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Looking and thinking when driving: The impact of gaze and cognitive load on steering

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ABSTRACT

Driving around bends at high speeds is a task performed by many on a daily basis but the underlying mechanisms of steering control remain largely unknown. Previous research has shown that when steering, gaze direction can be a critical component of success. However, with increased use of in-vehicle information systems (IVIS), there is growing competition over the same resources that are needed to steer (gaze as well as associated attentional resources). Although it can be argued that locomotor steering is an automatic task that can be performed without recourse to conscious "cognitive" control, much simpler locomotor-related tasks, such as judging one's heading, have been shown to be affected by concurrent attentional tasks (Wann, Swapp, & Rushton, 2000). Here we examined whether an attentional task placed at an offset fixation point influenced concurrent steering performance along a computer simulated road. The experiments either used gaze-fixation points that had similar properties to real-world road signs (i.e. moved relative to the vehicle) or were more akin to IVIS (i.e. fixed to the vehicle). Results showed that gaze fixation eccentric to future path caused systematic steering biases. The degree or type of cognitive load did not change the degree of steering bias, but there was some evidence of decreased lane variability when viewing the IVIS-type displays. No differences in steering performance were found between the different types of cognitive task. We conclude that where you look is critical for safe driving, and IVIS-type displays might make drivers more susceptible to cognitive interference.

1. Introduction

Locomotion, and driving in particular, fundamentally requires the ability to control steering to negotiate bends at high-speeds whilst taking appropriate trajectories along curved roadways. The effect of additional attentional demands imposed by activities such as cell phone use and interactions with in-vehicle systems have often been studied in terms of reaction times to critical events, such as braking, and lane keeping (e.g., Recarte & Nunes, 2003; Salvucci & Beltowska, 2008; Strayer & Drews, 2004). However, less is known about the effect of cognitive load on steering control, and in particular whether attentional demands interact with the direction of gaze and successful steering control.

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Direction of gaze has been shown to be critically important when steering around bends (Land & Lee, 1994; Wilkie & Wann, 2003). Although these studies propose two different models of locomotor control, both models require the driver to look towards regions of the road ahead. According to the 'Tangent Point' model of steering (Land & Lee, 1994), drivers should predominantly fixate the apex of the inside road-edge. However, the 'Active Gaze' model of steering (Wilkie & Wann, 2003; Wilkie, Wann, & Allison, 2008) proposes a close link between the direction of gaze and the steering trajectory taken by drivers: under conditions of unrestrained gaze, drivers have been found to fixate points on the road that lie on their future path (Wilkie, Kountouriotis, Merat, & Wann, 2010; Wilkie & Wann, 2003; Wilkie et al., 2008). The reciprocal also seems to be true: when gaze is forced onto points eccentric to the required curved path, drivers alter their steering trajectories to pass nearer to those fixation points (Kountouriotis, Floyd, Gardner, Merat, & Wilkie, 2012). This relationship has also been observed when maintaining a trajectory along straight roads (Readinger, Chatziastros, Cunningham, Bülthoff, & Cutting, 2002). At slow speeds (e.g. when walking) decoupling gaze and steering may have little effect on successful control, however, when driving at high speeds in rapidly changing environments decoupling gaze and steering is not advisable. Of course, in real world scenarios, drivers often have to look away from their future path to perform various tasks, e.g. to sample information from road signs or interact with an in-vehicle satellite navigation system. These tasks require drivers not only to look away from their future path, but to also perform some kind of cognitive task (e.g. read a sign or decipher a map). These concurrent tasks when driving may have an additional effect over and above eccentric fixations, and therefore need to be better understood.

In experimental settings, asking participants to perform a concurrent task whilst driving can result in changes in the natural gaze patterns due to the task itself, e.g. looking at the speedometer. However, even tasks that do not rely on vision and hence do not require participants to direct their gaze towards a specific location (e.g. an auditory in-vehicle information system or talking hands-free on a phone) have been shown to affect gaze behaviours during driving (Victor, Harbluk, & Engström, 2005). Such tasks can increase the duration of gaze fixations to the road centre, along with a decrease in saccades to the periphery (Recarte & Nunes, 2003; Victor et al., 2005). Even when gaze patterns do not change, it appears that greater attentional load can reduce the available resources for visual processing of the scene. For example, Strayer, Drews, and Johnston (2003) examined driving performance when drivers talked on a hands-free phone. They observed that participants were less likely to remember seeing billboards in the conditions where they were conversing on the phone compared to the control conditions, even though there was no difference between the two conditions in the number of fixations they made on these objects. Strayer et al. (2003) explain this finding in terms of relocating attention from driving towards the phone task.

In addition to these changes in gaze patterns, cognitive tasks may also change steering, with the variability of lane position reducing under cognitive load conditions (Engström, Johansson, & Östlund, 2005; Jamson & Merat, 2005). There is a tight coupling between gaze and steering: not only does steering guide the direction of gaze with drivers looking where they are going (Wilkie & Wann, 2003, 2005; Wilkie et al., 2010) but gaze direction guides steering with drivers steering where they look (Kountouriotis et al., 2012; Robertshaw & Wilkie, 2008). A question that arises, therefore, is whether increased cognitive demand affects eye movements (which in turn lead to changes in steering patterns), or whether cognitive demand affects steering patterns (which then leads to changes in eye movements). For example, Engström et al. (2005) used a cognitive load condition which did not require drivers to look at a visual display, but they reported both greater gaze concentration around the road centre and reduced lane keeping variation. Increased gaze concentration has also been shown in other studies using non-visual distraction tasks (e.g. Reimer, 2009; Victor et al., 2005). One possible interpretation of these findings is that the cognitive load increased gaze concentration around the road centre, and this in turn caused steering trajectories to pass closer to the point of gaze (as per Wilkie & Wann, 2003; Wilkie et al., 2008, 2010).

From this evidence it is difficult to conclude definitively that cognitive load influences steering directly (rather than via gaze mechanisms). Cooper, Medeiros-Ward, and Strayer (2013) examined whether the reduced lateral variation in steering under cognitive load was due to a reduction in lateral eye-movements (gaze concentration). Cooper et al. (2013) instructed drivers to look at an illuminated number plate on a vehicle ahead. The illuminated plate switched between either 3 or 5 vehicles in other lanes and the temporal frequency by which drivers changed their point of gaze from one vehicle to the next was varied. The low frequency gaze changes were supposed to be similar to the patterns exhibited during 'gaze concentration'. This study reported that increased cognitive load did indeed lower steering variability even when gaze changes were matched across 'no cognitive load' and 'high cognitive load' conditions. They concluded that the cognitive task caused attention to be removed from the lane-keeping task, which due to its automaticity improved (Medeiros-Ward, Cooper, & Strayer, 2014). Whilst it would seem this evidence indicates that the effects of cognitive load are independent of gaze direction, there were some limitations to this study. There were no trials where drivers looked solely towards the road ahead, but in the condition where gaze was predominantly directed to the road ahead ("static predictable") there was no reliable effect of cognitive load. It remains unclear, therefore, whether a cognitive load influences steering when natural gaze behaviours are adopted and drivers fixate their future path. A linked issue is that the non-visual nature of the cognitive task does not generalise to the common situation of retrieving and processing information from the point where you are looking (i.e. there was no task involving information at the point of fixation). Furthermore, Cooper et al. (2013) and Medeiros-Ward et al. (2014) only examined the task of maintaining a trajectory along straight roads. Although this can be a useful paradigm for answering questions related to lane-keeping, the task does not necessarily translate to the more general (and complex) case of steering curved trajectories, where the driver needs to take into account both feedback information from the near road edges as well as prospective information from the road ahead (Land & Horwood, 1995; Salvucci & Gray, 2004).