공학석사학위논문

Effects of In-vehicle Touchscreen Location and NDRT Difficulty Level on Driver Task Performance, Eye Behavior and Workload During Conditionally Automated Driving: Non-driving-related Task and Take-over

조건부 자율주행자동차 (Level 3)에서 차량 내 터치스크린 위치와 비운전 과업 난이도가 운전 성능, 시각 집중 패턴, 인지 부하에 미치는 영향에 대한 연구: 비운전 과업과 제어권 전환 과업 중심으로

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이 논문을 공학석사 학위논문으로 제출함

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Abstract

Effects of In-vehicle Touchscreen Location and NDRT Difficulty Level on Driver Task Performance, Eye Gaze Behavior and Workload During Conditionally Automated Driving: Non-driving-related Task and Take-over

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This thesis aimed to investigate the effects of non-driving related task (NDRT) in-vehicle touchscreen location and NDRT difficulty level on the driver's NDRT, take-over task performance, and subjective workload in a highly automated vehicle. Despite of the increasing use of in-vehicle touchscreen in the context of automated driving, little empirical evidence is available that investigates human interaction with in-vehicle touchscreen interface during automated driving.

The three NDRT in-vehicle touchscreen and two difficulty levels of NDRT were employed. The dependent measures were the following: NDRT and take-over task performance, eye gaze behavior, and subjective workload. The study has found significant effects of NDRT in-vehicle touchscreen location on all the dependent measures. The results indicated that Upper Right was found to be the best NDRT touchscreen location in terms of take-over performance. However, regarding the NDRT performance, Lower Right was found to be the best NDRT touchscreen location. Moreover, it showed that as the difficulty level of NDRT increases, it impairs the drivers' performance of NDRT and subjective workload. When comparing the three different NDRT in-vehicle touchscreen locations, the NDRT in-vehicle touchscreen is located closer to the windscreen appears to be optimal in reacting to critical situations; however, it is also necessary to consider NDRT touchscreen location from the perspective of the drivers' non-driving activities, particularly in the context of highly automated vehicles where the drivers are expected to perform NDRT. The study findings may help to determine the placement of onboard NDRT touchscreen for the presentation of information related to non-driving activities in a highly automated vehicle.

Keywords: In-vehicle touchscreen, Touchscreen location, Non-driving Related Tasks (NDRTs), Autonomous driving, Visual attention

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Chapter 1

Introduction

1.1 Research Background

Driver-vehicle interfaces are increasingly employing large touchscreens. One example is Tesla's interface design in which a driver controls most vehicle functions through a single 17-inch touchscreen in the middle of the dashboard (Levin, 2020). Similarly, Ford Mach-E and Rivian R1T provide a 15.5-inch and a 16-inch center stack touchscreen, respectively (Armstead, 2022; Jancer, 2022). According to a recent Future Market Insight report, the automobile touch screen control system market is expected to grow in line with the global digitalization trend rising rapidly in the forecast period from 2022 to 2032 (Kaitwade, n.d.)

The increasing use of touchscreens may be attributed to its advantages over traditional in-vehicle displays and controls. A touchscreen saves space by presenting multiple digitally generated displays and controls in a single physical area (Pitts et al., 2012; Scholkopf et al., 2021) and is capable of dynamically updating them according to changes in task context (Cockburn et al., 2018). Also, it can deliver unlimited interactive as well as non-interactive content to the driver through an internet connection (Huang et al., 2010; Ahmad et al.,2015; Chen et al., 2022). Moreover, replacing most of the physical controls with a large touchscreen reduces manufacturing costs (Cockburn et al., 2018). These advantages render touchscreens suited to the development of in-vehicle information systems, which support the driver in performing a variety of driving- and non-driving-related tasks.

The importance of touchscreens is thought to continually increase in the future as it is expected that the range of driver tasks will expand due to the advances in autonomous vehicle technology. An automated vehicle allows drivers to engage in various non-driving-related tasks (NDRTs), including working, watching videos and playing video games, whilst its automation level affects the range of feasible NDRTs and interaction styles (As cited in Murali et al., 2022). For example, in the context of a partially automated vehicle, a driver may download and play a video game through a touchscreen located within the driver's reach limits while the vehicle drives itself. The video game is only one of many interactive/non-interactive contents available through the touchscreen-based in-vehicle infotainment system. Upon a take-over request alarm issued by the vehicle signaling the need for an imminent take-over, the driver stops playing the video game, and, takes over vehicle control, while the touchscreen starts displaying driving-related information to assist the take-over and ensuing driving tasks.

1.2 Literature Review

Numerous human factors research studies have been conducted to inform the in-vehicle touchscreen interface design. Many of them were concerned with the Graphical User Interface (GUI) aspects of touchscreen interface design and examined the effects of GUI design variables on the performance of the primary driving and secondary touchscreen tasks during conventional human driving (no driving automation) (Burnett et al., 2013; Kim et al., 2014; Kujala et al., 2015; Xian et al., 2015; Crundall et al., 2016; Cockburn et al., 2018; Eren et al., 2018; Feng et al., 2018; Ma et al., 2018). Some examples of the GUI design variables considered were: touch-key size (Kim et al., 2014; Cockburn et al., 2018; Feng et al., 2018; Eren et al., 2018), number of on-screen touch-keys (Kujala et al., 2015; Feng et al., 2018), menu structure (Burnett et al., 2013; Kujala et al., 2015; Ma et al., 2018), strategy for scrolling information (Hoffman et al., 2005), number of on-screen text lines (Xian et al., 2015), number of steps required for the completion of a secondary task (Xian et al., 2015), text size (Crundall et al., 2016), and, on-screen scroll button location (Kujala et al., 2015).

Some other studies investigated the effects of physical user interface (PUI) design variables (Fuller et al., 2008; Hagiwara et al., 2013; Russomanno et al.,2017; Cockburn et al.,2018; Ma et al., 2018; Soomro et al.,2020). Examples of the PUI design variables included: touchscreen location (Fuller et al., 2008; Hagiwara et al., 2013), touchscreen size (Ma et al., 2018) and stencil layout design (Russomanno et al.,2017; Cockburn et al.,2018; Soomro et al.,2020). These studies also considered the human driving situation in which a driver performs the primary driving task along with a secondary touchscreen interaction task.

Fuller et al. (2008) investigated the effect of four different in-vehicle touchscreen locations on driving performance and secondary task performance and showed that location of in-vehicle touchscreen only significantly affects secondary task performance. Hagiwara et al. (2013) studied the effect of two different in-vehicle touchscreen locations on the driving performance and eye gaze behavior, illustrating that there was no significant effect on any of driving performance and eye gaze behavior. Ma et al. (2018) examined the effect of three different mainstream sizes of in-vehicle touchscreen: 8-inch, 10-inch, and 12-on driving performance and the eye gaze behavior and revealed that 12-inch touchscreen size has the least impact on driving performance and visual distraction. Three studies (Russomanno et al.,2017; Cockburn et al.,2018; Soomro et al.,2020) designed a new shape of in-vehicle touchscreen stencil layout which covers a traditional physical button to minimize the visual distraction of the driver, and further investigated its impact on driving performance. All of studies showed that having in-vehicle touchscreen stencil layout that covered a traditional physical button resulted in decrease of visual distraction and improvement of driving performance, which the layout that lacked in stencil could not provide. Some other studies were concerned with the effects of Graphical User Interface (GUI) design of in-vehicle touchscreen such as touch-key size on the in-vehicle touchscreen (Kim et al., 2014; Cockburn et al.,2018; Feng et al.,2018; Eren et al.,2018), number of touch-keys on the in-vehicle touchscreen (Kujala et al.,2015; Feng et al.,2018), menu structure on the in-vehicle touchscreen (Burnett et al.,2013; Kujala et al.,2015; Ma et al.,2018), strategy for scrolling information (Hoffman et al., 2005), number of text lines on the in-vehicle touchscreen (Xian et al., 2015), number of steps required for the completion of secondary task (Xian et al., 2015), text size of in-vehicle touchscreen information (Crundall et al., 2016), and location of the scroll button on the in-vehicle touchscreen (Kujala et al., 2015).

Some of the previous studies investigated the effects of different location of NDRT display on drivers' performance within a partially automated (Level 2) vehicle (Choi, 2019; Hensch et al.,2020). In particular, Choi (2019) examined the location of windshield and CD player (mid-console) with smartphone display using reading task. It showed that display location had no significant effect on secondary task performance but display location near the CD layer did result in worse driving performance compared to the windshield display location which placed closest to the driving environment. Hensch et al., (2020) looked at the influence of head-up display (HUD) and center console display location as secondary task display on the drivers' gaze behavior during takeover situation. They revealed that the HUD had longer eyes-on display time than the center console however, performance of secondary task was better at the location of center console than HUD.

Despite extensive past research, however, it appears that there are still significant research opportunities concerning the in-vehicle touchscreen interface design. One major research opportunity pertains to the design of touchscreen interfaces in the context of automated driving. Very few human factors studies seem to have investigated the design of touchscreen interfaces for automated vehicles, both in terms of the physical and the graphical user interface design.

This is despite the expectation that in-vehicle touchscreens will play important roles inside automated vehicles as advances in driving automation will result in expanding the range of driver tasks. Due to lack of research, human factors design knowledge relevant to the design of in-vehicle touchscreen interfaces for automated vehicles is currently insufficient.

1.3 Research Objectives and Questions

The long-term goal of our research is to address the research gap above by investigating the effects of touchscreen interface design in the context of automated driving, across different levels of driving automation. In an effort towards accomplishing the long-term goal, the primary objective of the current study was to examine the effects of in-vehicle touchscreen location on driver tasks in an SAE Level 3 conditionally automated vehicle. A Level 3 vehicle allows a driver to perform an NDRT while it is driving itself, but, upon a take-over request (TOR), the driver is required to immediately disengage himself/herself from the NDRT and switch to human driving. We hypothesized that the location of an in-vehicle touchscreen for a visuomanual NDRT (referred to as the NDRT touchscreen) would affect the driver task performance, gaze behavior and workload during conditionally automated driving, for both the NDRT and the take-over phase. This hypothesis was based on the reasoning that during the NDRT phase of automated driving, NDRT touchscreen location would determine the amount of visual information from the outside world (the road scenes through the windshield, the room mirror and the side-view mirrors), in a bottom-up fashion (Wickens, 2015; Wickens and McCarley, 2019); and, this would affect not only the NDRT but also the subsequent take-over task. In addition to the NDRT touchscreen location effects, this study also examined the effects of NDRT difficulty level. Two research questions entertained in this study were as follows:

RQ1: How do NDRT touchscreen location and NDRT difficulty level affect driver's task performance, eye gaze behavior, and workload during the NDRT phase of Level 3 conditionally automated driving?

RQ2: How do NDRT touchscreen location and NDRT difficulty level affect driver's task performance, eye gaze behavior, and workload during the take-over phase of Level 3 conditionally automated driving?

Chapter 2

Method

2.1 Participants

A total of 20 participants (14 males and 6 females) participated in this study. Their mean age and driving experience were 27.55 years (SD = 3.44, min = 23, max = 35), and, 4.47 years (SD = 4.63, min = 1, max = 17), respectively. All the participants had held a valid driving license for at least 1 year. Participant inclusion criteria were normal or corrected-to-normal vision acuity and right-handedness. The study received ethical approval from the Institutional Review Board of Seoul National University.

2.2 Apparatus

A driving simulator, consisting of an adjustable vehicle interior mock-up, three 42-inch LED monitors, and a PC was employed in this study (Figure 2.1). The adjustable vehicle interior mock-up was comprised of five components: a driver's seat, a steering wheel, a gearshift, a gas pedal, and a brake pedal. The three monitors were placed around the front of the vehicle interior mock-up - they provided a forward FOV angle of 183.6°. The UC-win/Road driving simulator software program (Forum8) was utilized to create virtual driving scenarios, run simulated driving experimental trials, and collect driving performance data. The tablet computer (Microsoft Surface 3) was employed to simulate an in-vehicle touchscreen for performing NDRTs (Figure2.2). Each participant's eye movements were recorded using a Tobii Pro Glasses 3 eyetracker. The Tobii Pro Glasses 3 had a horizontal field of view of 95°, a vertical FOV of 63°, and four eye-tracking sensors, with a sampling rate of 50Hz. The eye-tracking glasses were connected to a small computer called the recording unit. Eye-tracking data was coded and analyzed using the Tobii Pro Lab® Software version 1.171

Figure 2.1: Experimental setup

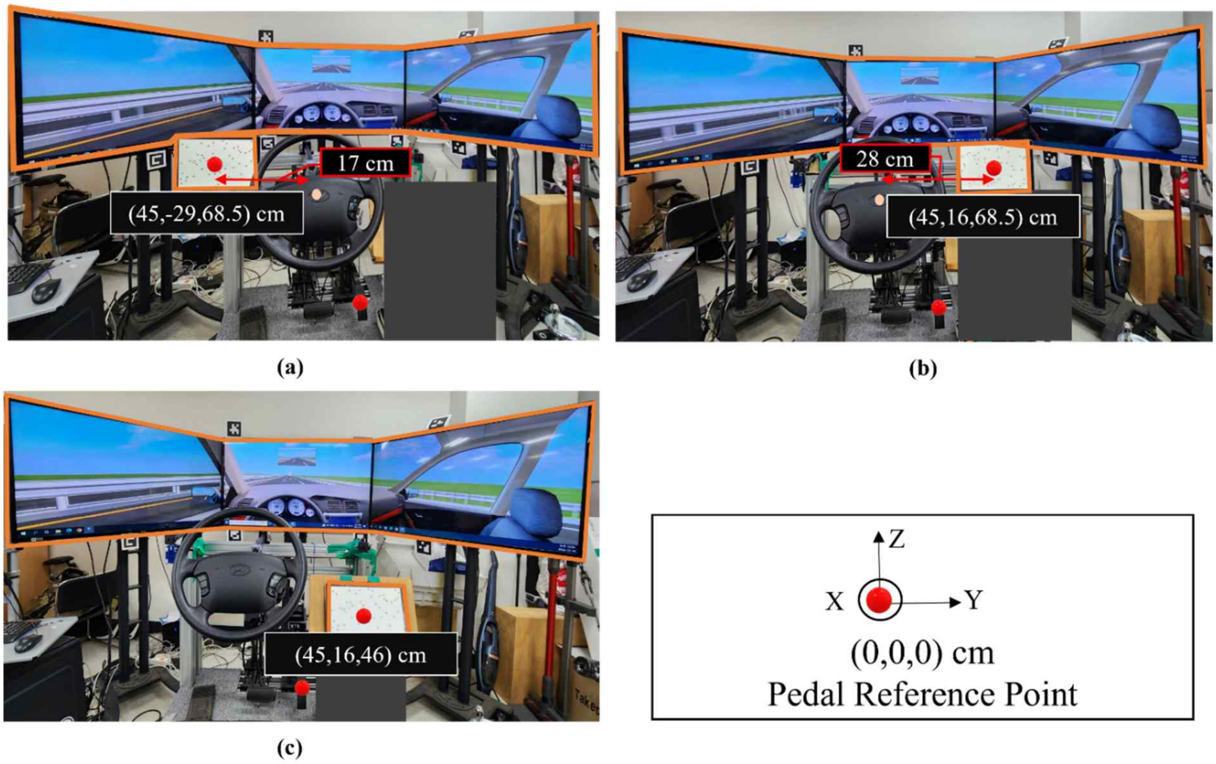

Figure 2.2: Three touchscreen locations. (a) Upper Left, (b) Upper Right, and (c) Lower Right. Each touchscreen location is specified with respect to the pedal reference point. The touchscreen was oriented vertically at Upper Left and at Upper Right, and, at an angle of 78° relative to the floor at Lower Right. The orange polygons mark the two AOIs: the NDRT touchscreen and the road (outside world).

2.3 Experiment

Prior to the experimental trials, the participants received a brief explanation of the study's purpose and were provided with a training session. The training session was to familiarize them with the driving simulator and the experimental task. The experimental task consisted of two successive sub-tasks: an NDRT followed by a take-over task in the context of SAE Level 3 automated driving.

The NDRT was a visual-manual task known as the Surrogate Reference Task (SuRT, ISO TS14198), and, it was performed using the tablet computer (Microsoft Surface 3) simulating an in-vehicle touchscreen. Three in-vehicle touchscreen locations were considered in this study: Upper Left, Upper Right, and Lower Right, as shown in Figure 2. The three touchscreen locations corresponded to typical locations of the left air conditioning vent, the dashboard center, and the bottom of the middle console found commonly in conventional vehicles. The three locations were chosen as they were all within the driver's reach limits. Some concept cars exhibited at Consumer Electronics Show (CES) 2020 and 2021, such as Sony's Vision-S and Lucid motor's Lucid Air, had a large touchscreen at the left air conditioning vent and the bottom of the middle console. The three locations were also expected to affect the driver's body posture and field of view, especially the extent of the road within the driver's field of view during the NDRT.

The SuRT requires a participant to examine a circle set consisting of a target circle and multiple distractor circles randomly located on a surface display. Typically, both the target circle and the distractors are open circles in black displayed on a white background; the target circle differs from the distractors in size. The participant is instructed to visually search for and finger-tap the target as quickly as possible. Then, the next circle set is presented and the process repeats. The SuRT is self-paced as the next circle set is not presented until the completion of the response for the current set. Even if the participant makes an incorrect response, the next display is presented without showing any error message. The configuration of target and distractors is randomized for each successive circle set.

In this study, each SuRT circle set consisted of a target circle and 49 distractors. Two difficulty levels (Easy and Hard) differing in the size of the target circle were considered. For the level Easy, the diameter of the target circle was 2.5 cm whereas that for the distractors was 1.2 cm (Figure 2.3). For the level Hard, the diameter of the target circle and that for the distractors were 1.5 cm and 1.2 cm, respectively (Figure 2.3).

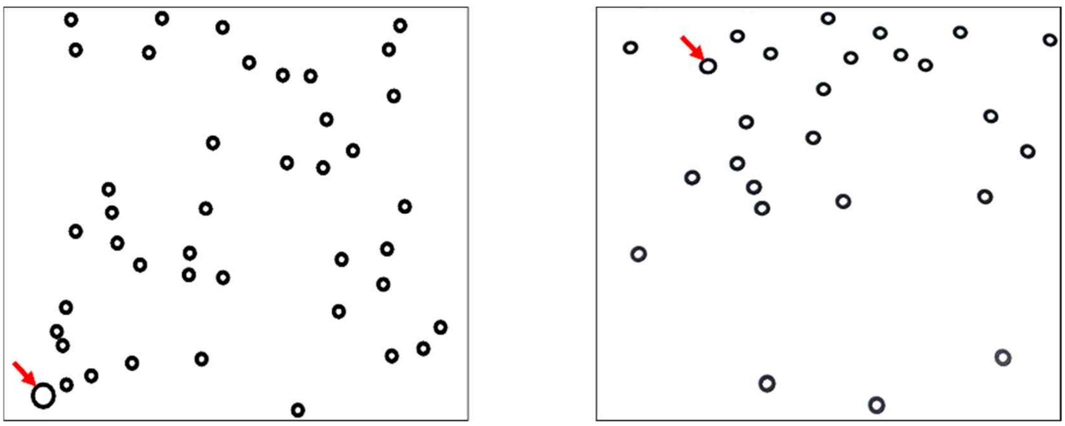

Figure 2.3: Two NDRT difficulty levels. (a) Easy. (b) Hard. Red arrows indicate the location of a target circle to click.

At the beginning of an experimental trial, the participants were instructed to perform only the NDRT (SuRT), while the simulated ego vehicle traveled in self-driving mode. The NDRT phase duration was 3 minutes - the participants were not informed of the duration. Again, the simulated ego vehicle was an SAE Level 3 automated vehicle. Thus, the participants were able to take their hands off the wheel and their eyes off the road while the vehicle was self-driving within system boundaries; however, the participants were instructed to be always ready to take control of the vehicle with notice (NHTSA, 2018).

At the end of the first 3-minute time interval for the NDRT, the take-over task phase began with a construction zone appearing on the second lane, 194m ahead of the ego vehicle. Simultaneously, a beeping sound of take-over alarm was auditorily presented, alerting the participant to make a safe lane change as quickly as possible. The instruction to the participant was that immediately after receiving the take-over alarm, the participant must put their hands back on the steering wheel, check the road ahead, the side-view mirrors, and the rear-view mirror, make a correct judgment, and execute a safe lane change. The participant did not use the pedals as the ego vehicle's speed was fixed at 100 km/h. The time budget for taking over control and making the lane change was 7 seconds. The experimental task was designed to serve as a generic representation of dangerous take-over situations for a Level 3 automated vehicle that demand drivers to stop an on-going NDRT, rapidly gain situation awareness through the available visual channels and make adequate lane change maneuvers to avoid imminent collision.

As is the case in the real-world lane changing task, the take-over subtask required considering surrounding vehicles on the first and the third lane for making a safe lane change. Prior to the appearance of the obstacle (construction zone), previously generated background vehicles moved away from the ego vehicle to disappear, and, three new vehicles came into the participant's view and surrounded the ego vehicle. This reconfiguration was completed 10 seconds prior to the take-over alarm, and, at the time of completion, the three surrounding vehicles were placed in one of the four configurations (scenarios) designed in advance (Figure 2.4). Each of the surrounding vehicles was moving at a constant speed without making any lane changes; the speed of each surrounding vehicle was determined between 85 km/h and 120 km/h. The positions of the three surrounding vehicles at the time of the completion of reconfiguration and their constant speeds in combination permitted only one of the two lane change options (either to the first or the third lane) to be safe. Successful decision-making for lane change could not be guaranteed unless the participant checked all three visual channels for driving (the roadway ahead, the side mirrors, and the rear-view mirror) and integrated the gathered information.

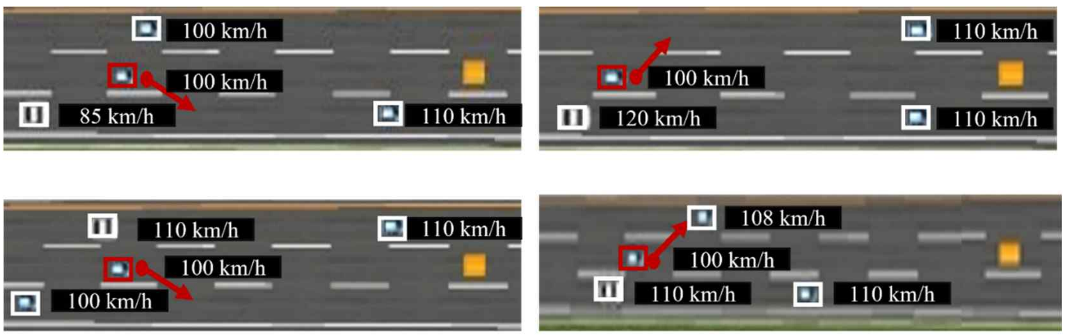

Figure 2.4: Bird's-eye view of the four take-over driving scenarios. It was captured at the moment of the take-over request issuance (a beeping sound). The ego vehicle is marked in a red box and each surrounding vehicle, in a white box. The obstacle is shown as a yellow filled-in square.

At the completion of an experimental task trial, the participant completed the NASA Task Load Index (TLX) questionnaire (Hart and Staveland, 1988), perceived body discomfort ratings on a 5-point scale (Corlett and Bishop, 1976), and NDRT touchscreen location preference rank he/she experienced during each of the two phases (NDRT and take-over task) of the experimental task trial. Then, the driving simulation was reinitialized, and the participant's vehicle was re-generated on the second lane again for the next trial. A total of 24 experimental trials were performed in one day, and after completing 12 experimental trials, 15 minutes of rest breaks were given to the participants.

Each participant conducted the experimental task in a total of 24 experimental trials. The experimental trials were the combinations of three touchscreen locations (Upper Left, Upper Right, and Lower Right), two NDRT difficulty levels (Easy and Hard), and 4 different scenarios selected. The experimental trial orders were randomized across the participants.

2.4 Experimental variables

The independent variables of the study were NDRT touchscreen location (Upper Left, Upper Right, and Lower Right) and difficulty level of NDRT (Easy and Hard) (Table 2.1).

Table 2.1: Experimental Variables

<table>
<tr><th rowspan="2">Independent variables</th><th colspan="3">Dependent variables</th></tr>
<tr><th></th><th>NDRT</th><th>Take-over task</th></tr>
<tr><td rowspan="3">• NDRT touchscreen location
▪ Upper Left
▪ Upper Right
▪ Below Right

• NDRT difficulty level
▪ Easy
▪ Hard</td><td>Performance measures</td><td>• Total number of clicking the circles
• Number of clicking the target circles
• Number of clicking the distractor circles</td><td>• The onset of lane changing maneuver
• Lane change completion time</td></tr>
<tr><td>Eye gaze behavior</td><td>• Total glance duration to NDRT touchscreen
• Total glance duration to road</td><td>• Total glance duration to NDRT touchscreen
• Total glance duration to road</td></tr>
<tr><td>Subjective measures</td><td>• NASA TLX
• Perceived body part discomfort rate
• Preference rank of NDRT touchscreen location</td><td>• NASA TLX
• Perceived body part discomfort rate
• Preference rank of NDRT touchscreen location</td></tr>
</table>

As for the dependent variables, a set of objective performance, eye gaze behavior, and subjective experience measures were adopted for each of the two experimental task phases, that is, the NDRT and the take-over task phase (Table 1). Detailed descriptions of the dependent measures are provided in the following:

For the dependent variables used for the NDRT, three NDRT performance measures were employed. They were the total number of clicks, the number of correct clicks (the number of successes), and the number of incorrect clicks (the number of errors). Also, eye gaze behavior was examined using the measure of total glance duration. This was to explore the driver's level of visual engagement and strategies for visual attention allocation strategies. Total glance duration is the sum of the lengths of the individual glances to an area of interest (AOI). The length of a single glance is defined as the time from the start of the saccade leading into the AOI to the end of the last fixation on the AOI (ISO 15007, 2002; Highway Traffic Safety Administration (NHTSA) Visual-Manual Guidelines, 2013; Tullis and Albert, 2008). Two AOIs were considered: the NDRT touchscreen and the road (Figure 2). Thus, two total glance duration measures were defined, one for the NDRT touchscreen and the other for the road. Lastly, the subjective measures employed were the NASA TLX (Hart and Staveland, 1988), perceived body part discomfort rate (Corlett and Bishop, 1976), and preference rank of NDRT touchscreen location. The NASA-TLX is used to measure the subjective perception of workload. It consists of six workload scores corresponding to different workload dimensions (Mental, Physical, Temporal, Performance, Effort, and Frustration) and an overall workload score. As for perceived body part discomfort rating, the participants assessed the physical discomfort for six different body parts (Head and Neck, Shoulder, Arm, Middle back, Lower back, Buttock) on a 5-point scale with the endpoints “No pain” (0) and “Severe” (5). For preference rank of NDRT touchscreen location, the participants were asked to rank the most preferred location.

For the dependent variables used for the take-over task, two take-over task performance measures were employed. They were response time and lane change task completion time. Response time was determined as the time duration between the take-over alarm issuance (equivalently, the obstacle appearance) and the first response of steering wheel movement. Lane change completion time was computed as the time duration between the take-over alarm issuance and the completion of the vehicle's lateral movement into the target lane. For each experimental task trial, the two measures were determined using the log data from the driving simulation software program. And, eye gaze behavior measures were identical to those used for the NDRT phase. Lastly, the subjective measures of NASA TLX (Hart and Staveland, 1988) perceived body part discomfort rate (Corlett and Bishop, 1976), and preference rank of NDRT touchscreen location.

2.5 Statistical analysis

A series of two-way repeated measures ANOVAs were conducted to test the effects of the independent variables and their interaction on each dependent measure. For each ANOVA, sphericity of data was tested using Mauchly's test. In cases where sphericity was violated, the degrees of freedom were corrected (Field, 2009). The Greenhouse-Geisser correction was used when the Greenhouse-Geisser estimate of sphericity (ε) was less than 0.75; the Huynh-Feldt correction was used otherwise. In cases where the main effect of NDRT touchscreen location was found to be statistically significant, post hoc multiple pairwise comparisons with Bonferroni correction were conducted. All statistical tests were conducted at an alpha level of 0.05 using SPSS 26 (IBM Corp., Armonk, USA).

Chapter 3

Result

3.1 NDRT performance measures

The two-way ANOVAs conducted on the NDRT performance measures identified some significant main effects (Figure 3.1 – 3.3). NDRT touchscreen location significantly affected number of incorrect clicks, $F(2.46, 64.20) = 4.54$, $p < .05$. The post-hoc multiple pairwise comparisons revealed a significant difference between Lower Right and Upper Right in mean number of incorrect clicks (Figure 3.1). NDRT difficulty level significantly affected total number of clicks, $F(1, 19) = 56.93$, $p < .001$ (Figure 3.2), and number of correct clicks, $F(1, 19) = 56.91$, $p < .001$ (Figure 3.3). Both mean total number of clicks and mean number of correct clicks were significantly higher for Easy than for Hard. No significant two-way interaction effect was found for any of the NDRT performance measures.

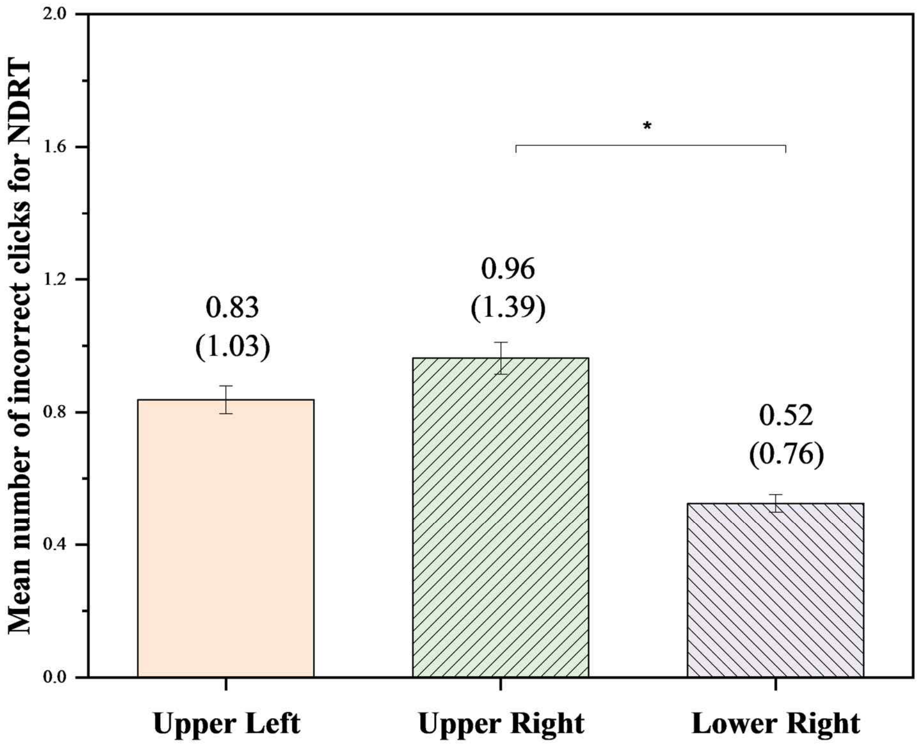

Figure 3.1: NDRT touchscreen location effect on number of incorrect clicks. The mean and standard deviation are presented for each NDRT touchscreen location. Asterisks indicate significance in pairwise comparison. *$p < .05$. **$p < .01$. ***$p < .001$.

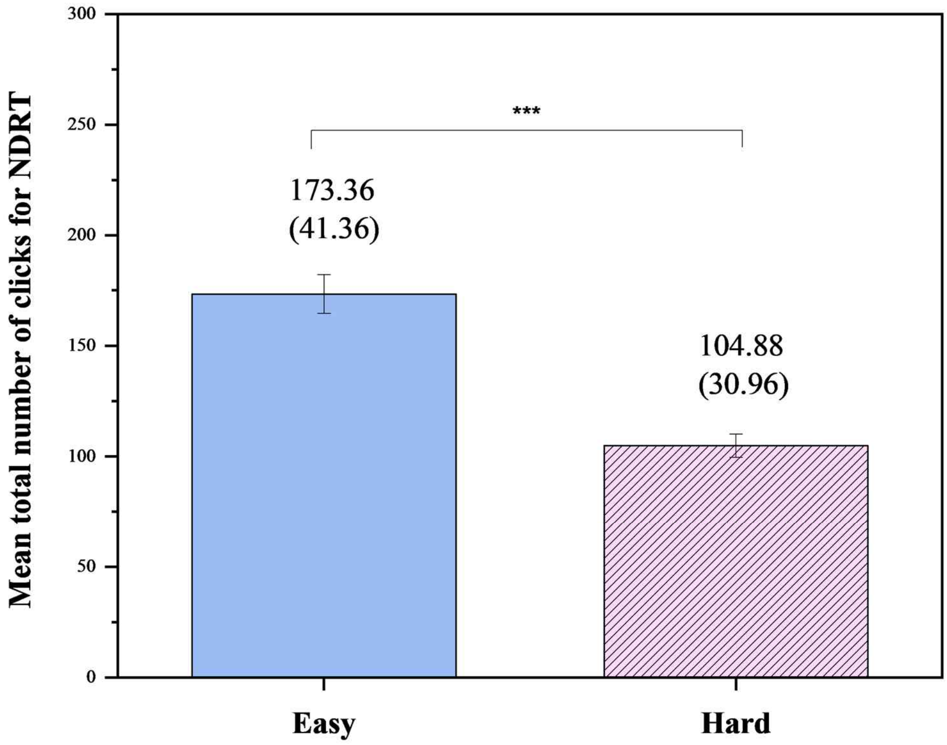

Figure 3.2: NDRT difficulty level effect on total number of clicks. The mean and standard deviation are presented for NDRT difficulty level. Asterisks indicate significance in pairwise comparison. $^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

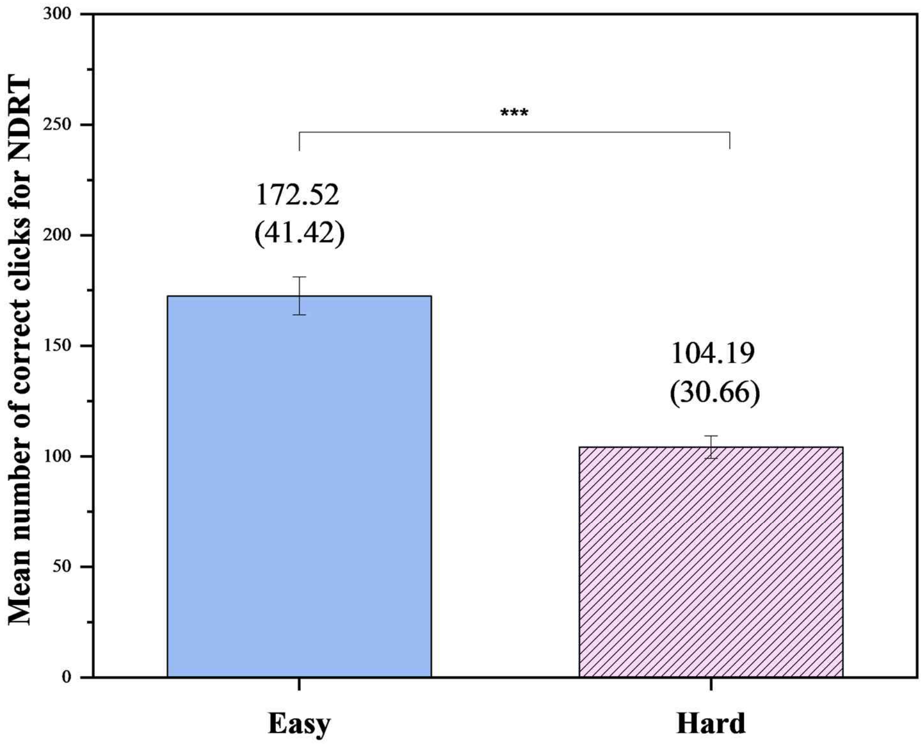

Figure 3.3: NDRT difficulty level effect on number of correct clicks. The mean and standard deviation are presented for NDRT difficulty level. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

3.2 Eye gaze behavior measures (NDRT phase)

The results of the two-way repeated measures ANOVAs conducted on the measures of eye gaze behavior during the NDRT phase of the experimental task were first, NDRT touchscreen location significantly affected both the dependent measures: total glance duration to NDRT touchscreen, $F(2, 38) = 13.33$, $p < .001$ (Figures 3.4), and total glance duration to the road, $F(1.43,54.57) = 4.72$, $p < .05$ (Figure 3.5). The results of the post hoc multiple pairwise comparisons indicated that Upper Right resulted in a significantly shorter total glance duration to NDRT touchscreen than Lower Right. Upper Left resulted in a significantly shorter total glance duration to NDRT touchscreen than Lower Right. It also indicated that Lower Right resulted in a significantly shorter total glance duration to the road than Lower Right. Second, NDRT task difficulty significantly affected neither the total glance duration to NDRT touchscreen nor the total glance duration to the road. Lastly, no significant two-way interaction effect was found.

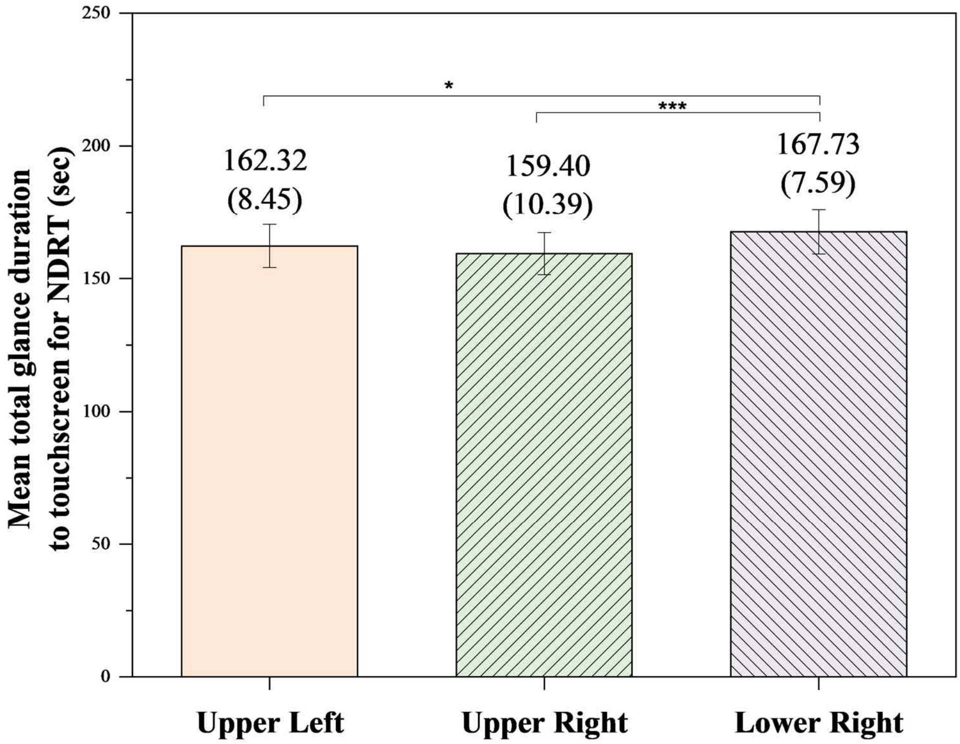

Figure 3.4: NDRT touchscreen location effect on total glance duration to touchscreen. The mean and standard deviation are presented for each NDRT touchscreen location. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

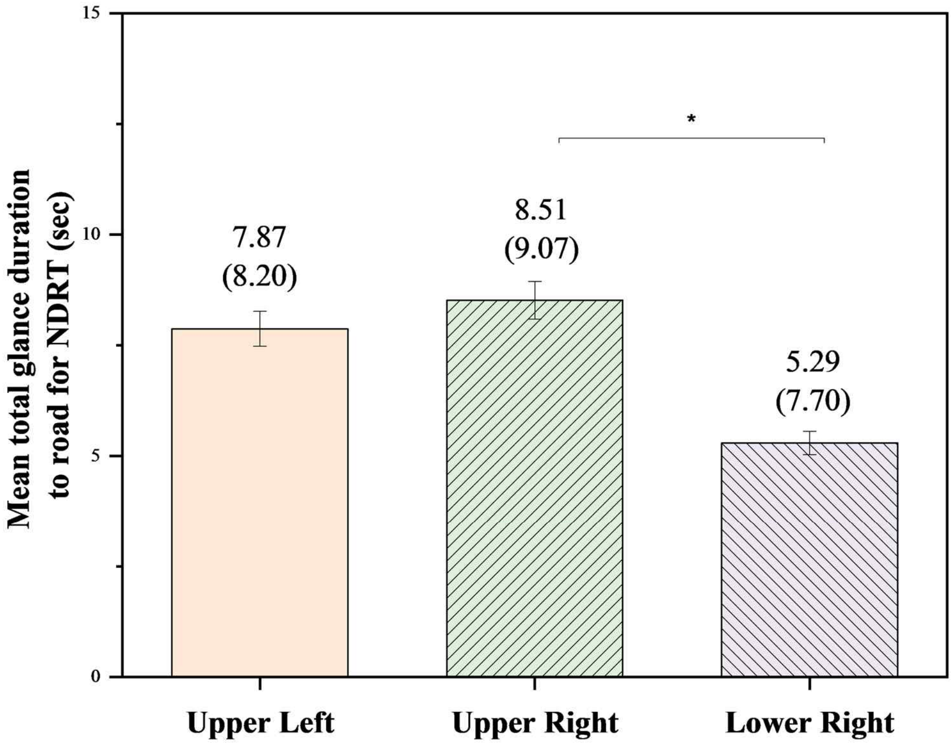

Figure 3.5: NDRT touchscreen location effect on total glance duration to the road. The mean and standard deviation are presented for each NDRT touchscreen location. Asterisks indicate significance in pairwise comparison. *$p < .05$. **$p < .01$. ***$p < .001$.

3.3 Subjective experience measures (NDRT phase)

The results of the two-way repeated measures ANOVAs conducted on the NDRT phase NASA TLX scores were first, a significant NDRT touchscreen location main effect was found only for the 'physical demand' dimension of the NASA TLX, $F(2, 36) = 8.89$, $p < .01$ (Figure 3.6). The post hoc multiple pairwise comparisons indicated that Lower Right resulted in a lower mean physical demand score than Upper Right and Upper Left. Second, NDRT difficulty level was found to significantly affect the mental demand, $F(1, 19) = 41.15$, temporal demand, $F(1, 19) = 22.52$, performance, $F(1, 19) = 23.09$, effort, $F(1, 19) = 35.31$, and overall demand, $F(1, 19) = 21.41$ scores, all with $p<0.001$ (Figure 3.7). The mean scores were significantly higher for Hard than for Easy for all the NASA TLX dimensions, except for the performance dimension. For the performance dimension that measures the participants' satisfaction with their performance in accomplishing the task, Easy showed a higher score than Hard - this indicates that the perceived performance level was lower in Easy than in Hard. Lastly, no significant two-way interactions were found for 5 out of the 6 NASA TLX dimensions and the overall demand score. Temporal demand was the only dimension that showed a significant two-way interaction, $F(1.44, 27.40) = 4.38$, $p < .05$ (Figure 3.8). The post hoc multiple pairwise comparisons indicated a significant difference in temporal demand between Easy and Hard, only at Upper Left.

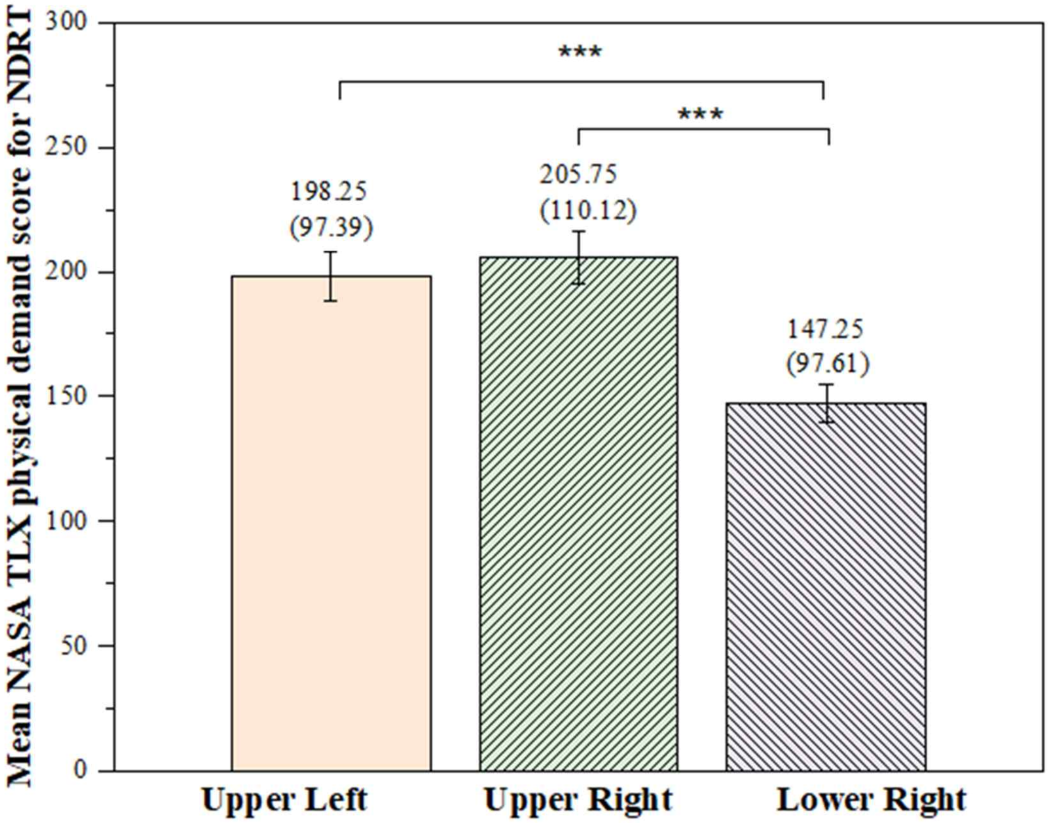

Figure 3.6: NDRT touchscreen location effect on NASA TLX physical demand score for NDRT. The mean and standard deviation are presented for each NDRT touchscreen location. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001

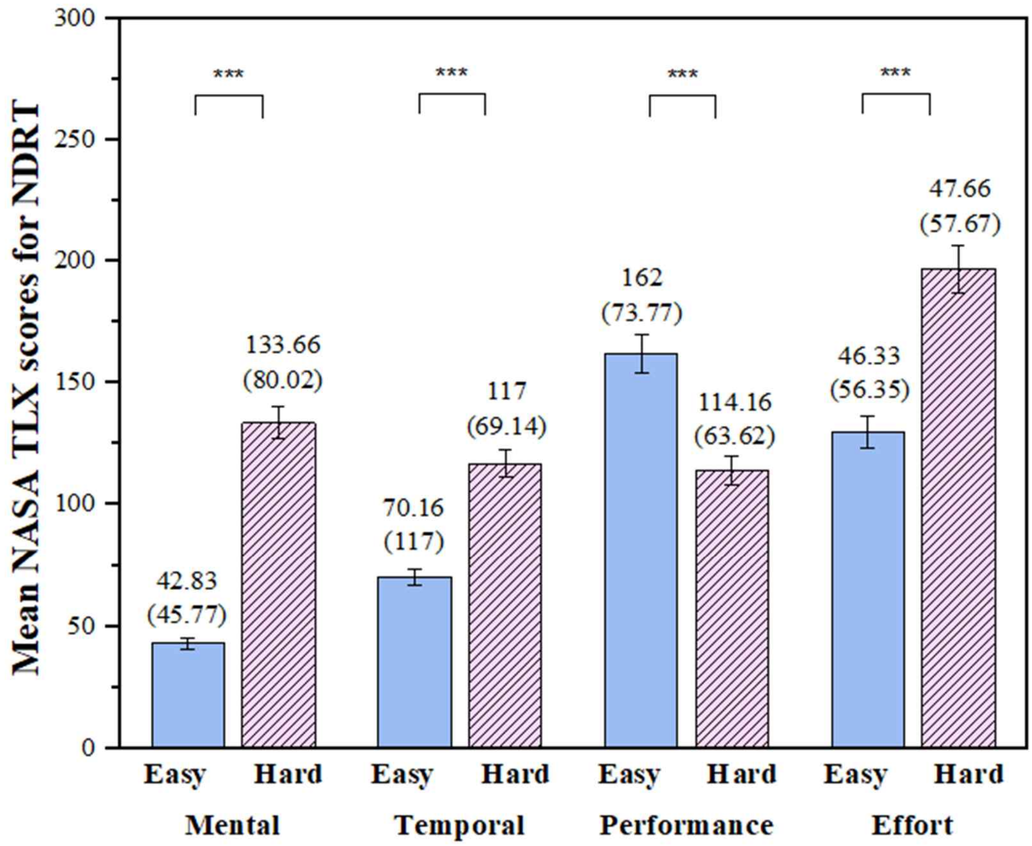

Figure 3.7: NDRT difficulty level effect on NASA TLX score for NDRT. The mean and standard deviation are presented for each NDRT difficulty level. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

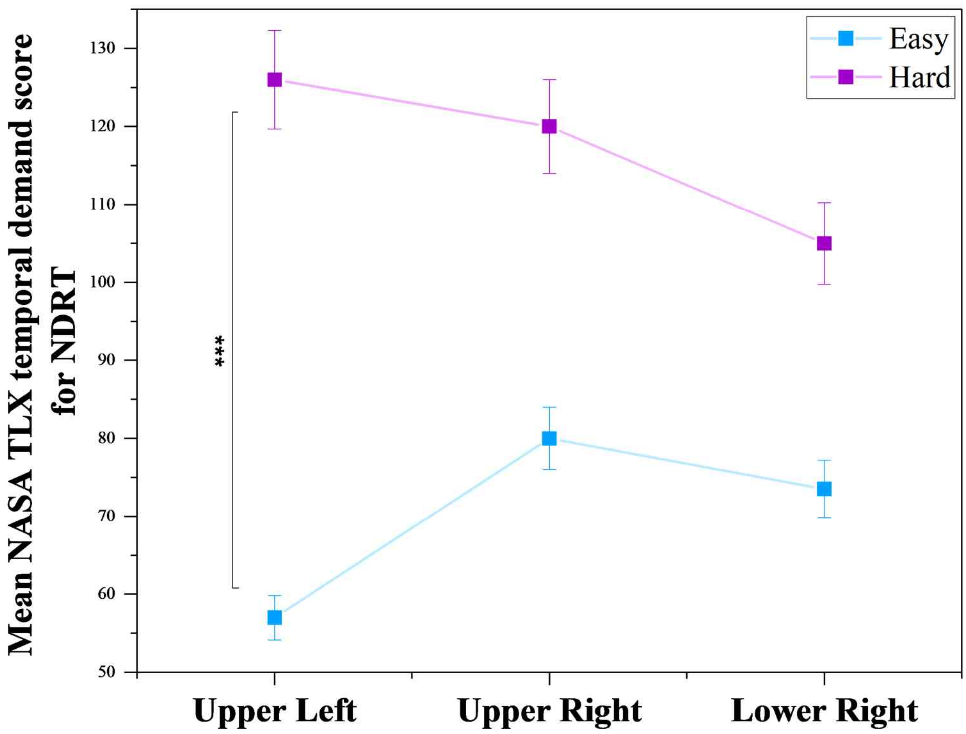

Figure 3.8: Interaction effect on NASA TLX score during NDRT. NDRT touchscreen location x NDRT difficulty level interaction effect on NASA TLX temporal demand score during NDRT phase. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

As for the NDRT phase local body part discomfort rating measures, the two-way repeated measures ANOVA revealed that first, NDRT touchscreen location did not significantly affect any of the local body part discomfort rating measures. Second, NDRT difficulty level significantly affected the arm, $p<0.001$, and the buttock discomfort rating score, $p<0.05$ (Figure 3.9). The mean arm discomfort rating score was significantly higher for Hard than for Easy. However, the buttock mean discomfort rating score was significantly higher for Easy than for Hard. Lastly, two-way interaction effects were significant for the arm, $F(2, 38) = 4.65$, $p < 0.05$ (Figure 3.10) and the buttock discomfort rating score, $F(1.75, 33.27) = 4.33$, $p < .005$ (Figure 3.11). The post hoc multiple pairwise comparisons indicated a significant difference in the arm discomfort score between Easy and Hard, only at Upper Right. As for the buttock discomfort rating score, post hoc multiple pairwise comparisons did not find any significant mean differences.

As for the preference rank of NDRT touchscreen location, a chi-square test revealed that the participants' preferred rank was not equally distributed across the NDRT touchscreen locations for both the easy ($\chi2(4) = 29.1$, $p <0.001$) and the hard NDRT difficulty level ($\chi2(4) = 14.7$, $p <0.001$) (Figure 3.12). It was found that the most preferred NDRT touchscreen location during NDRT was Lower Right in both levels of NDRT difficulty.

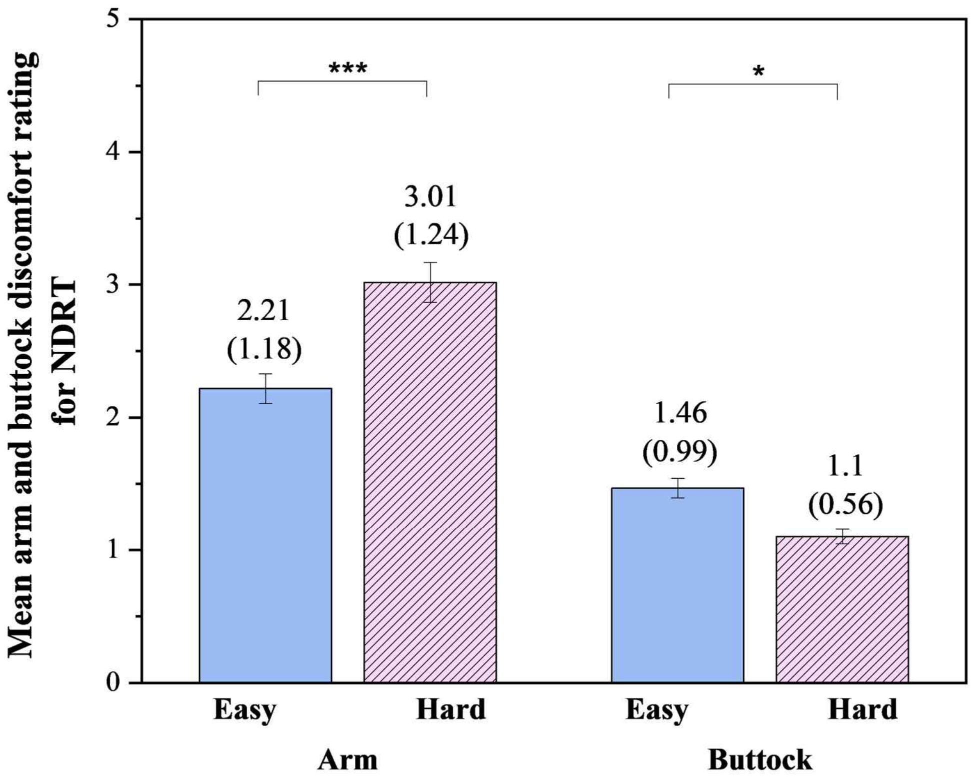

Figure 3.9: NDRT difficulty level effect on arm and buttock discomfort rating score for NDRT. The mean and standard deviation are presented for each NDRT touchscreen location and NDRT difficulty level. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

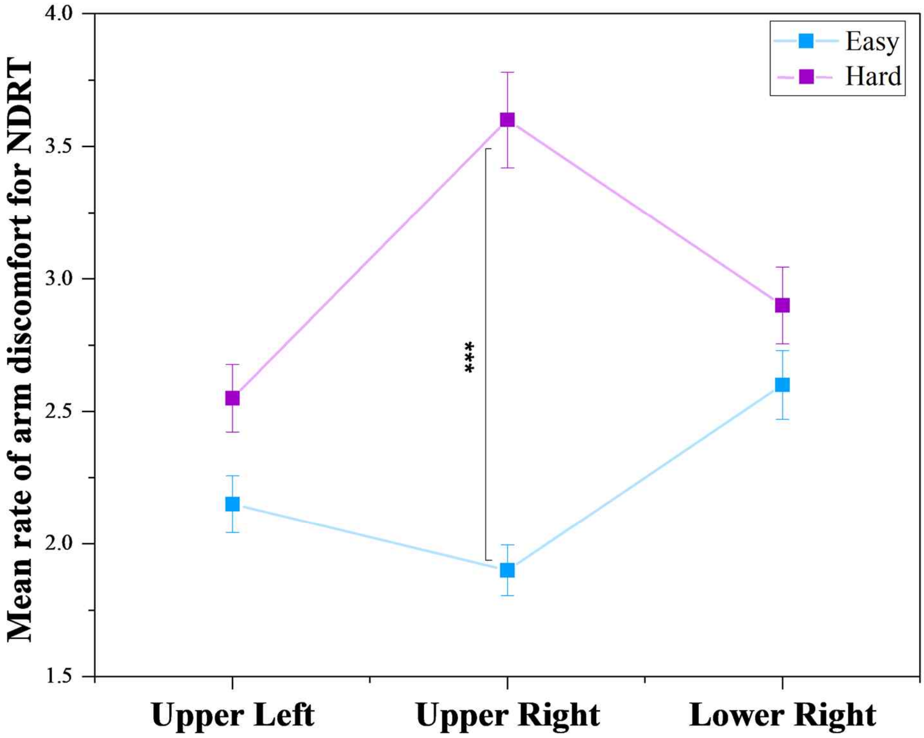

Figure 3.10: Interaction effect on arm discomfort rating score for NDRT. NDRT touchscreen location x NDRT difficulty level interaction effect on arm discomfort rating score for NDRT. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

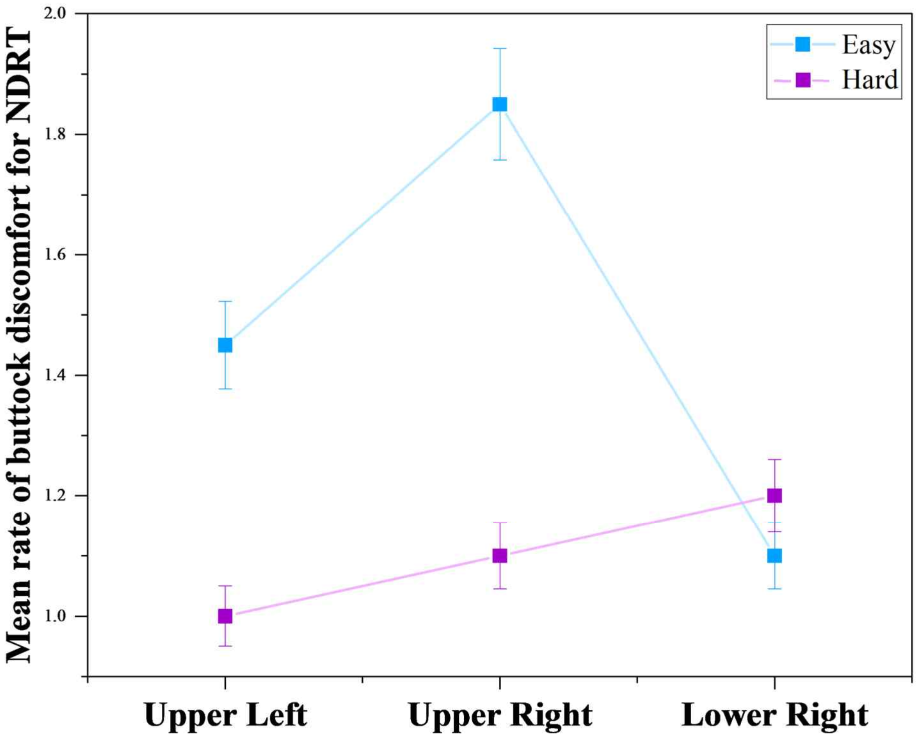

Figure 3.11: Interaction effect on buttock discomfort rating score for NDRT. NDRT touchscreen location x NDRT difficulty level interaction effect on buttock discomfort rating score for NDRT. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

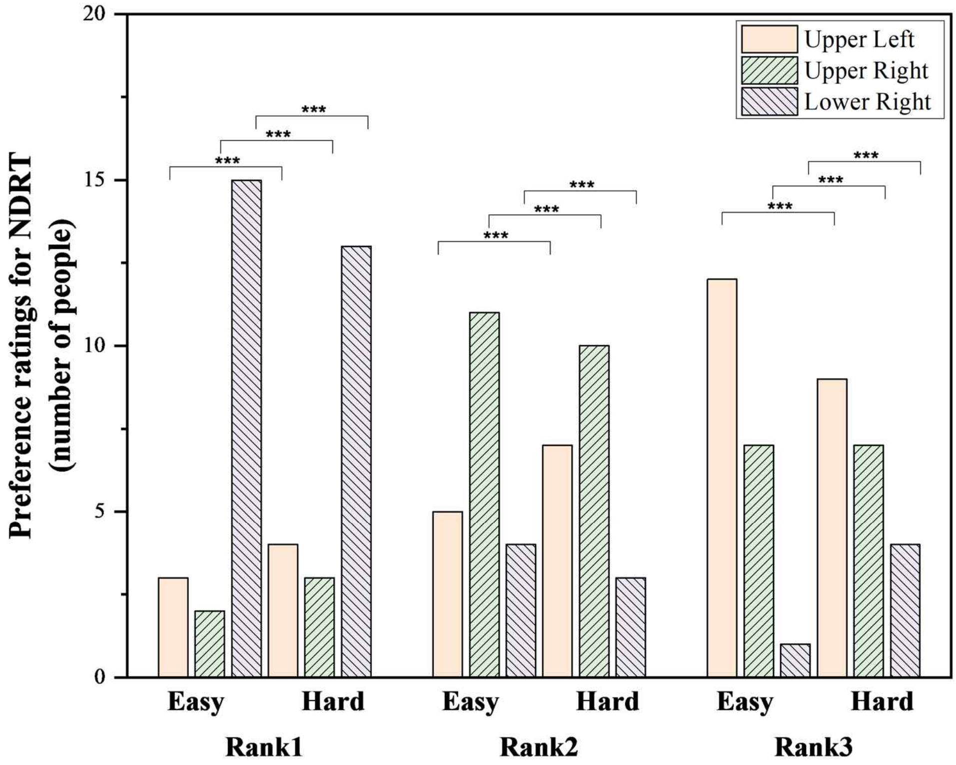

Figure 3.12: NDRT Touchscreen location preference rank for NDRT. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

3.4 Take-over task Performance measures

The ANOVAs on the take-over task performance measures revealed significant NDRT touchscreen location main effects. NDRT touchscreen location significantly affected response time, $F(1.40, 26.74) = 12.16$, $p < .001$ (Figure 3.13). Lower Right resulted in a significantly slower mean response time than Upper Right and Upper Left. NDRT touchscreen location also significantly affected lane change completion time, $F(2,38) = 15.17$, $p < .001$ (Figure 3.14). Lower Right showed a significantly slower mean lane change completion time than Upper Right and Upper Left. The ANOVAs found no NDRT difficulty level main effect and also no two-way interaction effects.

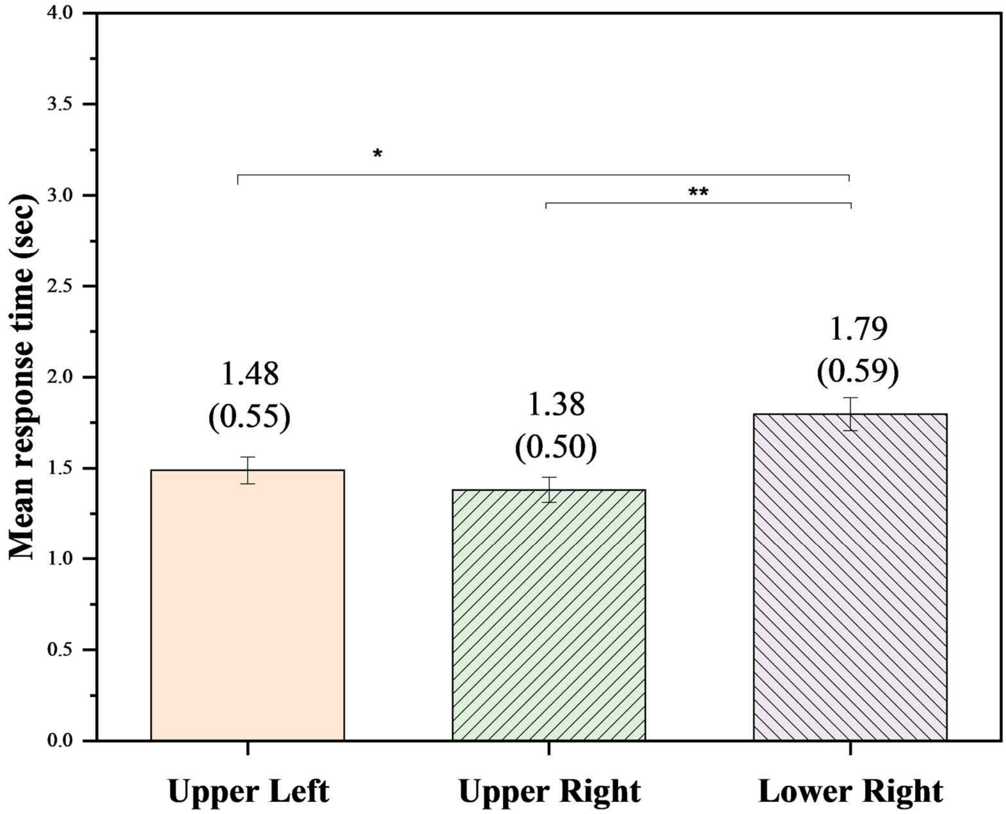

Figure 3.13: NDRT touchscreen location effect on take-over task response time. The mean and standard deviation are presented for each NDRT touchscreen location. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

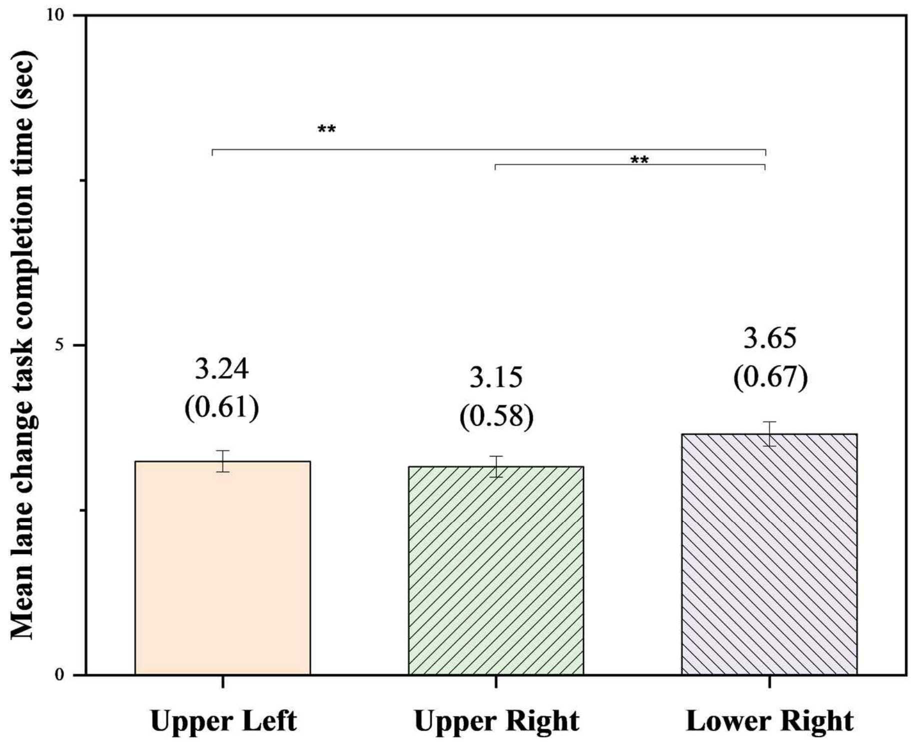

Figure 3.14: NDRT touchscreen location effect on lane change task completion time. The mean and standard deviation are presented for each NDRT touchscreen location. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

3.5 Eye gaze behavior measures (take-over task phase)

Across all participants and task trials, no eye glance to NDRT touchscreen was observed during the take-over phase of the experimental task. Thus, only the "total glance duration to the road" measure was subjected to the two-way repeated measures ANOVA. NDRT touchscreen location significantly affected total glance duration to the road, $F(2, 38) = 33.96$, $p < .001$ (Figure 3.15). The post hoc multiple pairwise comparisons found that Upper Right resulted in a shorter glance duration to the road than Upper Left and Lower Right. Also, Upper Left resulted in a significantly shorter glance duration to the road than Lower Right. Also, NDRT task difficulty did not significantly affect the total glance duration to the road and no significant two-way interaction effect was found.

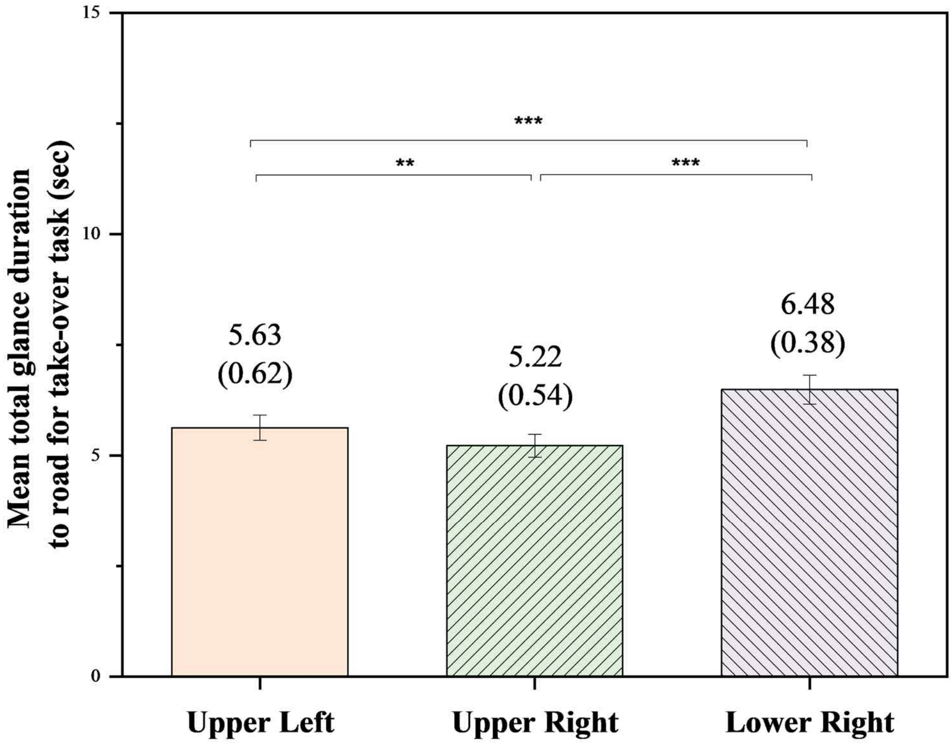

Figure 3.15: NDRT touchscreen location effect on total glance duration to the road for take-over task. The mean and standard deviation are presented for each NDRT touchscreen location. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

3.6 Subjective experience measures (take-over task phase)

The results of the two-way repeated measures ANOVAs conducted on the NASA TLX scores during the take-over phase were first, NDRT touchscreen location did not significantly affect any of the NASA TLX workload measures. Second, NDRT difficulty level was found to significantly affect the dimensions of mental, $F(1, 19) = 18.82$, $p<0.001$, temporal, $F(1, 19) = 5.75$, $p<0.05$, effort, $F(1, 19) = 5.53$, $p<0.05$, and overall, $F(1, 19) = 8.57$, $p<0.01$ (Figure 3.16). The mean demand scores of mental, temporal, effort, and overall were significantly higher for Hard than for Easy. Lastly, no significant two-way interactions were found for any of the NASA TLX workload measures.

As for the local body part discomfort rating measures, the two-way repeated measures ANOVAs revealed no significant main and interaction effects.

As for the preference rank of NDRT touchscreen location, a chi-square test revealed that the participants' preferred rank was not equally distributed across the NDRT touchscreen locations for both the easy ($\chi2(4) = 29.1$, $p <0.001$) and the hard NDRT difficulty level ($\chi2(4) = 14.7$, $p <0.001$) (Figure 3.17). It was found that the most preferred NDRT touchscreen location during take-over task was Upper Right in both levels of NDRT difficulty.

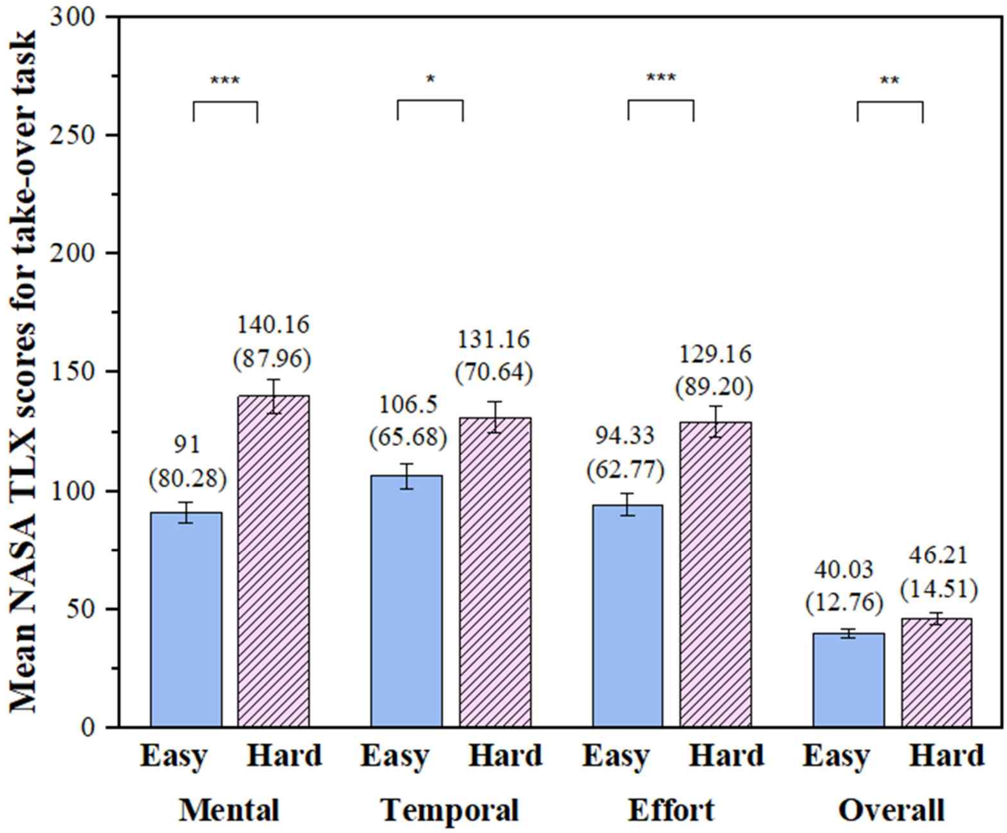

Figure 3.16: NDRT difficulty level effect on NASA TLX scores for take-over task. The mean and standard deviation are presented for each NDRT difficulty level. Asterisks indicate significance in pairwise comparison. *$p < .05$. **$p < .01$. ***$p < .001$.

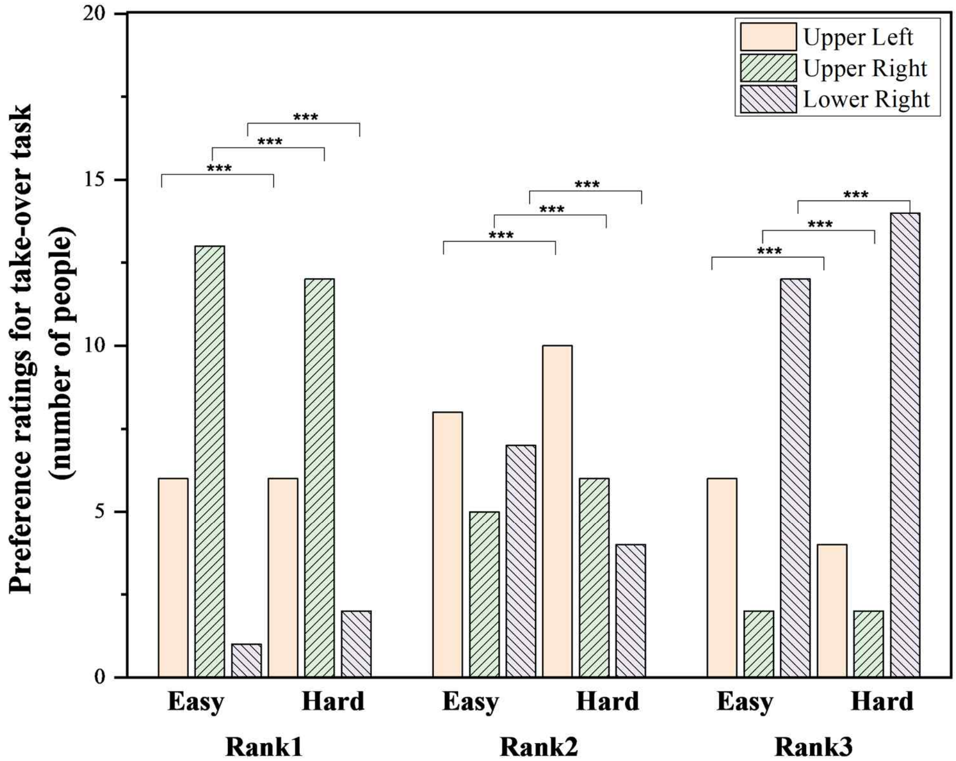

Figure 3.17: NDRT Touchscreen location preference rank for NDRT. Asterisks indicate significance in pairwise comparison. *p < .05. **p < .01. ***p < .001.

Chapter 4

Discussion

The objective of the current study was to investigate the effects of NDRT touchscreen location and NDRT difficulty level on driver task performance, eye gaze behaviors, workload, physical discomfort, and preference rank during SAE Level 3 automated driving. A driving simulator experiment was conducted. The experimental task consisted of two successive sub-tasks: an NDRT followed by a take-over task in the context of Level 3 automated driving. Three NDRT touchscreen locations (Upper Left, Upper Right and Lower Right) and two NDRT difficulty levels (Easy and Hard) were considered. The research questions were as follows:

RQ 1) How do NDRT touchscreen location and NDRT difficulty level affect driver's performance, eye gaze behavior, and workload during NDRT?

RQ 2) How do NDRT touchscreen location and NDRT difficulty level affect driver's performance, eye gaze behavior, and workload during takeover?

4.1 NDRT performance measures

Concerning RQ1, it was found that on average, Lower Right resulted in significantly fewer incorrect clicks than Upper Right (Figure 3.1). This difference in the NDRT performance is thought to be largely due to the difference in the amount of visual information from the outside world (the road scenes through the windshield, the room mirror and the side-view mirrors) available within the driver's visual field during the NDRT (SuRT) phase. While the participants were conducting the NDRT, in Lower Right, the outside world was largely occluded in the participants' field of view; on the other hand, Upper Right permitted a large part of it in the participants' peripheral vision. Therefore, in Upper Right, visual stimuli in the outside world (e.g., other moving vehicles) likely attracted the participants' visual attention in a bottom-up fashion and hindered the NDRT; but, such stimulus-driven processing and distractions were precluded in Lower Right during the NDRT. Relatedly, previous studies on human visual attention reported that external stimuli, especially, salient ones, such as movements and changes, and, easily accessible ones, tend to attract the participants' visual attention (Wickens and McCarley, 2019). The SEEV model (Wickens et al., 2003; Wickens et al., 2015; Steelman et al., 2017; Wickens and McCarley, 2019) of visual attention describes these tendencies in terms of two bottom-up factors, saliency and effort.

The above account of the NDRT performance difference on the basis of the bottom-up processing of human perception is further supported by the findings on the NDRT touchscreen location effects on the eye gaze behavior measures during the NDRT phase. Lower Right had a significantly longer mean glance duration to the NDRT touchscreen than the other two NDRT touchscreen locations (Figure 3.4), and, had a significantly shorter mean glance duration to the road (outside world) than Upper Right (Figure 3.5). These observations indicate that NDRT touchscreen location affected the participants' visual attention allocation during the NDRT.

Aside from the bottom-up processing of human perception, body posture may be a factor that contributed to the observed NDRT touchscreen location effect on number of incorrect clicks (Figure 3.1). Upper Right and Upper Left required raising the hand and arm up to the shoulder level whilst Lower Right did not. In ergonomics, elevated arm position is generally regarded as a stressful posture, and, has been shown to adversely affect hand/finger movement task performance (Wiker et al., 1989). Between Upper Right and Upper Left, the postures for the former were biomechanically more disadvantageous than those for the latter because the shoulder-to-touchscreen distance was larger for Upper Right than for Upper Left (Figure 2.2). Thus, the NDRT required larger shoulder joint moments and higher levels of muscular exertions for Upper Right than for Upper Left. This seems to provide an explanation as to the pairwise comparison results shown in Figure 3.1.

As for the results on the NASA TLX scores, NDRT touchscreen location was found to affect only the 'physical demand' score during the NDRT phase. Lower Right had a significantly lower mean physical demand score than the other two touchscreen locations (Figure 3.6). A couple of biomechanical explanations are provided here: first, Upper Right and Upper Left required raising the hand and arm up to the shoulder level whilst Lower Right did not. Elevated arm position is generally regarded as a stressful posture and has been associated with increased risks of upper extremity musculoskeletal disorders (Wiker et al.,1989; Karhu et al., 1977; Ludewig and Cook, 1996; Bergmann et al., 2001). Second, whilst the touchscreen was vertically oriented in Upper Right and Upper Left, it was tilted at the angle of 78° relative to the floor in Lower Right. The tilting of the touchscreen in Lower Right might have helped the participants performing the finger tapping in a more neutral wrist posture.

Regarding the NDRT difficulty level effects on the NDRT performance measures (Figure 3.2 and 3.3), NASA TLX scores (Figure 3.7), and the arm and buttock discomfort rating scores during NDRT (Figure 3.9). It was found that Hard resulted in smaller means for total number of clicks and number of correct clicks than Easy (Figure 3.2 and 3.3); and, also, Hard resulted in higher mean values for the NASA TLX mental demand, temporal demand, effort and overall scores than Easy (Figure 3.7). These results seem to suggest that the independent variable “NDRT difficulty level” was effectively manipulated. On the other hand, Easy was found to have a higher mean NASA TLX 'performance' score than Hard (Figure 3.7), which indicates that the participants felt that they were less successful in performing the NDRT (SuRT) in Easy than in Hard. It is not clear why. Perhaps, the participants thought that for Easy, they should have done better than they actually had done. It also revealed that NDRT difficulty level significantly affected the arm and buttock discomfort scores during NDRT (Figure 3.9). For the arm discomfort score, Hard showed a higher mean discomfort rating score than Easy. As for the observation related to the arm discomfort rating score, the smaller target size employed for Hard may be related to the increased discomfort score. Considering Gribble et al. (2003)'s findings of an inverse relationship between target size and muscle co-contraction, the decrease in the target circle size from Easy to Hard likely increased the muscle co-contraction level in the arm area. And muscle co-contraction is in general associated with increased biomechanical loadings on the tissues of the musculoskeletal system (Radwin et al., 2001). Regarding the buttock discomfort score, it is not entirely clear why Hard showed a lower mean discomfort rating than Easy. However, the observation is thought to be related to the impacts of the NDRT difficulty level on the local body sway movement pattern and the seat/buttock pressure distribution during the NDRT. Research studies examining movement kinematics and kinetics as well as seat/buttock pressure distribution are needed to provide further understanding.

A significant two-way NDRT touchscreen location NDRT difficulty level interaction effects were found for the NASA TLX temporal demand score (Figure 3.8) and the arm and buttock discomfort rating scores during NDRT (Figure 3.10 and Figure 3.11). As for the two-way interaction effect on the NASA TLX temporal demand score (Figure 3.8), The mean difference between the two NDRT difficulty levels, that is, Easy and Hard, was significant only for Upper

Left - the two NDRT difficulty levels did not show significantly different mean differences for the other two NDRT touchscreen locations. This is thought to be because the participants used the less dexterous left hand for Upper Left whilst using their dominant right hand for the other two NDRT touchscreen locations. Because of the decreased hand dexterity, the participants likely perceived the increase in the NDRT difficulty level from Easy to Hard more challenging for Upper Left, in terms of temporal task demands.

As for the two-way interaction effect on the arm discomfort rating score (Figure 3.10), the mean difference between the two NDRT difficulty levels, that is, Easy and Hard, was significant only for Upper Left - the two NDRT difficulty levels did not show significantly different mean differences for the other two NDRT touchscreen locations. This is thought to reflect that Upper Right was biomechanically the most disadvantageous (the largest shoulder-to-touchscreen distance and the elevated arm position) among the three touchscreen locations. When considered in light of the observation of Gribble et al. (2003), the increase in the NDRT difficulty level from Easy to Hard likely increased the muscle co-contraction level in the arm area. Since Upper Right is biomechanically the most disadvantageous (the most stressful), the increase in muscle activity due to the increased NDRT difficulty likely affected perceived discomfort in a more notable way for Upper Right than the other two NDRT touchscreen locations.

As for the result of the buttock discomfort rating score (Figure 3.11), even though a significant interaction effect was found, the post-hoc multiple comparisons did not find any significant mean differences. In addition, all the treatment means were very small (less than 2). This seems to suggest that buttock discomfort was not severe across the six conditions and no design intervention is needed to reduce buttock discomfort.

4.2 Take-over task performance measures

Concerning RQ 2, it was found that NDRT touchscreen location significantly affected the two take-over task performance measures (response time and lane change completion time). Lower Right showed the worst take-over performance (Figures 3.13 and 3.14) On average, response time and lane change task completion time were significantly longer for Lower Right than for the other two NDRT touchscreen locations. Relatedly, NDRT touchscreen location also significantly affected total glance duration to road during the take-over task phase (Figure 3.15). Lower Right showed the largest mean for total glance duration to road during the take-over task, followed by Upper Left and Upper Right.

The observations above seem logically related to the NDRT touchscreen location effects on the eye gaze behaviors and the NDRT performance during the NDRT phase discussed earlier. During the NDRT phase, Lower Right had a significantly smaller mean for total glance duration to road than Upper Right (Figure 3.4 and 3.5). The shorter glance duration to the road during the NDRT observed for Lower Right suggests that less information about the situation in the outside world was available to the participants at the beginning of the take-over phase for Lower Right. Thus, gaining situation awareness likely required more and longer visual information processing for Lower Right, as shown in Figure 3.15. This also explains the worst take-over task performance observed for Lower Right (Figures 3.13 and 3.14). Again, these findings can be explained on the basis of the bottom-up processes of visual attention control (Wickens et al., 2003; Wickens et al., 2015; Steelman et al., 2017). Overall, the current study results seem to reveal a trade-off between the NDRT and the take-over task performance mediated by NDRT touchscreen location.

NDRT difficulty level was found to significantly affect the NASA TLX mental demand, temporal demand, effort and overall scores for the take-over task (Figure 3.16). For these measures, Hard was associated with higher mean scores than Easy. These observations are interesting in that they indicate that the difficulty level of an on-going task (the NDRT in the context of this study) can affect the perceived workload of the interrupting task (the take-over task) during a task-switching situation. While it is not entirely clear what gave rise to the observed NDRT difficulty level effects, some possible explanations are provided in what follows.

During the NDRT phase, the NDRT utilized more mental/attentional resources in Hard than in Easy - the results shown in Figure 3.6 confirm it. Thus, it is reasonable to think that Hard resulted in faster development of mental fatigue (reduction in mental/attentional resources) than Easy during the NDRT phase, and, at the beginning of the take-over task phase, the mental/attentional resources available for the take-over task might have been less for Hard than for Easy – this is despite the fact that the prior NDRT task was only three-minute long. Mental fatigue is in general known to negatively impact information processing (Baker et al., 1994; Sanders, 2013; Meijman, 1997; Van der Linden et al., 2003; Kato et al., 2009). With no significant differences in the take-over task performance between Hard and Easy, the conjectured differences in the available mental/attentional resources would account for the observed NDRT difficulty level effects on the NASA TLX workload scores for the take-over task (Figure 3.16) - despite no universally accepted definition of mental workload, the notion of workload is related to the difference between the amount of resources available within a person and the amount of resources demanded by the task situation (Sanders and McCormick, 1993).

The NDRT difficulty level effects on the NASA TLX workload scores for the take-over task (Figure 3.16) may also be interpreted in light of previous findings on task switching. In particular, the findings from Wickens et al. (2016) seem useful. The study empirically demonstrated that during voluntary task switching with more than two tasks, more difficult tasks are less likely to switched away from once they are being performed, in addition to being less likely to switched to. Wickens et al. (2016) presented a 'cave' metaphor to describe these effects of task difficulty: *"Like a cave with a small entrance, a difficult task may be more difficult to enter initially (increasing switch resistance to it), but once inside the cave, it is more challenging to leave, so it results in longer stays. The more difficult on-going task is stickier."* The driver task of the current study in the context of SAE Level 3 conditionally automated driving is different from the experimental task of Wickens et al. (2016) involving voluntary task switching in that the issuance of the ToR required immediately switching to the take-over task. Nonetheless, the concept of the stickiness of a difficult on-going task may still be relevant accounting for the observed NDRT difficulty level effects (Figure 3.16).

Chapter 5

Conclusion

5.1 Summary and Implications

The current study demonstrated the effect of the NDRT touchscreen location and difficulty level of NDRT on the driver task performance, eye gaze behavior, and their subjective cognitive and physical discomfort during both NDRT and take-over task in the context of Level 3 autonomous driving. This study identified considerable NDRT touchscreen location effects for both the NDRT and the take-over task. It also revealed that NDRT difficulty level can affect not only the NDRT but also the subsequent take-over task. These results have implications for future in-vehicle technologies.

This study presents some important findings concerning NDRT touchscreen location and NDRT difficulty level for partially automated vehicles. First, NDRT touchscreen location affected NDRT and take-over performance robustly for both Easy and Hard difficulty levels of NDRT. A trade-off between two NDRT touchscreen locations, that is, Lower Right and Upper Right, was identified - Lower Right was more advantageous for the NDRT but less so for the take-over task when compared with Upper Right; on the other hand, the opposite was the case for the take-over task. This observation is identical to the result of the participants' preference rank of NDRT touchscreen location during NDRT in both levels of difficulty (Figure 3.12). In opposition to this, for the take-over task, the result of the participants' preference rank of the NDRT touchscreen location for the take-over task in both levels of difficulty (Figure 3.17). Second, NDRT touchscreen location affected the NASA TLX physical demand score for the

NDRT. Lower Right had a significantly lower mean physical demand rating than the other two NDRT touchscreen locations. Lastly, the difficulty level of an NDRT could affect the perceived workload of not only on-going NDRT task but also subsequent take-over task during conditionally automated driving.

The study findings appear to have some design implications. First, the aforementioned trade-off between the NDRT and the take-over task performance seems to represent a challenging design problem as it implies that improving the performance of the two driver tasks simultaneously, solely by optimizing NDRT touchscreen location may be difficult. Different interface design solutions must be explored to overcome the trade-off. One possible direction for a solution may be designing some attention guidance elements into the NDRT interfaces, which inform the driver as to where to focus at different time points according to contextual changes. AR technologies may be utilized to develop such attention guidance features. Second, it revealed that physical demand seems to be an important dimension of the in-vehicle NDRT touchscreen design. Efforts must be made to improve the body postures during the driver-touchscreen interaction. Lastly, the design of NDRTs for conditionally automated vehicles may need to ensure that NDRT difficulty level does not exceed an appropriate level. This study showed that an increase in the difficulty level of an NDRT could increase the perceived workload of the subsequent take-over task.

5.2 Future Research Directions

Some limitations of the current study are described here along with possible future research directions: first, this study considered only a single time budget for the take-over task (7 seconds). Future investigations may consider different time budgets to see how time budget might modify the effects of NDRT touchscreen location and NDRT difficulty level during Level 3 conditionally automated driving. Second, this study examined only NDRT touchscreen location among various physical user interface design variables relevant to the design of NDRT touchscreen (for examples, size and shape). Further investigations on the possible effects of other design variables are needed to establish comprehensive NDRT touchscreen design guidelines. Third, the current study recruited only younger drivers as the study participants. Future studies may consider different age bands including the older driver segment, as aging is associated with changes in human abilities such as a slowing of performance, decline in working memory capacity, deterioration in size of the lateral visual field, and reduction in body mobility (Sanders and McCormick 1993; Wickens et al. 2004; Bhise 2011). Also, driving experience might be an important personal variable that may modify the effects of NDRT touchscreen location and NDRT difficulty level. Relatedly, Mourant and Rockwell (1972) reported that novice participants sample the road environment more narrowly than experienced participants.

Finally, several future research directions are suggested here. First, investigating not only the spatial location of NDRT touchscreen but also the different sizes and shapes of the NDRT touchscreen may help in suggesting holistic NDRT touchscreen guidelines. Second, employing different demographic characteristics will further enhance our understanding of the impacts of different NDRT touchscreen locations on each task performance. For example, the effect of NDRT touchscreen locations may differ between novices and experienced participants or between younger and older participants. Mourant and Rockwell (1972) reported that novice participants sample the road environment more narrowly than experienced participants.

Moreover, aging is associated with changes in human abilities such as a slowing of performance, decline in working memory capacity, deterioration in size of the lateral visual field, and reduction in body mobility (Sanders and McCormick 1993; Wickens et al. 2004; Bhise 2011). Such changes in sampling strategy according to the level of driving experiences or ages must be taken into consideration when determining the position of the NDRT touchscreen.

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국문초록

본 논문에서는 고도화된 자율주행자동차에서 비운전 과업과 제어권 전환 과업을 수행할 때 적절한 비운전 과업 터치스크린 위치와 비운전 과업 난이도에 대해 알아보고자 한다. 고도화된 자율주행자동차에서는 운전자가 운전이 아닌 비운전 과업을 주로 수행하게 된다. 특히, 운전자가 자동차 내의 터치스크린을 통해 비운전 과업을 주로 수행하는 환경을 고려하였을 때, 운전자가 차량 내 터치스크린을 통해 편안하게 비주행 과업을 수행하는 것은 중요하다. 더불어, 비운전 과업을 수행하면서 때때로 발생하게 될 제어권 전환에도 안전하게 제어권 전환 과업 수행해야 한다. 운전자의 안전과 편안함을 동시에 고려하는 적절한 비운전 과업 터치스크린 위치와 비운전 과업 난이도에 대해 연구한 기존 논문이 없는 바, 본 논문에서는 서로 다른 터치스크린 위치 3곳과 2가지의 비운전 과업 난이도에 대해 운전자의 비운전 과업 성능과 운전 성능을 비교한다. 이에 대한 결과로 본 논문에서는 비운전 과업과 제어권 전환 과업 각각에 대해 운전자의 인지적, 신체적 부하를 줄이면서 동시에 안전한 운전에 적절한 비운전 과업 터치스크린 위치와 비운전 과업 난이도에 대한 설계 가이드라인을 제공한다.

주요어*:* 자율주행자동차, 비운전 과업, 제어권 전환 과업, 터치스크린

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