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Assessing the effects of auditory-vocal distraction on driving performance and physiological measures using a driving simulator

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A B S T R A C T

In this research, a driving simulator experiment with physiological sensors is conducted to quantify the effect of an increase in workload on driving performance and physiological state in the presence of particular road situations. A secondary cognitive task with multiple levels of difficulty designed to simulate auditory-vocal distraction is added to the primary driving task. Driving performance and physiological indices such as heart rate and skin conductance level are monitored throughout the experiment. Nonparametric statistical tests are used to test the effect of the secondary task at three different road situations frequently encountered in an urban context. It is hypothesized that an increase in workload leads to variations in the driver's physiology as well as decrement in his/her driving performance. Results of the study showed that the driver adopts a regulatory behavior at the operational level (e.g., reduces the speed) in order to allow the performance of the additional task and driving at the same time. The effect of the regulatory behavior is minor on the longitudinal and lateral control measures (e.g., the speed, the pedal depression, the lane position). However, the impact on the reaction time can have important implications for road safety. An increase in the heart rate and skin conductance level reflects the increase in the cognitive workload when performing the secondary task. No major differences are found in terms of the driving performance and the physiological measures across the difficulty levels of the secondary task at the three considered road situations. In order to maintain control of driving, particularly at the high levels of difficulty, some subjects are found to pay less attention to the secondary task and shift their focus towards the primary driving task. The study highlights the advantage of implementing the driver's cognitive workload measures in the development, design, and assessment of effective in-vehicle safety systems.

1. Introduction

Distraction has been identified by the National Highway Traffic Safety Administration (NHTSA) as an influential factor leading to recognition impairment while driving (NHTSA, 2008), and it is therefore considered a "risky behavior" (NHTSA, 2016). Distraction is a deviation in attention (Beratis et al., 2017), away from the primary task of driving, provoked by an

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internal or external stimulus (e.g., event, activity, object, person) causing a delay in the recognition of the information required for safe driving (Beanland, Fitzharris, Young, & Lenné, 2013; Chan & Singhal, 2013; Kaber, Liang, Zhang, Rogers, & Gangakhedkar, 2012; Stutts, Reinfurt, Staplin, Rodgman, 2001). In 2010, NHTSA addressed several variables related to distraction from internal sources and cognitive activities. Results showed that conversing with passengers was the most frequently recorded internal source of distraction. In this context, the present research focuses on auditory-vocal distraction while driving arising from cognitive workload.

Cognitive workload is directly related to the proportion of "mental capacity" spent by the human to execute a task (Brookhuis & de Waard, 2010). Considered as a latent form of distraction, workload is controlled by the context that defines the driver state. An increase in workload results in a negative type of stress known as distress. When this workload is excessive, the resulting stress is associated with road accidents (Brookhuis & de Waard, 2010). This study therefore aims at analyzing workload while driving and its impacts on driving performance with an eye towards measures that may mitigate the impacts of distraction on road safety.

1.1. The driver cognitive workload

The driver cognitive workload is defined in Brookhuis and de Waard (2010) as arising from the demand of the driving task and is classified into two types: (1) underload that contributes to impairment in both attention and alertness, and (2) overload that leads to distraction and lack in time and capacity required to process the information. Recent research work (Zhou, Yu, & Wang, 2016) studied the effect of compensatory beliefs in changing the driving behavior to self-regulate the increased demand from additional tasks at different levels. For instance, at the strategic level, the driver decides not to perform a secondary task (e.g., using a mobile phone), at the tactical level the driver regulates and adjusts the engagement time with the secondary task, and at the operational level, the driver reduces the speed when performing the secondary task.

1.2. Measurement approaches

Workload has been measured subjectively by means of self-reports (questionnaires) and by objective assessments such as driving performance and physiological measures obtained through sensors (Williamson, 2009). Miller (2001) reported that the primary task of driving can be evaluated through performance measures such as steering wheel movements (e.g., wheel reversals) and speed, while physiological measures can be classified into five areas: cardiac activity (e.g., heart rate, heart rate variability, blood pressure), respiratory activity, eye activity (e.g., eye blink rate and interval of closure), speech measures (e.g., pitch, rate), and brain activity (e.g., electroencephalogram, electrooculogram). Physiological activity naturally arises when additional workload is exerted leading to variation in physiological measures such as heart rate and skin conductance (Brookhuis & de Waard, 2011; Engström, Johansson, & Östlund, 2005; Hajek, Gaponova, Fleischer, & Krems, 2013). Mehler, Reimer, & Coughlin (2012) observe that physiological disturbances occur when the human body mobilizes resources in order to respond to the task demand and operate. Thus, monitoring physiological indices would give insight into workload magnitude (Mehler, Reimer, Coughlin, & Dusek, 2009). Under conditions of stress, anxiety, or workload increment, heart rate (in heartbeats per minute) increases, while it decreases with relaxation (Mehler, 2009; Reimer, Mehler, Pohlmeyer, Coughlin, & Dusek, 2006). Also, in response to stress, the sweat gland activity and the skin conductance level (also referred to as electrodermal activity) increase (Mehler, 2009).

A number of studies have collected physiological data to measure workload in the driving context. In Healey and Picard (2005), electrocardiogram, electromyogram, skin conductance, and respiration rate measures were continuously collected during real trips conducted by subjects in the Greater Boston Area. Results showed that heart rate metrics and skin conductance were the most correlated measures with the stress level while driving. Sensitivity of physiological signals as measurements of cognitive workload was inspected in Mehler et al. (2009) in conjunction with a driving simulator experiment by introducing a secondary cognitive "n-back" task (a delayed digit recall task). Physiological data including heart rate, skin conductance, and respiration rate, in addition to driving performance measures were collected. Results showed that the three collected physiological measures can provide indications of differences in the relative workload assigned to subjects prior to, or in absence of, significant performance level decrements.

1.3. Study motivations and objectives

The aim of this research is to quantify the effect of an increase in the cognitive workload arising from a secondary auditory-vocal task with multiple levels of difficulty. It utilizes a driving simulator experiment and physiological sensors, and quantifies the effect of the secondary task on the driving performance and physiological measures (heart rate and skin conductance) at three frequently encountered road situations: sudden crossing of pedestrians, sudden truck stop, and traffic light. A particular research question of interest is to identify the regulatory behavior of the driver in response to increasing levels of difficulty of the secondary task, i.e., to what extent drivers pay attention to the secondary task versus the primary driving task. As such, this study differs from previous research work (e.g., Mehler et al. (2009) and Niezgoda, Tarnowski, Kruszewski, and Kamiński (2015)) that has investigated the effect of an increase in workload in the absence of particular road events. Studying the effects of driving distraction particularly at situations in an urban context is important as the