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Identifying cognitive distraction using steering wheel reversal rates

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ABSTRACT

The influence of driver distraction on driving performance is not yet well understood, but it can have detrimental effects on road safety. In this study, we examined the effects of visual and non-visual distractions during driving, using a high-fidelity driving simulator. The visual task was presented either at an offset angle on an in-vehicle screen, or on the back of a moving lead vehicle. Similar to results from previous studies in this area, non-visual (cognitive) distraction resulted in improved lane keeping performance and increased gaze concentration towards the centre of the road, compared to baseline driving, and further examination of the steering control metrics indicated an increase in steering wheel reversal rates, steering wheel acceleration, and steering entropy. We show, for the first time, that when the visual task is presented centrally, drivers' lane deviation reduces (similar to non-visual distraction), whilst measures of steering control, overall, indicated more steering activity, compared to baseline. When using a visual task that required the diversion of gaze to an in-vehicle display, but without a manual element, lane keeping performance was similar to baseline driving. Steering wheel reversal rates were found to adequately tease apart the effects of non-visual distraction (increase of 0.5° reversals) and visual distraction with offset gaze direction (increase of 2.5° reversals). These findings are discussed in terms of steering control during different types of in-vehicle distraction, and the possible role of manual interference by distracting secondary tasks.

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1. Introduction

Although driver distraction is regularly cited as one of the leading causes of traffic accidents and near misses, how different types of distraction affect road safety is currently poorly understood. When studying the effect of driver distraction in the laboratory, researchers use a multitude of tasks to simulate distraction, as well as different driving environments and performance measures.

Information processing models (e.g., the Multiple Resource Theory proposed by Wickens, 2002) as well as working memory models (e.g., Baddeley, 1992) predict that the type of distraction used has a differential effect on driving performance, with most disruption seen by tasks which share the same response or processing resource. The majority of the published literature on the subject uses a broad distinction between two main types of distraction: visual distractions, which involve processing of some form of visual information (and therefore can change the natural eye-movement patterns), and non-visual (often referred to as "cognitive") distractions, which involve processing of information without a visual component.

In terms of their effect on driving performance, visual distractions have been shown to have two main effects: an increase in lateral deviation from the lane centre (e.g. Engström et al., 2005; Santos et al., 2005; Liang and Lee, 2010) and also increased deviation of gaze because the information that needs to be sampled is usually displayed away from the road centre, for example on a central console (e.g. Victor et al., 2005; Reyes and Lee, 2008). Godthelp et al. (1984) argued that the change of gaze from the centre of the road to some place off the road, such as an in-vehicle information system, results in large errors in heading direction, which in turn affect the lateral position of the vehicle.

If the increase in lateral deviation during a visual task is linked to the decrease of gaze concentration towards the road centre, it follows that placing this visual task around the road centre will likely lead to similar, or even better lane keeping performance, compared to baseline driving, as drivers' eyes will not be diverted towards a distracting in-vehicle task. Understanding how placement of the visual task in relation to the driving scene affects lateral control

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is of value, and may provide knowledge on the design of future in-vehicle-information systems.

Studying the effect of non-visually distracting (cognitive) tasks on driving performance has produced more mixed results. While some studies have also reported an increase in lateral deviation akin to that of visual tasks (e.g. Salvucci and Beltowska, 2008; Strayer and Johnston, 2001), other studies find the opposite effect, i.e. a *reduction* in lateral deviation (Atchley and Chan, 2011; Cooper et al., 2013; Engström et al., 2005; He et al., 2014; Jamson and Merat, 2005; Kubose et al., 2006; Reimer, 2009), and also a reduction in the deviation of gaze (Victor et al., 2005; Reimer, 2009), a phenomenon often referred to as "gaze concentration".

This reduction in lateral deviation under conditions of non-visual distraction is thought to be an indication of better lateral control (Cooper et al., 2013; Medeiros-Ward et al., 2014), which, at face value, it is. However, what drives this behaviour is not currently clear. It has been argued that this improvement in lateral control is due to a hierarchical control system, whereby increased attention to a simple (tracking) task disrupts performance (Cooper et al., 2013; Medeiros-Ward et al., 2014). By the same token, performing a competing and concurrent secondary task removes attention from the simple tracking (lane control) task. Since this improved lane keeping is also accompanied by increased gaze concentration to the road centre during secondary task engagement, a "lock in" state is observed by drivers, where their focus on the road centre affords less attention to peripheral stimuli (e.g. Lee et al., 2007; Merat and Jamson, 2008). Kountouriotis et al. (2015) showed that fixing gaze direction towards an eccentric target removed any differences in lateral control between visual and non-visual tasks when drivers were negotiating a bend. However, what has not yet been investigated is whether a visual task which mimics the gaze concentration on the centre of the road will result in the same reduced lateral variability as a non-visual task.

When examining the effect of non-visual tasks on lane keeping, many studies show reductions in measures such as the standard deviation of lateral position (SDLP) when performance is compared to baseline (e.g., Atchley and Chan, 2011; Engström et al., 2005; He et al., 2014; Jamson and Merat, 2005; Liang and Lee, 2010; Merat and Jamson, 2008), but the effect of such secondary tasks on steering control is not always clear. For example, high workload (visual and non-visual) leads to higher steering entropy (a measure of how predictable/random steering wheel movements are, Boer et al., 2005). Further work is therefore required to examine the effect of driver distraction using additional metrics of steering performance. Markkula and Engström (2006) proposed that steering wheel reversal rates (SRRs) are a useful metric for assessing the effects of visual and non-visual distractions. Steering wheel reversal rates measure the number of times the steering wheel changes direction by a set angle (and larger) per minute (Macdonald and Hoffmann, 1980). Analysis of data from the EU project HASTE (using both simulator experiments and field trials) showed that whilst non-visual distractions led to an increase of steering corrections in the range of 0.1–2°, visual distractions, where gaze is diverted from the road centre, led to an increase of steering reversals larger than 2° (Markkula and Engström, 2006). It appears, therefore, that SRRs measure two different components of the steering signal, depending on how they are defined. Whilst larger reversals are indicative of a change in direction of heading, it remains unclear whether smaller reversals (particularly reversals smaller than 1°) imply fine-tuning by the driver, or simply reflect increased steering activity that have little effect on the vehicle's trajectory. Therefore, examining SRRs alongside other steering control measures, such as steering wheel acceleration and steering entropy is necessary to compare the effect of different types of secondary task on steering and lane keeping measures.

The aim of the present paper is therefore two-fold: (a) to investigate further the apparent differences between visual and non-visual distractions on steering performance, and (b) to investigate the role of SRRs in identifying different types of driver distraction and its relation to other steering metrics. Three secondary tasks were therefore implemented for this driving simulator study: two visual tasks, one presented on an eccentric IVIS in the vehicle, which is comparable to the type of visual distractions used in the literature cited here, and one presented centrally on the back of a lead car to assess the effect of gaze concentration on the centre of the road, whilst performing a visual task. We argue that a visual task which does not require drivers to take their eyes off the road, but instead mimics gaze behaviour observed during a non-visual task (increased gaze concentration on the road centre) can potentially lead to similar steering control behaviours as a non-visual distraction task (such as improved lane keeping performance), while a visual task that requires changes in gaze direction should deteriorate lane keeping. A non-visual task was also used for comparison with the two visual tasks described.

2. Methods

2.1. Participants

Sixteen naïve participants took part in this study, eight of them males. The mean age was 35.12 ± 9.95 years and all had a valid driving license, with an average 14,887 annual mileage.

2.2. Design and procedure

2.2.1. Materials

The experiment was conducted in the University of Leeds Driving Simulator which consists of a Jaguar S-type cab with all driver controls operational. The vehicle is housed within a 4 m spherical projection dome and has a 300° field-of-view projection system. A v4.5 Seeing Machines faceLAB eye-tracker was used to record eye-movements at 60 Hz. The IVIS display used to display the Remote Arrows was a Lilliput 7" VGA touchscreen display with a resolution of 800×480, positioned approximately 28.3° to the left of the centre of the main scene and 25.4° lower of the horizon.

2.2.2. Secondary tasks

Three secondary tasks (two visual tasks and one non-visual task) were implemented in this experiment, as well as a baseline condition (Baseline) which involved only driving. Both visual tasks were inspired by the European HASTE project (see Jamson and Merat, 2005): participants were required to locate a target arrow (arrow pointing upwards) amongst distractors (arrows pointing in other directions), presented in a 4×4 grid. Unlike the manual response used in the HASTE experiments, participants were required to verbally report the position of the target arrow using the letter and number coordinates located around a grid (see Fig. 1). Also, in contrast to the HASTE set up, a target arrow was always present in these experiments. The main difference between the two visual tasks was the location of the arrows grids: in one set up the task was displayed on an in-vehicle interface to the left of the driver (Remote Arrows), whilst in the other it was displayed at the back of the lead car (Central Arrows). There was an auditory notification when a new grid appeared, and each grid remained visible until either the participant provided a response or seven seconds elapsed from its onset.

The non-visual task was a count back in sevens task (Countback), where the participants would hear a three digit number and would have to count backwards in steps of seven. Each task was presented in two blocks of 30 s.

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