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Abstract

The effects of imagery-induced distraction on hazard perception and eye movements were investigated in 2 simulated driving experiments. Experiment 1: sixty participants viewed and responded to 2 driving films containing hazards. Group 1 completed the task without distraction; group 2 completed a concurrent imagery inducing telephone task; group 3 completed a non imagery inducing telephone task. Experiment 2: eye-tracking data were collected from forty-six participants while they reacted to hazards presented in 16 films of driving scenes. 8 films contained hazards presented in either central or peripheral vision and 8 contained no hazards. Half of the participants performed a concurrent imagery-inducing task. Compared to undistracted participants, dual-taskers were slower to respond to hazards; detected fewer hazards; committed more "looked but failed to see" errors; and demonstrated "visual tunnelling". Telephone conversations may interfere with driving performance because the two tasks compete for similar processing resources, due to the imagery-evoking aspects of phone use.

Keywords: attention, dual tasking, cognitive workload, driving, imagery

Statement of relevance: Dual tasking whilst driving raises significant safety concerns. Identification of the cognitive and perceptual roots of distraction enables development of future technology and safety strategies. This research suggests that, rather than being discrete, the attentional resources required for driving and conversing are shared, explaining perceptual errors and deteriorated driving performance.

1. Introduction

It is well documented that increasing the demands on a driver's attention by means of a mobile telephone conversation can impair driving performance (Brown, Tickner and Simmonds, 1969; Alm and Nilsson, 1994, 1995; Stevens & Minton, 2001; Stein, Parseghian & Allen, 1989; Redelmeier & Tibshirani, 1997; Strayer and Drews, 2007). Explanations for this impairment are often couched in terms of an overall increase in cognitive workload, leading to slower cognitive processing and decreased executive control (Amado and Ulupinar, 2005; McKnight and McKnight, 1993). This 'domain-general' approach is supported by research demonstrating that, compared to undistracted drivers, dual tasking drivers show decreased hazard perception (Galpin, Underwood and Crundall, 2009; Strayer and Johnston, 2001), longer reaction times for critical events (Strayer and Drews, 2007), poor lane discipline (Reed and Robbins, 2008) and increased accident risk (Redelmeier and Tibshirani, 1997). Furthermore, dual tasking drivers often use compensatory strategies. They may drive slower, increase headway (Stevens and Minton, 2001) and dispense with tasks such as checking mirrors and using indicators (Reed and Robbins, 2008). These compensatory strategies are consistent with the idea that driving performance is impaired because of a generalised increase in workload: drivers may use these strategies in an attempt to decrease operational demands, so that more resources are available to allow for continued dual tasking (see also Platten, Schwalm, Hulsmann and Krems, 2014).

However, an emerging research literature is exploring more 'domain specific' explanations for the observed effects of dual tasking on driving performance. These suggest that performance deteriorates because both tasks share processing components. Multiple Resource Theory (Wickens, 1984; Wickens 2002; Horrey and Wickens, 2004) formalises the domain specific approach by highlighting the conditions which must be met for competent dual tasking to be achieved. According to this model, any task has three aspects; the sensory modality via which information is input for processing; a processing "code" (e.g. spatial coding for visual input, verbal coding for spoken input); and a response (e.g. a vocal or manual response). When dual-tasking, the two tasks must involve different modalities, codes and responses if they are not to interfere with each other. Driving involves visual input (focal vision for hazard detection and ambient vision for lane maintenance), spatial coding of information, and manual responses (steering, braking, etc.). Conversing on a phone requires auditory input, verbal coding and vocal responses. Therefore, in theory, it should be possible to combine driving and phone use. However, in practice, the extensive research literature demonstrates emphatically that talking on the phone whilst driving carries serious risk. This implies that resources which are theoretically only assigned to the telephone task might also be required for the driving task, or vice versa, leading to competition for resources (see Collet, Guillot and Petit, 2010, for a review of research in this area).

With this in mind, research is now investigating how so-called ‘crosstalk’ (Pashler, 1994) between tasks affects performance, by identifying the component parts of the two tasks which require common resources. The type of conversation engaged in has been examined. Findings suggest that driving performance can be impaired by greater conversational complexity (Alm and Nilsson, 1994, 1995; Almahasneh, Chooi, Kamel and Malik, 2014) and increased emotional involvement in a conversation (Briggs, Hole and Land, 2011). Bergen, Medeiros-Ward, Wheeler, Drews and Strayer (2013) suggest that the way in which we comprehend different types of sentence may explain the crosstalk and the consequent dual tasking difficulties. Bergen, Lindsay, Matlock and Narayanan (2007) showed that subject nouns and verbs in a sentence can trigger mental imagery, which is used to aid sentence comprehension. By using concurrent tasks of sentence comprehension and visual categorisation, they showed that sentences denoting upwards and downwards motion selectively interfered with a participant’s ability to categorise objects in the same part of the visual field. This implies that the same visual resources were required for both tasks. Research has also shown that as well as mental imagery, language about actions can trigger both actual movement (Glenberg and Kaschak, 2002) and activation in motor areas of the brain (Tettamanti et al., 2005). Similar findings have been reported for sentences with visual and auditory components (Zwaan, Stanfield, & Yaxley, 2002; Just, Newman, Keller, McEleney and Carpenter, 2004).

Bergen et al (2013) proposed that the content of a sentence could differentially affect driving performance, with sentences focusing on actions or visual items being more distracting than abstract sentences. Participants in a driving simulator were asked to follow a lead vehicle at a set distance and react when the vehicle braked. At the same time, they completed a sentence verification task. The sentences were either "action" (e.g. ‘to open a jar you turn the lid counter clockwise’), "visual" (e.g. ‘the letters on a stop sign are white’) or "abstract" (e.g. ‘the capital of North Dakota is Bismarck’). Reaction times in response to the lead vehicle's braking were similar for all language conditions (with all dual taskers showing longer RTs than controls). However, there were significant differences in following distance between the three language conditions. Participants who were distracted by the visual and action statements showed far greater deviation in their headway distance than those distracted by abstract statements and controls. Bergen et al (2013) claim that these findings demonstrate how different types of secondary task can differentially affect driving performance: whilst a domain-general approach could explain the increased reaction times shown by dual taskers compared with controls, it cannot explain why those distracted by visual statements showed greater deviation in following distance than any other participants. Instead, Bergen et al (2013) argue that crosstalk between the two tasks caused deterioration in driving performance: those responding to visual statements were already using the resources required for the driving task.

If conversation has a "visual" component, this has implications for drivers talking on the phone. The use of "visual" language could lead to the creation of mental imagery, which in turn might draw on cognitive resources required for normal visual perception of a scene. The suggestion that mental imagery and visual perception use similar resources and cortical areas is not new. Whilst there is disagreement regarding specifically which areas of the visual cortex are used in imagery (Farah, 1988; D'Esposito et al, 1997) brain scanning data have identified that perception and imagery produce similar neural activation patterns. In an attempt to explain the consequences of an interaction between imagery and visual perception, Craver-Lemley and Reeves (1992) argue that mental imagery lowers sensitivity to changes in a visual display (see also Rensink, O'Regan and Clark, 1997). This disruption persisted for up to six seconds after participants reported having stopped visualisation (see also Kosslyn and Thompson, 2003). In the context of driving, these findings could have serious consequences for hazard perception. Indeed, research on eye movements in dual tasking drivers has revealed that they demonstrate cognitive and visual tunnelling (Briggs et al, 2011; Recarte and Nunes, 2002); and can 'look but fail to see' pertinent items in the driving scene (Strayer, Drews and Johnson, 2003; Mack and Rock, 1998; Langham, Hole, Edwards and O'Neil, 2002).

The current investigation attempts to isolate how conversation-induced mental imagery might impair driving performance in dual-tasking drivers. Experiment 1 investigates the relationship between imagery-inducing distraction and hazard detection. Experiment 2 explores further the impact of imagery based distraction on hazard perception and visual awareness.

2. Experiment 1

2.1 Method

2.1.1 Participants

Sixty participants (20 male, 40 female) from the University of Sussex were recruited via an e-mail campaign. All participants received course credits for their involvement. They ranged in age from 18 to 63 years (M = 25.57 years, S.D = 8.4 years). All participants held a valid UK driving licence and had normal, or corrected to normal vision by self-report. Participants had an average of 7 years driving experience, were naive to the purposes of the study, and gave their full consent to participate.

2.1.2. Design

This study used an independent measures experimental design in order to assess the possible relationship between type of conversation task and driving performance, as measured by hazard perception. There was one primary task: participants viewed films of real driving situations and reacted to hazardous events within them. One group completed this task without distraction (undistracted, N= 20; 7 male, 13 female); another group were distracted with a concurrent statement-verification task designed to induce mental imagery (imagery inducing, N= 20; 7 male, 13 female); and a final group were distracted with a non imagery inducing statement-verification task (non imagery, N= 20; 6 male, 16 female). The dependent variables were the number of hazards detected and reaction times for these critical events.

2.1.3. Apparatus

2.1.3.1. Hazard perception task

Two 7 minute long videos were used. These were filmed from within a real vehicle, showing the driver's view. The videos incorporated part of the dashboard of the vehicle to help participants feel as if they were in the car. Films were recorded on occasions when weather conditions were fair, but not overly bright. Engine sounds were also included in the films to provide a more immersive representation of real driving conditions. The films followed the same route around an urban town environment. They contained seven hazardous driving events. These hazards were identified by 5 independent assessors who viewed the videos before the experiment. These assessors had a minimum of 10 years driving experience and were unaware of the aims of the study. Only those hazards which were unanimously deemed to require a response from a driver were included in the experiment. The hazards consisted of both staged and naturally occurring events. Event 1 was a pedestrian stepping out into the road (see fig. 1); event 2 was a vehicle parked on a junction; event 3 was an oncoming car on the wrong side of the road; event 4 was a pedestrian stepping out in front of the vehicle; event 5 was a car pulling out ahead of the vehicle; event 6 was traffic lights changing from green to red at the last minute; and event 7 was a car approaching at speed on a sharp corner.

INSERT FIGURE 1 HERE

Fig.1: Example screen shot of hazardous event 1

Each participant was tested individually. They sat 2m away from a 3m x 2m screen, onto which the driving films were projected at a refresh rate of 60Hz. The participant had a set of driving pedals in front of them, comprising accelerator and brake pedals. The participant’s task was to detect hazardous events which occurred in the films and react to them by using the brake pedal. A record of onset and duration of brake pedal depressions was made using software designed specifically for this investigation. Depressing the brake pedal had no effect on the video presented to participants. The entire presentation lasted for 14 minutes. Participants were informed that completing the ‘driving’ task was their primary objective.

2.1.3.2 Sentence verification task

The statements for the secondary sentence verification task (imagery or non imagery inducing statements) were recorded by a male voice. They were played aloud via a loudspeaker situated 1m to the participant's left. The statements were played at random intervals throughout the film. Participants were required to answer verbally with either a 'true' or 'false' response. For those in the imagery condition, the statements required participants to form a mental image in order to respond correctly (e.g. ‘In a rowing boat, the rower sits with his back to the front of the boat'). For those in the non-imagery inducing condition, no such imagery was required (e.g. ‘The official language of Mexico is Spanish’; see appendix for a full list of the stimuli used). The number of correct responses was recorded for analysis.

2.1.4. Procedure

Each participant completed the experiment individually, in a 30-minute session. After having completed a consent form they were randomly allocated to one of three conditions: undistracted driving; driving whilst distracted by non imagery inducing questions; or driving whilst distracted by imagery inducing questions. Participants were then informed that they would shortly be shown two driving films which might contain hazardous events. They were asked to press the brake pedal if they saw any events which they deemed hazardous. Those in the two distraction conditions were also asked to complete a secondary distraction task (either imagery inducing or non imagery inducing, dependent on condition). For these two groups, it was made clear to participants that quickly detecting and responding to hazards was to be treated as their primary task. On completion of the driving task, participants completed a brief questionnaire on driving experience before being debriefed.

3. Results

3.1. Performance on the sentence verification tasks

An independent measures t-test found no significant difference in the number of statements correctly verified between those distracted by imagery inducing statements (M = 12.80, SE = 1.01) and those distracted by non imagery statements (M = 13.90, SE = .69; t (34) = .90, ns). This suggests that the two distraction tasks were evenly matched in terms of difficulty, and that participants were engaging with both tasks presented to them.

3.2. Number of Hazards detected

A signal detection analysis was carried out on the number of hazards detected. This was chosen as a more representative measure of overall hazard detection performance, as not all participants reacted to all of the individual hazards presented. The resulting d-prime score is a composite measure of performance which takes into account both correct responses (correctly-detected hazards) and errors (missed hazards).

A one-way independent ANOVA was then calculated with d-prime score as the dependent variable. A highly significant main effect of driving condition (control, imagery or non imagery) on hazard detection was found (F (2, 57) = 60.40, p<.001, η_p^2 = .68). Further pairwise comparisons (using Bonferroni corrections) on the proportion of hazards detected showed significant differences between all three levels of driving condition (p <.001 in all cases). Undistracted drivers detected the most hazards (M = .77, SE = .03); those distracted by non-imagery inducing questions detected fewer hazards (M = .55, SE = .03); and those distracted by imagery inducing questions detected the fewest of all (M = .39, SE = .03). These findings suggest that distraction significantly impairs detection of hazards during a driving related task, and that this effect is greater if the distraction is imagery-based.

3.3. Reaction Times for Hazards

For each of the hazards presented, the participant’s reaction time (in milliseconds) was subtracted from the actual time in the film when the event occurred. Separate one-way independent ANOVAs were then carried out on the data for each hazard in turn. For all of the hazards, significant differences in reaction times were found dependent on driving condition (all at $p < .01$, see fig. 2). Furthermore, post hoc tests revealed significant differences between all three levels of driving condition for 4 out of the 6 hazards (hazards 2 and 4 showed no significant differences between imagery and non-imagery based distraction).

INSERT FIGURE 2 HERE

Fig. 2: Mean hazard reaction time (in seconds) dependent on driving condition.
Error bars show standard error. [a] = significant difference in RTs between all levels of experimental condition at $p<.01$; [b] =significant difference in RTs between undistracted and non imagery participants at $p<.05$; [c] = sig. difference in RTs between undistracted and imagery at $p<.05$.

Fig. 2 demonstrates that participants who were not distracted by a secondary task were significantly faster at responding to a critical driving event than those who were distracted. Furthermore, for the majority of hazards, the type of distraction (imagery or non imagery inducing) also affected reaction times, with those distracted by imagery taking significantly longer to respond to hazards than those distracted by non-imagery inducing statements.

4. Conclusions

These findings show that performing a secondary task when driving can significantly reduce a driver's hazard detection performance. Furthermore, when an individual is distracted by imagery inducing conversation, they may either fail to detect hazardous events in the driving scene or, if they do detect them, take significantly longer than undistracted individuals to react to them. Findings also indicate that the content of the secondary task has a differential effect on primary task performance, consistent with previous research. Performance in the secondary task was consistently good, regardless of distraction condition, whilst hazard detection performance deteriorated. This could suggest that dual tasking participants employed different cognitive strategies from those who were undistracted. Experiment 2 builds on these findings by measuring participants' eye movements, in an attempt to explain whether the errors made can be considered both cognitive and visual in nature.

5. Experiment 2

5.1. Method

5.1.1. Participants

Forty-six participants (11 male, 35 female) from the University of Sussex were recruited for the experiment via an e-mail campaign. All participants received course credits for their involvement. They ranged in age from 18 to 64 years (M = 24.24 years, S.D = 8.52 years). All participants held a valid UK driving licence and claimed to have normal vision. Participants had an average of 6.09 years driving experience, were naive to the purposes of the study, and gave their full consent to participate.

5.1.2. Design

This study used an independent measures experimental design to assess the effect of imagery-based distraction on eye movements and hazard detection. The primary task for all participants was to watch films of driving situations and respond to any hazards that appeared in them. Half of the participants also completed a secondary task that required the use of mental imagery. All participants had their eye movements tracked while they completed the tasks.

5.1.3. Apparatus

5.1.3.1. Hazard perception Task

Sixteen video clips were used, filmed from within a car. The clips were taken from a Driving Standards Agency hazard perception test (DSA, 2006) and showed the dashboard and forward facing driving view. The same viewing arrangements were used as in experiment 1. Participants again used the brake pedal to indicate their reaction to a hazard.

Eight of the driving films contained hazardous events (such as pedestrians stepping into the path of the vehicle, cars pulling out unexpectedly, etc.). Four of these occurred at the centre of the screen and four occurred at the periphery of the screen (see fig. 3). The remaining eight clips contained no hazards. Each clip lasted a maximum of 60 seconds. The entire presentation lasted for 17 minutes.

INSERT FIGURE 3 HERE

Fig 3: Examples of a central hazard, left, (clip 8) and a peripheral hazard, right, (clip 10)

5.1.3.2. Imagery Task

Sixteen sets of instructions were created for use in this task, which was adapted from Kerr’s (1993) procedure. Participants were required to imagine a 3x3 grid and picture themselves positioned in its middle square. They then mentally ‘travelled’ around the grid in response to ten instructions, such as "left" or "down", presented via a loudspeaker. After the last instruction, the participant had to tell the experimenter at which square they had ‘finished’ (see Fig. 4).

INSERT FIGURE 4 HERE

Fig. 4: Example of procedure for imagery task. Left shows starting position, right shows end position

5.1.3.3. Eye tracking Equipment

All participants had their eye movements tracked using a video based head mounted ASL 5000 eye tracker. The head mounted camera recorded what participants saw from their own viewpoint. Participants' eye movements were sampled, from the right eye, at a rate of 50Hz. Fixation points were then superimposed onto the video output of the head mounted camera. The temporal resolution of the eye movement equipment was 50Hz, and the spatial accuracy was 1 degree.

5.1.4. Procedure

Each participant completed the experiment individually, in a 30-minute session. After completing a consent form, they were randomly allocated to a condition (undistracted or dual tasking). After the eye tracker was calibrated, participants were informed that they would be shown a series of driving films and that they should press the brake pedal every time they saw a hazard. Half of the participants were also asked to complete the imagery task simultaneously. For this group, it was made clear to participants that quickly detecting and responding to hazards was to be treated as their primary task. On completion of the hazard perception task, participants completed a brief questionnaire on their driving experience. Finally, they were debriefed.

6. Results

6.1. Performance on the Imagery Task

As a check to see how much the dual tasking participants engaged with the secondary task, the mean number of grids correctly completed was calculated (M =12.95, SE = .86). The result indicates that participants were indeed engaged with the task, with performance well above chance level.

6.2. Number of Hazards Detected

As in Experiment 1, a signal detection analysis was carried out on each participant's hazard perception performance. The calculated d-prime value was then used as a dependent variable. An independent t-test revealed a highly significant difference in hazard perception performance between those who were undistracted and those who were dual tasking ($t(26) = 4.33$, $p < .001$, SE = .40). Undistracted participants detected more hazards (M = 2.72, SE = .38), and made fewer false alarms than their distracted counterparts (M = 0.99, SE = .12). These findings suggest distraction significantly impaired hazard perception performance.

6.3. Reaction Times for Hazardous Events

For these analyses, reaction times were calculated using the same procedure as in experiment 1. Individual independent t-tests were then carried out on the data from clips which contained a hazard. These were clips 1(a woman crossing the road in front of the participant's vehicle, in the centre of the screen); 4 (a car pulling out between parked vehicles, at the periphery of the screen); 6 (a van braking suddenly in front, centre); 8 (the participant's car was cut up on a roundabout, periphery); 10 (a car pulling out of a junction, periphery); 12 (road workers in the road, centre); 15 (a car door opening in front of the participant's vehicle, centre) and 16 (a child stepping into the road, periphery). For all of the clips containing a central hazard (clips 1, 6, 12 and 15) dual tasking participants took significantly longer to respond than did the undistracted participants (see Fig. 5a). No such significant differences were found in reaction times for those clips which contained a peripheral hazard (clips 4, 8, 10 and 16), although notably fewer dual tasking participants responded to these clips than undistracted participants, reducing statistical power (see Fig 5b).

INSERT FIGURE 5A AND 5B HERE

Fig. 5a and 5b: Mean reaction times for critical events dependent on condition and hazard location. Error bars represent standard error.* = significant difference from undistracted participants at $p < .05$,
** = significant difference from undistracted participants at $p < .01$.

6.4. Eye Tracking Data

The variance of the horizontal and vertical range of fixations was recorded, plus the number of fixations made within a 30 second period during each driving task (recorded 2 minutes after each task had begun). This was achieved by superimposing the fixations made by a participant, in the selected time frame, over the recording of the presented driving scene, providing a visual display of the range and number of fixations made. The variance of the location of the recorded fixations was then calculated, providing a representative score of the visual behaviour of the participants. The variance was chosen for analysis as it was considered a more informative measure of eye movements than the mean or range alone and it is less affected by individual idiosyncrasies in scanning behaviours.

6.4.1. Operational definition of "fixation"

When hazards were present, participants were considered to have fixated on the hazard if their eye remained on the hazard for 250 ms or longer. For hazards containing people, a fixation was recorded only if it was on the person rather than on nearby items (e.g. the shopping trolley in figure 1). Locations of fixations were judged independently by one of the experimenters (G.B.) and a second naive observer: there was 100% agreement on this measure.

6.4.2. Effects of fixation variance on distraction and hazard location within the scene

All participants provided data for clips containing no hazards, central hazards and peripheral hazards. A 2x3 mixed ANOVA was performed, with independent measures on task (undistracted or dual tasking) and repeated measures on hazard location (none, central or peripheral). Regardless of hazard location, there was a significant difference in fixation variance between undistracted and dual tasking participants ($F (1, 42) = 45.42$, $p < .001$, $\eta_p^2 = .52$; undistracted: $D (23) = .19$, ns; dual tasking: $D (23) = .18$, ns). Across all conditions, there was a significant difference in fixation variance when hazards were presented in the centre of the scene compared to when they were presented in the periphery ($F (2, 84) = 7.62$, $p < .001$, $\eta_p^2 = .15$). There was no significant interaction between hazard position and task ($F (2, 84) = 2.29$, $p > .05$, $\eta_p^2 = .05$).

Post hoc analyses revealed a significant difference in fixation variance between clips containing no hazard and those containing a peripheral hazard ($p < .05$) and between central and peripheral hazards ($p < .001$). There was no difference between a central hazard and no hazard ($p > .05$, see fig. 6).

To determine if hazard location selectively affected fixation variance, two further one-way repeated measures ANOVAs were carried out (one for undistracted participants and one for dual tasking participants). For undistracted participants, there was a significant difference in fixation variance based on hazard location ($F (2, 44) = 5.99$, $p < .01$, $\eta_p^2 = .21$; none: $D (23) = .19$, ns, centre: $D (23) = .17$, ns, periphery: $D (23) = .15$, ns). Post hoc analysis revealed that there was a significant difference in fixation variance for hazards presented in the centre and in the periphery ($p < .01$). No differences were found between having a peripheral hazard and no hazard or between a central hazard and no hazard (both $p > .05$: see fig. 6). In contrast, no such significant differences were found for dual tasking participants ($F (2, 44) = 2.22$, $p > .05$, $\eta_p^2 = .09$; none: $D (23) = .18$, ns, centre: $D (23) = .15$, ns, periphery: $D (23) = .14$, ns: see fig. 6).

INSERT FIGURE 6 HERE

Fig. 6: Mean variance of eye movements dependent on hazard location and driving task (error bars represent standard error)

As shown in fig. 6, regardless of hazard location, undistracted participants consistently demonstrated greater variance in their eye movements than those who were dual tasking. Furthermore, hazard location significantly affected the eye movements of all participants. Whilst undistracted participants increased their eye movements for the clips containing a central hazard, dual tasking participants showed a decrease in their eye movements. Undistracted participants minimised their eye movements in response to the clips containing a peripheral hazard, but still showed significantly more variance than dual tasking participants, who showed their lowest variance in fixations at this point.

6.5. Looked but failed to see errors (LBFS)

For this analysis each clip containing a hazard was used. By combining the eye tracking data with the reaction time data, it was possible to identify "looked but failed to see (LBFS)" errors, where a participant fixated on a hazard without reacting to it. The total number of LBFS errors made by each participant for these hazardous clips was used for overall analysis.

An independent t-test revealed that there was a significant difference in the number of LBFS errors made by undistracted and dual tasking participants ($t(35.94) = -5.48$, $p < .001$, $r = .67$) with the former ($M = 0.69$, $SE = 0.14$) making fewer errors than the latter ($M = 2.26$, $SE = 0.24$).

The errors were then divided between those made for central and peripheral hazards. A 2x2 mixed ANOVA was carried out, with repeated measures on hazard location (central or peripheral) and independent measures on task (undistracted or dual tasking). There was a marginally significant main effect of hazard location on the number of LBFS errors that were made ($F(1, 42) = 3.69$, $p = .06$, $\eta_p^2 = .08$). A highly significant effect of driving task was also found ($F(1, 42) = 37.87$, $p < .001$, $\eta_p^2 = .47$). No significant interaction was found between task and hazard location ($F(1, 42) = 0.58$, $p > .05$, $\eta_p^2 = .01$, see fig. 7).

INSERT FIGURE 7 HERE

Fig. 7: Mean number of LBFS errors dependent on experimental condition and hazard location (error bars represent standard error)

Fig. 7 demonstrates that undistracted participants made significantly fewer LBFS errors than dual tasking individuals. In all cases, all participants made more peripheral LBFS errors than central errors. However, this error rate increased dramatically when participants were dual tasking.

7. Conclusions

Dual tasking individuals detected fewer hazardous events than undistracted participants; displayed longer reaction times for those events they did detect; showed decreased visual scanning patterns (the more so when presented with a peripheral hazard); and produced a much higher rate of LBFS errors.

8. General Discussion

The current study investigated the distracting effect of imagery on dual tasking driving performance. It demonstrates that domain-specific cross talk, between the tasks of driving and holding a phone conversation, is responsible for impaired driving performance. The results support Bergen et al's (2013) study, both in terms of domain specific and domain general accounts. Dual tasking drivers who were distracted by imagery tasks demonstrated decreased hazard detection, increased reaction times to detected hazards and an increased rate of LBFS errors. Participants distracted by non imagery tasks also showed deteriorated driving performance, compared with undistracted controls. However, those distracted by imagery showed the greatest decrement in driving performance. This suggests that whilst any type of secondary task can produce a generalised increase in cognitive workload (supporting a domain general explanation), specific aspects of the imagery task served to introduce cross talk between tasks. This led to competition for shared resources and degraded primary task performance (consistent with a domain specific explanation). Bergen et al (2013) claim that 'Visual language interferes with tactical control of a vehicle…because it induces a code conflict. While spoken language is primarily oral–auditory, its content can vitally engage perceptual and motor systems also deployed for perceiving the environment while driving and responding appropriately' (p.127). This interpretation could clearly explain the data provided by participants who were distracted by imagery: secondary tasks with a visual component may have interfered with attention and subsequent perception of the driving scene, thus affecting sensitivity to changes in the scene (Craver-Lemley and Reeves, 1992).

The suggestion of a code conflict is also consistent with Wickens' (1984, 2002) Multiple Resource Theory. In our study, it could be argued that those participants who were distracted by imagery used visual coding for both the driving and the conversation tasks. This introduced competition for shared resources, thus explaining the decreased performance in the driving task. Such findings are also consistent with previous eye tracking studies demonstrating that increased cognitive workload serves to decrease visual scan patterns, resulting in impaired driving performance (Matthews, Bryant, Webb and Harbluk, 2001; Recarte and Nunes, 2000; Harbluk and Noy, 2001) and a greater frequency of LBFS errors (Strayer et al, 2003). Craver-Lemley and Reeves' (1992) suggestion that imagery lowers an individual's sensitivity to change in a visual scene is supported by the present study: participants who completed imagery inducing tasks noticed fewer unexpected events than either those distracted by non-imagery inducing tasks or undistracted controls. Furthermore, when dual tasking participants did notice changes in the visual scene, they were more likely to notice those presented in the central, rather than the peripheral, visual field, supporting the claim that visual and cognitive tunnelling had occurred (Recarte and Nunes, 2000; Harbluck and Noy, 2002). The eye tracking data in experiment 2 add further weight to this argument. Dual tasking drivers consistently reduced the variance of their fixations, leading them to attend to a small, focused area of the driving scene, directly ahead of them. This may explain why dual taskers were more likely to notice hazards presented centrally, as the peripheral areas were largely neglected. It also explains the increased reaction times for detected hazards, increased number of LBFS errors and overall reduced hazard detection.

In practice, this decrease in visual awareness has serious implications: dual tasking drivers may appear to be focusing on pertinent aspect of the driving scene when in fact they are not.

Conversely, those who drive without being distracted by phone use appear to sample and perceive more information about the scene, including hazards presented both centrally and in the peripheral fields. This leads to better hazard perception, decreased RTs to hazards and far fewer LBFS errors.

8.1. Methodological limitations

Alternative explanations for the current findings need to be considered. In line with Rensink et al (1997), it could be argued that the tasks requiring the use of imagery were simply more difficult than those which did not. Rather than isolating imagery as the specific element responsible for increasing cognitive workload, it could simply be the case that the task demands imposed by the imagery and non-imagery inducing statements were not equal. Equally, it is possible that the tasks which were designed not to induce imagery nevertheless did so. A similar criticism could be levied against experiment 2. Kerr's (1993) imagery task is challenging when completed by itself; when combined with driving, perhaps it increased participants' workload beyond any level which would be achieved by a 'normal' telephone conversation. However, despite the relatively artificial nature of the imagery tasks, the goal of the investigation was to specifically investigate the impact of imagery on cognitive workload and visual awareness. Thus, although the imagery tasks were extreme compared to the level of imagery which might be involved in natural conversation, this was considered to be necessary to ensure that imagery, rather than other strategies, was actually being used to solve the problems. Whilst it is impossible to claim that those in the non-imagery inducing conditions did not use imagery to answer the questions presented to them, the differences between imagery and non-imagery based distraction have been shown in the data. Nevertheless, a pre-study aimed at identifying and evaluating individual statements for imagery inducing features would have been beneficial. This would have ensured that those deemed least likely to induce imagery were selected for the non-imagery inducing tasks. Future investigations should also ensure that the task demands imposed by different secondary tasks are equal, as well as providing a subjective measure of cognitive workload and questioning participants on the strategies they employed to complete the secondary tasks.

A further area of potential criticism is the presentation of the driving situation. Both studies used video presentation and hence the driving tasks were not fully interactive: pressing the brake pedal had no effect on what the participant saw in the driving scene. Due to the lack of feedback, participants may have been less involved in the driving task. They may not have reacted as they normally would, given the clear lack of danger to themselves. This study, as with any simulation, also suffers from the fact that a dual-tasking participant might not give as much priority to hazard detection as would a driver in real life, where the consequences of impaired hazard perception may be severe. Nevertheless, the investigations appear to have achieved face validity as, in line with previous results, distracted 'drivers' either failed to react to hazards or took longer to do so than undistracted participants. In order to increase validity, further investigations making use of a simulator, and measuring additional operational and tactical actions (such as steering control, headway distance, etc.) would be beneficial.

8.2. Future investigations

By identifying a possible visual element to mobile telephone use, this investigation delves deeper into understanding how and why distraction occurs when dual tasking, rather than simply identifying if it occurs. It shows the usefulness of considering the content of the conversation when investigating the effects of mobile phone use on driving performance. It also explains the apparent inconsistency between Wickens' (1984) Multiple Resource Theory and the empirical data on drivers' inability to dual-task: if mobile phone conversations evoke imagery, they will compete for the same visual-spatial processing resources as the driving itself. Nevertheless, there is still a great deal of scope for further investigation in this field, particularly in light of research suggesting that competent dual tasking performance can be learned (see Shinar et al, 2005) and that more experienced dual taskers may be less affected in visual and cognitive terms than novices (Watson and Strayer, 2010). As one of our reviewers pointed out, it would be interesting to know whether the effects of visual imagery on driving performance were moderated by the drivers' age. It is an open question whether they might be ameliorated by experience (with drivers perhaps able to apply compensatory strategies to maintain performance) or unavoidably exacerbated by cognitive decline.

However, if conversation can be reliably shown to draw on visual resources then interventions should be considered to educate drivers about the differential demands that conversations may place on them. With the progressive introduction of increasingly complex in-vehicle information systems, many of which are voice operated for reasons of safety, it is clear that further research into the specific nature of cognitive distraction on visual perception is essential. One implication of our findings is that any driver interface (whether visual or auditory) that evokes visual imagery has the potential to impair driving performance by competing with the driving environment for cognitive resources.

9. References

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Appendix 1: Stimuli used in experiment 1 for sentence verification task

Imagery Inducing Questions

1) In a car, the accelerator pedal is on the right side
2) A five pound note is the same size as a ten pound note
3) The president of America, George Bush, has grey hair parted on the right side
4) The American flag has blue stars on a red background
5) In a rowing boat, the rower sits with his back to the front of the boat
6) The door to an apartment opens to the outside
7) Cows have hanging ears
8) The black keys on a piano are shorter than the white keys
9) On a computer keyboard, the letter ‘A’ is on the far left
10) In England, you give way to traffic from the left on a round-about
11) On a mobile phone key pad, the letter ‘D’ is on the number 3 key
12) When you push scissor handles together, the blades open
13) Revolving doors move in an anti-clockwise direction
14) On a snooker table, there are eight pockets
15) A dog’s front legs are longer than its hind legs
16) A book turned 90 degrees to the left opens towards you
17) A no entry sign is a white circle with a red horizontal bar through it
18) On a camera, the capture button is on the right hand side
19) A capital letter ‘M’ is made up of four straight lines
20) A cube has 6 sides

Non Imagery Inducing Questions

1) Leap years have 366 days
2) To square a number means to multiply it by itself
3) JFK was assassinated in New York in 1963
4) Three sevens are greater than four fives
5) The current President of France is Jacques Chirac
6) The currency of Germany is the Deutsch Mark
7) The author of the Harry Potter series is male
8) The capital of Australia is Sydney
9) ‘Bon appetit’ means ‘have a nice day’
10) Nitrogen is the most prevalent gas in the atmosphere
11) A spider has 8 legs
12) DVD stands for digital video device
13) The battle of Hastings was in 1066
14) The official language of Mexico is Spanish
15) Brighton is the only city without a cathedral
16) A tomato is a fruit
17) America has 51 states
18) The letter ‘U’ comes before the letter ‘V’ in the alphabet
19) 25 twenty pence pieces makes £4
20) A kilometre is shorter than a mile