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# Driver's adaptive glance behavior to in-vehicle information systems

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ABSTRACT

The purpose of this study was to examine the adaptive behavior of drivers as they engage with in-vehicle devices over time and in varying driving situations. Behavioral adaptation has been shown to occur among drivers after prolonged use of in-vehicle devices, but few studies have examined drivers' risk levels across different driving demands. A multi-day simulator study was conducted with 28 young drivers (under 30 years old) as they engaged in different text entry and reading tasks while driving in two different traffic conditions. Cluster analysis was used to categorize drivers based on their risk levels and random coefficient models were used to assess changes in drivers' eye glance behavior. Glance duration significantly increased over time while drivers were performing text entry tasks but not for text reading tasks. High-risk drivers had longer maximum eyes-off-road when performing long text entry tasks compared to low-risk drivers, and this difference increased over time. The traffic condition also had a significant impact on drivers' glance behavior. This study suggests that drivers may exhibit negative behavioral adaptation as they become more comfortable with using in-vehicle technologies over time. Results of this paper may provide guidance for the design of in-vehicle devices that adapt based on the context of the situation. It also demonstrates that random coefficient models can be used to obtain better estimations of driver behavior when there are large individual differences.



## 1. Introduction

In-vehicle information systems (IVIS) have evolved substantially in the past decade and have gained popularity among passenger car users. In addition to navigation services, IVIS can provide drivers valuable information on traffic conditions, time delays, and alternative routes (Blanco et al., 2006; Lee, 1997; Vashitz et al., 2008). IVIS tasks that involve visual scanning require drivers to continually shift their visual attention between the roadway and the in-vehicle display. Larger lane deviations and slower responses to other vehicles on the road has been observed when drivers look away too often from the road (Dingus et al., 1989; Donmez et al., 2007). Further, off-road glances that exceed 2 s during a safety-critical event can impact lane-keeping performance (Zwahlen et al., 1987), and when the sum of off-road glances is longer than 2 s in the 5-s window prior to a safety critical event, the risk of crashes/near-crashes is elevated (Klauer et al., 2006). Horrey and Wickens (2007) showed that complex IVIS tasks significantly increased the proportion of long glances (i.e., more than 1.6 s) when compared to simple IVIS tasks, even though the mean glance duration was similar for both tasks. Therefore, designing in-vehicle displays that reduce drivers' off-road glances is essential to enhance driver safety.

### 1.1. Driver behavioral adaptation

In the transportation domain, drivers need to continually adapt their behavior to different vehicles, technologies, and roadways to reach their destination safely. Driver behavioral adaptation can be defined as the behavior that occurs following some change in the road/vehicle/user system that was not intended by the engineers and designers (OECD, 1990). After some prolonged use of IVIS, drivers may change their behavior given the continual engagement in the IVIS tasks while driving. As drivers become more familiar with the system and the tasks, their behavior may change negatively or positively. Negative behavioral adaptation refers to the phenomenon where drivers become riskier with greater engagement in systems that were intended to enhance safety. Positive behavioral adaptation occurs when drivers' safety continually improves because the system facilitates greater awareness of roadway hazards or the risks of engaging with in-vehicle technologies.

Studies show that over time, some drivers can improve lane keeping and speed control while talking on a mobile phone (Shinar et al., 2005) while others can improve their response time to hazard

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events while using an iPod (Chisholm et al., 2008). However, Strayer et al. (2011) noted that response times to novel sudden events (as encountered in actual driving) are unlikely to become better. In fact, Chisholm et al. (2008) observed worse driving performance when drivers were engaged in complex iPod tasks when compared to a driving only condition, even after prolonged use. This suggests that drivers may not be able to improve dual-task performance to a safe level even after long-term use.

IVIS tasks may lead to distraction and safety consequences when both the task and roadway demands are high and exceed the driver's capacity to respond to critical roadway events (Lee et al., 2008). Drivers may also recognize that there is an increased risk of using IVIS under more demanding driving situations and change their behavior accordingly. For example, Tsimhoni and Green (2001) have shown that drivers' mean glance duration to secondary tasks would decrease from 1.8 s on straight roads (i.e., low driving demand) to 1.2 s on curves (i.e., high driving demand). And Jamson and Merat (2005) showed that when the demand from an IVIS was high, drivers were likely to give up on the IVIS task and focus on the driving task, which resulted in less degradation in response time.

### 1.2. Individual differences on driver distraction and behavioral adaptation

There are many individual differences in terms of risk taking and multitasking abilities, and the magnitude of distraction that IVIS can pose can differ among drivers. To some degree, the "average" behavior may not be representative of the behavior of risk takers or inexperienced drivers, who are more likely to have crashes when compared to the average population.

The effects of driver distraction are often examined on sub-groups to identify differences based on age, gender, and driving experiences. Younger drivers have been shown to be more affected by secondary tasks and have higher likelihood of crash involvement as they tend to direct their attention to the roadways less effectively, neglect hazards, and are more willing to engage in distracting activities and take risks (Deery, 1999; Ferguson, 2003; Fisher et al., 2002; Williams, 2003). Wikman et al. (1998) found that young and inexperienced drivers tend to look away from the roadway with longer glances compared to others.

Even within the same demographic population, drivers can exhibit different personality traits, driving habits, and willingness to take risks, which has been shown to influence driving safety and likelihood to engage in distractions. The results from a recent study suggest that drivers texting experience has little to do with glance behavior and attention to hazards while texting and driving (Samuel et al., 2014). This may suggest that drivers' glance behavior while distracted might be more related to their willingness to take risks than merely their experiences on the secondary tasks. Studies have shown that drivers that are high sensation-seekers or have poor attitudes toward speeding are more likely to be involved in crashes (Hassan and Abdel-Aty, 2013; Ulleber, 2001). Heavy multitaskers tend to be more distracted and affected by irrelevant tasks, compared to people who do not usually multitask (Ophir et al., 2009). Although secondary tasks impact driving performance for many drivers, Strayer et al. (2011) showed that a small percentage of drivers are actually "supertaskers" whose driving performance do not appear to be as affected.

Given the differences in responses to distracting tasks, it is possible that drivers also exhibit different adaptive behavior with changing situations based on different tasks and driving demands, exposure to new systems, and extended use of IVIS. High-risk drivers are more likely to adapt and improve their driving behavior after using real-time feedback systems that warn of unsafe behavior (Donmez et al., 2010; McGehee et al., 2007). However, few studies have underscored the impact of behavioral adaptation for different IVIS tasks and driving demand.

### 1.3. Study objectives

The objective of the current study is to examine both positive and negative behavioral adaptation with respect to IVIS. The positive adaptation may occur when drivers try to compensate for the increased risk of using IVIS under high traffic demand by decreasing their glance durations off the road. Alternatively, negative adaptation is also possible with multiple exposures to the IVIS task as the drivers may actually increase their glance durations toward the IVIS for some situations. The context where each type of adaptation may occur is explored as part of this study.

## 2. Method

### 2.1. Participants

Twenty-eight drivers (14 males and 14 females) who were native English speakers and drove at least 7000 miles per year were recruited from the Seattle, Washington area. The study focused on drivers 30 years old and younger because previous studies have shown that younger drivers were more likely to have longer glances off the road while using IVIS devices (Peng et al., 2013) and tend to have more risky glance behavior (Wikman et al., 1998). The participants were further divided into two age ranges: less than 25 years old ($n = 16$) and 25–30 ($n = 12$). Other recruitment inclusion criteria include being in good general health conditions, comfortable using computers, touchscreens, and communicating via text messages. Participants were compensated for their time in the study ($20 per hour with up to 5 h of participation), and provided with parking validation if needed.

All drivers had at least a high school diploma, and on average obtained their driver's license at 17–18 years old (Table 1). Five drivers reported that they drove less than once a week, and the remaining drivers reported driving at least once weekly. For the participants between 18 and 25 years, 50% of them had at least one moving violation, and 37.5% of them had at least one crash in the past three years. For participants above 25 years old, 16.7% of them had moving violations or crashes in the past three years. However, none of the crashes were reported as being the fault of the respondent.

### 2.2. Experimental design

The study used a within-subject design with six IVIS task conditions of interest (2 task types × 3 text lengths). All task conditions were conducted under two traffic conditions and repeated over three driving sessions in 7 consecutive days (Fig. 1). The IVIS tasks and driving environment were similar to Peng et al. (2014).

The six IVIS task conditions include short (4 characters), medium (6 characters), and long (12 characters) text entry, and short (20–40 characters), medium (60–80 characters), and long (120–140 characters) text reading. For the text entry tasks, participants were asked to enter a word using a touchscreen keyboard, and for the text reading tasks, they were asked to read a non-scrolling phrase using the same screen.

There were two traffic conditions (1) without and (2) with traffic in both directions. In the without traffic condition, there was only one lead vehicle on the simulated roadway and no other vehicles. In addition to the lead vehicle, the "with traffic" condition included other vehicles passing from the opposite direction approximately every 7 s, one vehicle drove behind the driver, and two other vehicles drove on the right side of the driver (Fig. 2). There were no lead vehicle braking events in any of the driving scenarios. The simulated