EFFECTS OF AUTOMATION AND TAKEOVER TIME BUDGET ON YOUNG DRIVERS' PERFORMANCE AND WORKLOAD

A Thesis

by

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ABSTRACT

Young drivers are involved in higher number of crashes compared to other age groups. Highly automated vehicles are expected to improve traffic safety and reduce human errors. However, there are still concerns about the effects of automation and takeover time budget (TOTB) on driver performance and workload. The objective of this study was to assess the effects of unreliable automation, non-driving related tasks (NDRTs), and TOTB on young drivers' takeover performance and workload when faced with critical incidents. Twenty-eight young drivers participated in a within-subject driving simulation study. Driver workload was measured using physiological measures including percentage change in pupil size and blink rate, subjective measurement of driver activity load index, and secondary task performance. Driver takeover performance was measured using maximum lateral acceleration, minimum time to collision, and takeover time. Results suggested that when faced with critical incidents, 8s of TOTB might be sufficient for young drivers to safely take over the control of the vehicle. However, providing longer TOTBs (i.e., 10s) can further reduce drivers' mental workload. Performing a demanding NDRT significantly impaired drivers' takeover performance and increased their workload. However, the results regarding the effect of automation on drivers' mental workload and takeover performance were inconclusive, which might be due to short observation periods, and individual or recall biases. The findings of this study can provide guidelines for vehicle manufacturers to improve the design of highly automated vehicles, which can ultimately improve driver performance and reduce workload.

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1. INTRODUCTION

Young drivers are involved in significantly higher number of crashes than middle-aged or older drivers (AAMI, 2012; NHTSA, 2015; Scott-Parker & Oviedo-Trespalacios, 2017). According to the national highway traffic safety administration (NHTSA), young drivers were involved in more than 45 percent of all the crashes from 2016 to 2018 (NHTSA, 2018). From a behavioral viewpoint, young drivers are specifically identified as a vulnerable group due to their unsafe driving behaviors (Massie et al., 1995). Studies have shown that young drivers' involvement in risky driving behavior such as self-assertive driving, excessive driving speed, and rule violations is a major contributing factor to their higher rate of crash related injuries and deaths. In addition, young drivers were found to underestimate the potential danger of driving situations and overestimate their driving skills (Machin & Sankey, 2008). Distracting in-vehicle technologies are also a particular hazard to young drivers (Lee, 2007; McGehee et al., 2007; Neyens & Boyle, 2007). However, young drivers are more likely to be engaged in secondary tasks when driving as compared to other age groups (Olsen et al., 2005). Studies have found that young drivers have limited ability to effectively direct their attention to the roadway (Fisher et al., 2002), scan a smaller part of the driving environment, and make longer fixations as compared to the experienced drivers (Mourant & Rockwell, 1972). Klauer et al. (2014) reported that young drivers are increasingly engaged in unsafe secondary tasks during the first 18 months of driving, ranging from 7% to 14% of their driving time depending on the type of secondary task. For example, in a naturalistic driving study by Goodwin et al. (2012), novice young drivers were engaged in different secondary tasks including wireless device use (6.7% of driving time), adjusting controls

(6.2%), personal hygiene (3.8%), and eating/drinking (2.8%). In a study by O'Brien et al. (2010), 80% of high school age adolescents reported that they talked on a phone at least once while driving. In another study, 72% of young drivers reported having texted when driving in the past 30 days (Ehsani et al., 2013). One of the motivations for developing automated vehicles is the freedom such automation provides in performing secondary tasks such as checking emails, having interactions with the phone, and/or using in-vehicle entertainment systems (Gibson et al., 2016) although there are still some concerns about the effects of automation on drivers and other traffic participants.

1.1. Highly automated driving

Based on the definition by the NHTSA, vehicle automation is classified in six levels (levels 0–5). Highly automated driving (HAD) refers to limited self-driving automation (NHTSA level 3 of automation), which can support the driver with longitudinal and lateral vehicle control but the driver must be ready to take back the control at any time with the automated driving system's request (NHTSA, 2013; Yoon et al., 2019). Driving in the HAD mode has been found to enhance traffic efficiency, reduce the probability of human errors, and improve driving safety (NHTSA, 2018). Recent studies suggested that autonomous vehicles would decrease the number of road crashes and fatalities by 25% to 90% (Anderson et al., 2014; Bansal et al., 2016; Litman, 2017). However, there are still problems associated with HAD that have negatively impacted driver behavior and acceptance of the technology (Xu et al., 2018). For example, after about 14 months of google automated cars testing, it was found that the self-driving cars were 'out of automated status' 272 times, and there were 69 situations in which drivers preferred to cancel the automation mode (Google, 2015).

HAD systems allow drivers to disengage from the driving task and instead perform non-driving related tasks (NDRT) (e.g., interacting with their phone) as they support both longitudinal and lateral control (NHTSA, 2013). While drivers in the HAD condition are not expected to be constantly and fully aware of their driving environment, they are required to take over the manual control of the vehicle in case of automation failures (NHTSA, 2013). When the HAD system prompts a takeover request, the drivers should take over the manual control of the vehicle by (1) shifting their attention to the road; (2) cognitively processing the vehicle situation and making a decision; (3) repositioning themselves to get back to the control loop; and (4) implementing the takeover reaction via steering wheel and/or brake pedal (Gold et al., 2013; Petermeijer et al., 2017; Petermeijer et al., 2015; Zeeb et al., 2015). Thus, several studies were conducted to understand how drivers manage these so-called take-over situations (Damböck et al., 2013; Gold et al., 2015; Gold et al., 2013; Hergeth et al., 2015; Louw et al., 2015; Radlmayr et al., 2014; Wiedemann et al., 2015).

A HAD system should be able to detect the system's boundaries such as missing lane markings, lead vehicles, construction zones, traffic obstacles, and heavy weather conditions. If the system detects the boundaries, it asks the driver to take over the manual control of the vehicle within a sufficient takeover time budget (TOTB)—the time between the event onset and an impending crash. It is important that the driver is informed of this transition early enough to avoid potentially hazardous situations and guarantee a safe take-over process (Lorenz et al., 2014). To improve usability and acceptance of HAD systems, sufficient TOTB should be set to allow safe and comfortable takeover (Gold et al., 2013). Figure 1 shows the sequence of a takeover process with a transition from the HAD mode to the manual mode.

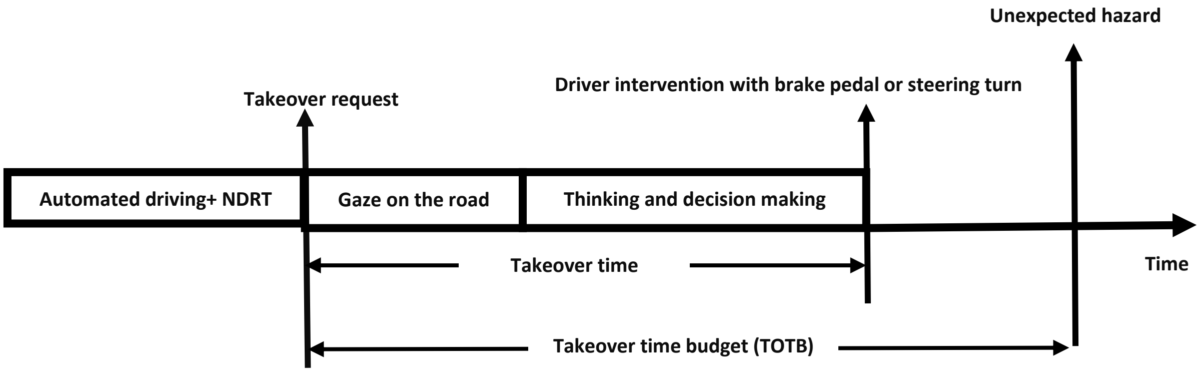

Figure 1: Takeover process

1.2. Effect of automation on driver takeover performance and workload

Driver takeover performance can be impacted by several factors including level of automation (LOA) (Louw et al., 2015). A literature review study by Son et al. (2018) indicated that takeover reaction time, minimum time to collision (TTC), maximum lateral acceleration, deviation of the lane position, and driver gaze behaviors are frequently used dependent variables to measure driver takeover performance. Previous studies found that use of automation increases drivers' reaction time to critical situations, especially when they are engaged in a NDRT (Gold et al., 2015; Happee et al., 2017; Louw et al., 2015; Wu et al., 2019). For example, Louw et al. (2015) suggested that drivers had slower reaction to the hazards in the HAD condition as compared to the manual driving condition. One possible explanation for the longer reaction time is because drivers of highly automated vehicles are not required to be permanently aware of the driving task (Jamson et al., 2013). In addition, some studies found an increased interaction with secondary tasks in the HAD mode as compared to the manual driving (Carsten et al., 2012; Wandtner et al., 2018b). Takeover performance significantly reduced when drivers were distracted by a NDRT in the HAD mode as compared to the manual driving mode or the HAD condition without a NDRT

(Merat et al., 2012). In another study, Merat et al. (2014) found that when drivers are distracted by a NDRT, they found taking over the vehicle control and lane changing more challenging in the automated driving condition as compared to when the secondary task is performed in the manual driving mode. Although some studies such as Körber et al. (2015) investigated the effect of driver age on takeover performance in the HAD condition, their study was limited to specific traffic situations, did not measure driver workload, and did not include effects of TOTB on driver performance. Körber et al. (2015) did not find any significant effect of age on takeover reaction time but found that older drivers maintained a longer TTC and therefore, exhibited a safer takeover. The findings of these investigations provided motivation for assessing the effect of automation on young drivers' takeover performance and workload.

Automated vehicles are expected to reduce workload—referring to the amount of information that an individual's working memory can hold at one time (Fraser et al., 2015)—as compared to manual driving since the driver is not required to control the vehicle. However, unless the driving task is fully automated, lower levels of automation such as HAD might increase workload since the driver has to remain attentive to reclaim manual control if required (Banks & Stanton, 2016). For example, Banks and Stanton (2016) found that drivers experienced a higher workload in the HAD condition as compared to the manual mode since the driver's role switches from an active road user to a passive monitor when changing from manual driving mode to the HAD condition. However, other studies found that highly automated vehicles reduce drivers' workload (Chen et al., 2019; Hjälmdahl et al., 2017; Large et al., 2017; Park et al., 2019). For example, in a driving simulation study and using subjective measures of cognitive workload, de Winter et al. (2016) reported that participants experienced a relatively higher overall workload in the manual mode as compared to the HAD. Some other studies found no effect of automation on drivers' cognitive workload. For example, Wille et al. (2008) did not find any significant difference in the subjective workload experienced by truck drivers in automated versus non-automated trucks.

Winter et al. (2016) conducted a driving simulator study to investigate the effect of automation on driver's workload measured by secondary task performance and NASA Task Load Index (TLX). Results revealed that automation generally improved secondary task performance and reduced self-reported physical demand and effort compared to manual driving. However, driving with imperfect automation was frustrating to drivers. Winter et al. (2016) study had several limitations. First, drivers were asked to perform an artificial secondary task, which might have limited generalizability to real in-vehicle tasks (e.g., route navigation). Second, the drivers were not provided with any training in the use of automation and had to learn how to respond to critical incidents during the experiment itself. Furthermore, subjective workload measurement techniques might suffer from individual and recall biases and cannot capture subtle differences in workload during takeover situations.

1.3. Effect of takeover time budget on driver takeover performance and workload

Although many studies investigated the effect of TOTB on driver takeover performance, there are some discrepancies in their findings. While some studies proposed that 5s of TOTB is sufficient for drivers in the HAD condition to successfully take over the control of the vehicle (Mok et al., 2015), other studies suggested that even 7 seconds TOTB is not enough to have a safe takeover performance (Gold et al., 2013). Gold et al. (2013) compared driver performance with 5s and 7s of TOTB using a driving simulator-based experiment and found that drivers could make decisions faster and react more quickly with shorter TOTB (i.e., 5s of TOTB), but the takeover quality in terms of maximum lateral acceleration and shoulder check (awareness of the situation) was worse. A more recent study compared driver takeover performance with 3, 6, 10, 15, 30, and 60s. It found that drivers needed at least 10s to successfully take over the vehicle control from the automated mode to the manual mode (Wan & Wu, 2018).

An insufficient TOTB may increase driver workload, generate erratic driver reaction, and impair driver trust (Saffarzadeh et al., 2013). However, no study investigated the effect of TOTB on driver cognitive workload. This might be due to the fact that a majority of studies in this domain used subjective measures of workload (Eriksson & Stanton, 2017a; Large et al., 2017; Schwalk et al., 2015; Wu et al., 2019; Yoon & Ji, 2019), which were not sensitive to capture the subtle differences in TOTBs (Naismith et al., 2015). To address this issue, this study used a combination of eye-tracking and subjective measures of workload to capture the effect of different TOTBs on driver workload. Du et al. (2020) designed a driving simulator study to measure the effect of TOTB on driver secondary task performance. They compared the effects of 4s and 7s of TOTB and did not find any significant difference in secondary task accuracy and completion time. However, the range of TOTBs in Du et al.'s study was limited, and therefore, in our study a wider range of TOTBs (i.e., 5s, 8s, and 10s) was investigated.

1.4. Effect of non-driving related tasks

With higher levels of automation in the vehicle, drivers have tendency to get engaged in NDRTs. Several studies focused on the effect of secondary tasks on driver performance or workload (Bueno et al., 2016; Dogan et al., 2019; Eriksson & Stanton, 2017b; Gold et al., 2015; Happee et al., 2017; Vogelpohl et al., 2019; Vogelpohl et al., 2018; Wandtner et al., 2018a; Wu et al., 2019; Yoon & Ji, 2019; Yoon et al., 2019; Zeeb et al., 2016). Results of these studies suggested that drivers had significantly longer reaction time in takeover situations when they were engaged in a NDRT as compared to driving without any secondary task (Eriksson & Stanton, 2017b; Vogelpohl et al., 2019; Yoon et al., 2019). While some studies found that visual-auditory tasks (e.g., watching a video) led to longer takeover time as compared to the visual-motor tasks (e.g., smartphone interaction) (Yoon & Ji, 2019), other studies suggested opposite findings (Yoon et al., 2019). In addition, the findings suggested that drivers who were engaged in visual-motor NDRTs experienced higher levels of workload as compared to the drivers who were engaged in visual-auditory NDRTs (Wandtner et al., 2018a; Yoon & Ji, 2019). Drivers in these studies included a mix of young and middle-aged drivers (age range between 19 and 57 yrs.), which might limit their generalizability to young drivers. In addition, the NDRTs in previous investigations presented natural activities that drivers might engage while driving under the HAD condition (e.g., reading a newspaper, watching a video, interacting with cell phone). This study was focused on the effect of a complex NDRT, which imposed both visual and cognitive load and required the use of side screen display implemented in the vehicle (similar to in-vehicle displays in highly automated vehicles).

1.5. Problem statement, research objectives, and hypotheses

Young drivers are involved in significantly higher number of vehicle crashes as compared to middle-age and older driver (NHTSA, 2015; Scott-Parker & Oviedo-Trespalacios, 2017; Williams, 1996). HAD is expected to improve traffic safety and decrease the probability of human errors. However, there are still concerns and challenges regarding the effects of automation and TOTB on driver takeover performance and workload. This study aimed at closing this research gap and assessed the effect of automation on driver takeover performance and workload. The second objective of this study was to find the most efficient TOTB to improve young drivers' takeover performance and reduce workload. Most of the previous studies used the NASA-TLX questionnaire to measure driver workload (Chen et al., 2019; Hjälmdahl et al., 2017; Large et al., 2017; Park et al., 2019). The Driving Activity Load Index (DALI) measure is a revised form of the NASA-TLX, which is adjusted specifically to the driving task (Pauzié, 2008). This study used the DALI questionnaire to evaluate drivers' subjective workload. In addition to subjective measures, eye-related measurement such as percentage change in pupil size (PCPS) and blink rate are appropriate methods to measure and monitor driver workload in driving simulator studies, if the infrastructure of the experiment is under full control of the researcher (Brookhuis & De Waard, 2010). Eye-related measures are widely used to study driver workload because of their ease of use and providing continuous measures of workload in real-time as compared to the subjective measures (Merat et al., 2012; Recarte et al., 2008; Ryu & Myung, 2005). Blink rate has been used in several driver workload assessment studies with mixed results attributable to the distinction between mental and visual workload (Brookings et al., 1996; De Waard & Brookhuis, 1996; Van Orden et al., 2001). Marquart et al. (2015) and Recarte et al. (2008) provide justifications for the contrary results on the relationship between workload and blink rate. It was found that blink rate can distinguish between visual and mental workload. Visually demanding tasks such as driving may lead to blink inhibition. However, blink rate increases when drivers need to look away from the driving task and shift their attention to a cognitively demanding task. Therefore, a visually demanding task may decrease, and a cognitively demanding task may increase blink rate. Several studies found a blink rate increase during HAD conditions as compared to manual driving (Cha, 2003; Merat et al., 2012), which suggested that HAD relieves a driver more from visual tasks than from the mental tasks. In this study, we used the PCPS data and blink rate as physiological measures of workload to validate the findings of subjective workload measurements.

Based on the literature review, the following hypotheses (H) were tested in this study:

H1: When faced with critical incidents, young drivers would have better driving performance when they are in the manual control of the vehicle, compared to when they are required to take over the control of the vehicle from the HAD condition (Merat et al., 2014).

H2: Young drivers would experience less workload under the HAD condition than the manual driving mode (De Winter et al., 2014).

H3: 8s of TOTB would be ideal for young drivers to have a safe takeover performance as compared to 5s and 10s of TOTB (Gold et al., 2013; Mok et al., 2015; Wan & Wu, 2018).

H4: Young drivers would experience less workload with 8s of TOTB as compared to 5s and 10s of TOTB (Gold et al., 2013; Mok et al., 2015; Wan & Wu, 2018).

H5: Young drivers would have better takeover performance when they are not engaged in NDRTs as compared to when they are involved in NDRTs (Eriksson & Stanton, 2017b; Vogelpohl et al., 2019; Yoon et al., 2019).

H6: Young drivers would experience less workload in takeover situations when they are not engaged in NDRTs as compared to when they are involved in NDRTs (Merat et al., 2012; Yoon & Ji, 2019).

It is important to note that the selection of 5, 8, and 10s of TOTB was based on the results from previous studies (Gold et al., 2013; Mok et al., 2015; Wan & Wu, 2018). Mok et al. (2015) did not find any significant difference in driver performance with 5s of TOTB as compared to the

8s. However, Gold et al. (2013) indicated that drivers with 7s of TOTB under the HAD condition exhibited worse performance as compared to the manual mode. In addition, Wan and Wu (2018) concluded that drivers in the HAD condition needed at least 10s of takeover lead time to have a safe takeover, however, Wan and Wu (2018) did not include 8s of TOTB in their study and only compared driver takeover performance with 3, 6, 10, 15, 30, and 60s.

2. METHOD

2.1. Participants

Twenty-eight young drivers (14 males and 14 females) within the age range of 18 to 30-year-old (*M* = 25.14 yrs., *SD* = 3.34 yrs.) were recruited for this study. Eight participants have previously participated in automated vehicle studies, 18 participants had some experience with advanced driver-assistance systems (ADAS), and two participants had experience with highly automated vehicles. All participants had valid driver license and were sampled from the student population at Texas A&M University. To reduce biases that may influence the results, participants were not taking medications that would impair their driving performance or decision making. All participants had normal 20/20 vision. Prior to participating in the study, each participant read and signed the informed consent form. The Texas A&M University Institutional Review Board (IRB) approved the study protocol. The experiment was conducted in 2020; however, all the Covid-19 protocols (e.g., social distancing, cleaning the experiment setup, providing personal protecting equipment such as face masks, and pre-screening health checklist) were followed (see Appendix A for more information)

2.2. Apparatus

2.2.1. Driving simulator

A high-fidelity driving simulator (Realtime technologies, Inc., Ann Arbor, MI) was used in this experiment (Figure 2). The simulator consisted of a Ford Fusion mounted platform with a cylindrical projection screen providing 270° field of view (i.e., five projector screens) with five LCD screens (one dashboard, one side screen, two side mirrors and one rear-view mirror). The secondary task was displayed on the side screen and the drivers could interact with it using a touch screen (Figure 2). A set of full-size driving controls, including accelerator, brake pedal, steering wheel, turn signals, and manual/auto transition button on the steering wheel were used to provide drivers with real-time feedback. Four external audio speakers were mounted on the edge of the vehicle platform and provided audio cues about the vehicle's motion (e.g., acceleration and deceleration) and takeover requests.

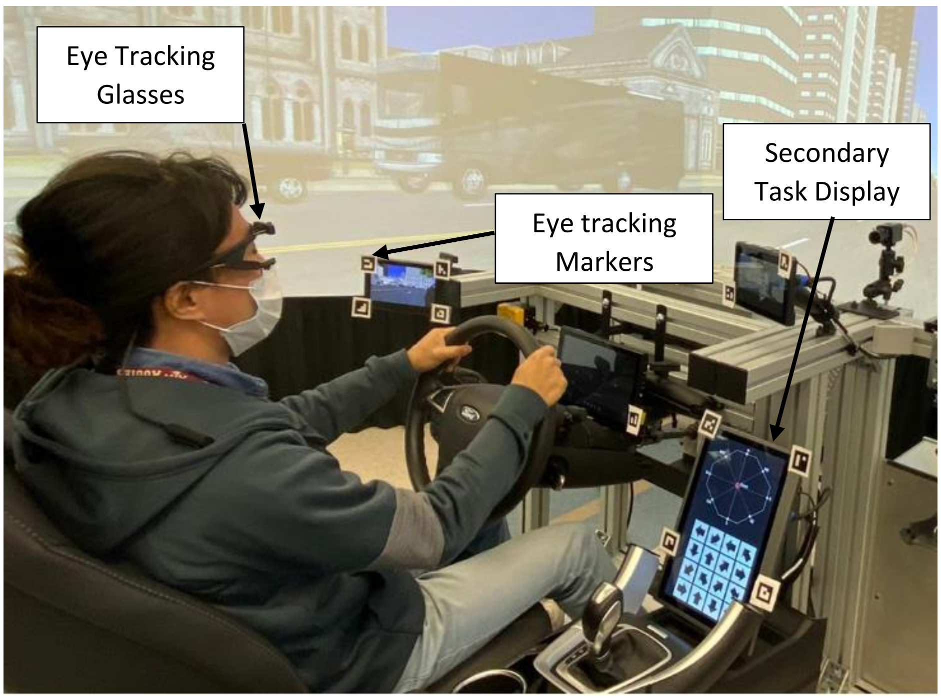

Figure 2: Driving simulator setup

2.2.2. Eye tracking glasses

A Pupil-core eye tracking system (Pupil Labs, Germany) was used to collect driver pupil data (Figure 2). The system hardware included one world camera and two eye cameras. The eye cameras detect and track the pupil with 3D models. Gaze parameters were gathered in normalized 3D gaze positions and binocular vergence. Eye movements were recorded at a frequency of 120 Hz in 192 $\times$ 192 pixels.

2.3. Independent variables

The independent variables manipulated in this study included: (1) driving condition (i.e., manual driving vs. HAD), (2) TOTB (i.e., 5s, 8s, and 10 s), and (3) NDRT (ON/OFF). In the HAD condition, the driver was asked to take over the control of the vehicle within a TOTB, which was defined the time between the event onset and an impending crash. In this condition, an auditory takeover alert, "automation-off", was used to warn the drivers that they needed to take over the control of the vehicle. In the manual driving condition, the TOTB was defined as the time remaining before a rear-end accident at the time when the lead vehicle brakes, if the course and speed of the subject vehicle maintained. No warning was given in the manual condition (Gold et al., 2013; Happee et al., 2017). Table 1 illustrates the independent variables and their levels in the study.

Table 1. Independent variables

Driving condition	Highly automated driving (HAD)
	Manual
Non-driving related task	On
	Off
Takeover time budget	5s
	8s
	10s

2.4. Experimental design

The study followed a within-subject design including six driving scenarios (2 Driving conditions × 3 TOTBs). Drivers were not informed of the TOTB and driving condition prior to each scenario. However, with a shorter TOTB (i.e., 5), the visual luminance of the lead vehicle on driver's retina is bigger as compared to the 8s and 10s of TOTB at the moment of the critical incident. Therefore, the shorter TOTB leads to a more urgent situation. Each driving scenario included two critical incidents (i.e., a leading car that braked suddenly). Drivers were engaged in a NDRT twice in each scenario: once in combination with the critical incident and once in a similar section of the road without an incident. The drivers were asked to react immediately to avoid the critical incident by pressing the brake or turning the steering wheel.

2.5. Driving scenarios

Participants were instructed to drive the simulated urban roadway (Figure 3), follow all traffic controls, maintain their vehicle in the middle of the right lane all the time (except when maneuvering at intersections or taking over the lead vehicle), and maintain the speed of 40 mph. The order of six driving scenarios was randomized. The simulation was designed to represent as accurately as possible a realistic urban driving environment with four lanes, following regulations published by the Roadway Design Manual of Texas Department of Transportation (TxDOT, 2020). Each driving scenario included two critical incidents and the location of critical incidents varied among the trials to limit any potential learning effect from one trial to another (Zahabi & Kaber, 2018).

Figure 3: An example of driving scenario

2.6. Non-driving related task

The NDRT was designed to impose both visual and cognitive load while driving and involved the use of the side screen display as shown in Figure 2 (Engström et al., 2005; Kaber et al., 2012; Liang & Lee, 2010). The task simulated the spatial processing of navigation and required the driver to listen to audio clips describing a path and to touch an arrow (e.g., east, north, and southwest) showing the direction that the person faced at the end of the path. A map with eight directions was located on the top of the screen as shown in Figure 4. The participants were instructed with an audio to move to one of the stations from the center, turn clockwise or counterclockwise, and then exit at another station. For example, when the audio message of "the person walked to the northwest exit and turned counter-clockwise. Touch an arrow that shows the orientation where the person looking at." was played, participants selected an arrow representing the orientation of the person using the touch screen (in this case, it would be the arrow toward southwest). Then, the second part of the audio was played which contained the message of "After passing the northwest exit, the person passed three more exits. Touch an arrow that shows the orientation where the person looking at." The participants responded via touch screen again (in this case, the answer would be the arrow toward east) (Figure 4). Participants were instructed to answer the questions as accurately and quickly as possible. Since participants had to remember their orientation and the path in their working memory throughout the two parts of the message and search for and select an arrow from the display, this task required a combination of visual and cognitive demands.

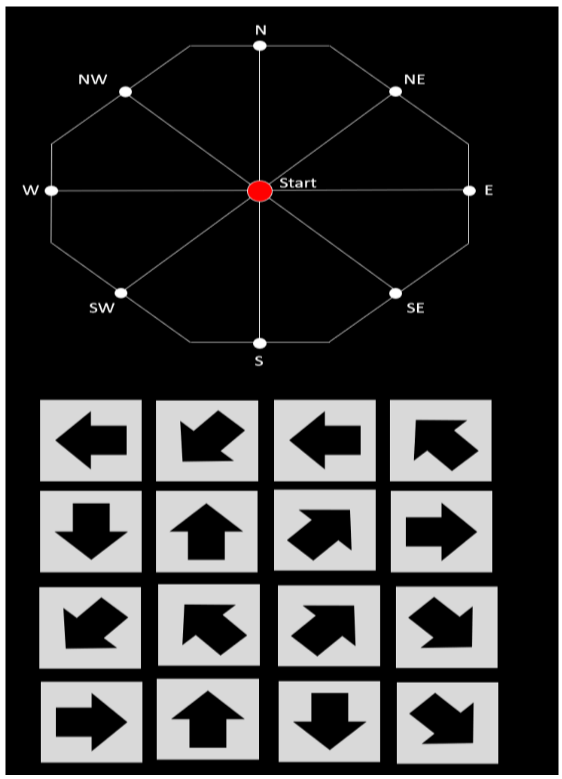

Figure 4. Secondary task display

2.7. Dependent variables

The dependent variables included measures of takeover performance and mental workload. Driver takeover performance measures included minimum TTC (Saffarzadeh et al., 2013; Wan & Wu, 2018), maximum lateral acceleration (Wan & Wu, 2018), and takeover time (Vogelpohl et al., 2019). TTC was defined as the time that the two vehicles would collide if they continue at their present speed and on the same path and was used as an indicator of the potential collision severity based on Hirst (1997). Lateral acceleration was used to assess the quality of the takeover based on Gold et al. (2013). Takeover time was defined as the time between takeover request issuance and the time when drivers reached the limit of 2 degrees steering wheel angle or 10 percent braking pedal position (Gold et al., 2013). Driver workload was measured using a combination of physiological (i.e., average PCPS and blink rate), subjective measures (i.e., DALI questionnaire) (see appendix B), and secondary task performance (i.e., accuracy and task completion time). These measures have been used in prior studies to assess driver workload (Hjälmdahl et al., 2017; Palinko et al., 2010). Table 2 illustrates the dependent variables and specific measures used in this study.

Table 2. Dependent variables

Driver performance	Minimum time to collision (min TTC)
	Maximum lateral acceleration
	Takeover time
Driver workload	Percentage change in pupil size (PCPS)
	Blink rate
	DALI score
	Secondary task performance

2.8. Procedure

Prior to the experiment, all participants completed and signed the informed consent form and the demographic questionnaire. The simulator sickness questionnaire was used to measure any potential motion sickness symptoms prior to the study (Kennedy et al., 1993). Participants were trained to use the driving simulator. The training trials included simulation of an urban driving environment similar to the actual experiment scenarios. Specific vehicle maneuvers were included in the training such as stopping at a red light, turning right or left at intersections, driving at the posted speed limit, and maintaining the vehicle in the middle of the right lane. At the end of the training, driver speed and lane deviations were calculated across trials to guarantee conformance with established performance criteria, including $|\text{lane deviation}| \leq 1.37$ ft and $|\text{speed deviation}| \leq 1$ mph (Horrey & Wickens, 2004; Zahabi & Kaber, 2018). Once the participants passed the training criteria, they were provided with instructions on the NDRT. After the training, drivers were administered another simulator sickness questionnaire to ensure absence of simulator sickness symptoms. In addition, they were provided with the DALI pairwise comparison sheet to identify the relative weight of different workload contributors. Subsequently, the eye tracking system was calibrated for the participants and the baseline pupil size was captured for 2 min. while participants were seated in the cab.

For the actual experiment trials, participants were instructed that driving was the primary task and they needed to complete the NDRT using the side screen as accurately and quickly as they could. They were also told that critical incidents (i.e., a lead vehicle suddenly brakes) could occur during trials. After each trial, they were asked to complete the DALI questionnaire. Participants were provided with a 5-min break between trials. The simulator sickness questionnaire was evaluated again after the trial. The experiment took approximately 2 hours to complete and all participants were paid $30 for the participation.

2.9. Data analysis

A data screening process was conducted on driving performance and eye tracking data to identify any outliers before conducting any inferential statistical tests. Diagnostics were conducted on all dependent variables to satisfy parametric test assumptions of normality and equal variance. Residual normality was assessed by inspection of normal probability plots and Shaprio-Wilk’s Goodness-of-Fit tests and variance homoscedasticity was checked using Bartlett's tests. In case of parametric assumption violations, sinh-arcsinh (SHASH) transformation (for takeover time, maximum lateral acceleration, secondary task completion time, and PCPS data) or the data were ranked and non-parametric procedure was used (for minimum TTC and blink rate). In addition, ordinal logistic regression analysis was used to analyze the secondary task accuracy.

Driver background information including age, gender, experience in automated driving studies, experience with ADAS, experience with automated vehicles, and trial number (1-6) were included in the model as covariates and were removed if found to be insignificant. Tukey's Honest Significant Difference (HSD) post-hoc multiple comparison was applied to identify differences among levels of any significant effects, if applicable. A significance level of $p \leq 0.05$ was set as a criterion for the study.

3. RESULTS

3.1. Driver takeover performance

3.1.1. Takeover time

Drivers exhibited a significantly shorter takeover time with 5s of TOTB as compared to 8 and 10s in the HAD mode *($F(2,130.5)=14.48$, $p<0.0001$, $\eta_p^2=0.18$)* (Figure 5). NDRT was also found to significantly increase driver takeover time *($F(1,129.3)=4.12$, $p=0.04$, $\eta_p^2=0.03$)*. However, there was no significant interaction between the NDRT and TOTB *($F(2,129.4)=2.96$, $p=0.06$, $\eta_p^2=0.04$)*.

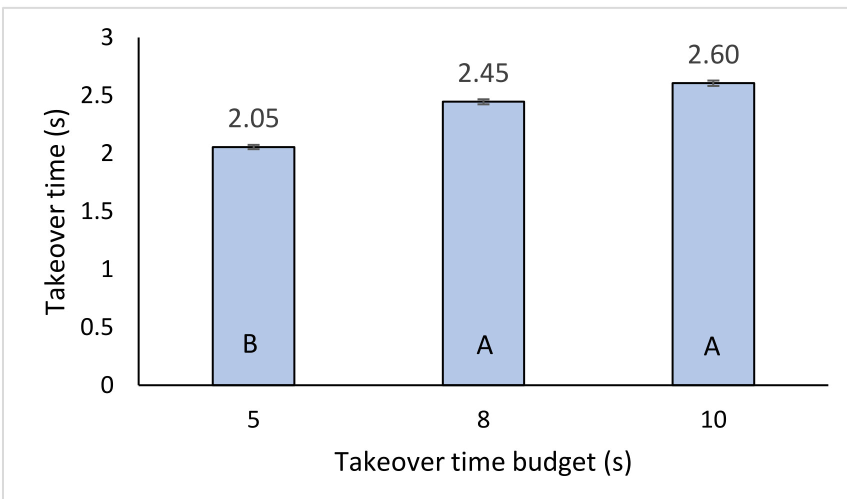

Figure 5: Effect of takeover time budget on takeover time in the HAD mode

3.1.2. Maximum lateral acceleration

There was a significant effect of TOTB *($F(2,292.2)=34.22$, $p<0.0001$, $\eta_p^2=0.19$)* on maximum lateral acceleration. Drivers exhibited a significantly higher maximum lateral acceleration with 5s of TOTB as compared to 8s and 10s (Figure 6). There was no significant effect of driving condition *($F(1,292.3)=0.79$, $p=0.37$, $\eta_p^2<0.01$)* or NDRT (*$F(1,292.1)=1.15$, $p=0.28$, $\eta_p^2<0.01$*) on the response.

Furthermore, there was no interaction between the TOTB and NDRT *(F(2,292.1)=2.23, p=0.11,* η_p^2*=0.01)*, driving condition and NDRT (*F*(1,292.1)=2.23, *p*=0.09, η_p^2*=0.01*), and TOTB and driving condition *(F(2,292.2)=1.68, p=0.19,* η_p^2*=0.01)*.

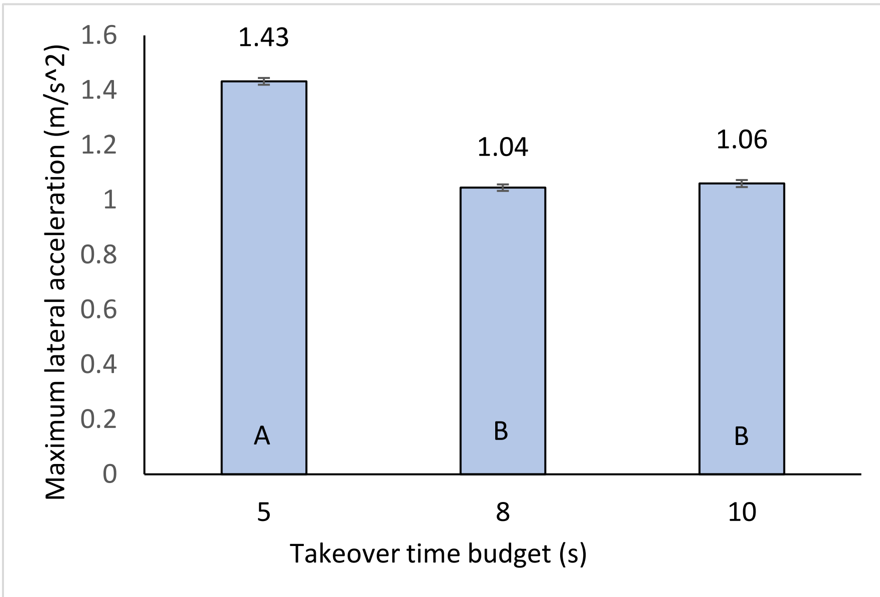

Figure 6: Effect of takeover time budget on maximum lateral acceleration

3.1.3. Minimum time to collision

Drivers exhibited a significantly longer minimum TTC in the HAD condition as compared to the manual mode *(F(1,291.4)=30.01, p<0.0001,* η_p^2*=0.09)*. Furthermore, minimum TTC increased with TOTB *(F(2,291.3)=236.55, p<0.0001,* η_p^2*= 0.94)* as shown in Figure 7. In addition, drivers had a shorter minimum TTC when they were performing the NDRT *(F(1,291.1)=5.07, p=0.03,* η_p^2*= 0.02)*. There was a significant two-way interaction between driving condition and TOTB *(F(2,291.2)=12.42, p<0.0001,* η_p^2*=0.08)* as shown in Figure 8. In the HAD condition, there was a significant difference between the minimum TTC of drivers with 5s, 8s, and 10s of TOTB. However, under the manual condition, there was no significant difference between the minimum TTC of 8s and 10s of TOTB. There was also a significant interaction between NDRT and TOTB

(F(2,291)=3.42, p=0.03, η_p^2=0.02). However, there was no significant interaction between driving condition and NDRT *(F(1,291.1)=0.25, p=0.61, η_p^2<0.01)*.

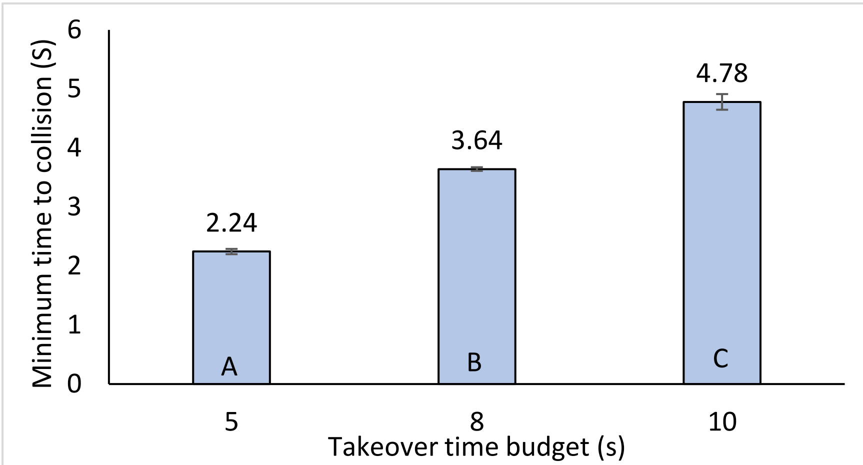

Figure 7: Effect of takeover time budget on minimum TTC

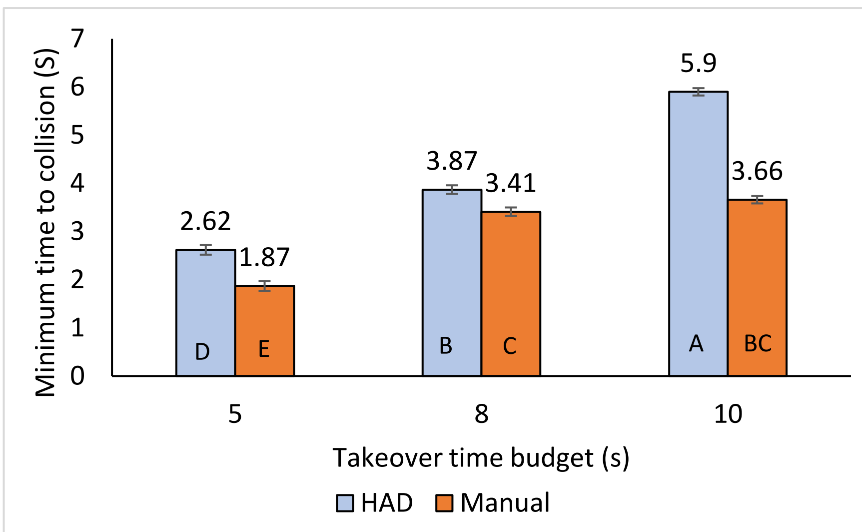

Figure 8: Interaction of takeover time budget and driving condition

3.2. Driver workload

3.2.1. Average percentage change in pupil size

An ANOVA on SHASH transformed average PCPS data suggested that there was a significant effect of NDRT *(F(1, 280)=8.69, p=0.003, η_p^2=0.03)*, and a significant interaction between the driving condition and TOTB (*F(2, 280.1)=10.92, p<0.0001,* η_p^2*=0.07*) (Figure 9), and between the TOTB and NDRT (*F(2, 280)=8.09, p<0.001,* η_p^2*=0.05*). However, there was no significant effect of driving condition (*F(1, 280.1)=1.16, p=0.28, ,* η_p^2*=0.004*) or TOTB (*F(2, 280.1)=0.05, p=0.94,* η_p^2*=0.00*), and no interaction between the driving condition and NDRT (*F(1, 280)=0.02, p=0.89,* η_p^2*=0.00*). PCPS increased (i.e., higher cognitive workload) in situations where the drivers were engaged in the NDRT (*M*=16.14, *SD*=14.3) as compared to the no secondary task condition (*M*=9.91, *SD*=15.7). Tukey post-hoc analysis showed that with 8s of TOTB, drivers experienced a higher PCPS (higher level of workload) in the HAD condition as compared to the manual mode (Figure 9). Furthermore, PCPS decreased (i.e., cognitive workload decreased) as trial number increased (*F(1, 280)=50.24, p<0.001,* η_p^2*=0.15*).

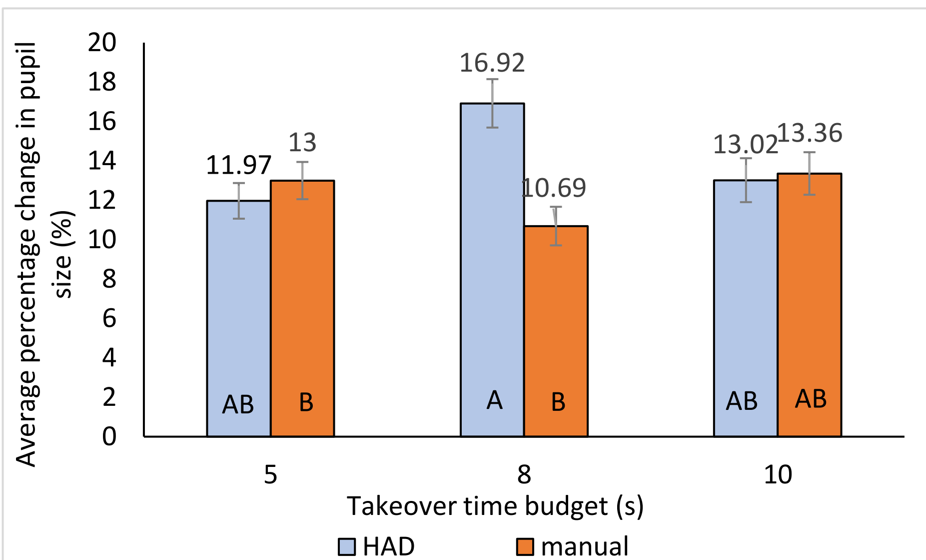

Figure 9: Interaction effect of driving condition and takeover time budget on PCPS

3.2.2. Blink rate

There was a significant effect of driving condition (F(1, 291.1)=4.93, p=0.027, η_p^2=0.02) and TOTB (F(2, 291.1)=36.05, p<0.001, η_p^2=0.19) (Figure 10) on the blink rate. Drivers had higher blink rate in HAD (M=0.62, SD=0.03) as compared to the manual mode (M=0.53, SD=0.03). However, there was no significant effect of NDRT on blink rate (F(2, 291)=2.51, p=0.11, η_p^2=0.008). There was no interaction between driving condition and TOTB (F(2, 291.1)=2.29, p=0.1, η_p^2=0.01), driving condition and NDRT (F(1, 291)=0.9, p=0.34, η_p^2=0.003), and TOTB and NDRT (F(2, 291)=0.49, p=0.61, η_p^2=0.003).

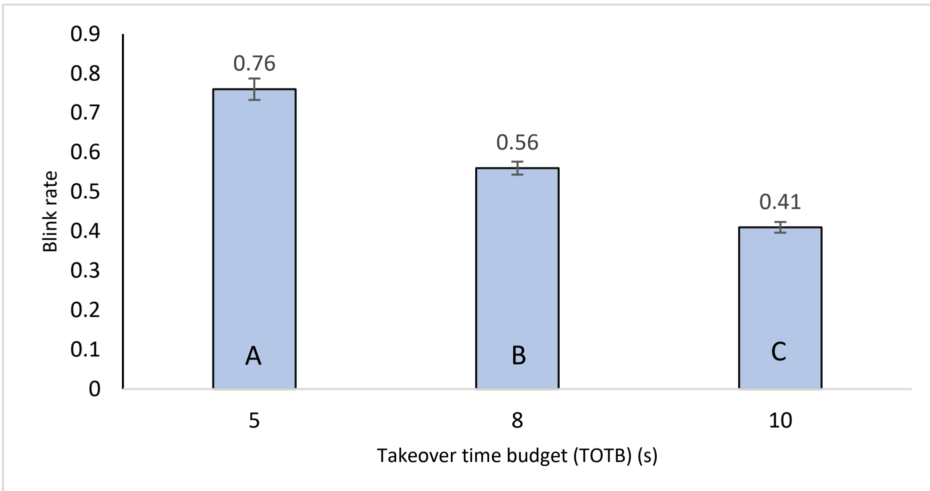

Figure 10: effect of takeover time budget on blink rate

3.2.3. Driver perceived level of workload

An ANOVA on Box-Cox transformed DALI scores revealed no significant effect of TOTB (*F(2, 132.5)=0.18, p=0.83,* η_p^2*<0.01*) and driving condition (*F(1, 132.3)=1.93, p=0.16,* η_p^2*=0.01*) on DALI score. However, there was a two-way interaction between the driving condition and TOTB (*F(2, 132.4)=5.97, p=0.05,* η_p^2*= 0.08*). With the 10s of TOTB, drivers reported a higher level of workload in the manual condition as compared to the HAD condition (Figure 11). There was also a significant effect of the trial number *(F(1,132.3)=31.60, p<0.001,* η_p^2*=0.19).* As the duration of the experiment increased, drivers reported a lower level of subjective workload.

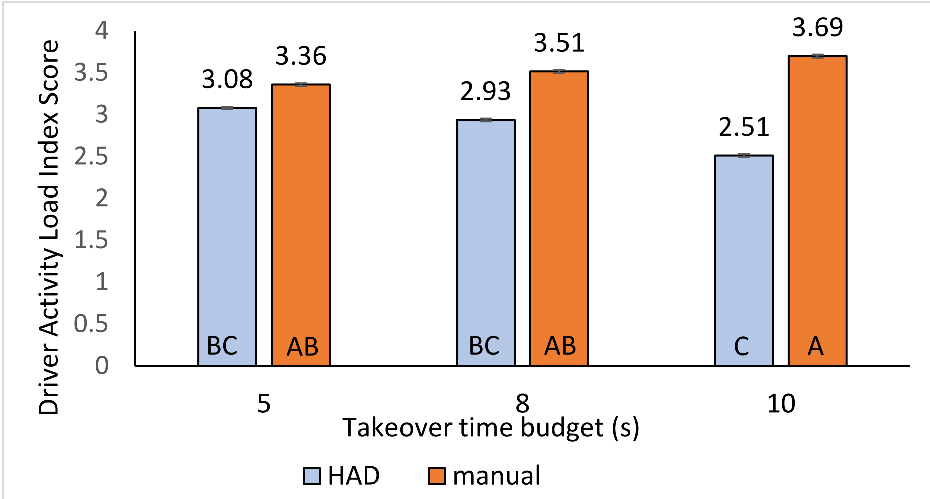

Figure 11: Interaction of driving condition and TOTB on DALI score

3.2.4. Secondary task performance

3.2.4.1. Secondary task accuracy

An ordinal logistic regression on secondary task accuracy revealed that drivers had a significantly higher accuracy with 5s of TOTB as compared to the 8s (OR=0.84; 95% CI=0.18, 1.64; p=0.013). There was no significant difference between the 8s and 10s of TOTB in terms of secondary task accuracy. There was also no significant effect of driving condition on the response (OR=0.054; 95% CI=-0.23, 0.33; p=0.7).

3.2.4.2. Secondary task completion time

An ANOVA on secondary task completion time revealed a significant effect of TOTB on secondary task completion time (F(2,116.8)=8.32, p<0.001, η_p^2=0.12). Secondary task times significantly increased with 5s and 8s of TOTB as compared to 10s (Figure 12). There was no significant effect of driving condition (F(1, 116.5)=0.46, p=0.49, η_p^2=0.004) or interaction between the driving condition and TOTB (F(2, 116.7)=0.10, p=0.9, η_p^2=0.002).

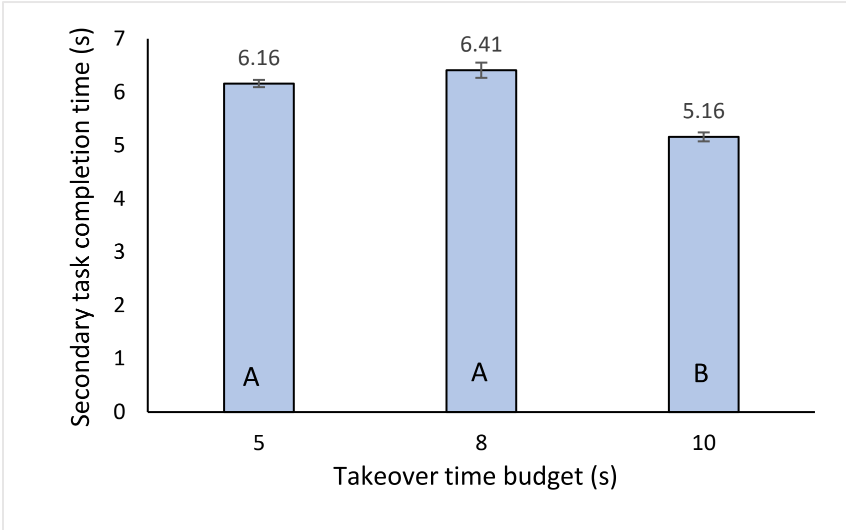

Figure 12: Effect of takeover time budget on secondary task completion time

4. DISCUSSION

4.1. Driver takeover performance

The first hypothesis (H1) posited that when faced with a critical incident, drivers would have better driving performance when they are in the manual control of the vehicle, compared to when they are required to take over the control of the vehicle from the HAD condition. This hypothesis was not supported by the data. The results indicated that there was no significant effect of driving condition on maximum lateral acceleration. However, unlike Dogan et al. (2019), drivers had a longer minimum TTC under the HAD condition as compared to the manual driving condition. The minimum TTC can reveal critical danger in the takeover process, and the larger the minimum TTC, the safer the takeover process. One possible explanation for this discrepancy is that Dogan et al. (2019) experimental design did not include any NDRT. However, since young drivers usually have risky driving behaviors and are willing to engage in secondary tasks (Hosking et al., 2009; McEvoy et al., 2006), in our study, drivers were asked to perform a NDRT in both HAD and manual driving conditions. Negotiating a hazard when driving in the manual mode and performing a NDRT simultaneously can overload the driver and therefore, results in a shorter minimum TTC and a more critical situation. Merat et al. (2014) reported a worse performance in the HAD condition as compared to the manual mode even when the driver was engaged in a NDRT. However, it is important to note that Merat et al. (2014) used twenty questions task (TQT), which is less cognitively and visually demanding as compared to the navigation task used in this study. The findings of this investigation suggested that young drivers might have safer takeover performance (in terms of minimum TTC) under the HAD condition than the manual driving condition when they are engaged in demanding visual and cognitive NDRTs. However, this finding should be interpreted with caution since there was no effect of driving condition on other takeover performance responses.

Hypothesis 3 (H3) stated that 8s of TOTB would be ideal for drivers to have a safe takeover performance as compared to 5s and 10s of TOTB. This hypothesis was mainly supported by the data. Young drivers in this study had significantly higher maximum lateral acceleration and shorter takeover time with 5s TOTB as compared to 8s and 10s conditions. In addition, results indicated that minimum TTC increased as the TOTB increased, which indicates a safer takeover performance with 10s TOTB as compared to 5s and 8s. Although minimum TTC with 5s TOTB (M=2.24, SD=0.04) was shorter than the safety-critical 3s minimum TTC suggested by previous studies (Hirst, 1997), both 8s and 10s TOTB led to a longer minimum TTC on average than 3s. Therefore, 8s can also be considered as a safe TOTB based on the minimum TTC results, which supports H3.

Although 5s TOTB led to a significantly shorter takeover time, it had a negative effect on the quality of takeover with a significantly higher maximal lateral acceleration as compared to 8s or 10s. Drivers with 8s and 10s of TOTB were found to gradually take over the lead vehicle suggested by a smoother lateral acceleration. This might be related to the urgency of the situation with 5s of TOTB. When a takeover request is issued, drivers should shift their attention to the road, cognitively process the situation, make a decision, reposition themselves, and intervene by rotating the steering wheel or pressing the brake pedal (Gold et al., 2013; Petermeijer et al., 2017; Petermeijer et al., 2015; Zeeb et al., 2015). Decision making and processing the situation depend on the TOTB and the rear-end scenario's kinematics, quantified in terms of visual looming of the lead vehicle on the driver's retina (Louw et al., 2017). Driver repositioning, braking or steering behavior can also be affected by TOTB. With 8s and 10s of TOTB, drivers have more time, and therefore, they can more smoothly follow the takeover steps, analyze the distance and kinematics of the lead vehicle, make a logical decision, and negotiate the hazard. Although 5s of TOTB led to the fastest takeover time, the success of a takeover maneuver should not only be measured by takeover time, but also by checking the quality of the takeover. Therefore, longer TOTBs led to a safer takeover performance as indicated by a smaller maximum lateral acceleration and longer minimum TTC. Even though the 10s condition gave participants more time than the 8s TOTB condition, there was no significant difference between these two conditions in terms of takeover time and maximum lateral acceleration responses when negotiating the critical incident, which further supported H3.

The findings of this study suggested that 8s of TOTB can be sufficient for a safe takeover performance when young drivers are engaged in demanding NDRTs requiring cognitive, perceptual, and motor demands. Although Mok et al. (2015) did not find any significant difference in driver performance with 5s and 8s of TOTB, our results suggested that drivers exhibited better performance with 8s of TOTB than 5s. First, the design of experiment and hazard situations may affect drivers' understanding of the situation and as a result, change their behavior. Mok et al. (2015) used a construction zone as a critical incident and automation failed due to the lack of lane markings. Drivers were asked to continue their path through the pylons without taking over the front vehicle. Second, Mok et al. (2015) used a passive NDRT (i.e., watching a video) in their study, while the NDRT in our study was more complex and required a driver's interaction with the side screen. Although our study suggested that 8s of TOTB might be a sufficient transition time to successfully take over the manual control of the vehicle, there is a need to further investigate driver situation awareness and weather (s)he is aware of the surrounding environment and other traffic occupants.

Hypothesis 5 posited that drivers would have better takeover performance when they are not engaged in NDRTs as compared to when they are involved in NDRTs. This hypothesis was generally supported by the data. Results indicated that young drivers had longer takeover time and shorter min TTC when they were engaged in the NDRT. The findings are aligned with earlier investigations using other NDRTs (Eriksson & Stanton, 2017b; Vogelpohl et al., 2019; Yoon et al., 2019) and further validate the generalizability of their findings to young drivers. This finding is also supported by multiple resource theory Wickens (2008) since the NDRT required the same resources with the driving task (i.e., visual and cognitive demands) and therefore, performing the this task while driving can impair driving performance.

4.2. Driver workload

Hypothesis 2 (H2) posited that drivers would experience a lower workload with the HAD system than the manual driving mode. This hypothesis was not supported by the data. With the 5s and 10s of TOTB, there was no significant difference between the HAD and manual condition in terms of the average PCPS data. However, with the 8s of TOTB, drivers exhibited lower workload under the manual condition as compared to the HAD condition. With 5s of TOTB, since the time was too limited to perform the NDRT before negotiating the critical incident, it was observed that participants negotiated the critical incident first and then resumed the NDRT as they were instructed that the driving task is the primary task. With the 10s of TOTB, since participants had sufficient time, the NDRT did not have an impact on the PCPS and therefore, there was no significant difference in workload between the manual and HAD conditions. The PCPS data suggested that with 8s of TOTB, drivers experienced a higher level of workload under the HAD condition as compared to manual driving. The 8s TOTB situation might have been more challenging since drivers had to decide on which task they needed to do first and therefore they experienced more workload. This finding is aligned with the results of Banks and Stanton (2016) who found that drivers can have a higher workload under HAD, as compared to the manual driving since the takeover can impose cognitive demand with the switching in the role from a passive monitor to an active road user.

The findings of blink rate data were also aligned with the PCPS results as drivers exhibited higher blink rate (less visual demand as compared to the mental demand) under the HAD condition as compared to manual driving. This finding indicated that the HAD condition relieved drivers more from the visual tasks than from the mental tasks as they are not required to continuously monitor the driving environment and further supports the results of prior studies (Cha, 2003; Merat et al., 2012). Our finding is not aligned with the results of Merat et al. (2012) who found that in the absence of NDRT, blink rate was higher when the drivers transitioned from the HAD condition as compared to the manual driving mode. However, in the presence of the NDRT, the pattern reversed, and drivers had lower blink rate in the HAD condition than the manual driving. It is important to note that Merat et al. (2012) used a twenty questions task (TQT) which is similar to a telephone conversation and does not require visual resources. However, we used a more complex and multimodal NDRT which required cognitive, perceptual, and motor demands.

Hypothesis 4 (H4) stated that drivers would have less workload with 8s of TOTB as compared to the 5 and 10s of TOTB. This hypothesis was not supported by the data. There was no significant effect of TOTB on average PCPS or perceived level of workload. However, the findings of secondary task completion time and blink rate suggested that 10s of TOTB was more effective in reducing drivers' mental workload as compared to 5s and 8s of TOTB. This might be due to the increase in drivers' temporal demand (due to time pressure), which is in line with Wang et al. (2016) who found that time pressure in combination with a cognitively demanding task can increase mental workload, and therefore increase the blink rate.

Subjective workload results were not in line with the findings of physiological and secondary task performance measures. Results from the DALI questionnaire indicated that with 10s of TOTB, drivers perceived a significantly lower workload in the HAD condition as compared to the manual mode. In 10s of TOTB drivers had sufficient time to engage with the NDRT and negotiating the hazard. However, with 5s and 8s of TOTB, drivers might have felt more pressure and urgency in negotiating the hazard. Therefore, they perceived lower level of workload in the HAD condition only in the long TOTB situation as compared to the manual driving. This finding further supports our initial assumption that subjective measures of workload such as DALI might not be sensitive to capture the subtle differences in TOTBs and therefore might not provide a complete picture of driver workload in takeover situations. This is because participants provided their perceived level of workload at the end of the scenario and might have forgotten the amount of workload they felt during the takeover requests or critical incidents. Prior studies comparing workload of drivers in manual and HAD conditions, only used subjective measures and found the HAD condition to reduce drivers' workload (Large et al., 2017; Schwalk et al., 2015; Wu et al., 2019;

Yoon & Ji, 2019). However, the findings of this study suggested that subjective measures might be biased and might not show subtle differences in workload during takeover requests.

Hypothesis 6 suggested that drivers would experience less workload in takeover situations when they are not engaged in NDRTs as compared to when they are involved in NDRTs. This hypothesis was partially supported by the data. Average PCPS significantly increased when drivers were engaged in NDRTs. Use of highly automated vehicles can change drivers' behavior especially young drivers, such as enabling them to engage in NDRTs. However, the findings of this study suggested that engagement in NDRTs can significantly impair young drivers' performance and increase their workload during critical incidents. The findings support the results of earlier investigations (Wandtner et al., 2018a; Yoon & Ji, 2019) and further validate the generalizability of their findings to young drivers.

However, our study did not find any significant effect of NDRT on blink rate. Although Liang and Lee (2010) used the same NDRT, they found that the combined visual and cognitive secondary task increased the number of blinks. It is important to note that Liang and Lee (2010) did not include the HAD condition and critical incidents in their study, and they only focused on the effect of NDRT with manual driving and cruise control. The nonsignificant blink rate result might also be due to the short duration of data collection blocks (i.e., 5s, 8s, or 10s). Future investigations should validate the findings of blink rate reported in this study under longer data collection periods.

Although this study was focused on the effects of HAD on young drivers due to their risky driver behavior and high crash rates, there is a need for future studies to specifically evaluate the effects of HAD on older adults. Previous studies have shown that as age increases, drivers experience impairments in their performance such as having slower perception of hazards (Horswill et al., 2008), longer reaction time to hazards (Warshawsky-Livne & Shinar, 2002), and slower information processing (Verhaeghen & Salthouse, 1997). In addition, older drivers were found to make more mistakes in assessing the speed of other vehicles (Scialfa et al., 1991), take longer to switch between the tasks (Kray & Lindenberger, 2000), and have limitations in handling new situations and take timely decisions (Guerrier et al., 1999). Furthermore, their interaction with automation is different from young drivers because they perceive automation reliability differently and therefore, it affects their trust (Sanchez et al., 2004). Although older drivers are more experienced as compared to the young drivers, it is expected that the ability to monitor an automated vehicle, take over in hazardous situations, and respond appropriately within seconds is degraded for older people.

5. LIMITATIONS AND FUTURE RESEARCH

One limitation of our study the use of a fixed-base driving simulator, which did not include motions. This setup might have limited simulator realism. Furthermore, all roadway scenarios were presented under daylight conditions and moderate traffic density. Results may not be applicable to more complex roadway conditions or higher simulated traffic densities. Future studies should evaluate the findings of this investigation under other and more complex roadway conditions. Finally, our study was specifically focused on young driver due to their high-risk driving behaviors. There is a need to further investigate the effect of automation and TOTB on older adults who have less trust and experience in using highly automated vehicles.

6. CONCLUSION

The objective of this study was to evaluate the effects of unreliable automation, NDRTs, and different TOTBs on young drivers' takeover performance and workload when faced with critical incidents. Results suggested that 8s of TOTB might be sufficient for young drivers to safely take over the control of the vehicle. However, providing longer TOTBs (i.e., 10s) can further reduce drivers' mental workload. Performing a demanding NDRT significantly impaired drivers' takeover performance and increased their workload. However, the results regarding the effect of automation on drivers' mental workload and takeover performance were inconclusive, which might be due to short observation periods, and individual or recall biases. The findings of this study can be beneficial for vehicle manufacturers to improve the design of highly automated vehicles and to provide an efficient TOTB to ensure safe driver performance and reduce workload.

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APPENDIX A

Human Participants Research Infection Control Plan

PI Name: Maryam Zahabi

Department: Industrial and Systems Engineering

Target Start Date (June 15 or after): 07/06/20

Research Personnel (n) 2 **Research Space (total SQFT)** 1,344

Research Population (check all that apply)

☐ Minors ☑ Adults (18-65 years) ☐ Adults (65+ years)

☐ Persons with one or more of the following conditions: *Asthma, Chronic Kidney or Lung Disease, Diabetes, Hemoglobin Disorders, Immunocompromised, Liver Disease, Serious Heart Condition, Severe Obesity.*

Research Location (*check all that apply*)

☑ Texas A&M University ☐ Non-institutional community settings

☐ External clinical or other established institutional settings (e.g., schools, prisons, hospital

IRB protocol #s: IRB2019-1427D

PART A: FLOOR PLAN (*TAMU research spaces only*)

ATTACH an annotated floor plan of your human participant research space showing:

a. Zones for each of the following (as appropriate)
    - Visitor space (red)
    - Space where only TAMU faculty, staff, and students are permitted/have access (yellow)
    - Face-to-face testing of human participants space (orange)
b. Designated entrances and exits
c. Location of Signage
d. Placement and type of any physical barriers to separate participants and research personnel.
e. Placement of research personnel and participants to achieve inter-individual social distancing requirement of 6 feet, unless the nature of the research requires closer interaction of researchers with participants. In such cases, additional PPE requirements and safety procedures should be specified in the narrative.

Part A: NARRATIVE

PPE required for your research:

Participants will be informed the strict requirement to wear a mask or face covering before entering the lab (according to standard administrative procedure 34.99.99.M0.03, face covering is required for any on-campus visits and will be strictly enforced). However, upon arrival a box of surgical masks will be available in case the participant does not wear a surgical mask or the mask is suspected to be unsafe (have exhalation valve or not unfit).

Infection control training delivery plan:

• All researchers have completed the 2114130: Protocol and Certification for System Member Employees course on TrainTraq and shared their completion certificate with the PI. The course covers the use of PPE, appropriate social distancing, cleaning etc.
• Issues related to non-compliance either from researcher or participant will be reported to the PI. Those who resist using PPEs will not be allowed to participant in the study.

Cleaning procedures:

To maintain hand hygiene each surface touched by lab member ("X" in Figure 1) or participants ("P" in Figure 1) and all the equipment worn by the participants (e.g., eye-tracking) will be cleaned using EPA-approved disinfectant that is effective against COVID-19 at the end of each visit. There will be1-hr time between participants to allow cleaning.

Lab personnel's use of PPE during participant interactions:

• Cloth masks or sugical masks MUST be worn at all times by all members of the lab even when researchers are not interacting with participants. Cloth masks must be washed at least twice a week. The masks and gloves MUST be worn by all lab personnel when interacting with participants face to face.

Participants' use of PPE during study:

• Surgical gloves and hand santizers will be provided on a desk by the lab entrance in case participant prefers to wear one. Instructions on how to use gloves and masks safely will be provided by email before participants' arrival.
• Participants will be informed the strict requirement to wear a mask or face covering before entering the lab. However, a box of surgical masks will be available in case the participant does not wear a mask or the mask is suspected to be unsafe (have exhalation valve or not unfit).

Social distancing protocol:

• When participants enter the lab, they will be asked to sit at the driving simulator cab (marked as "P" in Figure 1). The experimenter will sit at another workstation approximately 12 feet away (marked as "X" in Figure 1). • The experimenter will be seated at their designated space when participant arrives and will maintain their position until the participant leaves the lab. • No more than two people (including participants) may be allowed in the lab.
• The sanitized equipment (the eye-tracking glasses and heart rate strap) will be placed on the passenger's seat.

Screening protocol for lab personnel:

Upon arrival all lab personnel MUST use a non-contact thermometer provided on a desk by the lab entrance to measure their temperature. Any personnel with a temperature over 100.0F (obtained with a non-contact thermometer) is required to exit the lab, reschedule their study visit, if applicable, and encouraged to seek medical care. Suspected cases of COVID-19 will be reported on https://redcap.tamhsc.edu/surveys/?s=4HAMAHC98D. Staff will be required to record temperature readings daily starting one week prior to the first interaction with a participant.

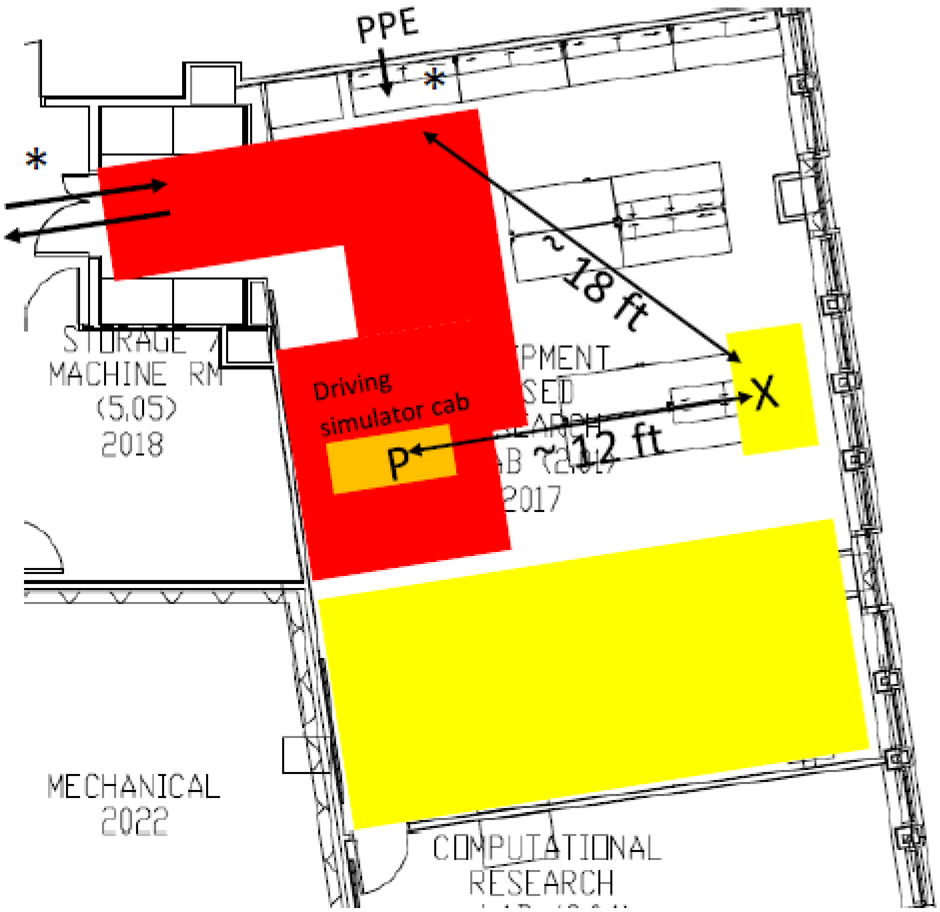
Screening protocol for participants:

• All participants will participate in verbal pre-screening via phone before the session using the checklist provided by TAMU VPR (Appendix B). • Participants will complete a screening acknowledgement as soon as they are seated in their station using the template provided by the TAMU VPR (Appendix C). Upon arrival all participants MUST use a non-contact thermometer located on a desk by the lab door to mesure their temperature (instructions will be posted).

Contact Tracing and Reporting:

• All symptom assessments for both lab personnel and participants will be logged using the template provided by TAMU VPR (Appendix D) upon arrival. The empty form will be on a clipboard located on the desk by the lab door and after the daily completion, it will be maintained in a locked cabinet inside the lab. Suspected cases of COVID-19 will be reported on https://redcap.tamhsc.edu/surveys/?s=4HAMAHC98D.

Figure 1 illustrates the lab layout, participants and experimenter setup, spaces available to the participant and lab researchers, entry/exit, as well as measurements. While no physical barrier will be used for this study, the space between the participant and the experimenter is designed such that they are at least 12 feet apart.



*=signage will be posted in these places

P=participant setup, X=Experimenter setup

PPE: Location of masks, gloves, hand sanitizers, and non-contact thermometer for the participant

Human Participant PRE-SCREEN Health Checklist

Have you received a diagnosis of COVID-19 in the past 14 days

In the last 14 days, have you had:

1.	Fever >100.0 F	YES	NO
2.	Cough	YES	NO
3.	Shortness of breath or difficulty breathing	YES	NO
4.	Chills	YES	NO
5.	Muscle aches	YES	NO
6.	Sore throat	YES	NO
7.	Loss of taste or smell	YES	NO
8.	Diarrhea	YES	NO

Have you had contact with a known or presumed COVID patient in the last 14 days? YES NO

If the answer to any of the above questions is YES, the participant should not be admitted to the research space.

This information does not need to be maintained as part of the research record unless the data will be analyzed as part of the research (requires protocol modification)

COVID-19 SCREENING ACKNOWLEDGEMENT

Texas A&M University is implementing measures to help reduce the spread of COVID-19 in Texas. These measures are part of standard health protocols and guidance issued by the Texas Department of State Health Services.

You will be asked screening questions to see if you have signs or symptoms of COVID-19, if you have had close contact to a person who is suspected or confirmed to have COVID-19, or if you have recently traveled to a restricted area.

If any of your answers are positive, or if you decline the screening, your visit will be rescheduled after a period of at least two weeks. You will also be asked to follow-up with your normal health care provider.

Your participation in the COVID-19 screening is voluntary. Any information you provide to us will be kept completely confidential and used or disclosed for public health purposes, only.

If you have any questions or concerns, please contact:

Insert PI or Study Coordinator name and contact information

_____________________________ _______________

Signature **Date**

Employee Temperature Log

Please record daily temporal temperature

Date	Time	Name	Temp		Have you had contact with anyone diagnosed with COVID-19 in the past 2 weeks?	Do you have shortness of breath?	Have you had a fever in the past 2 weeks?	Any temp over 100.0 or a "yes" to any question will not be permitted to enter

Participant Temperature Log

Please record daily temporal temperature

Date	Time	Name	Temp		Have you had contact with anyone diagnosed with COVID-19 in the past 2 weeks?	Do you have shortness of breath?	Have you had a fever in the past 2 weeks?	Any temp over 100.0 or a "yes" to any question will not be permitted to enter **Staff Initials**

APPENDIX B

Driving Activity Load Index

During the test you have just completed you may have experienced some difficulties and constraints with regard to driving task.

You will be asked to evaluate this experience with regard to 6 factors, which are described below. Please read each factor and its description carefully and ask the experimenter to explain anything you do not fully understand.

Title	Endpoints	Description
Effort of attention	Low/high	To evaluate the attention required by the activity- to think about, to decide, to choose, to look for and so on
Visual demand	Low/high	To evaluate the visual demand necessary for the activity
Auditory demand	Low/high	To evaluate the auditory demand necessary for the activity
Temporal demand	Low/high	To evaluate the specific constraint owing to timing demand when running the activity
Interference	Low/high	To evaluate the possible disturbance when running the driving activity simultaneously with any other supplementary task such as phoning, using systems or radio and so on
Situational stress	Low/high	To evaluate the level of constraints/stress while conducting the activity such as fatigue, insecure feeling, irritation, discouragement and so on

For each of the pairs below, circle the scale title that represents the more important contributor to workload when you are performing the driving task.

Effort of attention	or	Visual demand
Effort of attention	or	Auditory demand
Effort of attention	or	Temporal demand
Effort of attention	or	Interference
Effort of attention	or	situational stress
Visual demand	or	auditory demand
Visual demand	or	Temporal demand
Visual demand	or	Interference
Visual demand	or	Situational stress
Auditory demand	or	temporal demand
Auditory demand	or	Interference
Auditory demand	or	situational stress
Temporal demand	or	Interference
Temporal demand	or	situational stress
Interference	or	Situational stress

For each factor you will be required to rate the level of constraint felt during the test on a scale from 0 (very low level of constraint) to 5 (very high level of constraint), with regard to the driving task.

Global attention demand:

Think about the mental (i.e. to think about, to decide…), visual and auditory demand required during the test to perform the whole activity.

Low					High
0	1	2	3	4	5
☐	☐	☐	☐	☐	☐

Visual demand:

Think about the visual demand required during the test to perform the whole activity.

Low					High
0	1	2	3	4	5
☐	☐	☐	☐	☐	☐

Auditory demand:

Think about the auditory demand required during the test to perform the whole activity.

Low					High
0	1	2	3	4	5
☐	☐	☐	☐	☐	☐

Stress:

Think about the level of stress (i.e. fatigue, insecurity, irritation, feelings of discouragement) during the whole activity.

Low High
0 1 2 3 4 5
☐ ☐ ☐ ☐ ☐ ☐

Temporal demand:

Think about the specific constraints felt due to time pressure of completing tasks during the whole activity.

Low High
0 1 2 3 4 5
☐ ☐ ☐ ☐ ☐ ☐

Interference:

Think about the disturbance to the driving task when completing supplementary tasks (i.e. via the in-vehicle information system) simultaneously.

Low High
0 1 2 3 4 5
☐ ☐ ☐ ☐ ☐ ☐