Using a Vibrotactile Seat for Facilitating the Handover of Control during Automated Driving

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ABSTRACT

Studies have found that drivers tend to neglect their surrounding traffic during automated driving. This may lead to a late and inefficient resumption of control in case of handover of the driving task to the driver. The authors evaluated the effectiveness of a vibrotactile seat displaying spatial information regarding vehicles approaching from behind to enhance the driver preparedness to the handover of control. A simulator experiment, involving 26 participants, showed that when drivers were required to regain control of the vehicle, having a vibrotactile seat improved speed and efficiency of reactions in scenarios requiring lane changing immediately following a handover. In addition, eye-tracking analysis showed that the participants had more systematic scan patterns of the mirrors in the first two seconds following the transition of control request. Interestingly, this effect exists in spite of the finding that during automated driving mode, having a vibrotactile display led to fewer glances at the road.

KEYWORDS

Automated Driving HMI, Driving Simulator, Eye Tracking, Handover of Control, Haptic Feedback, Vibrotactile Displays, Vibrotactile Seat

INTRODUCTION

Self-driving vehicles represent a potentially disruptive and beneficial change to the way in which we travel. This new technology has the potential to increase safety on public roads, decrease traffic congestion and enhance driver satisfaction (Anderson et al., 2014). Thus, it is not surprising that leading automotive makers and major corporations have been announcing plans to introduce self-driving vehicles in the next decade (Litman, 2014). However, despite promising technological breakthroughs in the field of automated driving, the reliability of these technologies still largely depends on external conditions such as the road type, weather and daylight conditions. It is therefore likely that in the near future vehicles will only have limited self-driving capabilities. In semi-automated vehicles, the vehicle will be in full control of the driving task only under certain traffic and environmental conditions, otherwise the driver is expected to be in control of the driving task. According to NHTSA (2013) and SAE (2014) levels of automations definitions, conditionally-automated driving (level 3 automation)

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is a setting in which drivers rely on the vehicle to monitor for changes that will require them to regain control. The driver is still expected to be available for occasional control during automated mode, and must be prepared to resume full responsibility for driving within an acceptable amount of time.

The requirement to prepare the driver for the handover of control raises a number of key issues. Previous studies found that drivers’ awareness of surrounding traffic is relatively low in automated driving situations because they allocate less attention to the road and more attention to other tasks which are non-driving related such as watching movies or texting (Llaneras, Salinger & Green, 2013; Carsten et al., 2012). In the aviation domain, a similar phenomenon, termed automation complacency, has also been reported in studies examining vigilance and monitoring in automated aviation environments. Automation complacency refers to the finding that flight crews tend to rely fully on the automated system for flight tasks and pay less than sufficient attention to monitoring these tasks (Parasuraman, Molloy & Singh, 1993; Parasuraman & Manzey, 2010). The implication is that drivers’ responses will be delayed and insufficient when requested to resume control, since they will have to scan the entire traffic environment before making an appropriate action.

The current study tested a solution to increase driver awareness to surrounding traffic during automated driving. We examined a system that projects continuous information about the relative spatial position of approaching vehicles onto a vibrotactile display embedded in the back of the driver’s seat. We predicted that when drivers would be asked to regain control of the vehicle they would do so more quickly and efficiently since they would already have a high level of awareness of vehicles in their surroundings. The focus on the haptic modality is based on a growing body of literature that has established the potential advantages of providing driving-related information via the haptic modality (Petermeijer, de Winter & Bengler, 2015). Several studies have examined the usefulness of vibrotactile interfaces as a way to project spatial and temporal information. These studies have found that vibrotactile displays consisting of a number of vibrating elements are quite effective and intuitive in terms of presenting directional information such as sequence and location (Tan et al., 2003; Van Erp & Van Veen, 2004). Van Erp and Van Veen (2001) presented navigation directions such as right turn and left turn to drivers either as a visual display or a vibrotactile seat display. The participants reported lower levels of cognitive workload and exhibited better response times for the vibrotactile navigation display than without it. Terrence, Brill and Gilson (2005) examined the effect of alert modality on the participants’ ability to localize alerts. The results indicated that tactile feedback robustly improved both localization accuracy and reaction time as compared to the auditory modality.

Other studies found that using haptic displays to present warning signals to drivers are more effective compared to equivalent warning signals presented in other sensory modalities (Fitch et al., 2007; Ho, Tan, & Spence, 2005; Meng & Spence, 2015; Prewett et al., 2012). Their explanation is that the sense of touch is less involved in driving and other secondary tasks in which drivers engage, such as talking on the phone or listening to radio, and therefore is a more suitable channel for providing information. For instance, it has been shown that auditory collision warning signals are rendered ineffective by the addition of a phone conversation whereas tactile warnings still produced significantly faster reaction times compared to a no-warnings condition (Mohebbi, Gray & Tan, 2009). This is also applicable to automated driving situations, since drivers are likely to be involved in non-driving activities that tap the auditory or visual modalities. Vibrotactile interfaces may enhance the driver experience by delivering a great deal of information rapidly and simultaneously compared with other modalities (Lee, Hoffman & Hayes, 2004).

The automotive industry also presents interest in vibrotactile interfaces, which are already being used to alert drivers to safety discretions such as lane departure or potential collisions. For example, the 2013 Cadillac XTS integrated haptic feedback into its collision mitigation and avoidance systems, where a haptic warning is provided in the appropriate location within the seat (cushion and back), spatially mapping a direction of a collision threat to a point in the seat (Capp, 2012).

The present study examined whether providing continuous tactile information using a vibrotactile seat increases drivers’ awareness of the surrounding traffic and consequently leads to faster and more
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