The Effect of Driver Engagement in Autonomous Driving based on Flow Experience

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Abstract

As the vehicle controls the driving itself, driver’s role changes into only a supervisor. These changes in this role directly affect driver’s behavior inside the vehicle. Especially, the driver and the system for semi-autonomous driving require not only more suitable interaction but also proper intervention and exact control. This study investigates driver behavior patterns in autonomous driving based on the 4-channel model of flow theory. For this, we investigated the driver engagement and behavioral change according to the 4 conditions which are caused by the combination of NDRT’s difficulty and the driver’s skill. Driver engagement and mental workload were assessed by Flow short scale (FSS) and NASA-TLX. Then the optimal experience and driver’s action guidelines are determined enabling the appropriate interaction between the driver and vehicle. The results of this study on the driver engagement can contribute to solving issues of collaboration in the intelligent systems and the level of user control as well.

Keywords: Autonomous driving, Flow theory, Non-driving related task (NDRT), Driver engagement

1. Introduction

As the development of autonomous driving technology, most drivers don’t need to highly focus on the typical driving. In other words, while the vehicle controls the driving itself, driver’s role changes into only a supervisor [1]. Changes in this role directly affect driver’s behavior inside the vehicle. In addition, driver’s behavior is determined by the level of automation and attention to driving tasks [2]. Driving time can be used for non-driving-related tasks (NDRTs) [3]. In particular, there are some ambiguous aspect in terms of the role of driver in semi-autonomous driving compared to manual or fully autonomous driving [4]. Therefore, the driver and the system for semi-autonomous driving require not only more suitable interaction but also proper intervention and exact control.

In the case of semi-autonomous driving, the length of Take-Over Request (TOR)-time in take over scenarios is mainly studied previously to ensure the adaptation of new system [2-3]. Mental workload about drivers performing NDRT in highly autonomous driving is also studied [1]. Especially, the driver performing NDRTs is required to allocate visual attention in take-over [5]. In addition, drivers sometimes need to be prepared to catch the steering wheel in case of an accident or traffic jam [5]. However, as the increasing of driver’s adaptability of autonomous driving technology, drivers have been able to give attention to NDRTs. This type of driving, and then, enable the driver to engage the NDRTs [3]. Thus, there is some limitation to study driver’s behavior through an existing evaluation perspective.

The flow condition represents the optimal experience to the task performance [9]. This means the condition of individual who performs optimal challenge and task with the highly concentrated status. In fact, It has been studied to enhance the user satisfaction and to derive optimal experience [6]. According to the flow theory, a flow is experienced when the operator’s skill level balances with the challenge of activity Csikszentmihalyi [9]. Based on the previous theories, recent studies suggest that flow condition can also occur in autonomous vehicle environment [7-8]. For instance, the driver’s behavior was defined in regards to three conditions such as Boredom, Flow, and Anxiety. The Boredom condition, which is one of the possible conditions, is generated when the activity’s challenge is relatively low, and the anxiety condition is induced when the task challenge is high.

However, the flow model has been modified to a quadrant model (4-channel model) due to the inconsistent results of typical model (3-channel model) [9]. The modified model suggests that flow is experienced only at the high level of operator’s skill and challenge of activity. Therefore, it is necessary to apply the quadrant model which can capture the behavior change through classifying the skill level of the operator performing NDRTs in the autonomous driving environment. In addition, previous studies have suggested that flow condition requires a level of attention resource similar to mental workload [10]. Other studies have suggested that condition of the driver also influence the take-over performance [5]. Thus, the purpose of this study is to prove the relationship between drivers' flow condition who performing NDRT and mental workload and to investigate how 4 conditions affect driving performance.
2. Method

2.1 Participants
In this study, 12 participants aged between 28 and 31 took part in the experiment (M = 29.25, SD = 1.29). 6 (50%) male and 6 (50%) female were participated respectively. They had held their drivers’ licenses for a mean of M = 6.67 (SD = 1.72) years.

2.2 Apparatus
In this study, the driving simulator, macbook and ipad screen used shown figure 1-(a). For this driving simulator (Logitech), consisted of 3 units of 27-inch LCD monitors, steering wheel, pedal, driver’s seat, simulation software (Open DS). The software of this driving simulator, Open DS was set to conditionally L3-automated system on the road. The vehicle in the Open DS was set to run repeatedly the M-shaped road.

2.3 Experimental task and design
In semi-autonomous driving environment, drivers can focus on NDRTs, such as reading books or using smartphones [5]. These various NDRTs contribute to determining the demand level of the driver [3]. These NDRTs include tasks such as Reading, Quiz, Writing, Tracking, n-Back, Addition. According to 4-channel model about flow theory [9], operator can experience flow condition only when his skill and challenge of activity are high. Particularly, motivation can increase the skill level of the operator performing the NDRTs. There are extrinsic motivation and intrinsic motivation, both of which can play a role of motivation [11]. Especially, verbal reinforcement(praise) and extrinsic rewards are positive effects on motivation [6]. We thus used motivation (extrinsic/intrinsic) to improve the participant's skill. This motivation is to induce Relaxation condition and Flow condition in 4-channel models.

For this study, we used the Drawing and Addition task to the participants in the NDRTs show figure 1-(b). These types of NDRT can make a difference in driver's condition. These 2 tasks were applied to suit our experiments shown figure 2. The Addition task and the Drawing task each have 2 difficulty levels. This level of difficulty used to control the challenge of activity in flow theory. Addition task (SIMPLE) was the addition of 2 number with 2-digits each (less than 50), such as 14+37, shown in the macbook screen at the right-hand side of driver. Participants were asked to choose UP or DOWN as the correct answer. And Addition task (COMPLEX) was the addition of three number with three-digits each (less than 50), such as 18+28+13, and participants selected 50 or UP or DOWN. Likewise, we have set up Drawing task about 2 difficulty levels, SIMPLE and COMPLEX.

Level of SIMPLE was a few of points shown in the screen. Participants were asked to use the apple pencil to connect the points. Results about the level of SIMPLE are line or figure. On the other hand, Level of COMPLEX was the several points shown in the screen. Participants were asked to use connect the points. Results about the level of COMPLEX are character.

2.4 Experimental procedure
The instructor informed the participants about the experiment and purpose of our experiment. He or she gave the information consent, and surveyed their demographic information. Particularly, participants who involved in the experiment had not experience autonomous driving. Thus, they watched videos related to autonomous driving. Afterwards, they practiced driving for 15 minutes on the driving simulator. In addition, Preliminary practice were performed on NDRTs in advance to help participants understand. Then, this experiment was conducted in take over scenarios.

During the autonomous driving, the participants naturally performed the NDRTs. According to [1], semi-autonomous driving at a speed of were set 100km/h. Then, when the time budget of 8 seconds for take-over request time heard, the participants put their hands on the steering wheel and continued his or her manual driving. According to [1], These time budgets were claimed empirically safe for quality of take over scenarios. In this experiment, the participants experienced total of 8 combinations of NDRTs in random order to lead them into 4 conditions (Apathy, Relaxation, Anxiety, Flow). Thus, they performed 2 NDRTs consisting of 4 conditions (Apathy, Relaxation, Anxiety, Flow).

In this study, we used the perceived demand level (9-point Likert scale) of the FSS (Flow Short Scale) to investigate whether the driver perceived a difference in the difficulty level of NDRTs. We then used the FSS composed of 10 questions (7-point Likert scale) to assess drivers’ condition. According to [6], these FSS used in previous study to assess level of engagement. In addition, we used NASA-TLX to measure participants' mental workload. Finally, the reaction time measured in the software of the driving simulator. The definition of reaction time used in this study is "Time between TOR and start of maneuver [2]".
3. Results

We investigated the difference in the perceived demand level of the NDRTs performed by the participants with different gender. The gender did not have a significant effect on all dependent variables such as the perceived demand level ($F(1,10) = 1.448$, $p = 0.257$), Flow experience ($F(1,10) = 1.021$, $p = 0.336$), mental workload ($F(1,10) = 0.021$, $p = 0.888$), and reaction time ($F(1,10) = 4.724$, $p = 0.055$). In addition, we investigated whether the condition of participants performing NDRT Types (2) and Conditions (4) differently. At this time, 2-way RM-ANOVA analysis method was used. As a result of the analysis, NDRT types have a significant effect on the perceived demand level ($F(1,10) = 93.969$, $p < 0.001$), Mental workload ($F(1,10) = 12.435$, $p = 0.005$), and Reaction time ($F(1,10) = 6.106$, $p = 0.033$). But, no significant effect on the Flow experience ($F(1,10) = 0.007$, $p = 0.936$). In three variables with significant differences, Drawing task was rated lower than Addition task.

As a result of the analysis, the conditions have a significant effect on the all dependent variables such as perceived demand level ($F(3,8) = 58.053$, $p < 0.001$), flow experience ($F(3,8) = 82.674$, $p < 0.001$), mental workload ($F(3,8) = 71.348$, $p < 0.001$), and reaction time ($F(3,8) = 13.942$, $p = 0.002$). However, post-hoc pairwise comparison showed differently in figure (2). Perceived demand level showed statistically differences in order of Anxiety ($M = 6.333$, $SD = 1.685$), Flow ($M = 4.667$, $SD = 1.834$), Apathy ($M = 3.625$, $SD = 1.715$) and Relaxation ($M = 3.250$, $SD = 1.482$) condition. At this time, the difference of conditions between Apathy and Relaxation was not statistically significant ($p = 0.148$).

Flow experience showed statistically differences in order of Flow ($M = 4.758$, $SD = 0.641$), Relaxation ($M = 3.779$, $SD = 0.569$), Anxiety ($M = 2.658$, $SD = 0.710$) and apathy ($M = 2.354$, $SD = 0.501$) condition. Mental workload showed significant differences in order of Anxiety ($M = 62.236$, $SD = 15.161$), Flow ($M = 36.69$, $SD = 12.859$), Relaxation ($M = 29.902$, $SD = 12.065$) and Apathy ($M = 17.284$, $SD = 8.334$) condition. Particularly, the difference of conditions between Flow and Relaxation was not statistically significant ($p = 0.174$). Reaction time showed significant differences in order of Flow ($M = 3.665$, $SD = 0.754$), Anxiety ($M = 3.075$, $SD = 0.468$), Relaxation ($M = 2.585$, $SD = 0.363$), and Apathy ($M = 2.585$, $SD = 0.363$) condition. However, there was no significant difference between Anxiety and Relaxation condition ($p = 0.385$).

Figure 2. The results of pot-hoc pairwise comparison

4. Discussion and Conclusion

This study used flow theory and NDRTs type to set the design of 4 different conditions of skill/challenge experiments in semi-autonomous driving environment. The results indicate that the 2 types of NDRT were differently accepted about perceived demand level by the participants. Participants perceived Addition task ($M = 5.750$, $SD = 1.695$) as a higher demand level than Drawing task ($M = 3.188$, $SD = 1.497$). Thus, the participants can accept the NDRTs, which require cognitive load, as a high level of difficulty. These results indicate that the NDRT types affect the perceived demand level of the driver.

In addition, the results indicate that the design of 4 conditions were implemented as predicted, as shown by results of the perceived demand level. In our study, participants perceived the Anxiety condition as the highest demand level, appeared by Flow condition, Relaxation, and Apathy condition were in order about perceived demand level. These findings are consistent with the results of [6-7] claim that participants perceived the demand level differently in performing those NDRTs as Anxiety were high, Flow were medium, and boredom were low. Although perceived demand level in this experiment was limited to 3, mental workload and flow level showed different results.

Then, the flow experience are perceived differently by participants depending on the 4 conditions. These results indicate that the 4 conditions induce the different flow experience of the driver. Participants showed the most immersive experience in flow condition, followed by Relaxation condition, Anxiety and Apathy condition were in order about FSS. These are not consistent with [8][12] claim that Flow condition rated the higher flow experience than the others (Boredom, Anxiety condition). In previous studies claimed that the Boredom and anxiety condition are not assessed differently. This result show that when we set skill/challenge experiments, we could better experience flow in the Relaxation condition and Flow condition influenced by motivation. In addition, our findings are consistent with [11] claim that the motivation influenced flow experience.

This experiment found that the NDRT types and 4 conditions had an effect on mental workload. Participants accepted mental workloads differently when performing 2 types of NDRT. Participants felt more mental workload when performing Addition ($M = 40.247$, $SD = 19.986$) than Drawing task ($M = 32.784$, $SD = 19.986$).
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