Exploring the role of healthy distraction on driver performance

Kristen, Pammer

The Research School of Psychology,
The Australian National University, Canberra, ACT, Australia, 0200
Kristen.pammer@anu.edu.au

Abstract

Looked-but-failed-to-see crashes describe car crashes in which drivers are apparently looking directly at an unexpected object on the road yet report failing to see it, resulting in a collision. A cognitive mechanism that explains these crashes is inattentional blindness (IB); a phenomenon that occurs when observers fail to notice an unexpected, though clearly visible object in their visual field when their attention is engaged elsewhere. We have been conducting a series of experiments in which we use a static, driving-related, IB task. The primary task involves making safety decisions about briefly-presented driving scenarios. After a given number of trials, an unexpected stimulus, e.g., a person, animal or object, is placed on the side of the road. We have demonstrated differential processing of unexpected stimuli, suggesting that drivers make broad attentional sweeps of all objects when driving. In a separate stream of research, we have also demonstrated that attention can increase for an unexpected stimulus in IB in the presence of distraction. Distraction refers to an additional stimulus that draws attention away from a primary task, however these results suggest that task-irrelevant distractions have the potential to facilitate conscious processing of unexpected stimuli such as hazards in driving. Combining the two streams of research, it is possible that transient distraction when driving might facilitate attention, suggesting that some distraction may be a good thing. These results have important implications for understanding driver distraction, as well as models of attention where the effect of distraction on attention may reflect a U-shaped function

Introduction

The primary focus of the attention literature in driving is about maintaining attention and exploring which factors might distract attention away from this goal. With the development of more sophisticated in-car technology, and the increasing visual complexity of the driving environment, there is substantial research investigating the impact of increasing distractions on driving performance. A current search of the scientific literature for "driver distraction" reveals almost 500 scientific articles in the last 10 years (Web of Scienceapps.webofknowledge.com/). However, the reality is that attention must be distractible. Behaviourally relevant stimuli such as a pedestrian, dog, runaway ball, or cyclist, must capture the attention of the driver, and failure to do so will have disastrous consequences. Research in our lab and others has been motivated by understanding the factors involved in attentional capture; what the circumstances are in which attention is captured, and more importantly, under what circumstances does an unexpected object fail to capture attention? Specifically, recent research has pointed to the intriguing possibility that a certain level of distraction is in fact necessary for optimal performance in detecting unexpected objects – a phenomenon that may be referred to as 'healthy distraction'. Thus, the current paper is a brief review of the relevant literature with a segue into some of the research that has been conducted in the Applied Cognition and Transport Safety (ACTS) Laboratory at the Australian National University. This research has been conducted over the last 5 years by the author, colleagues and various students, who have been acknowledged in the appropriate section. This review concludes with the suggestion that *some distraction when driving may be a good thing by increasing driver awareness.*

Attentional load and under-load in driving

Psychological theories of attention are united in the evidence that as cognitive load increases, attention decreases. (e.g., Cartwright-Finch & Lavie, 2007; Lavie, 1995). There are good cognitive models to explain why this occurs. The basic premise is that there is limited attentional capacity to devote to the world around us at any time, and as the requirements for attention increase, the cognitive resources that can be devoted to specific tasks decreases. This is referred to as Cognitive Load Theory (Lavie 1995). Thus, driving consumes a certain amount of attention, if distracting events are added to the driving situation, such as rain, heavy traffic and the driver talking on a mobile phone. Each of these events divert some of the limited cognitive capacity, away from the primary task of driving the car, the likely consequence of which is that the driver becomes increasingly less likely to detect hazards and unexpected events. However, both anecdotally and empirically, there may be utility in also looking at the other end of the attention spectrum; when driving has become so automatic that we fail to engage our attentional system sufficiently to detect hazards, with the same devastating consequences.

Almost all drivers have experienced what has become known as highway hypnosis, or time-gap experiences. This is the experience of suddenly become alert when driving after having ‘drifted off’ for a period of time. Time gap experiences have been associated with lower hit rates to unexpected events when driving, and slower reaction times (Chapman, Ismail & Underwood, 1999).. The Psychological explanation for this phenomenon is that when attention is sufficiently under-engaged, the brain ‘switches-off’ from the primary task. This under-engagement can occur in the driving situation as a consequence of combining a highly automatic task such as driving, with an unvarying environment. This attentional under-load, is clearly as important to the driving situation as attentional overload.

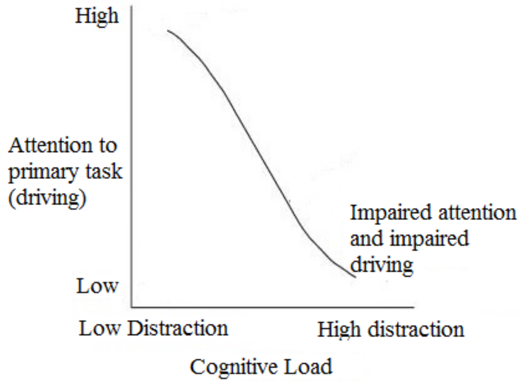

Figure 1. The negative relationship between distraction and driving when distraction is high

A model of attentional load in driving

The cognitive load theory of distraction suggests that there is a linear negative relationship between increasing distraction and decreasing attention to a primary task such as driving. This is consistent with our intuitive notion of driving becoming harder as distractions increases, and it is entirely consistent with the cognitive literature. This is represented in Figure 1

However, under-load in driving or any task requiring sustained attention, can be equally detrimental, with a similar linear relationship that is the reverse of the one above. In this case, there is a proposed linear positive relationship between attention and driving, such that attention for a primary task such as driving, decreases as cognitive load (and hence attentional engagement) decreases. Refer to Figure 2

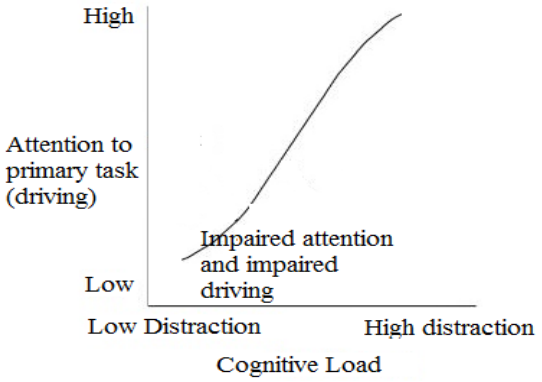

Figure 2. The positive relationship between distraction and driving when distraction is low

One possible interpretation of this, is a model of attention which suggests that our ability to detect unexpected events is at peak performance when there is a certain amount of distraction in the environment, somewhere between under-engaged, but before cognitive load starts to deteriorate performance. This is consistent with the intuitive recognition that when drivers ‘drift off’, their common response is to turn on the radio to ‘wake themselves up”. Thus a ‘healthy’ level of distraction is likely to increase a driver’s awareness of additional objects and hazards, but in addition to this also increase performance on the primary task of driving. Refer to Figure 3

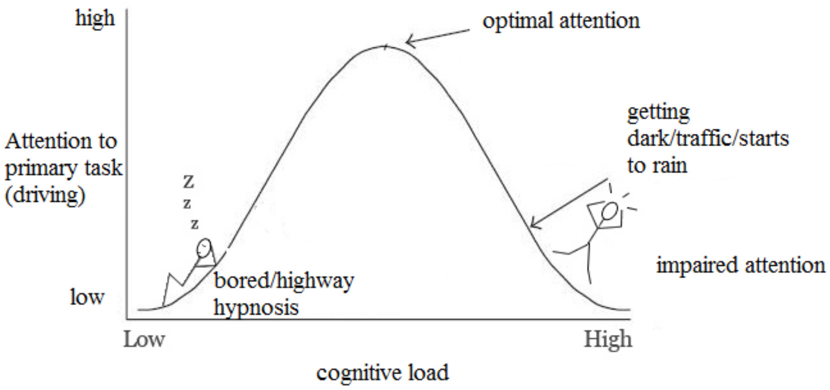

Figure 3. The inverted-U shaped relationship between distraction and driving, from low to high levels of distraction

Models for the relationship between attention and cognitive load

The model in Figure 3 is consistent with the well-known relationship between stress and performance. The relationship was first described by Yerkes and Dodson (1908) in the context of animal learning. They demonstrated that there was an inverted-U relationship between learning to discriminate between two stimuli, and the intensity of electric shocks delivered for punishment when the animal got the discrimination incorrect. This model was subsequently adopted to reflect the inverted-U relationship between arousal and performance. In this model, performance on a dependent variable is lowest when arousal is low, increases to an optimal level with moderate levels of arousal, and then decreases again as arousal increases.

The parallels between the Yerkes-Dodson law and the one proposed here are clear. Indeed, one could conceptualise the inverted-U model proposed here as being a variant on the Yerkes-Dodson law. This is important because it then has the value of psychological parsimony in terms of theory and physiology, cleanly explaining both cognitive load and cognitive under-engagement into a single model. This allows the derivation of testable hypotheses and predictions. It also has the value of biological parsimony. There are other theories that have been submitted to explain decreases in performance when under-engaged, particularly in the driving context (e.g., Young & Stanton, 2002), however, it is more biologically plausible that models of behaviour are ubiquitous across physiological systems; if it works for arousal, it makes sense that it should also work for attention. Thus attention for a primary task such as driving, is likely to be optimal when there is a little bit of distraction to engage attention. Indeed, recent findings in our lab suggest that some types of distraction may increase attention for performance on a primary task (Beanland et al, 2001; Beanland, et al, 2010).

The notion of under engagement resulting in poor attentional performance has been considered in the human factors literature for some time (e.g., Frankman & Adams, 1962) under behavioural concepts of vigilance, fatigue, monitoring, and so on. The notion of 'cognitive engagement' in the current paper may also be akin to the notion of 'Motivation intensity' elsewhere (Brehm & Self, 1989) or 'vigilance' in some instances (refer to Warm, Parasuraman, Mason & Matthews, 2008 for a review). Within this literature, there is some contention regarding the aetiology of vigilance decline – the situation where vigilance decreases over time. It has been suggested that vigilance is effortful and stressful, becoming more so over time (e.g. Warm, Dember & Hancock, 1996). This is certainly the case. However, stressful is not the same thing as cognitively demanding in terms of cognitive load. Elevated levels of catecholamines during vigilance tasks speak to this possibility (Frankenhaeuser, Nordheden, Myrsten, & Post, 1971), but could equally reflect the mean response over time to the stress associated with having 'drifted off'.

Indeed, that linear decreases in cerebral blood volume commensurate with decreases in vigilance, as is increase in frontal alpha signals (Kamzanova, Kustubayeva & Matthews, 2014) (increasing power in alpha reflects decreasing alertness), is consistent with progressive decreases in cognitive engagement (although it should be noted that Kamzanova et al, argue against this conclusion). Similarly, a subtle understanding of the notion of fatigue is such that it could reflect commitment of effort to complete a task, not engagement in the task itself (Earle, Hockey, Earle & Clough, 2015). However, evidence that lane maintenance can get better with some degree of cognitive distraction (e.g., Medeiros-Ward, Cooper & Strayer, 2013), is consistent with the notion of ‘healthy distraction. Suffice to say that there remains considerable debate around the existence and understanding of the left side of the curve in Figure 3 here.

Our research

The driving situation is one which requires constant monitoring of the visual environment and continuous filtering of visual information in order to attend to the most important cues. In many cases however, we fail to see something of critical importance when driving. Looked-but-failed-to-see crashes (Hills, 1980; Treat 1980), have been implicated as the third most frequent type of driver error (Brown, 2005). Cognitively, the looked-but-failed-to-see experience maps precisely onto a known psychological phenomenon called Inattentional Blindness (IB). In IB, an observer fails to see an unexpected stimulus or event while attending to another, primary task (Mack & Rock, 1998; Beanland, Allen & Pammer 2011; Koivisto & Revunsuo, 2008). IB is closely related to hazard detection when driving (White & Caird, 2010), and thus provides a sound experimental framework with which to study this issue.

We have conducted a number of experiments using IB demonstrating that attention for the unexpected object increases with some types of distraction. The basic task paradigm involves requiring participants to track multiple objects around a computer screen for trials of 15-40 seconds each - all trials ran for the same length of time in any one experiment, the different times here (15-40sec) reflect experimental manipulations between experiments. The participant is required at the end of each trial to indicate how many objects ‘bounced’ off the edge of the screen. For example, the participant may be required to track the black objects, ignoring the white, keeping a silent tally of how many times they ‘hit’ or ‘bounce’ off the edge of the screen. After a certain number of trials, a critical trial occurs in which an additional unexpected object appears. At the end of the critical

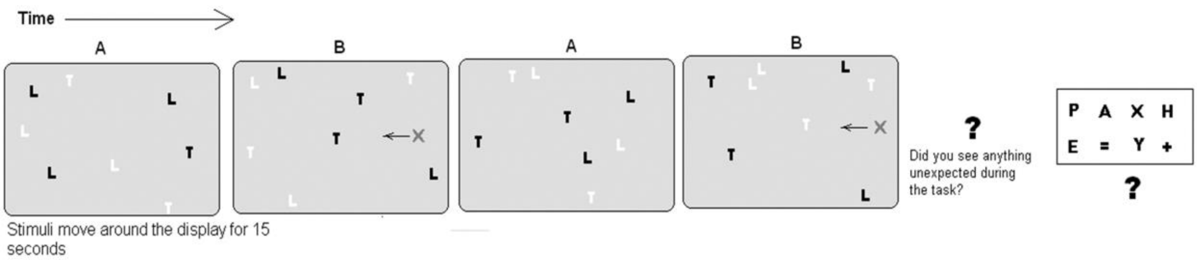

Figure 4. The standard IB ‘bounce’ task used in our lab to measure detection of the unexpected object. Primary task performance is based on how well the participant tracks the letters as they move around and ‘bounce’ off the edge of the computer screen.

trial, the participant is asked if they had seen anything other than the shapes they were to be tracking. Participants who noticed the unexpected object are asked to describe it and point it out from a selection sheet of plausible alternatives. Participants who did not notice it are nevertheless asked to “make a guess” as to which object might have appeared on the screen. The dependent variable is whether the participant reports seeing the unexpected object or not. Refer to Figure 4, and the following references for more detailed descriptions of the relevant methodologies

(Beanland, Allen & Pammer, 2011; Pammer, Korrell & Bell, 2015). Each experiment of this type typically takes less than 10 minutes to run.

Using this, and similar IB tasks, we have demonstrated a consistent finding; low levels of visual or auditory distraction appear to increase noticing of the unexpected object, typically with no additional effect on primary task performance (tracking the bouncing objects). The first studies in this area were student projects (e.g., Beanland, Pammer & Colton, 2010). In the first of these, participants performed the above IB task while simultaneously exposed to one of three types of audio stimuli: music (with or without lyrics Beanland, Allen & Pammer 2011; Koivisto & Revunsuo, 2008), speech, no audio and general background noise (café sounds). Consistent with load theory, our initial hypotheses were that rates of noticing in IB would decrease with increasing distraction. In fact what we found was the opposite effect. Rates of noticing got better with concurrent music and then even better with concurrent language (refer to Figure 5).

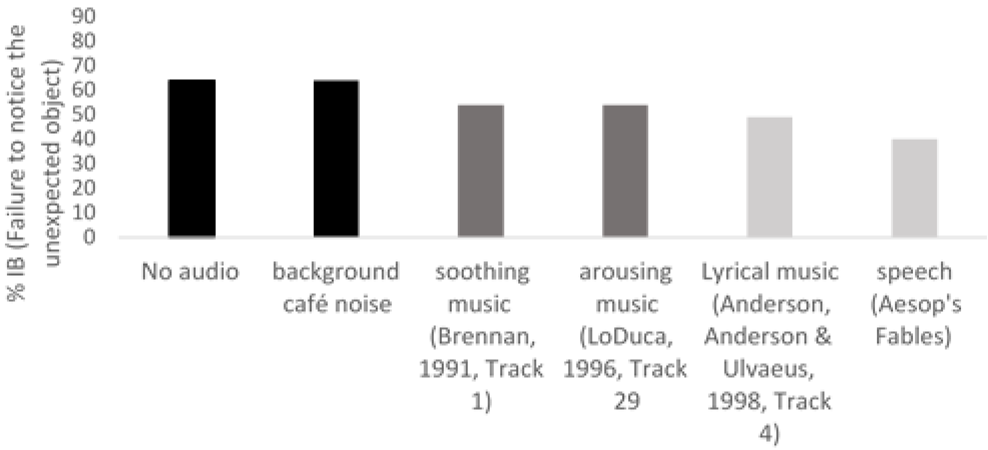

Figure 5. Rates of IB when different types of auditory distractors were played concurrently via headphones while the participant was doing the task (adapted from Beanland et al, 2010)

Overall, 62% of participants in the no-audio condition experienced IB, compared to participants who listened to language where 56% noticed the unexpected object, $\chi^2(1, N = 34) = 4.9, p = 0.27$, and the instrumental conditions where 47% noticed the unexpected object (this was not significantly different from the control conditions). This finding prompted us to explore this effect more systematically.

In Beanland, Allen and Pammer, (2011), participants performed the standard IB task and we systematically varied cognitive load and concurrent auditory stimuli to determine if the change in rates of IB could be due to effects of cognitive load. In this case, load was manipulated by changing the speed of the tracked objects from fast (high load) to slow (low load). Similarly, the audio stimuli – in this case well-known lyrical music – was either presented actively, where the participant was to listen for tones within the music while performing the IB bounce task, or passively, where participants were simply asked to listen to the concurrent music.

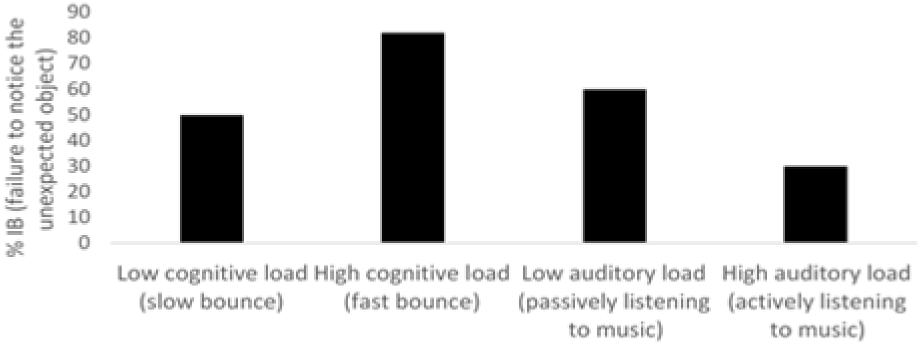

Figure 6. Rates of IB when auditory distractors were varied with cognitive load (adapted from Beanland et al, 2011)

Overall 54% of participants experienced IB, with rates of IB varying significantly across conditions, χ^2 (3, N = 100) = 13.69, p = .003. Compared to low cognitive load (52% IB), IB was significantly higher under high cognitive load (80% IB), χ^2 (1, N = 25) = 7.85, p = .005. Conversely, participants under high auditory load exhibited significantly lower IB rates (28% IB), χ^2 (1, N = 25) = 5.77, p = .016, compared to the low visual load condition. There was no difference between low visual load and low auditory load (56% IB), χ^2 (1, N = 25) = 0.16, p = .689. Thus, as expected, the high cognitive load task had the highest rates of IB (lowest rates of noticing), however the lowest rates of IB (highest rates of noticing) was when participants were actively listening to the music while performing the IB task.

The finding that attention for an unexpected object in an IB task increases with auditory distraction, has been replicated using visual distraction. In Pammer, Korrell and Bell, (2015) participants did the IB bounce task in which was embedded a transient screen 'flicker' that occurred for two frames. The distractor flicker was explained to participants at the end of the

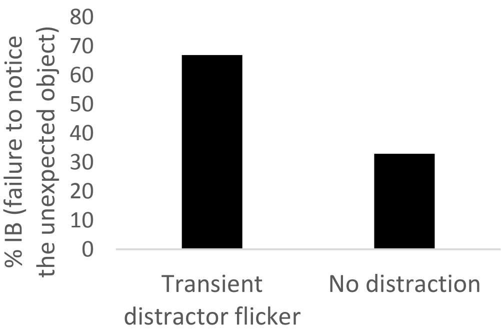

Figure 7. Rates of IB with transient visual distraction in the form of a screen flicker (adapted from Pammer et al, 2015)

experiment as an irritating 'glitch' in the program. It was however carefully constructed to appear at specific points in the experiment, including at the start of the critical trial. Consistent with the auditory distractin studies, the presence of unrelated, transient screen flicker halved the rates of IB. Refer to Figure 7, χ^2 (1, N= 121) =10.118, p =.001, Φ=.306. Even more interestingly, rates of IB remained the same irrespective of whether participants noticed the flicker distraction.

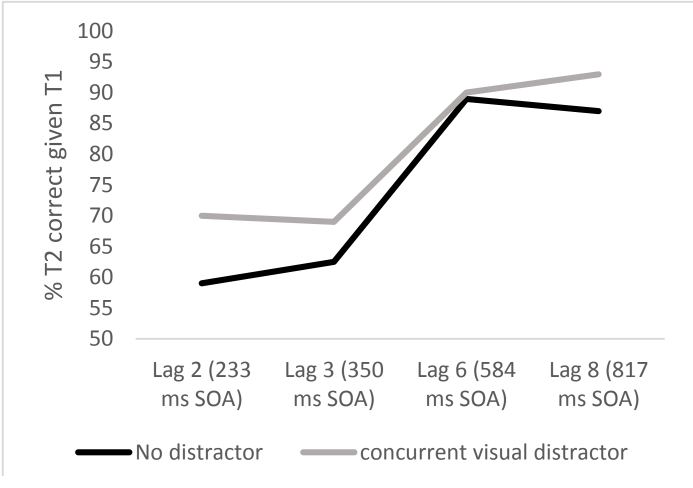

Figure 8. Decrease in masking in an AB task when the stimuli are presented with a surrounding visual distractor (adapted from Carter & Pammer, 2009 [unpublished honours thesis])

We have also demonstrated an increase in visual attention using tasks other than IB. In Attentional Blink (AB), a sequence of stimuli such as numbers and letters flash up rapidly, one after the other, spatially superimposed to form a RSVP (Rapid Serial Visual Presentation) sequence. The dependent variable is the ability to detect two targets (T1 and T2), embedded one after the other in the sequence. Participants are able to see the first letter with relative ease, but often miss seeing the second letter if it appears within a 100-500 millisecond window of the first letter (Shapiro, Arnell & Raymond, 1997). A number of studies have demonstrated that when participants engage in an AB task with an associated distractor, the 'blink' in attention is significantly reduced (i.e., attention gets better for the second target). For example, Arend, Johnston and Shapiro (2006) found that participants were more likely to notice the T2 when an irrelevant 'star-field' pattern of dots were presented around the borders of the display. Similarly, Olivers and Nieuwenhuis (2005) found that the Attentional Blink was significantly reduced in conditions which had a distracting task (such as thinking about a recent holiday or listening to music) compared to a control condition. We have replicated these findings, demonstrating that the Target 2 becomes easier to see at the point of maximum masking when surrounded by a concurrent visual distractor F(3, 20) = 6.46, p = .003, partial η^2 = .48, refer to Figure 8.

Limitations and future directions

The collective result from this series of studies is that using basic tests of attentional selection such as IB and AB, suggest that participants' ability to detect a target improves if the task is accompanied by some unrelated auditory or visual distraction. This has important implications for attention in driving. The attention tasks that we have used here are good correlates of attentional mechanisms that are used when driving, for example both require monitoring multiple moving objects. However the task still remains a highly simplified version of the driving experience. Recently we designed a novel IB task in which participants made driving judgments that were pertinent to typical driving scenarios, we measured IB as whether they detected an unexpected object in each scenario. The unexpected object has been a relevant object on the side of the road such as a child, a dog or a garbage bin (Pammer, Bairnsfather, Burns & Hellsing, 2015), a motorcycle (Sabadas & Pammer, *under review*), or unexpected objects like a kangaroo in a city driving scene or a man in a business suit in a rural driving scene (Pammer & Blink, 2013). These tasks provide a strong theoretical link between cognitive tests of attention, and the applied experience of driving. We are currently conducting the distraction studies with these driving-IB tasks. We predict that transient auditory distraction will increase detection of an unexpected object in a driving-IB task, just as we have demonstrated in standard cognitive-IB tasks. In another study, we are explicitly exploring the nature of this inverted-U; the relationship between driving and attentional allocation. Here participants will be driving in a simulator while singing along to their favourite music. We will systematically vary the driving and singing environments to monitor the relationship between spontaneous singing (distraction) and difficulty in the driving environment.

Specific questions and objectives

The overarching aim of this research path is to understand the role of high and low levels of distraction in IB, and hazard detection when driving. We anticipate that while there is a point at which driver distraction impedes attentional performance, we also believe that there is in fact a 'healthy' level of distraction is necessary to maintain optimal driving performance. Within this, specific sub-goals and questions include the following:

- Can we describe the idiosyncratic nature of driver distraction: We anticipate that not everyone is created equal when it comes to distraction. Similar to the observation that some people need to work or study while listening to the radio while others require complete silence, what are the parameters at an individual level to determine how 'healthy-distraction' varies between people?
- Can we develop a psychological understanding of the consequences of driver distraction on IB and hazard detection?
- Does the notion of distraction change in highly trained drivers? We have developed contacts over the last 2 years with the Australian Federal Police and state ambulance services to explore the role of increased distraction and hazard perception in highly experienced drivers.
- What is the connection between distraction and automaticity? Generally, driving is familiar and automatic, requiring little cognitive input. We speculate that it is the aspect of automaticity in driving that makes it particularly susceptible to highway-hypnosis, and then IB and poor hazard detection as a consequence.
- Does sub-optimal attentional engagement also result in poor performance on the primary tasks – in this case the physical act of driving? Thus, healthy distraction might not only increase vigilance to hazards, but also improve task specific driving behavior.
- Can this research provide a theoretical framework for the development of in-car technology? The results would provide a rationale for in-car features designed to help the driver focus. However, findings may also provide basis for a debate regarding the use of cruise-control and other assistive in-car technology. Making the driving situation easier is unlikely to result in better driver behavior.

Conclusions

A driver 'drifts off', veering dangerously into the shoulder of the road. Shaken, he turns on the radio to help him focus. Attention, and our ability to detect unexpected events appears to be at peak performance when there is a certain amount of distraction in the environment, somewhere between under-engaged, but before cognitive load starts to deteriorate performance. The question of interest, is why does attention decrease when distraction is low? Logic would suggest that when the brain has little else to do, that it would be more likely to detect unexpected events, however our results indicate that this is not the case. Answering this question will allow us to determine how we can keep attention at optimal levels in the driving environment. Thus a 'healthy' level of distraction is likely to increase a driver's awareness of additional objects and hazards, but in addition to this also increase performance on the primary task of driving, and suggesting that some distraction is vital for safe driving.

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