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# Impact of information bandwidth of in-vehicle technologies on drivers' attention maintenance performance: A driving simulator study

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ABSTRACT

Previous research indicates that inexperienced drivers' ability to maintain their attention on the forward roadway during driving is poorer than experienced drivers, leading to more frequent, excessively long, off-road glances that elevate the risk of crashes. However, whether their poorer attention maintenance ability depends on complexities of in-vehicle technologies has been underexplored. This study directly manipulated information bandwidth (easy or complex) of an in-vehicle monitor and asked twenty-four drivers aged 18-21 to perform a visual number judgment task with either 5 digits (easy) or 11 digits (complex), during simulated driving. Participants had to verbally respond within 15 s whether each string of presented digits contained more odd or even digits. Eye movements were recorded using an eye tracker. Results show that the drivers produced a greater number of off-road glances and longer summed excess glance durations under a 1.5-s threshold when the in-vehicle task imposed greater information processing demand. In practice, designers of in-vehicle technologies should consider information-processing demands of in-vehicle tasks required by the technologies to minimize the frequency of excessively long off-road glances during driving.



## 1. Introduction

Driver inattention to the forward roadway has been consistently reported as one of the major causes of on-road crashes (e.g., Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). In 2014, there were 3179 people killed and an estimated additional 431,000 injured in motor vehicle crashes involving motorists engaging in some forms of in-vehicle tasks other than the primary driving task (National Highway Traffic Safety Administration, 2015). A naturalistic study of 42 newly licensed teen drivers, for example, shows that they were 8 times as likely to be involved in a crash while dialing a cell phone and 4 times as likely to be in a crash while texting as compared to situations in which they were not performing driving-irrelevant secondary tasks (Klauer et al., 2014).

In-vehicle technologies can detract drivers' attention away from the forward roadway and adversely impact their driving performance and related cognitive processes. Such technologies include in-vehicle route guidance or navigation systems

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(Tijerina, Parmer, & Goodman, 1998), in-vehicle infotainment systems (Lee, 2007), and in-vehicle interaction technologies such as speech or voice to text functions (Maciej & Vollrath, 2009), touch-based controls (Jæger, Skov & Thomassen, 2008), and gesture-based interfaces (Pickering, Burnham & Richardson, 2007). Infotainment systems, for example, can interfere with drivers' ability to control the vehicle at the operational level (Lee, 2007), interaction with secondary tasks involving in-vehicle technologies (IVTs) lead to compensatory speed reductions, reduced headway and increased brake pressure (Lansdown, Brook-Carter, & Kersloot, 2004), and visual-manual IVTs were associated with longer eyes-off-road times, more frequent glances at the IVT and a greater number of lane exceedances (Tijerina et al., 1998).

Drivers may temporarily shift their attention from driving to some other stimuli such as an object, person or task (Hedlund, Simpson, & Mayhew, 2005), inattention to the forward roadway identified as a key contributor to more than 65% of vehicular crashes for young drivers (McKnight & McKnight, 2003). Previous research demonstrated that drivers' ability to maintain attention on the forward roadway during driving both on road (Chan, Pradhan, Knodler, Pollatsek, & Fisher, 2010) and simulator assessments (Divekar et al., 2013), is poorer in young novice drivers than experienced drivers. For example, Chan et al. (2010) directly compared attention maintenance performance between newly licensed young drivers and experienced drivers, and showed that the young drivers executed off-road glances longer than 2 s in roughly 55% of the scenarios while the experienced drivers did only 24%. Typically, to study drivers' attention maintenance performance, researchers measure off-road glance duration between the time of driver's eyes leaving the forward roadway and that of returning to the forward roadway, and analyze proportions of off-road glances longer than some thresholds. One common threshold value is 2 s, as off-road glances longer than 2 s can pronouncedly elevate the risk of a crash (e.g. Klauer et al., 2006, 2015), or one may analyze off-road glance distributions across multiple threshold levels for more fine-grained analysis (Yamani, Horrey, Liang, & Fisher, 2015; Bicaksiz, Palmer, Yamani, & Samuel, 2017).

Pollatsek, Divekar, and Fisher (2012) suggested a novel measure of glance behavior, *summed excess glance durations*, during a given time interval in which the driver is trying to complete a secondary task while driving. The excess glance duration is defined as:

1. If glance duration $\leq$ threshold, then excess glance duration = 0, else
2. If glance duration > threshold, then excess glance duration = glance duration − threshold.

Then, the excess glance durations are summed for each participant in each experimental condition. This measure thus provides an estimate of the likelihood of crash by weighting on off-road glance durations longer than a threshold (e.g., 2.0 s), based on the assumption that such especially long glances are riskier than shorter ones, and therefore is a more sensitive estimate of crash risk predicated on unusually long glances greater than the aggregated proportion of off-road glances at a specific threshold value.

While ample evidence indicates poorer attention maintenance performance among young novice drivers compared to experienced drivers, a wide variety of the in-vehicle tasks used in the previous research such as finding a street on a map or counting change masks the locus of the effect. That is, do drivers make excessively long off-road glances due to elevated difficulty in peripheral processing (controlling a hand to pick up a map and maintain it within an area of their vision) or central information processing (visually scanning a map to locate to a target street)? To address this question, Yamani et al. (2015) analyzed visual demands of the previously used in-vehicle tasks and found that the in-vehicle tasks with higher levels of visual demand (e.g., map search task) produced greater proportion of glances longer than 2 s than those with less visual demand (e.g., coin search task). However, previous work on attention maintenance (Pradhan et al., 2009; Divekar et al., 2013; Yamani, Samuel, Knodler, & Fisher, 2016) employed a variety of real-world tasks (such as tuning the radio, searching for change in the glove box, searching a street on a navigation map, activating the emergency flashers/high beam, searching for a CD in a case, etc.), which limited the experimental control of visual demand and the manipulation of information bandwidth.

Following early models on supervisory control (e.g., Carbonell, 1966; Senders, 1964), the SEEV model (Wickens, Goh, Helleburg, Horrey, & Talleur, 2003) predicts that observers are more likely to look at an information channel that provides more task-relevant information (i.e., high information bandwidth). The SEEV model assumes that an operator's visual attention is determined by four independent factors, Salience, Effort, Expectancy, and Value. Briefly, salience refers to the extent to which basic visual features attract attention within a display (Itti & Koch, 2000) and effort means the physical cost of scanning between different visual spaces. Expectancy grows as levels of uncertainty increase at task-relevant information sources (e.g., Senders, 1964) and value mirrors criticality of information perceived by the operator in order to successfully complete the task. Within this framework, we manipulated drivers' expectancy by requiring them to process information of different bandwidth within the simulated in-vehicle display while holding the other parameters constant. The SEEV model thus predicts that a driver distributes more visual attention to task-relevant information sources of high expectancy, or of greater levels of uncertainty (e.g., Senders, 1964). Drivers may execute especially long off-road glances when performing some in-vehicle tasks partly because the primary source of task-relevant information is visual (e.g., map search).

The aim of the current study is to examine the effects of information bandwidth of an IVT number judgment task adapted from Horrey, Wickens, & Consalus (2006) on drivers' attention maintenance performance during simulated driving (Pollatsek et al., 2012). While driving in a simulator, we asked drivers to perform the IVT number judgement task: Each driver was asked to decide whether a random string of digits (5 digits vs. 11 digits) presented on the IVT monitor placed to the right