effect of blur level on response time was of similar magnitude under both the no distractor and distractor conditions ( $F(3, 57) = 1.119, p = 0.35, \text{partial } \eta^2 = .056$ ).

Table 1 Mean (+ SE) response time for each combination of blur and distractor conditions.

Distractor condition	Blur (D)	Mean (sec)	Standard Error
Distractor	0.00	5.41	0.62
	+0.50	5.46	0.86
	+1.00	5.68	0.66
	+2.00	5.75	0.65
No distractor	0.00	5.12	0.82
	+0.50	5.10	0.68
	+1.00	5.44	0.88
	+2.00	5.75	0.72

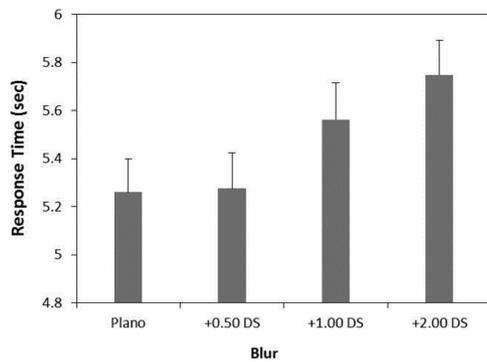


Fig. 3. Group mean (SE) normalised response time for the HPT as a function of different levels of blur.

There was a significant main effect of blur on the response time to hazards ( $F(3, 57) = 7.91, p < 0.01, \text{partial } \eta^2 = .294$ ), such that the mean response time increased for the higher levels of blur in comparison to the no blur condition. In pairwise comparisons, there was no significant difference in response time for +0.50 DS blur compared to the no blur condition, however, for higher levels of blur (+1.00 DS and +2.00 DS) the response times increased significantly (0.00 vs +1.00 DS,  $p = 0.01, \text{Cohen's } d = -.64$ ; 0.00 DS vs +2.00 DS  $p < 0.01, \text{Cohen's } d = -.74$ ) (Fig. 3). The +0.50 DS blur condition also differed significantly from both the +1.00 DS and +2.00 DS blur conditions ( $p < .01, \text{Cohen's } d = -0.69$  and  $-0.73$  respectively), however the +1.00 DS and +2.00 DS blur conditions did not differ significantly from one another ( $p = 0.116, \text{Cohen's } d = -0.37$ ). For reference a Cohen's  $d = .2$  is considered a small effect,  $.5$  is considered a medium effect, and  $.8$  is considered a large effect.

There was also a significant effect of the auditory distractor condition on response times  $F(1, 19) = 5.88, p = 0.02, \text{partial } \eta^2 = .236$ , where the group mean response time was significantly longer for the distractor condition compared to the no distractor condition ( $\text{Cohen's } d = 0.37$ ) (Fig. 4).

Examination of the proportion of hazards correctly detected (true hits) as well as proportion of non-hazards selected (false alarms) showed that neither was significantly affected by the presence of either blur or distractors. A separate analysis was conducted examining those trials in which the navigation instructions were possible and those which were impossible. No main effects or interactions involving this factor were observed.

#### 4. Discussion

This study sought to investigate the effects of visual blur and simulated navigation instructions on response times to road hazards in the HPT. While previous research has investigated the effects of other

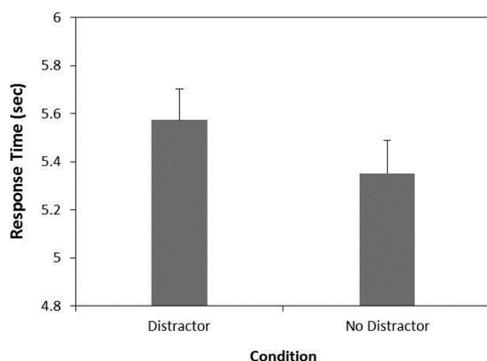


Fig. 4. Group mean (SE) normalised response time to the HPT as a function of distractor condition. Data shows the mean of the four blur conditions.

in-vehicle distractors on various aspects of driving performance, our research is the first to investigate the direct effect of navigation instructions displayed in the auditory modality alone on hazard perception response times. In this study we examined the cumulative effects of increasing levels of blur in conjunction with auditory navigation instructions, and their effects on hazard identification response times, while in a previous study these effects were examined for only one level of blur (Lee et al., 2016). In this study we observed that simulated navigation auditory instructions significantly slowed participants response times to hazards, and while this did not interact with the effects of visual blur, the effects were additive, with poorest performance on the HPT being associated with the combination of +2.00 DS blur and navigation instructions.

The response time to hazards increased with increased levels of blur, where for the +1.00 D and +2.00 D blur conditions, the participants were significantly slower in responding to hazards compared to baseline, while for the +0.50 D condition the increase in reaction time was not significantly different compared to the no blur condition. The decrease in visual quality of the HPT driving scenes for higher levels of blur may be the reason for the slower recognition and processing of the environmental cues from the driving scene (Harley et al., 2004; Pashler, 1984). This may have concomitantly reduced the availability of higher level cognitive processes for perception of the hazards (Wingfield et al., 2005), resulting in slower responses to the hazards in the driving scene. The results from our study also showed that blur did not have any effect on the total number of hazards detected, suggesting that blur slowed participants' reaction to hazards in the driving scene but their ability to accurately detect the hazard was not affected.

Previous research has shown that auditory distractors may alter participants' visual search patterns, which could significantly delay the detection of a hazard if the search pattern moves the participant's gaze away from the location of the hazard at the time of its appearance (Victor et al., 2005). One obvious problem with auditory navigation instructions is that they require the participant to look in the direction suggested by the instructions, in order to locate the relevant turn or intersection in the driving environment. In an unfamiliar environment, this means that participants will not adopt their usual eye movement patterns to scan for other relevant road information during these times, which has the potential to slow down recognition of potential hazards. An open question, however, is whether this differs from self-navigation, in which participants would need to scan the same locations (looking for an exit or turnoff, for instance) without the aid of advance knowledge of its distance away. Auditory instructions are also likely to be less distracting than consulting a paper map while driving (Dingus et al., 1997, 1995; Srinivasan and Jovanis, 1997). However, the relative benefits of such technologies are challenging to address in laboratory-based research, such as in the present study. It is also important to note that in a real driving environment, participants are likely to have enhanced situational awareness derived from navigating the route, which might help them plan out their approach, and distribute their attention more effectively. While the approach taken in this study provided us with the opportunity to assess these effects in controlled and safe conditions, real-world driving studies need to be undertaken under in-traffic conditions in order to establish whether more efficient scan patterns occur under self-navigation conditions. The findings of the present study suggest that, particularly among those with reduced vision due to blur, the effort of finding the location of a turn based on auditory instructions may result in drivers failing to notice the presence of hazards in the roadway.

It is important to note that neither the true hit rate (in terms of overall number of hazards detected) nor the false alarm rate (in terms of responses to non-hazards) were affected by either the visual blur or navigation conditions. Therefore participants in this experiment would not have missed the hazard, were it present in a real driving environment, but rather would have been slower to respond to it. Nonetheless, such a change in response time is likely to have real implications in the

case of a genuine traffic conflict, where even a small delay in responding could be the difference between a collision and safe avoidance of a hazard. It is critical that these factors are now investigated in on-road testing to establish the extent to which they can interact and impact on participants' response times in real-life conflict situations.

In terms of the design of the study, it is important to note that the conditions could not be fully counterbalanced. In particular the manipulation of blur required participants to experience the blur conditions in increasing order of magnitude. Participants adapt to a given level of blur such that after being exposed to, for instance +2.00 Diopters of blur, their vision slowly improves under that level of blur. If they were then exposed to a lower level of blur (e.g., +0.50 Diopters) there might be less effect than if the same level of blur were presented as the first condition of the experiment. Only by presenting the conditions in increasing order of magnitude could the effect of each blur condition be observed. In this experiment the order of the navigation manipulation was also held constant: participants always completed the no-instruction condition first. Given that the conditions were not counterbalanced, it is not possible to rule out a potential role of fatigue influencing participants' response times over the course of the experiment. However, the protocol employed in the study, interspersed 14 min of rest time which involved watching a movie between each 7 min block of testing, and the HPT task is not onerous, consisting merely of passively watching the displayed video of a driving scene, and tapping a touch screen when the hazard appears. Nonetheless it would be beneficial to investigate another paradigm (potentially employing multiple sessions), to rule out the potential that some fatigue may have influenced the pattern of results presented here.

Although the sample size of the current experiment was relatively small, it is notable that there were strong and robust effects of both visual blur and auditory distraction on response times. A strength of the current study is that by employing a repeated-measures design and systematically manipulating both blur and auditory distraction within the same individuals, differences in performance cannot be ascribed to factors which vary between individuals (age, general health, experience, risk taking etc.) which might otherwise confound the results. Although we cannot be certain how naturally occurring visual blur from uncorrected refractive error affects driving in a real-world environment, or how those who choose to use navigation devices differ from those who do not in terms of their driving style, we have demonstrated in the controlled conditions of the laboratory, that the presence of these factors can increase the latency with which people are able to perceive and respond to important visual information relevant to their driving. It is worth considering that these effects are likely to be greatly exacerbated among drivers who have impairments of cognitive, visual or motor function, as is the case for some older drivers.

In terms of future research directions, it is important to determine whether these findings are replicated in on-road testing, and to include a comparison group employing self-navigation. Future research should also examine the extent to which the effects described here interact with other sensory or cognitive impairments. It would also be of interest to determine whether other aspects of driving (e.g., lane keeping, time to contact and time headway judgments, braking and cornering) are affected by blur or distraction, either alone or in combination.

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