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How we can measure the non-driving-task engagement in automated driving: Comparing flow experience and workload

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ABSTRACT

In automated driving, a driver can completely concentrate on non-driving-related tasks (NDRTs). This study investigated the flow experience of a driver who concentrated on NDRTs and tasks that induce mental workload under conditional automation. Participants performed NDRTs under different demand levels: a balanced demand–skill level (fit condition) to induce flow, low-demand level to induce boredom, and high-demand level to induce anxiety. In addition, they performed the additional N-Back task, which artificially induces mental workload. The results showed participants had the longest reaction time when they indicated the highest flow score, and had the longest gaze-on time, road-fixation time, hands-on time, and take-over time under the fit condition. Significant differences were not observed in the driver reaction times in the fit condition and the additional N-Back task, indicating that performing NDRTs that induce a high flow experience could influence driver reaction time similar to performing tasks with a high mental workload.

1. Introduction

Since the introduction of adaptive cruise control (ACC) in the 1990s, a variety of technologies have been introduced to increase the level of automation in vehicle driving (Bishop, 2005). With the addition of various functions related to driving safety in the current advanced driver assistance system (ADAS), automated driving at Society of Automotive Engineers (SAE) Level 2 is now possible. The purpose of ADAS was to support driving such that driver error would be reduced or even eliminated, while enhancing efficiency during traffic and transport (Brookhuis et al., 2001). The concept of driver support has often been associated with bypassing human control inputs in an effort to eliminate driver error (Banks and Stanton, 2016). The early functionality of tools such as ACC took the form of a system taking over some of the driver's tasks; the functionality of such tools has since evolved into an automated system that takes over multiple driving tasks (NHTSA, 2013). In automated driving, the human role shifts from that of an active driver to that of a system supervisor who monitors the situation and takes over control of the vehicle in certain situations. When the vehicle becomes fully automatized, the driver will be expected to assume the role of a passenger (Diels and Bos, 2016). Therefore, as the level of vehicle automation increases, the driver will be excluded from the primary role of driving.

The introduction of automated driving has also changed the situation for drivers performing NDRTs. In manual driving, the driver only performed additional secondary tasks as needed while mainly focusing on the primary task of driving. During this process, driver distractions occurred, causing problems in reaction time and driving performance (Merat and Jamson, 2009; Young and Stanton, 2007). However, with automated driving, the driver can now focus primarily on performing NDRTs (Carsten et al., 2012; Saxby et al., 2013). Thus, fundamental changes are expected in human–vehicle interaction (HVI), apart from the safety and convenience that can be achieved by the introduction of automated driving.

Previous studies related to manual driving have mainly analyzed the effects of driver performance of secondary tasks on the driver's mental workload, response time, and situation awareness. Several studies have shown that the driver's mental workload negatively affect the driver reaction time and situational awareness. On the other hand, studies related to automated driving have mainly focused on the performance and safety aspects of adopting this technology. For example, studies have been conducted on changes in driving performance with the adoption of automated driving functions (Merat et al., 2014). One comparative study examined the changes in the driver's state, such as changes in driver's attention and situation awareness, for manual and automated driving at SAE Levels 2 to 4 (Endsley and Kaber, 1999). However, in the initial studies related to automated driving, the experiments were conducted with drivers monitoring the driving situation without performing any particular secondary tasks. Therefore, these previous studies lacked realism and were limited by employing artificial

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Fig. 1. Setup of the fixed-based driving simulator.

or standardized tasks as part of NDRTs. In fact, when a naturalistic task is used as a secondary task, a difference in the results of experiments has been identified (Shinar et al., 2005). Thus, research on driver's state when performing naturalistic NDRTs in automated driving situations is lacking.

In manual driving, the driver simultaneously performs both driving and secondary tasks. Evaluation of the driver's mental workload in the context of these dual tasks has been an important research topic. Performing dual tasks affects the driver's mental workload and causes driver distraction. However, in a high-level automated driving situation where there are fewer restrictions on the driving task and active driving situation monitoring is not required, the driver can concentrate on performing NDRTs. In this case, the question arises as to whether analyzing the driver's state during automated driving using the same technique used in manual driving would be appropriate; in other words, would analyzing only the mental workload or situation awareness of the driver be insufficient?

The situational characteristics of automated driving, which can be accomplished through the absorption in a particular task, can be explained by the term "flow." Csikszentmihalyi (1975) proposed the term flow to describe intense engagement or complete absorption in a task (McQuillan and Conde, 1996). Studies on flow and its benefits have been conducted in a variety of contexts, such as reading, media use, and leisure time (Csikszentmihalyi and LeFevre, 1989; McQuillan and Conde, 1996; Sherry, 2004). Tozman et al. (2015) reported that flow could occur when driving a vehicle via a driving simulator. They used experimental settings that manipulate a difficulty level to induce boredom, flow, and anxiety. In their experimental design, a fit condition was set to induce flow through the demand level, which was designed to fit the participant's skill level. The other levels were low (boredom condition) and high (anxiety condition) demand levels. Thus, this study was planned to analyze the driver's state in automated driving by evaluating the flow experience and mental workload of a driver performing NDRTs, and also analyze the relationship between the reaction time of the driver and take-over requests (TOR).

This study is based on the assumption that the mental workload and flow state affect the reaction time of the driver. Mental workload refers to the amount of attentional resources required to complete a task (Wickens, 2002; Young and Stanton, 2004). Mental workload can impact the driver's attentional resource capacity and lead to a decrease in performance. Therefore, increasing levels of difficulty in mental tasks will result in performance deterioration (Wickens, 2008). Flow is a state of pleasantness, where a person feels in control and focused, and a balance exists between the demands of a task and the skills of the person. The flow state requires similar attentional resources as mental workload (Connolly, 2007). Based on this definition, we attempt to analyze the relationship between the flow experience and driver reaction time.

This study investigates how the drivers' subjective states affect the driver's reaction time upon a TOR for the control of a vehicle. Thus, the objectives of this study are as follows: 1) to assess the flow experience and mental workload of a driver performing tasks with different demand levels, 2) to analyze the reaction time of the driver performing NDRTs in simulated automated driving, 3) to investigate the relationship between the flow experience and reaction time of driver, and 4) to investigate the difference between the N-Back task and other tasks.

2. Experiment 1

Experiment 1 was designed to assess the flow experience and the mental workload of a driver performing NDRTs and additional N-Back tasks.

2.1. Participants

Thirty-two participants (male = 19, female = 13) with ages ranging from 23 to 39 (M = 28.22, SD = 4.434) participated in *Experiment 1*. All participants had a driver's license and drove regularly (M = 2.78 times per week, SD = 2.362). No participants had previous experience with automated driving. In particular, we recruited participants with corrected visual acuity of 0.1. For the participants who wore glasses, only those with a corrected visual acuity of more than 0.1 when wearing contact lenses were qualified for the study. The limits on the corrected visual acuity were designed to eliminate risk factors that might hinder the experiment, especially during the use of eye-tracking devices in *Experiment 2*.

2.2. Materials and apparatus

2.2.1. Driving simulator

A fixed-based driving simulator was designed to provide the participants with an environment similar to the driver's seat of a real vehicle (Fig. 1). The driving simulator consisted of a desktop computer, simulation software (City Car Driving v1.5), driver's seat, steering wheel, and foot pedals (Logitech Force Feedback Racing Wheel). Three liquid crystal display (LCD) monitors (27 inches) were arranged in front of the driver's seat to provide a surround panoramic view for the driver during the task. The driver's seat, which was connected to a power supply (12 V), was adjusted to fit the participant's body. Moreover, a tablet (iPad Air 2, 9.7 inches) was placed at the center fascia on the right side of the steering wheel so that the participants could perform the tasks required to be done during the experiment. This driving simulator was set to provide conditionally automated driving at SAE Level 3: the vehicle will fully take over the driving responsibilities under restricted conditions, but the human driver is expected to take over when the automated driving system asks for it (Committee, 2014). Therefore, participants can have their hands off the steering wheel and eyes off the road when performing tasks.