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Concurrent processing of vehicle lane keeping and speech comprehension tasks

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ABSTRACT

With the growing prevalence of using in-vehicle devices and mobile devices while driving, a major concern is their impact on driving performance and safety. However, the effects of cognitive load such as conversation on driving performance are still controversial and not well understood. In this study, an experiment was conducted to investigate the concurrent performance of vehicle lane keeping and speech comprehension tasks with improved experimental control of the confounding factors identified in previous studies. The results showed that the standard deviation of lane position (*SDLP*) was increased when the driving speed was faster (0.30 m at 36 km/h; 0.36 m at 72 km/h). The concurrent comprehension task had no significant effect on *SDLP* (0.34 m on average) or the standard deviation of steering wheel angle (*SDSWA*; 5.20° on average). The correct rate of the comprehension task was reduced in the dual-task condition (from 93.4% to 91.3%) compared with the comprehension single-task condition. Mental workload was significantly higher in the dual-task condition compared with the single-task conditions. Implications for driving safety were discussed.

1. Introduction

The use of in-vehicle information systems and mobile devices has increased rapidly over the past few decades. For a long time, drivers' interaction with in-vehicle systems has been limited to radio and air-condition controls by pressing buttons and turning knobs. Then drivers started to use cell phones for telephone conversation while driving. With the growing prevalence of mobile devices or smartphones in recent years, drivers are surrounded by more distractions than ever before. A major concern about the use of in-vehicle devices and mobile devices is their impact on driving performance and safety. The work reported in this paper is an experimental investigation of the impact of concurrent speech comprehension on vehicle lane keeping performance using improved experimental control of the confounding factors identified in previous studies.

Using in-vehicle or mobile devices while driving can create two types of load, including visual load and cognitive load. Visual load is produced by tasks that require drivers to move their visual attention away from the driving scene, for example, text messaging. Such visual tasks compete with driving for the limited visual attention resource. The effects of concurrent visual tasks on driving performance have been relatively well-established. Since driving requires continuous visual processing, it is not surprising that a visual task almost always degrades driving performance to some extent. Numerous studies have found negative effects of visual load, including increased reaction time and decreased correct rate in response to traffic events (Lamble et al., 1999; McKnight and McKnight, 1993), increased lateral position variation (Engström et al., 2005), and degraded car following performance (Drews et al., 2009). With converging evidence, 39 states in the U.S. have banned text messaging for all drivers up till November 2012.

Compared with visual load, the effects of cognitive load on driving performance are still controversial and not well understood. Cognitive load in this research field often refers to the mental demand from a concurrent auditory task, such as voice control and telephone conversation. As predicted by multiple resource theory (Wickens, 2008), a secondary task using the auditory channel (e.g., speech conversation) should have less interference with the primary task using the visual channel (e.g., driving), compared with a secondary task that also uses the visual channel (e.g., text messaging). Still, epidemiological surveys of traffic accidents have found association between increased cell phone calls and higher risk of accidents (Redelmeier and Tibshirani, 1997; Violanti and Marshall, 1996). To examine the effects of cognitive load, numerous experiments have been conducted in both simulated and real-world driving scenarios. The results of traffic event reaction performance showed mostly negative effects of cognitive load, but the results of speed control (i.e., longitudinal control) and lane keeping (i.e., lateral control) are mixed and inconclusive.

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1.1. Effects of cognitive load on event reaction performance

Most studies have shown that cognitive load degrades event reaction performance. Recarte and Nunes (2003) found that conversations, no matter by phone or with a passenger, impaired visual detection of flashing targets in the driving scene. McKnight and McKnight (1993) asked their subjects to respond to video-recorded traffic situations and found that cell phone conversations significantly reduced the number of vehicle control responses. In addition, both abstract mental tasks (Alm and Nilsson, 1995; Lamble et al., 1999) and naturalistic conversations (Strayer et al., 2003) performed over the phone have led to increased brake reaction time to the braking maneuver from the lead vehicle. There are a few studies that failed to find any significant effect. In these cases, the phone task was often less demanding, requiring only passive listening without the need for immediate action (Recarte and Nunes, 2003; Strayer and Johnston, 2001). Overall, as suggested by Horrey and Wickens (2006) in a meta-analysis study, the negative effects of cell phone conversations on traffic event reaction performance are significant and relatively well-established.

1.2. Effects of cognitive load on speed control performance

Few studies have examined whether conversations affect speed control performance. Rakauskas et al. (2004) found that conversations caused larger variations in both accelerator pedal position and driving speed (i.e., degraded performance). Similarly, Kubose et al. (2006) found more variable velocity in both concurrent speech production and comprehension conditions compared with driving only. However, a recent study found the opposite effect – that is, drivers exhibited smaller variability in velocity (i.e., improved performance) when driving with concurrent speech tasks (Becic et al., 2010). Regarding average driving speed, some studies found that conversations led to slower driving speed (Rakauskas et al., 2004), but other studies found no significant effect (Engström et al., 2005). These mixed results indicate the existence of confounding factors such as the strategic tradeoff between driving and conversation tasks. A better understanding of this issue requires further experiments with these confounding factors controlled, which will be discussed in more detail later in this paper.

1.3. Effects of cognitive load on lane keeping performance

Another important component of driving is to steer the vehicle and maintain lane position. In contrast to the discrete nature of traffic event reaction, lane keeping is a continuous task that requires uninterrupted visual–manual control. The cognitive load involved in lane keeping may be high for novice drivers but can decrease with the development of driving skills (Groeger, 2000). After fully mastering the skills, experienced drivers may perform lane keeping automatically with very little conscious control and attention. One may then expect little or no effect of conversations on lane keeping performance; however, it is difficult to draw any conclusion from existing empirical findings, which are mixed with seemingly contradictory results. There have been studies showing that concurrent cognitive load improved lane keeping performance (Becic et al., 2010; Brookhuis et al., 1991; Engström et al., 2005; Kubose et al., 2006; Liang and Lee, 2010), degraded lane keeping performance (Just et al., 2008; Strayer and Johnston, 2001), or had no significant effect (Alm and Nilsson, 1995; Kubose et al., 2006; Rakauskas et al., 2004). With a closer look, we have identified several confounding or uncontrolled factors (as summarized in Table 1) that may offer explanations to these contradictory results. A confounding factor is a variable that is not included in an experimental design but may vary systematically between different experimental conditions and affect a dependent variable.

The first potential confounding factor is the strategic tradeoff between different tasks. Driving is a task that has multiple components by itself, including traffic event reaction, speed control, and lane keeping. It is possible that drivers choose different strategies and allocate attention resources differently among these components in different driving scenarios. As shown in Table 1, most of the existing experimental designs used driving tasks with multiple components, and the potential strategic tradeoffs were not controlled. A method to control such tradeoffs is to confine driving to a single-task of lane keeping only, while vehicle speed is automatically control like in cruise control modes. In addition, the potential strategic tradeoff between the driving task and the phone task also needs to be controlled, because the strategy about which task should take priority may reasonably affect the performance of each task. However, most of the existing experiments did not report the instructions regarding the assignment of priority and did not examine the performance of the speech task, both of which are necessary for improved experimental control.

The second factor is lane keeping difficulty, which is determined by both driving speed and the type of roads used in an experiment. If a road is straight and easy to follow, as in some of the previous experiments, a lane keeping task may not require frequent steering corrections, and therefore its performance may become insensitive to (i.e., not affected by) a concurrent conversation task. When a lane keeping task is very easy and the resulting mental workload is very low, the performance may also be low because of the lack of excitement and motivation (White, 1959), which may explain why lane keeping performance was found to be improved by a concurrent task in some of the previous studies. To examine drivers' performance capability, the lane keeping task in the current study needs to be sufficiently difficult. The difficulty level also needs to be consistent between the driving-only and dual-task conditions, because otherwise the change in lane keeping performance may be due to the change in lane keeping difficulty rather than the interference from the concurrent cognitive task. This requires vehicle speed to be controlled, because slower speed simplifies the lane keeping task, while faster speed makes it more difficult.

The third factor is the effort to actively process the cognitive task. Some of the previous studies did not report cognitive task performance. To properly evaluate the effect of speech comprehension on lane keeping, an experiment needs to show sufficiently high performance of the comprehension task in the dual-task condition, in order to ensure that drivers are indeed actively engaged in speech comprehension. Another issue is the type of cognitive tasks. There are mainly three types of cognitive tasks used in the previous studies: numerical calculation, speech production, and speech comprehension, which may involve different brain mechanisms. Studies have suggested that numerical calculation and speech or language skills rely on different neural bases (Gelman and Butterworth, 2005). Brain imaging results have also shown that language production and comprehension involve different brain regions (Price, 1998). These different mechanisms may not interact with the concurrent lane keeping task in the same way, which may be a cause of the contradictory results in the previous studies. Experiments are needed to examine these different types of tasks separately.

The fourth factor is motivation. Several previous studies found a counter-intuitive result: lane keeping performance was improved by a concurrent cognitive task. As discussed by Becic et al. (2010), an explanation of these results may be the lack of motivation in the driving-only condition, especially when the task difficulty was low and no incentive was used to promote high performance. A concurrent cognitive task may act as an excitement to increase drivers' motivation and effort in the dual-task condition, thereby improving performance. To examine drivers' multi-task capability, incentives