Non-driving-related tasks, workload, and takeover performance in highly automated driving contexts

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Abstract

This study investigates the influence of non-driving-related task (NDRT) on takeover performance in a highly automated driving (HAD) context and the effect of workload on driver’s takeover performance. A driving simulator was used to evaluate how well a driver resumes control of a vehicle after being in a HAD situation during which they performed a NDRT. For both the visual performance and takeover capability, there was a significant difference based on the task carried out; however, the reaction times when reaching for the steering wheel did not differ among the tasks. The result on workload demonstrate that NDRT type has significant effect while a positive correlation between the performance dimension and takeover was found. In addition, takeover performance for interaction with the entertainment console exhibits a significantly positive correlation, whereas watching a video or interacting with a smartphone exhibits mostly a significantly negative correlation with workload dimensions. These results provide implication on the effect of tasks desired and enabled to be performed by drivers in HAD and its influence on the transition of control.

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1. Introduction

The automotive industry has been gradually making major changes to the classic concept of the car through innovative technologies including navigation, assistance, and communication systems (Brauer, 2015). Indeed, vehicles are rapidly becoming more intelligent and automated owing to the development and introduction of technologies that assist drivers, such as active cruise control (ACC), lane-keeping assistance (LKA), and intelligent braking systems (IBSs) (Choi & Ji, 2015; Flemish et al., 2008; Vollrath, Schleicher, & Gelau, 2011). These systems can reduce the number of accidents due to distractions, poor performance, and human error (Yang & Coughlin, 2014). The main goal of these systems is to increase the comfort level of the driver by reducing the demand imposed by the driving tasks (Koo et al., 2015). Moreover, recent studies on autonomous vehicles have described the benefits of automated systems, presenting drivers with new in-vehicle experiences, such as the opportunity to engage in more dynamic social interaction, vehicle leisure, or the use of various technologies while relaxing or engaging in work activities (Kim, Yoon, Kim, & Ji, 2015; Ive, Sirkin, Miller, Li, & Ju, 2015; Yang & Coughlin, 2014).

The US Department of Transportation’s National Highway Traffic Safety Administration (NHTSA) has proposed five levels of automation for automated vehicles where level 0 refers to no automation, and level 4 to full self-driving automation. How-
ever, from levels 1 through 3, drivers need to be involved in certain aspects of the manipulation and control of the vehicle, depending on the systems that have been automated. Given these changes in the automotive industry, researchers and car developers are faced with the challenge of developing safe vehicles by balancing the role of automated systems and the permitted changes in driver behaviors.

Concerns remain regarding the negative influence of high levels of automation, such as a decrease in context and situation awareness (Jamson, Merat, Carsten, & Lai, 2013; Strand, Nilsson, Karlsson, & Nilsson, 2014; Vollrath et al., 2011), which decreases driving performance. This decrease in driving performance is because drivers of highly automated vehicles are not required to be continuously aware of their driving environment, and can thus undertake other non-driving-related tasks (NDRT) (Jamson et al., 2013). Such a shift in engagement can critically affect visual attention by increasing the amount of time the driver glances out of the loop (Llaneras, Salinger, & Green, 2013), as well as physical behaviors, such as when the driver’s hand is removed from the steering wheel. Semi- and highly automated cars still require human involvement in driving tasks, and thus the attention of the driver is still required (Koo et al., 2015). That is, the involvement of drivers is necessary on certain occasions, such as when resuming manual control in an emergency by switching from a NDRT to manual operation of the vehicle. Given that research in this field is at a relatively early stage, the issues and phenomena that arise when humans interact with highly automated systems require careful attention.

1.1. Non-driving-related task and vehicle automation

The cognitive, physical, and visual skills of drivers have traditionally played an important role in driving performance (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Matthews, Sparkes, & Bygrave, 1996; Young & Regan, 2007). Previous studies on secondary task demonstrated that drivers are not allowed to perform these tasks while driving owing to a decrease in driving performance (Blanco, Biever, Gallagher, & Dingus, 2006; Horberry, Anderson, Regan, Triggs, & Brown, 2006) and situational awareness (Baumann, Rösler, & Krems, 2007; Ma & Kaber, 2005). Although some researchers have argued that new assistive technologies allow drivers to physically interact less frequently with vehicles, this does not imply that drivers can completely ignore driving tasks (Richards & Stedmon, 2016).

An assistive system can change drivers’ behaviors, such as enabling them to engage in NDRT (Carsten, Lai, Barnard, Jamson, & Merat, 2012; Jamson et al., 2013; Rudin-Brown & Parker, 2004). Rudin-Brown and Parker (2004) indicated that drivers using ACC are more likely to shift their attention from their driving task to a secondary task, which has an overall negative effect on their driving performance. In addition, Jamson et al. (2013) demonstrated that drivers are more actively involved in secondary tasks when using an assistive system, shifting their visual attention from the road, compared to when driving manually. Carsten et al. (2012) investigated how driver engagement in secondary tasks changes depending on the level of automation, which is based on the number of assistive systems in the vehicle. Their results revealed that drivers engage more in secondary tasks as the level of automation increases, thereby reducing drivers’ attention and causing them to take their eyes off the road.

According to the Society of Automotive Engineers (SAE), every system incorporated into a vehicle should allow the driver to complete a task within 15 s while the vehicle is parked (SAE J2364). To date, however, there have been no guidelines and only a few studies on the types of tasks that drivers can undertake in a highly automated vehicle.

1.2. Driver’s transition of control in HAD

Vehicle automation does not necessarily imply a lack of human intervention in the manipulation of the vehicle (Casner, Hutchins, & Norman, 2016; Gold, Damböck, Bengler, & Lorenz, 2013; Gold, Damböck, Lorenz, & Benfler, 2013). Drivers are still required to be able to take control of their vehicle in an emergency, such as when approaching the end of a road or when faced with an unexpected hazard (Gold & Bengler, 2014; Merat & Lee, 2012). In previous studies, the task of resuming control of a vehicle from a highly automated situation was referred to as a “takeover” (Gold, Damböck, Lorenz, et al., 2013; Walch, Langer, Baumann, & Weber, 2015). The ability of drivers to resume control of their vehicle under a highly automated driving (HAD) situation mostly focuses on the environmental factors affecting such a takeover (Gold, Körber, Lechner, & Bengler, 2016), the influence of visual attention on the resulting takeover (Merat, Jamson, Lai, Daly, & Carsten, 2014), and the time required for drivers to completely resume control of the vehicle (Giesler & Muller, 2013; Gold & Bengler, 2014; Gold, Damböck, Lorenz, et al., 2013). Studies have emphasized the amount of time required by driver to resume control of the vehicle and when an alert should be issued. Researchers have suggested that a request should be issued between 5.7 s and 8.8 s prior to takeover under a HAD situation, and the mean time required to re-engage control is between 2.1 s and 4.1 s (Giesler & Muller, 2013; Gold & Bengler, 2014; Gold, Damböck, Lorenz, et al., 2013).

Secondary tasks demanded under HAD situations have been identified as playing a critical role in the takeover time and performance (Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014). Radlmayr et al. (2014) stated that there is no significant difference in the effect on a driver’s takeover for different NDRT. Gold, Damböck, Lorenz, et al. (2013) investigated drivers’ takeover by measuring the time required to complete a task using a driving simulator. Their study involved presenting the participants with critical driving situations in which they were required to carry out cognitively and manually demanding secondary tasks under HAD conditions. The results of this experiment showed that there is no significant difference in the two conditions when taking over control of a vehicle. However, other studies have found that the driver’s state before taking over control of the vehicle greatly affects the quality of takeover performance (Naujoks, Mai, & Neukum, 2014).
1.3. Importance of workload in HAD

One area of interest when discussing driving performance is the workload effect. Extensive research has been conducted regarding the effect of the workload during manual driving as well as when performing secondary tasks. For instance, during manual driving, there is an increase in the workload when drivers perform secondary tasks, leading to an increase in out-of-the-loop-type situations and degradation of driving performance (Horberry et al., 2006; Lansdown, Brook-Carter, & Kersloot, 2004; Merat, Jamson, Lai, & Carsten, 2012; Niezgoda, Tarnowski, Kruszewski, & Kamiński, 2015; Yoon, Lim, & Ji, 2015).

With respect to HAD, studies focusing on the effect of the workload are at the initial stage. Young and Stanton (2002) have indicated that a driver’s cognitive workload and automation are closely related. That is, in an HAD environment, the impact of a vehicle leads to changes in mental processing by drivers (Beattie, Baillie, Halvey, & McCall, 2014). Similarly, automated vehicles have characteristics that allow drivers to engage in tasks other than driving, which might influence both their driving performance and mindset (Banks, Stanton, & Halvey, 2014). In the early studies conducted by Stanton and Young (1998), the authors claimed that although vehicle automation reduces the workload, it also creates problems such as inefficiency when reclaiming control of the vehicle. Engagement in a secondary task while driving an automated vehicle plays a critical role in the driving performance, particularly when the driver is asked to take over control of the vehicle (Merat et al., 2012). However, very few studies have addressed the issue of the workload imposed by HAD, in which we might propose that the paradigm of “secondary tasks” changes to “NDRT”; that is, not only is driver overload a concern but also driver underload (Beattie et al., 2014; Jamson et al., 2013).

1.4. Research objective

This study focused on natural activities that might be performed by the drivers in a level 3 vehicle, which feature limited self-driving automation. A driving simulator setup was used to investigate the drivers’ abilities to resume control in response to takeover request alert after carrying out different types of NDRT in a HAD. The task workload was also of interest upon resuming control of the vehicle. We explored the relationship between the takeover performance and workload for each NDRT. From the results obtained, we attempted to provide insight into the influence of NDRTs and the workload incurred under HAD situations when a driver is required to take over control of the vehicle, and to identify issues that both industry and academia must consider in future research on autonomous vehicles.

2. Method

A laboratory experiment was conducted using a driving simulator to determine the influence of NDRT when drivers are required to resume control of the vehicle in a HAD situation. The simulator assisted drivers with both lateral and longitudinal driving tasks, such that participants could engage in NDRT. This experiment was done in accordance with a protocol approved by the Institutional Review Board (IRB), with written informed consent from all subjects.

2.1. Participants

Twenty-seven participants (17 males and 10 females) with a valid driver’s license were recruited for the driving simulator experiment through an advertisement placed on an Internet blog. Monetary compensation was offered for their participation. They were aged between 24 and 38 ($M = 29.1, SD = 3.78$). The participants had between 1 and 15 years of driving experience ($M = 5.8, SD = 4.57$). All the participants had normal vision and did not wear glasses during the eye-tracking experiment.

2.2. Experimental design

The study consisted of a within-subject design of drivers’ takeover performance measurements (gaze on time, fixation time, hands-on time, and takeover time) and subjective assessment of workload by NASA Task Load Index (NASA-TLX) for three different NDRT (interacting with entertainment console, smartphone interaction, and video watching) in a HAD context.

2.2.1. Takeover performance measure and self-reported workload

Since previous studies on takeover performance, gaze reaction time, first fixation on the road, the amount of time in which the drivers’ hands were on the steering wheel, and the overall takeover time were selected as dependent variables to collect data on takeover performance (Gold et al., 2016; Lorenz, Kerschbaum, & Schumann, 2014).

Table 1 lists the variables for the measurement of the performance based on the visual, physical, and overall performance of the drivers when resuming manual control of a highly automated vehicle. Therefore, as a measure of visual performance, we determined the time required for drivers to fix their eyes on the road after an alert was issued, and the time required for their gaze to switch from a NDRT to the view ahead (through the windshield). To determine the level of physical performance, we selected the time required for a driver to grasp the steering wheel. We also focused on determining whether
visual performance and physical performance varied between tasks for the takeover performance of drivers, which has been of significant importance since the study by Llaneras et al. (2013). Lastly, the overall performance was measured based on the takeover time. The takeover time measures how quickly a driver can resume manual control of a vehicle upon the issuance of an alert. We measured the resumption of manual control as the moment when the participants interacted with the longitudinal controller or turned the steering wheel by more than 5°, which was possible because the emergency alert to take over control required participants to change to the middle lane and slow down.

The NASA-TLX was used to assess the self-reported workload imposed on participants. This index is a retrospective measure that allows participants to apply a rating after a set of tasks is completed (Bustamante & Spain, 2008). The index used six dimensions to provide a rating of the overall workload, including the mental demand, physical demand, temporal demand, performance, effort, and degree of frustration. The rating of the task load index provided a range between 0 and 100 points.

2.2.2. Non-driving-related task (NDRT)

NDRT selected for this study were based on previous studies (Kim et al., 2015; Llaneras et al., 2013; Merat et al., 2014) on natural tasks desired to be performed or possible to be carried out in automated driving. Selection of tasks were done depending on the degree of engagement required, specially taking into consideration the need for visual and physical demands. Using this approach, (1) interacting with an entertainment console, (2) watching a video, and (3) interacting with a smartphone were selected as NDRT for this experiment (Table 1). The interaction task with the entertainment console involves continuously searching for a radio station. The participants were asked to search for a radio station, and once it was found, the participants were asked to search for the next radio station. The participants were asked to search for as many radio stations as possible, such that the participants continuously engaged in the activity. Although the performance of the users was measured, the results were not taken into consideration for the experimental analysis. For the video watching task, participants were required to watch a video of individuals (male and female) passing a ball. They were asked to count how many times the male actors made a pass and inform the experimenter the total number of passes after the takeover request was issued. The participants were told that counting the number of passes was important, such that the participants will need to pay attention to the video. Finally, for the smartphone interaction task, participants were asked to play the smartphone game “1–50,” which involves pressing numbers from 1 to 50 as quickly as possible. This game was selected for the experiment because it is easy to understand, and requires visual attention as well as physical interaction. We explained to the participants that their mission was to obtain the best score in the game to keep them focused on the task.

2.3. Driving simulator

The driving simulator featured a real car seat that the participants could adjust as desired, a Logitech® MOMO® Racing Force Feedback Wheel and Pedal, and a 55-inch Samsung Smart television set. For the driving simulator, we used the City Car software. To provide the participants with auto pilot mode, an experimenter in a separate room with an extra Logitech® MOMO® Racing Force Feedback Wheel and Pedal simulated the auto driving by Wizard of Oz method. The experimenter switched the input device for each transition of console. In addition, a SensoMotoric Instruments (SMI) eye-tracker was used to collect data on the participants’ eye movements. Two video cameras were used to record the actions of the participants. For the experimental tasks, we used an LG G2 smartphone and an Apple iPad Air 2.

2.4. Procedure

Prior to taking part in the experiment, participants were asked to complete a brief demographic questionnaire on basic information and questions related to the driving experience. Next, we explained the processes of the driving simulator, the overall objective of the experiment, and HAD. Next, the participants were given a practice session of approximately 5 min (or

**Table 1**

Summary of objective measurement variables used for the experiment.

<table>
<thead>
<tr>
<th>Category</th>
<th>Measurement variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual performance</td>
<td>Gaze-on time</td>
<td>Time taken by driver to complete the first gaze reaction through the windshield after the issuance of a takeover request</td>
</tr>
<tr>
<td></td>
<td>Fixation time</td>
<td>Time taken by driver to complete the first fixation on the road (target in this case) after the issuance of a takeover request</td>
</tr>
<tr>
<td>Physical performance</td>
<td>Hands on steering wheel time</td>
<td>Time taken by the driver to grasp the steering wheel after the issuance of a takeover request</td>
</tr>
<tr>
<td>Takeover performance</td>
<td>Takeover time</td>
<td>Total time taken by the driver to take over manual control of the vehicle after the issuance of a takeover request</td>
</tr>
</tbody>
</table>

In this case, we considered that the driver had resumed control when their hands were completely on the steering wheel and there was an interaction with the vehicle, such as a 5° rotation of the wheel or an interaction with the brake pedal.
more if desired) to drive with the simulator along a road similar in characteristics to the one used for the experiment to familiarize themselves with the process of driving the simulator. They were also able to experience takeover request and practice the transition from HAD to manual driving. During the practice session, participants did not engage in any NDRT, thus no task was given for the HAD (see Fig. 1).

The main experiment consisted of three sessions given in counterbalanced order, in which participants engaged in one of the NDRT for each session. In each session, the participants were asked to take over control of the vehicle at three points along the overall track (after approximately 3.5, 8, and 14 km) while performing the same NDRT. At the end of the session, a self-assessment of the workload based on the NASA-TLX questionnaire was collected. The overall track was 15 km long, and the takeover request was in the form of a beep sound warning. The takeover request was issued in a straight road segment, in a non-emergency situation, when the number of lanes changed (from 3 lanes to 4, and from 4 lanes to 3). Although the takeover was issued on a straight road segment, after re-engaging control of the vehicle, the participants were required to change lanes to maintain the second lane of the road. Manual driving was at a speed of 60 km/h. Before the beginning of each session, we explained the NDRT that participants would be involved in. Then, eye-tracking calibration was performed for each individual session. Between sessions, participants were allowed to take a break between 5 and 10 min. The overall experiment took approximately 90–120 min.

2.5. Data collection

An SMI goggle-type eye-tracker was used to collect data on the participants’ eye movements and gaze during the experiment. This wearable goggle-type eye-tracker records binary input data from both eyes at a sampling rate of 60 Hz. From the eye-tracking, we collected data on the time required for a participant’s gaze to move from a NDRT to a driving task (in-loop), and the time required for the driver’s eyes to be fixed on the road using SMI BeGaze 3.4 software. Two video recorders recorded the takeover performance of the participants for each session. The video recording was done to obtain information on the overall behavior when taking over control of the vehicle as well as quantitative data on the time required for the participants to grasp the steering wheel. For the quantitative data, each video was analyzed using the Adobe Premiere Pro CS6 video editing software at a sampling rate of 60 fps and experimenters recorded each video by observation. To ensure reliability of the data obtained from video analysis, data collection was done by three different experimenters and cross-checked.

Fig. 1. Description of the experimental procedure.
A total of 243 takeover trial data was gathered for the take-over performance, 81 for each NDRT. For the statistical analysis, we excluded data obtained from the first trial of the first session (9 takeover data for each task) of the takeover performance experiment as the first trial of the takeover task from the first session was used as part of the practice session and was not taken into consideration for the statistical analysis. Since all participants participated in all NDRT, a total of eight takeover trial data was collected for each participant. Giving a total of 216 take-over data, with 72 for each NDRT. Subjective data of participants’ workload was collected at the end of each session, thus a total of 27 responses for each NDRT were obtained for the statistical analysis.

2.6. Statistical analysis

We conducted three sets of analysis. First, we analyzed the effects of a NDRT on the takeover performance. For the analysis of the takeover performance, a one-way analysis of variance (ANOVA) was used for the dependent variables: gaze-on time, fixation time, hands-on time, and takeover time ($\alpha = 0.05$). We then examined the effects of NDRT on drivers’ workload when they resumed control of the vehicle as measured by the NASA-TLX for all sub-scales and overall workload score by the one-way ANOVA. Before carrying out the analysis, the Shapiro–Wilk test of normality was carried out to check normality. The significant difference was further examined by post-hoc pairwise comparison using the Tukey’s HSD test. Finally, we compared the relationship between each workload dimension and the overall workload on the takeover performance.

3. Results

3.1. NDRT and re-assuming control of the vehicle

The effect of NDRT when re-assuming control of the vehicle was examined. The ANOVA results showed that there were significant differences between tasks in terms of the gaze-on time ($F(2, 213) = 6.566, p < 0.01$), time to first fixation ($F(2, 213) = 6.400, p < 0.01$), and overall takeover time ($F(2, 213) = 3.914, p < 0.05$). However, there was no significant effect for the hands on the steering wheel time ($F(2, 213) = 1.002, p = 0.369$) (Table 2).

Post-hoc analysis revealed that the shifting of the participants’ gaze to the windshield was significantly faster for the interaction with entertainment console (task 1) relative to the viewing tasks, which required the participants to use their smartphone (task 2) or watch a video (task 3) (Table 2). The same result was apparent for the time taken for the participants to fix their eyes on the road. Finally, for the overall takeover time, the fastest response was obtained for the task involving watching a video, followed by the task involving interacting with a radio, and lastly, the task in which the driver interacted with a smartphone.

3.2. Workload for NDRT

The Shapiro–Wilk test of normality gave the following statistical results for each of the tasks: $W(27) = 0.960 (p = 0.362)$, $W(27) = 0.938 (p = 0.109)$, and $W(27) = 0.974 (p = 0.705)$. From the results of the normality analysis, we can conclude that the null hypothesis was not rejected; therefore, the normality was not rejected. The results obtained from the ANOVA of the workload for the different tasks showed that each task had a significant effect ($F(2, 78) = 3.978, p < 0.05$) (Table 3). A post-hoc analysis showed that task 1, i.e., interaction with the entertainment console, scored significantly lower than task 2, interaction with smartphone, and task 3, video watching.

A detailed analysis of the NASA-TLX dimension was carried out to determine which dimensions of the workload were involved. The results showed that the task applied had a significant effect on some of the workload dimensions (Table 3). For instance, mental demand ($F(2, 78) = 4.238, p < 0.05$), temporal demand ($F(2, 78) = 6.643, p < 0.01$), and effort ($F(2, 78) = 3.819, p < 0.05$), all exhibited a significant difference depending on the task, while physical demand ($F(2, 78) = 0.404, p = 0.669$), performance ($F(2, 78) = 2.548, p = 0.085$), and level of frustration ($F(2, 78) = 1.444, p = 0.242$) did not.

Table 2

Results of objective measurements of taking over control during HAD while interacting with a different task. Time in seconds (s).

<table>
<thead>
<tr>
<th>Task</th>
<th>Mean gaze-on time (SD)</th>
<th>Mean fixation time (SD)</th>
<th>Mean hands-on steering wheel time (SD)</th>
<th>Mean takeover time (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entertainment console interaction</td>
<td>0.52 (0.33)</td>
<td>0.80 (0.40)</td>
<td>1.40 (0.29)</td>
<td>1.62 (0.36)</td>
</tr>
<tr>
<td>Smartphone interaction</td>
<td>0.66 (0.27)</td>
<td>0.96 (0.25)</td>
<td>1.41 (0.30)</td>
<td>1.60 (0.36)</td>
</tr>
<tr>
<td>Video watching</td>
<td>0.70 (0.36)</td>
<td>0.98 (0.33)</td>
<td>1.48 (0.48)</td>
<td>1.80 (0.58)</td>
</tr>
<tr>
<td><strong>P-value</strong></td>
<td><strong>0.002</strong></td>
<td><strong>0.002</strong></td>
<td><strong>0.369</strong></td>
<td><strong>0.021</strong></td>
</tr>
</tbody>
</table>

Sig. at *: $p < 0.05$, **: $p < 0.01$. 
A post-hoc analysis revealed that task 1, interaction with the entertainment console, had a significantly low score in terms of mental demand and effort relative to tasks 2 and 3. Meanwhile, for the temporal demand, tasks 1 and 2 were grouped as significantly low relative to interacting with the smartphone (Fig. 2).

### 3.3. Correlation between subjective workload and takeover performance

A correlation analysis was carried out between the results obtained from the NASA-TLX questionnaire and the results obtained from the objectively recorded measurements. The results showed that the overall workload was negatively correlated with the takeover performance \( (r = -0.203, p < 0.01) \) (Table 4). This indicates that an increase in the workload decreases the takeover time. Moreover, a significant positive correlation was identified between the mental demand and the results obtained from the experiment addressing the amount of gaze-on time \( (r = 0.148, p < 0.05) \) and fixation time \( (r = 0.158, p < 0.05) \), while there was a negative correlation for the takeover performance \( (r = -0.198, p < 0.01) \). Surprisingly, for the physical demand dimension, a negative correlation was associated with the gaze-on time \( (r = -0.208, p < 0.01) \), fixation time \( (r = -0.174, p < 0.01) \), hands on the steering wheel time \( (r = -0.255, p < 0.001) \), and takeover time \( (r = -0.242, p < 0.001) \). The statistical output indicates that the correlation coefficient for the hands-on time was the strongest, followed by the takeover time. For the temporal demand dimension, there was a significant negative correlation for the hands-on time \( (r = -0.160, p < 0.05) \) and takeover time \( (r = -0.148, p < 0.05) \). For the performance dimension, the gaze-on time \( (r = 0.245, p < 0.001) \), fixation time \( (r = 0.255, p < 0.001) \), hands-on time \( (r = 0.167, p < 0.05) \), and takeover time \( (r = 0.090, p < 0.05) \) were all found to have positive correlations. Finally, the frustration dimension was found to have a negative correlation with respect to the takeover time \( (r = -0.162, p < 0.05) \). As indicated earlier, all the dimensions of the NASA-TLX were not corre-

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### Table 3

| Task               | Overall workload | 
|--------------------|------------------|---|---|---|---|---|---|---|---|
|                    | NASA-TLX dimensions | Mental demand | Physical demand | Temporal demand | Performance | Effort | Frustration |
| Entertainment console interaction | 40.9 (14.1) | 44.8 (20.4) | 39.5 (17.9) | 37.7 (18.9) | 39.3 (22.8) | 43.6 (20.4) | 40.4 (55.6) |
| Smartphone interaction | 49.0 (12.1) | 59.8 (16.9) | 35.4 (22.6) | 41.3 (19.0) | 50.8 (19.5) | 56.1 (20.0) | 50.4 (21.7) |
| Video watching | 51.6 (17.0) | 57.1 (22.8) | 40.2 (22.1) | 57.5 (25.2) | 49.0 (17.7) | 57.7 (21.2) | 48.0 (23.6) |
| **P-value** | **0.023** | **0.018** | **0.669** | **0.002** | **0.085** | **0.026** | **0.242** |

**Notation for post-hoc analysis = “a” & “b”**

Sig. at *: \( p < 0.05 \), **: \( p < 0.01 \)

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**Fig. 2.** Results of workload assessment. Task 1 = interacting with entertainment console \( (n = 27) \), Task 2 = smartphone interaction \( (n = 27) \), and Task 3 = video watching task \( (n = 27) \).
Results from correlation analysis between subjective workload of NASA-TLX and objective measurements during takeover experiment.

<table>
<thead>
<tr>
<th>Takeover performance</th>
<th>Overall workload</th>
<th>NASA-TLX dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mental demand</td>
</tr>
<tr>
<td>Gaze-on time</td>
<td>0.059</td>
<td>0.148^a</td>
</tr>
<tr>
<td>Fixation time</td>
<td>0.070</td>
<td>0.158^a</td>
</tr>
<tr>
<td>Hands on steering wheel time</td>
<td>-0.131</td>
<td>-0.077</td>
</tr>
<tr>
<td>Takeover time</td>
<td>-0.203^b</td>
<td>-0.198^b</td>
</tr>
</tbody>
</table>

Sig. at a: p < 0.05, b: p < 0.01, c: p < 0.001.

A Pearson’s correlation analysis of the NASA-TLX dimensions and takeover performance was carried out with respect to each task. The results of the analysis showed that there were significant differences in the correlation for each task. For instance, for task 1, that is, interaction with the entertainment console, the overall workload was significantly correlated with a positive slope for the gaze-on time (r = 0.274, p < 0.05) and fixation time (r = 0.313, p < 0.01). The conclusion is that the mental demand, performance, and effort dimensions were significantly correlated with the gaze-on time and fixation time (Table 5). For task 2, interacting with a smartphone when a takeover request is issued, there was a significantly negative correlation between the amount of time the drivers’ hands were on the steering wheel with respect to the mental demand, physical demand, temporal demand, and overall workload (p < 0.01). At the same time, the takeover time, mental demand (r = −0.347, p < 0.01), and temporal demand (r = −0.267, p < 0.05) were found to have a significantly negative correlation. Finally, for video watching task, the workload was found to have a negative correlation with the hands-on time (r = −0.231, p < 0.05) and takeover time (r = −0.360, p < 0.001). A detailed analysis of the workload dimension demonstrated that there was a significantly positive correlation for the performance dimension with respect to the gaze-on time (p < 0.05) and fixation time (p < 0.05) for interaction with the entertainment console; and gaze-on time (p < 0.01), fixation time (p < 0.01) and hands-on time (p < 0.01) for video watching task. For smartphone interaction task, there was no significant correlation between performance measure and takeover behavioral measures. Meanwhile, for interaction with the entertainment console, the correlation with NASA-TLX dimensions were found to have a positive slope, while for smartphone interaction and video watching task, negative slope between takeover behavioral measures and NASA-TLX were presented (Table 5). For instance, mental demand had a significantly negative correlation with respect to the takeover. The physical demand dimension was found to have the strongest negative correlation with the gaze-on time, fixation time, hands-on time, and takeover time (p < 0.001). For temporal demand, the takeover time was the only item that had a significant correlation (r = −0.248, p < 0.05). Finally, the effort was negatively correlated with the fixation time (r = −0.243, p < 0.05), hands-on time (r = −0.244, p < 0.05), and takeover time (r = −0.358, p < 0.001). In addition, for the level of frustration dimension, there was a significantly negative correlation for the fixation time (r = −0.303, p < 0.01), hands-on time (r = −0.244, p < 0.05), and takeover time (r = −0.376, p < 0.001).

Table 4
Correlation between NASA-TLX dimensions and objective measurements regarding takeover performance for each task.

<table>
<thead>
<tr>
<th></th>
<th>Interaction with the entertainment console</th>
<th>Smartphone interaction</th>
<th>Video watching task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gaze on Fix. Hands on Takeover</td>
<td>Gaze on Fix. Hands on Takeover</td>
<td>Gaze on Fix. Hands on Takeover</td>
</tr>
<tr>
<td>Mental demand</td>
<td>r 0.362^b 0.351^b 0.204 -0.047</td>
<td>r 0.006 -0.137 -0.326^b -0.347^b</td>
<td>r -0.014 -0.071 -0.124 -0.244^b</td>
</tr>
<tr>
<td>Physical demand</td>
<td>p 0.002 0.002 0.079 0.688</td>
<td>p 0.960 0.253 0.006 0.004</td>
<td>p -0.445 -0.514^-a -0.447^-c -0.469^-c</td>
</tr>
<tr>
<td>Temporal demand</td>
<td>r 0.074 0.108 0.134 0.018</td>
<td>r -0.123 -0.140 -0.309^-b -0.183</td>
<td>p 0.000 0.000 0.000 0.000</td>
</tr>
<tr>
<td>Performance</td>
<td>r 0.531 0.362 0.252 0.879</td>
<td>r 0.304 0.242 0.009 0.113</td>
<td>p 0.359^-b 0.383^-d 0.325^-b 0.129</td>
</tr>
<tr>
<td>Effort</td>
<td>r 0.234^b 0.232^a 0.184 0.120</td>
<td>r 0.043 -0.026 -0.006 0.067</td>
<td>p 0.002 0.001 0.004 0.265</td>
</tr>
<tr>
<td>Frustration</td>
<td>r 0.045 0.048 0.115 0.303</td>
<td>r 0.717 0.829 0.958 0.587</td>
<td>p 0.169 -0.243^-a -0.244^-c -0.358^-a</td>
</tr>
<tr>
<td>Overall workload</td>
<td>r 0.275^-a 0.293^-b 0.167 -0.059</td>
<td>r -0.105 -0.111 -0.181 -0.137</td>
<td>p 0.147 0.041 0.035 0.001</td>
</tr>
<tr>
<td></td>
<td>p 0.018 0.012 0.152 0.611</td>
<td>p 0.382 0.354 0.135 0.261</td>
<td>p 0.161 0.052 0.046 0.001</td>
</tr>
</tbody>
</table>

Sig. at a: p < 0.05, b: p < 0.01, c: p < 0.001.
4. Discussion

Different types of NDRT influence a driver’s behavior when resuming control of a vehicle in a HAD situation. Based on the results of previous studies (Endsley & Kiris, 1995; Giesler & Muller, 2013; Lorenz et al., 2014), it was possible to identify that visual attention, when out of the loop, is one of the most important factors related to the task of resuming control of an HAD. In the experiment, eye-tracking data, such as the time required for the participants to shift their gaze to the windshield or the time required to fix their eyes on the road, were significantly affected by the characteristics of the NDRT being performed. Therefore, this had a significant effect on the total time taken for the participants to takeover control of the vehicle by demanding more time for activities requiring more visual attention. Louw, Madigan, Carsten, and Merat (2016) that driver out of the loop due to automation influenced on the gaze fixation when reengagement to the driving task was asked, which varies within one second. As presented in the previous research by Louw et al. (2016), results from the present research showed that depending visual attentional resource demanded from the NDRT, the time taken for drivers to shift and fix on the road varies also for natural task in HAD. From the results of post-hoc analyses, it became clear why interacting with an entertainment console is significantly different from watching a video or interacting with a smartphone. Based on previous studies focusing on secondary tasks performed during manual driving, visual attention was considered one of the most important factors of driving performance (Horberry et al., 2006; Lee, Lee, & Boyle, 2007). The results from this study have confirmed that visual attention still plays an important role in HAD. In the experiment, tasks 2 and 3 required high levels of visual attention, and even complete visual attention, which also influenced the time required for the participants to shift their visual attention back into the loop. In a real driving context, this might differ in that interacting with the entertainment console is a task that is discrete and does not require full and continuous visual attention, allowing drivers to shift their visual attention from the loop to out of the loop. On the other hand, watching a video or using a smartphone required continuous and total visual attention of the participant on the task, which was reflected in the results of the gaze-on time.

For the time that the participants’ hands were on the steering wheel, there was no significant difference between the three tasks, even though there were tasks that did not require the drivers to perform any physical activity, such as watching a video. Nevertheless, the fact that there was no significant difference could be explained by the instruction to the participants to keep their hands off the steering wheel owing to the automated lateral control of the vehicle. On the other hand, the overall takeover time was less when the driver was smartphone interaction (task 2), followed by interacting with the entertainment console (task 1), and finally, video watching (task 3). During manual driving, the interaction effect between the visual demand and physical demand of a secondary task demonstrated an influence on driver distraction (Young, Regan, & Hammer, 2007). During HAD, it can be deduced that visual demand does not only influence the process of taking over control of a vehicle, but in some respects, an interaction with the physical demands of the task will also influence takeover performance. That is, as proposed by previous researchers, NDRT demand a degree of physical, as well as mental, and visual involvement (Beattie et al., 2014; Carsten et al., 2012; Casner et al., 2016; Gold & Bengler, 2014; Gold, Damböck, Lorenz, et al., 2013; Hergeth, Lorenz, Vilimek, & Krems, 2016; Merat et al., 2012, 2014; Naujoks et al., 2014). However, in this research, we focus on natural task with a combination of physical and visual resource demand as well as cognitive demand, and we were interested in analyzing the effect of each task on the transition of control in HAD.

A comparison of the gaze-on time, initial fixation time, hands on the steering wheel time, and takeover time of a task allows an understanding of certain characteristics of a driver. However, the workload results revealed that the perceived degree of physical demand had no significant effect on resuming control of the vehicle. As indicated by the results of the hands on the steering wheel time, the three tasks did not show any significant difference, which could explain why there was also no significant difference for the subjective assessment. Moreover, since the study by Matthews, Legg, and Charlton (2003), physical demand based on a self-rating of the NASA-TLX has shown certain limitations when assessing the physical dimension compared to other dimensions. That is, the participants are less aware of the physical demand experienced during driving simulator experiments when asked to conduct NDRT that are common in a driving context, and are thus potentially automated. Furthermore, during the experiment, the participants were asked to re-engage control of the vehicle, which is a new task for drivers, and requires high mental and cognitive engagement, while the act of moving their hands towards the steering wheel is more automatic. The effort expended by the participants when switching their attention from one task to another, regardless of what they were doing, is also illustrated by results obtained from the correlation analysis between the NASA-TLX and experimental data, where physical demand showed a significantly negative correlation with the eye-tracking data, as well as the hands on the steering wheel time and the overall takeover time.

Some of the results from the analysis exhibited a significantly negative correlation between the takeover performance measure and workload dimensions. For instance, the takeover time exhibited a significantly negative correlation with respect to the overall workload score of the NASA-TLX. Also, a significant negative correlation was observed between the mental demand and the takeover time for smartphone interaction and video watching task. However, an attempt was made to understand this result by applying the workload underload theory (Hancock, Williams, & Manning, 1995). Young and Stanton (2002) stated that a driver underload may have as much of a negative effect on the performance as an overload, indicating that a driver’s workload should be maintained at an optimal level. Previous researches on attention and vigilance also stated that the very low level of workload leads to decrease in performance and error rate (Wickens & McCarley, 2007). Thus, presenting an invested U-shaped relationship between performance and workload, which states that certain level of workload in necessary to maintain high performance and constant attention (Young & Stanton, 2002). Based on previous
researches, for the underload case with NDRT, we obtained results indicating that an underload might have a negative relationship with takeover performance of the drivers. During HAD, drivers are under less pressure to pay attention to the driving task, making it difficult to re-engage after a sudden request compared to during a low level of automation. One possible explanation for this is that drivers tend to consider it a high workload when asked to manually drive compared to HAD, even under additional NDRT, as indicated by the results of a self-rating through a NASA-TLX questionnaire (Young & Stanton, 2002). Moreover, another point is that, drivers’ transition of control requires to shift from a NDRT to the driving task, that is, at the moment of takeover there might be a sudden increase of workload from low degree of workload to high degree of workload. Meanwhile, the results obtained from the questionnaire helped to establish that the performance dimension is the only dimension that has a significantly positive correlation with the time required for the driver to resume control of the vehicle. The addition of a new task for HAD, which consists of taking over control of the vehicle, increased the perceived workload, while there was no significant difference between the three tasks. This results were also seen in the correlation analysis between the NASA-TLX and the objective measurement, were the slope for interaction with the entertainment console is slightly different than for smartphone interaction task and video watching task. There was a significantly positive correlation between the subjective and objective measurement for interaction with the entertainment console. The results of the correlation for interaction with the entertainment console could be shown as positive correlation due to the characteristic of the NDRT as it can be classified as a habitual action conducted by drivers during manual driving, and they were accustomed to it. This was also easily observed in the behaviors of the drivers during the experiment. Most of the participants shifted their eyes from the entertainment console to the road as during manual driving. Moreover, it was possible to see from their behavior that they interacted with the entertainment system using only one hand, thereby preparing for any emergency situation that might occur, which was different from their behavior during the video-viewing and smartphone interaction tasks.

5. Conclusion

This study investigated the effects of NDRT when re-assuming control of a vehicle in a HAD situation. Three representative tasks that drivers frequently and willingly performed in a highly automated vehicle were selected. The results from the experiment showed that the effects of different tasks were significantly relevant when the driver resumes control of the vehicle. Based on the results, it can be concluded that automated systems should not change the driver’s responsibilities when driving; rather, such systems should change the role that the driver must play within the vehicle.

The results of this research provide insights into how driver behaviors are changing due to the introduction of automated systems, and how these changes affect conventional driving tasks. We believe that the main task of a driver will shift from controlling to monitoring, and that it will be important for the driver to be able to quickly resume control of the vehicle. This study yielded basic results on the influence of NDRT, as well as the workload when a driver resumes control of a vehicle after being in a HAD situation. The results indicate that a mental underload have a negative relationship with drivers’ behavior when reassuming control of the vehicle. However, there were some limitations in this study. First, we assessed the participants’ workload using a subjective self-rating of the NASA-TLX at the end of each session. Although this is a widely used methodology, the self-assessment of each participant’s workload might have led to a bias in the results obtained as participants were asked to recall the perceived workload during the engagement with the NDRT. Objective physiological measurements of the workload, such as the driver’s heart rate, could reinforce the study, as could an investigation into the relationship among the different situational awareness aspects. Second, although this study compared the influences of different NDRT, further research with a control group where only a takeover task is required is necessary to further understand the behavioral aspect of drivers when the transition from a NDRT to a driving task occurs.

Our results have permitted the understanding of the issues related to a driver’s resumption of control, where the driver makes a transition from a HAD scenario to manual driving; further research on the aspects and characteristics of NDRT that could have a significant influence on the takeover task is required. Furthermore, the question of whether mental workload is still one of the most important factors affecting changes in driver behaviors and mental processing when there is a transition from manual to autonomous driving should be investigated deeper. Hence, research that focuses on understanding the changes in a driver’s mental processing and how such an understanding can be utilized to help maximize the driver’s performance will be important. The results of this research could offer insight into the human behavior in highly automated vehicles, although challenges remain in our understanding of how different levels of demands, such as cognitive, physical, and visual, might influence or affect a driver when resuming control of a vehicle.

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Appendix A. Supplementary material

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