The Effects of TOR on EEG Data in Level 3 Autonomous Vehicles

by

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DEDICATION

This study is wholeheartedly dedicated to my beloved parents and sisters, who have continually made me feel their moral, spiritual, emotional, and financial support.

ABSTRACT

At present, most of the leading automobile manufacturers and people who work in the academic field conduct studies about self-driving cars. Self-driving capabilities have improved in automobiles, and the potential benefits and dangers of this innovation for individuals and the environment are deliberated broadly. One potentially dangerous situation that has been studied in detail is related to the process of take-overs when autonomous vehicles, specifically the ones at level 3, fail. Most of the hazards caused during these take-overs can be attributed to a variety of factors, which can be classified as environmental factors, vehicle factors, and human factors. Lately, human factors have stood out as an area of study to improve the safety performance of level 3 autonomous vehicles. Some of the most important examples of human factors are the driver’s distraction and emotional states during the take-over process of an autonomous vehicle, both of which have great potential in reducing the “driver's" driving skills and leading to fatal accidents. Most of the autonomous vehicles on the market, are at level 3, which the drivers have to take over the control of the vehicle in some road scenarios when the vehicle fails unexpectedly. When the autonomous vehicle fails, the "driver" is provided with a short time span, which will be referred to as buffer-time in this study, before s/he takes the control of the vehicle. Many scholars investigated the optimum buffer-time that will have the most positive effect on the driver's take-over performance, but they have not reached an agreement. However, an early buffer-time of 8 seconds and a late buffer-time of 4 seconds have been utilized in various prior studies. Because of this reason, it is important to understand the effects of early and late buffer-times (4 and 8 seconds) on driver’s emotional states. This study investigates the effect of buffer-time (4 and 8 seconds) on

the driver's emotional states. 20 young drivers participated in this study. This experiment took place utilizing an in-house developed driving simulation called GMOST, and during the experiment participants' EEG data was recorded with EMOTIV EPOC+. At the same time, participants engaged with the n-back secondary task as an activity that they are engaged in just prior to the take-over requests that they receive when the vehicle fails. While the results signified that there is a slight statistical difference between the two buffer times on emotional states, these differences are not sufficient or significant enough to distinguish two different buffer time groups (participants in 4 seconds and the ones in the 8-second group).

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CHAPTER 1

INTRODUCTION

With the increasing number of works in the automotive sector, there have been various studies to increase driver assistance such as lane-keeping, parking, speed maintenance, blind-spot monitoring, and enhanced night vision [1], [2]. At the same time, highly automated vehicles became one of the important and sophisticated areas of study over the past years. Automated cars can likely enhance highway safety by reinforcing drivers in different positions. Based on the Society of Automotive Engineers (SAE) and The National Highway Traffic Safety Administration (NHTSA), autonomous cars can be defined on five-level segments [3]. In this taxonomy, as the level rises, drivers' interaction with the vehicle proceeds inverse proportion. In other words, drivers may decouple from operation and control of the vehicle [1], [4].

These autonomous vehicles have been categorized into 5 levels. At level 0, drivers are responsible for the full control of the vehicle (brake, steering, gas pedal) at all times and must observe the roadway and safe control of the vehicle [5]. However, vehicles that contribute supportive and assistance systems such as collision warnings, lane-keeping warnings, blind-spot warning as well as the automated inferior operations such as wipers, headlights, turn-signals would be recognized as "Level 0" vehicles because the vehicle itself does not intent to changes of gas-pedal, steering, or braking. At level 1 and level 2, vehicles are equipped with automated systems that take control of specific functions (e.g. adaptive cruise control, electronic stability control), dynamic brake support in emergencies) [6]. Furthermore, the driver is required to proceed to control the vehicle constantly, need to monitor the roadway, and take control of the vehicle in case of a safety issue. At level 4 (full self-driving automation), the driver is free to control the vehicle, and does not need to monitor traffic or roadway in any case. The vehicle is capable to handle and deal with any safety issues. The vehicle performs all driving features by itself, and the driver only needs to provide destination or navigation input to make the vehicle ready to operate the trip.

At level 3, vehicles have a technology that takes full control of the vehicle, and the driver is free to deal with the control of driving task or pay attention to the roadway and traffic anytime. As soon as the driver hears the warning, called Take Over Request (TOR), the driver is expected to take control over the vehicle. TORs may be prompted for two types of reasons. The first one is when a system boundary is reached, and the second one is when the system fails. The system boundary is reached when the traffic and environmental conditions are not within the scope of situations that the autonomous vehicles can handle. Some examples of these are an unexpected stationary object in the middle of the road, sudden heavy snow, imminent accident ahead, construction on the road, etc. The second type is when the vehicle's system fails due to a hardware and/or software-related issue. When one of these failures happens, the driver is prompted with a TOR, upon which the driver needs to take over the control of the vehicle within a short transition or buffer time (i.e., 4 seconds). However, because the driver may be occupied with a secondary task when the TOR is prompted, the driver may not be physically, informatively, psychologically, and emotionally ready to take control over the vehicle. The driver's unreadiness compounded with his/her occupation with a secondary task at the time of the TOR will negatively affect his/her driving behavior performance and may lead to accidents.

TORs are prompted with a transition time for the driver before the driver takes control of the vehicle. This transition time, called buffer-time in this study, has been studied greatly. Erikson et. al. reviewed 25 different buffer times from prior studies related to TOR time, and they found that the mean takeover-request lead time was 6.37 ± 5.36 s. However, there was no agreement on sufficient buffer time between reviewed papers [7]. Thus, buffer times were decided to close, according to Erikson et. al., mean TOR times as 4 and 8 seconds.

It has been reported that the driver's emotional state has a negative impact on driving behavior. For example, Steinhauser et al. stated in their research that angry drivers could cause aggressive driving and violation of traffic rules [8]. Also, Jeon et al. mentioned that participants in positive moods predicted positive events as more likely than participants in negative moods, and those in positive moods showed better performance.[9]

However, no study has investigated the effect of buffer-time on driver's emotions. Therefore, the purpose of this study is to examine the effects of buffer time (4 and 8 seconds) on driver's emotional states, including their engagement, excitement, stress, relaxation, interest, and focus.

CHAPTER 2

LITERATURE REVIEW

2.1 SYSTEM FAILURE AND TAKE-OVER REQUEST

In some situations, the vehicle is not able to continue handling automated driving; therefore, the driver is required to take control of the vehicle. It means that the vehicle reaches system failure and gives the warning to remind the driver to take the longitudinal and lateral control. This situation can be defined as Take-Over-Request. There have been studies examining the different types of failures. For example, Kuehn et al. implemented an experiment that includes different types of scenarios that cause system failures [10]. These are the absence of road markings, sensor or software errors, road works, and extreme weather conditions [11]. Bazilinskyy et al. stated several scenarios could cause system failures, such as reaching a target highway exit, changing lanes because of approaching a slow-moving car, construction, technical failure, and accident in the road[12]. Moreover, an obstacle on the road [13]–[15], sharp bend[1], [10], [16], construction ahead of the road[1], [17], [18], heavy weather conditions such as fog rain, snowing [1], [17], [18] can be reasons to occur system failure in level 3 autonomous vehicles. Besides, signalized intersection zones can lead to hazardous events for the level 3 autonomous car in more likely urbanized environments where traffic density is high [4]. Thus, this gives a high chance of system failure happening in highly automated cars.

Level 3 autonomous vehicles have environmental sensing capabilities and can make informed decisions such as speeding past a slow-moving vehicle [19]. But they still have to be overridden by a person. If the system fails to fulfill the task, the driver must remain alert and ready to take control. This notification is provided by the vehicle in specific scenarios. Bazilinskyy et. al. explain these scenarios as imaginable, such as the autonomous vehicle is reaching the target highway exit, has to make a lane change due to approaching a slow-moving vehicle, reaching technical failure, and facing an accident in the roadway [12]. With the developing technology, IoT is started to be used in smart traffic systems, especially avoiding congestion in the high passing intersections to improve traffic flow [20]. The intersection manager operates on a first-come, first-served basis, based on the incoming vehicle's speed and distance from the collider at the intersection, which was applied to the intersections to detect vehicle order and allow pass-order decisions [21]. Therefore, take-over requests in the level 3 autonomous vehicle can occur in this intersection management flowing scenario as well.

2.2. BUFFER TIMES

There have been studies looking at the optimal buffer-time for the best take-over performance in terms of quality and timing of these take-overs. However, there is no agreement for specific buffer times to get sufficient take-over quality and timing.

In addition to the quality and timing of take-overs, buffer times may affect the driver’s emotions. It is influential to examine the effects of buffer times on driver’s emotions because evidence of neuronal activity in the brain seems to affect cognitive processes and human action by different pathways [22].

2.3. SECONDARY TASK

There have been many studies about the secondary task to understand how distracting affects drivers' safety, take-over quality, and take-over time in Level 3 autonomous vehicles. Also, drivers can engage with the secondary task or spend more time by looking away from the forward roadway at higher levels of self-driving cars [23]– [25]. However, this situation may allow to arise a safety issue [26] or change drivers' emotional state badly [27], [28] by distracting drivers from a situation that he/she has to take over the control when the Level-3 autonomous vehicles' fail. Some studies show that the bad effects of secondary tasks influence the take-over quality and time in autonomous vehicles.[7], [23], [29], [30]. In addition, human failure causes up to 90% of all traffic incidents.[31]**,** and According to the National Highway Traffic Safety Administration, distracted drivers were involved in 17% of automobile accidents [32]. There are three forms of distraction in the car: manual, visual, and cognitive [32]

1 - Manual distraction occurs as drivers may take their hands off the steering wheel to complete other tasks.

2- Drivers become visually distracted as they are undertaking activities that enable them to look away from the roadway.

3 - Cognitive distraction occurs as drivers execute activities that enable them to divert their mental focus away from driving.

There are numerous different types of secondary tasks explored in prior studies such as reading text [7], [10], [33], watching a video [30], playing a game, 20-Questions Task [23], [34], n-back task [13], [29], [30], SuRT(Surrogate Reference Task) [35]–[38]. This study implemented n-back task as the secondary task because it is a cognitive, visual, and manual distraction [29], [34].

2.4. THE DRIVER'S EMOTION

Drivers' emotional state may impair the take-over quality and may be affected by the buffer-time, but it has not been investigated to report any finding. Emotion is both a cognitive capacity and a response to external sensory stimuli in humans [35]. Different kinds of emotional state were found to affect drivers' capacity to monitor a vehicle and cause a driver to make a mistake [39]. Drivers' **engagement**, **excitement**, stress, relaxation, interest, and focus are among such emotional states that may impact driving behaviors. For example, high levels of excitement were reported to predict membership to a traffic offender group [40], lack of engagement, fatigued driving. Also, drowsiness was reported to be one of the major causes of traffic accidents [41], [42]. In addition to these examples, stress was also reported to increase anger leading to risky driving behavior including speeding, erratic driving, and shorter times and distances to crashes [43], [44].

Excitement, engagement, stress, relaxation, interest, and focus could be measured through Electroencephalography (EEG) technology. Electroencephalography (EEG) is an electronic physiological monitoring technology that records the emotional states as activities of the brain [42]. There have been numerous studies using EEG technology as a non-invasive method to measure and collect data about drivers' emotional states. For example, EEG was used to measure physiological and driving behaviors of sleep-deprived drivers [45], evaluate driver distraction [46], investigate the effects of various sounds in vehicles on drivers' relaxation and concentration [42], measure the emotional stress level in self-driving vehicles [47], report nerve activity in each brain region, mental fatigue, level of attention and awakening of the brain, and alertness or engagement after a long period of simulated driving [41], [48].

However, no study has examined the emotional states of the driver before, during, and after TORs are prompted at various buffer times when the system of a level-3 autonomous vehicle fails prior to intersections.

2.5. PROBLEM STATEMENT AND RESEARCH QUESTION

It is understood that most of the studies examined that the effect of different emotional states on the driving performance, and perceived workload; however, no study investigated the effects of different buffer times on the driver's emotional states. Therefore, the research question is decided as follow.

- What is the effect of buffer times (4 seconds and 8 seconds) on drivers' emotional states, i.e., engagement, excitement, stress, relaxation, interest, and focus?

Specifically, are drivers emotionally more prepared to take control of the autonomous vehicles with an early buffer-time (8 seconds) as compared to a late buffer-time (4 seconds) and vice versa?

CHAPTER 3

EXPERIMENTAL SETUP

3.1. GMOST

The research was carried out using GMOST, a multi-player driving simulator. The terrain for the traffic in the simulator is 3 miles by 3 miles in size (see Figure 2). Traffic lanes, signage systems, residential areas, office buildings, trees, and other natural structures populate the environment, simulating a real-world traffic system. Esayroads3d, which was imported from the Unity Terrain Tools website, provided the roads. Some roads have two lanes with a 25-mph speed limit, and some have three lanes with a 45-mph limit. Intersection operators took the place of traffic lights and stop signs at intersections. Around 50 to 120 self-driving cars were created and used in the simulation. They were spawned at numerous locations in the environment, each with six different destinations. Once the agents arrive at their destination, they are rerouted to the new destination chosen randomly. The A* route search algorithm is used for routing. [49]. A* path search kit was imported from the Unity assets store, and it searches for the shortest path between two points using waypoints. The script in the kit was altered to make the game run at a respectable pace. The traffic density was set to be high, with cars spaced 100 meters apart in all directions and a 4-second distance in all directions [50]. When the 'driver' presses the brake pedal more than 10% or steers the car to a 2-degree deviation, the vehicle's autonomy feature is stopped operating. Moreover, the autonomy can be activated and deactivated by clicking a button on the steering wheel.

The intersection operator is based on a first-come, first-serve, relying on the oncoming vehicle's speed and distance from the intersection's collider. The intersections are not regulated by traffic signals or stop signs. Instead, Unity game object colliders are mounted at each intersection to establish a self-sufficient intersection manager that senses vehicle order and makes pass order decisions. The intersection manager is made up of different software modules that are responsible for organizing traffic, detecting passing vehicles, and interacting with vehicles. The software stores the intersection name and ID. Each intersection manager has a circular border area to detect, monitor, and operate. The intersection manager was designed to tackle two scenarios to improve safety. First, if there is no driver nearby, the intersection manager places the cars in a queue and encourages them to pass one by one as though they were in a typical passing condition. The second is when all cars, with and without a driver, enter the intersection to have the right of way. In this case, the intersection manager adds the car with a driver as a special case, and warning signals are sent to the other AI agents in the intersection. The first vehicle to enter has a preference to drive across the intersection without slowing, while the other drivers wait for the next vehicle in line to pass. When the driver disengages the automation, he or she must take direct control of the car and follow the intersection manager's orders, which are either pass or stop.

All AI Agents, including the driver’s cars, have a ray-cast feature built on their vehicles to track the speed, distance, and direction of AI vehicles. This feature helps to prevent collisions by creating more realistic space between cars. Depending on the length of the detector line, the ray-cast may be changed as needed. When an autonomous car fails and the driver must take over, the presence of the manual vehicle is observed, and a visual warning is shown on the driver's dashboard informing them of the order in which they must proceed. Others remain seated until it is their time to move.

In GMOST, right-angle intersections were built at about every half-mile throughout the environment. Around 155 meters before the intersection, the intersection manager alerts the vehicles of their turn (proceed or stop) with a visual color displayed on their dashboard.

The simulator's physical components include a metal frame (Volair Sim Cockpit Chasis) on which three LCD screens (LG 29" IPS LED FHD 21:9 UltraWide FreeSync Monitor), a driver seat, and steering wheel, as well as gas and brake pedals, are installed (Logitech G920 Driving Force). Three installed LCD screens displayed the front and side views of the environment (Figure 1). The front windshield and dashboard are shown on the middle LCD screen. A directional indicator, the n-back secondary task window, visual information for the order of pass, a speedometer, and a visual TOR alert for device failure can all be seen on the dashboard. The 'driver' has a 180-degree field of view supported by three LCD panels. A rearview mirror and side mirrors were installed to have a rear vision and side views, respectively. Speakers were used to playing back road and engine sound [51].

Figure 1:Physical GMOST Equipment

Figure 2:The map of the simulation

3.2. SYSTEM FAILURE AND BUFFER-TIME

In the experimental setup, drivers are asked for taking over the autonomous vehicle in case of sensing the Take- Over Request, and this happens 4 or 8 seconds prior to the intersection. In some cases, there is no failure, which means the participant does not need to take over the control, and the autonomous vehicle is able to handle the direction that pops up on the dashboard without any hazardous situation. System failure has been decided to be offered to the user with the modality of auditory and visual warning.

3.3. EMOTIV

EPOC+ is a wireless 14 channel (nodes) EEG device designed for scalable and contextual human brain research and provides access to professional-grade brain data [52]. Each participant wearing the EPOC+ device had their user profile, and their data is rescaled over time to improve the EPOC+'s accuracy. Saline solution was applied to the nodes on EPOC+ to help with making the proper connection with the participants' scalps as well as for keeping the nodes in place [53]. A profile is created for each participant, who went through a brief calibration process at the beginning of the experiment.

EPOC+ records the following six different types of emotions: instantaneous engagement, excitement, stress, relaxation, interest, and focus, as these are the most likely emotions to affect driving behavior. Excitement (instantaneous) is defined a as "feeling or awareness of physiological arousal in a positive value" [53]. Engagement is defined as "alertness and the conscious direction of attention towards task-relevant stimuli" [53].

The EPOC+ scores each channel on a scale from zero to one where a higher channel score corresponds to a greater intensity of the emotion. For example, the more engaged a person is the higher their channel score is, or a higher score on other emotions channel represents a higher level of stated emotions [53]. The user does not require any training in order for the EPOC to be able to successfully detect emotion. Emotiv has not publicly released its classification algorithms; therefore, it is unknown how these emotions are detected.

EPOC+ device setup took a few minutes at the beginning of each session because each node needed to have contact with the participant's scalp, which required moving the hair away to make room for the node to have contact with the scalp. For EPOC+ to record any data, all 14 nodes needed to have perfect contact with the scalp indicated by 100% contact, which was achieved for all participants in this study.

Emotiv Professional software recorded data while a small code was written in GMOST to connect COM5 and COM6 serial ports which trigger marking two points by an external application called Virtual Serial Port and the buffer-time (4 or 8 seconds). These two points are marked as 2 seconds prior to TORs and the vehicle leaves the intersection,

3.4. N-BACK AS A SECONDARY TASK

Cognitive distraction plays an important role in safely taking control of autonomous vehicles when they fail and prompt TORs. We aimed that getting maximum distraction by applying eyes, hands, and minds-off road tasks. Therefore, to achieve cognitive distraction, the N-back secondary task is used, which involves memorization of the order of letters. In the n-back secondary task, for example, letters between "Y, S, U" were presented in a random order, with 10-second intervals between letters. When a displayed letter matches the two prior letters, participants are asked to press the B button on the steering wheel, which means the letters are the same (Fig. 3). Otherwise, in the condition of the letters are different, participants are asked to press button X on the steering. After the participants press the button, a new letter appears on the dashboard's right side, and participants pay attention to this task when the autonomous vehicle has full control of the vehicle. Thus, participants are allowed to be distracted from driving and the roadway and they can engage with the n-back secondary task.

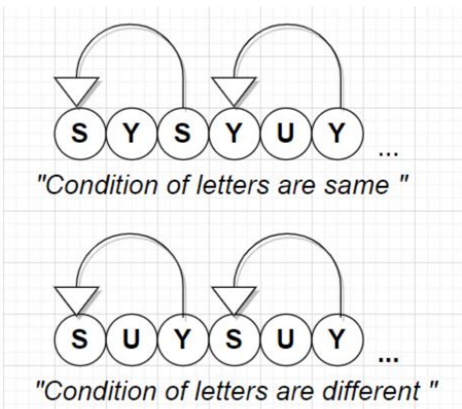

Figure 3: Conditions of n-back task

Figure 4: Visual representation of n-back in simulation

3.5. TAKE OVER REQUEST (TOR)

In the simulation, two different kinds of take-over request (TOR) concepts were implemented. These are auditory and visual warnings. The auditory TOR was obtained of double high- itched beeps(240 ms beeps of 2800 HZ with 100 ms interval in between) according to guidelines of NHTSA for crash warnings[49], [54] and visual TOR obtained of a warning message pops up on the dashboard with a red background "Fail Hands-On" text printed (Figure. 5). On the other hand, if the vehicle is on the autonomy feature, the "Auto ON Hand Out" printed warning message pops up (Figure. 5)

Figure 5: Representation of Auto-not active or Auto-active

3.6. PARTICIPANTS

In total, 20 individuals (19 male and 1 female aged between 20-35 years) participated in this experimental study. They all had state-issued driver's licenses and prior driving experiences. The autonomous vehicle implemented in the simulation had two system failures which are 4 seconds and 8 seconds prior to all intersections. To get the equal number of failures for each participant, an algorithm was implemented, in which participants receive instances of two buffer-time by choosing random fail times from out of three fail times in the list, 0 second (no failure), 4 seconds, and 8 seconds), and passing each intersection causes the elimination of occurred buffer time from the list. At the end of the third intersection, this list renews with three buffer times continuously. Therefore, all participants received a random and equal number of buffer times. Each participant received a total of 15 8 seconds (8SG) and 15 4 seconds (4SG) failures. None of the participants had any previous experience with EEG or Emotiv.

Figure 6: The main screen view of the GMOST simulation

CHAPTER 4

EXPERIMENTAL PROCEDURE

The experiment was completed in two weeks for an approximately 1-hour session per participant with a total of 20 participants. At the beginning of each session, participants have explained the purpose of the experiment. After the verbal explanation was completed, they were asked to be seated, and they adjusted their seats to the appropriate distance. Then, participants were asked to do a trial as they drove the vehicle manually with the steering wheel, gas pedal, and brake pedal to adapt to the simulation environment and experience the sensation of the steering, gas pedal, and brake pedal. Then, they were encouraged to activate the autonomous feature to experience how the autonomous vehicle functions in the traffic. At the same time, instructions regarding how to play the n-back secondary task game were given. This training took place approximately half of an hour in each session.

After participants felt comfortable driving the vehicle and ready to start, port connection settings were set between EMOTIV PRO app to Virtual Serial Port application to be able to trigger the EMOTIV PRO app marking down feature in specific time intervals during the experiment.

The participants were told that they do not need to pay attention to the roadway when the autonomous feature is active, and they were encouraged to occupy n-back secondary task, memorizing the letters, and pushing the button depends on if the letter is same or different with two previous letters. Once they push the button or wait 10 seconds without any response, a new letter shows up on the right bottom of the monitor. If the participants were prompted with the Taking-Over Request (TOR) by audial and visual warning, they have to take over the control of the vehicle and follow the instruction of the intersection manager, which would be to either pass the intersection or stop. In case of the stop, which they were not given the right of way, participants were inquired to press the brake pedal to stop at the crossing point, and, after that they should continue when presented with a green light on the dashboard and traffic sign demonstrating that they are given the right of the way. During the experiment, participants were faced with 30 intersections on average and were driven about 25 minutes in each session.

4.1. DATA COLLECTION

Epoc+ device, EmotivPro v2.6.3.335, and Virtual Serial Port applications are used to record data to measure participants' six emotional states; engagement, excitement, stress, relaxation, interest, and focus levels. Before, during, and after TORs are prompted at two different buffer-times, 4 and 8 seconds prior to intersections as the system failure occurred with level-3 autonomous vehicles. EmotivPro v2.6.3.335 along with recorded real-time changes in emotions experienced by the participants. The signals detected by the nodes are wirelessly transferred to a local machine via a wi-fi USB dongle.

4.2. DATA ANALYSIS

This study compared two groups (independent variables): 4-second group (4SG) and 8-second group (8SG) on EGG data in terms of engagement, excitement, stress, relaxation, interest, and focus.

In an attempt to analyze the effect of buffer-time on brain data (EEG), this study required a MANOVA analysis with the groups as the independent and the six emotional states collected via the EEG as the independent variables. The levels of significance (alpha) were set at .05 level. Hotelling T^2 was used to determine the overall multivariate significance of dependent variables on the groups.

CHAPTER 5

RESULTS AND DISCUSSIONS.

The purpose of this study is to examine the effects of buffer-time on drivers' emotions in terms of engagement, excitement, stress, relaxation, interest, and focus in a level-3 autonomous vehicle when a system failure occurs before an intersection while the driver is involved in a secondary task and is out-of-the-loop. The aim is to find out if the buffer-time has any effect on the driver's emotions via EEG brain data when a system failure in an autonomous vehicle occurs prompting TORs just prior to intersections.

Tables 1 and 2 show the EEG brain data mean and standard deviation scores, respectively, for engagement, excitement, stress, relaxation, interest, and focus levels by all participants across 4SG and 8SG. As seen in table 1, engagement and focus levels were higher for participants in 8SG as compared to the ones in 4SG. On the other hand, excitement, stress, relaxation, and interest levels were higher for participants in 4SG and compared to the ones in 8SG. However, the scores on all emotional states were very close to make an interpretation as to which group of participants had a higher score on a specific emotion.

TABLE 1
The Means for EEG Data across the Two Groups

Groups	Engagement	Excitement	Stress	Relaxation	Interest	Focus	N
4SG	0.589486	0.347414	0.410169	0.269848	0.550981	0.41356	20
8SG	0.609097	0.319753	0.405382	0.268436	0.548833	0.42536	20

TABLE 2
The Standard Deviations for EEG Data across the Two Groups

Groups	Engagement	Excitement	Stress	Relaxation	Interest	Focus	N
4SG	0.145002	0.202049	0.251262	0.113401	0.123520	0.21384	20
8SG	0.164813	0.216619	0.224563	0.118906	0.138421	0.17906	20

A multivariate analysis of variance was run to examine differences between 4SG and 8SG groups when the six emotional states (engagement, excitement, stress, relaxation, interest, and focus) considered together. The box's test of equality of covariance matrices showed that observed covariance matrices of the dependent variables are not equal across groups (sig. .001). Levene's test of equality of error variances showed that the variances are equal across groups on all dependent variables.

As seen in Table 3, the multivariate analysis failed to show a statistically significant difference between the two groups when all six dependent variables were considered together (Pillai's T = .022, F = 1.45, p=.193, multivariate eta squared = .022). This result indicates that there was no statistically significant difference between the participants in the 4SG and 8SG groups on their emotional states.

TABLE 3
Comparison of Mean Values of Engagement, Excitement, Stress, Relaxation, Interest, and Focus across Groups

Groups	Value	F	Sig. (alpha=.05)	Partial Eta Squared	Observed Power
Pillai's T	.022	1.45	.193	.022	.566

P < .005

Examination of the coefficients for the linear combinations distinguishing the two groups indicated that excitement (Eta squared = .004, p = .189) contributed the most, although not statistically significant, to distinguish 4SG and 8SG groups. Also, it was found that the relaxation (Eta squared = .0, $p = .904$) contributed the least, and statistically not significantly, to distinguish the two groups. These results as well as follow-up one-way MANOVA tests indicated that 4SG and 8SG groups were not statistically significantly different on any of the emotional states, including engagement, excitement, stress, relaxation, interest, and focus.

CHAPTER 6

CONCLUSIONS

In this experimental study, EEG data were recorded and analyzed to understand the effects of two different buffer times, 4SG and 8SG, on driver's emotion during Level 3 Autonomous vehicle simulation. The recorded data of 20 participants showed that buffer times (4 and 8 seconds) didn't impact the driver's 6 different emotional states (engagement, excitement, stress, relaxation, interest, and focus) both collectively as well as individually. Before the investigation started, we were expecting that buffer times could affect the driver's emotions because drivers also engage with the secondary task, which means they are isolated and distracted from the roadway, and short transition time (4 seconds) gives less emotional preparation opportunity to the driver in contrast of long transition time (seconds). Although there is a slight difference between the effect of 8 seconds on engagement and focus levels in terms of 8 seconds engagement and focus levels is higher, and the other emotional states (excitement, stress, relaxation, interest) are higher in 4 seconds. These do not provide significantly distinguishable results. This means the six emotional states are not affected by buffer-time, whether the TOR is prompted 8 seconds or 4 seconds prior to the failure of the autonomous vehicle. Because this is the novel study to explore, implementations and conditions for the experiment can be extended. As an example, even though we could not get significant results, more participants could affect the results in different way. Furthermore, buffer-times we used in the experiment were so close to each other, and the results might change by making the difference higher between buffer times like 3 and 10 seconds.

APPENDIX A

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February 21, 2021

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RE: HSRC PROTOCOL NUMBER: 014-2020CR
TITLE: Driver Readiness to Take Control of Autonomous Vehicles

Dear Dr. Arslanyilmaz, et. al.:

The Institutional Review Board has reviewed the aforementioned project, previously approved on September 24, 2019, under Expedited Category 7. Since there have been no adverse events or changes to the project, it continues to meet the criteria of minimal risk. The Committee has determined that it is approved for an additional year. If work on the protocol is not completed by February 20, 2022, you will need to submit a Continuing Review form at that time.

Any changes in your research activity should be promptly reported to the institutional Review Board and may not be initiated without IRB approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the Institutional Review Board.

The IRB would like to extend its best wishes to you in the conduct of this study.

Sincerely,

Dr. Severine Van Sambrook
Director, Research Services, Compliance and Initiatives
Authorized Institutional Official

SVS:cc

c: Dr. Carol Lamb, Chair
School of Computer Science, Information and Engineering Technology

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February 21, 2021

Dr. Abdurrahman Arslanyilmaz, Principal Investigator
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Mr. Ivan Bosniak, Co-investigator
Mr. Nathaniel Arthur, Co-investigator
School of Computer Science, Information & Engineering Technology
UNIVERSITY

RE: HSRC PROTOCOL NUMBER: 014-2020M1
TITLE: Driver Readiness to Take Control of Autonomous Vehicles

Dear Dr. Arslanyilmaz, et. al.:

The Human Subjects Research Committee has reviewed the modifications you have requested to the above-mentioned protocol. The change of qualified student personnel and increased number of participants does not increase the risk associated with your project. Therefore, your project continues to meet the condition of minimal risk and is fully approved.

Any other changes in your research activity should be promptly reported to the Institutional Review Board and may not be initiated without IRB approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the IRB.

The IRB would like to extend its best wishes to you in the conduct of this study.

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REFERENCES

[1] M. Gibson *et al.*, "Situation Awareness, Scenarios, and Secondary Tasks: Measuring Driver Performance and Safety Margins in Highly Automated Vehicles," *SAE Int. J. Passeng. Cars Electron. Electr. Syst.*, vol. 9, no. 1, pp. 237–242, May 2016, doi: 10.4271/2016-01-0145.

[2] "Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts:...: Search Everything." https://eds-b-ebscohost-com.eps.cc.ysu.edu/eds/detail/detail?vid=1&sid=46fefafc-cb69-42fd-815c-d1835bc367ad%40pdc-v-sessmgr03&bdata=JnNpdGU9ZWRzLWxpdmU%3d#AN=edsair.od......2485..3f9511e94d2a41686a7a23d3d939cdf4&db=edsair (accessed Apr. 07, 2021).

[3] "Preliminary Statement of Policy Concerning Automated Vehicles," National Highway Traffic Safety Administration, 2013.

[4] A. Borowsky and T. Oron-Gilad, "The effects of automation failure and secondary task on drivers' ability to mitigate hazards in highly or semi-automated vehicles," *Adv. Transp. Stud.*, no. 1, pp. 59–70, Apr. 2016, doi: 10.4399/978885489179106.

[5] C. D. D. Cabrall, R. Happee, and J. C. F. de Winter, "From Mackworth's clock to the open road: A literature review on driver vigilance task operationalization," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 40, pp. 169–189, Jul. 2016, doi: 10.1016/j.trf.2016.04.001.

[6] D. J. Fagnant, "The future of fully automated vehicles : opportunities for vehicle- and ride-sharing, with cost and emissions savings," Thesis, 2014.

[7] A. Eriksson and N. A. Stanton, "Takeover time in highly automated vehicles: noncritical transitions to and from manual control," *Hum. Factors*, no. 4, p. 689, 2017, doi: 10.1177/0018720816685832.

[8] K. Steinhauser *et al.*, "Effects of emotions on driving behavior," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 59, pp. 150–163, Nov. 2018, doi: 10.1016/j.trf.2018.08.012.

[9] M. Jeon, B. N. Walker, and J.-B. Yim, "Effects of specific emotions on subjective judgment, driving performance, and perceived workload," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 24, pp. 197–209, May 2014, doi: 10.1016/j.trf.2014.04.003.

[10] F. Naujoks, C. Mai, and A. Neukum, "The Effect of Urgency of Take-Over Requests During Highly Automated Driving Under Distraction Conditions," Jul. 2014, vol. 7.

[11] K. Holländer and B. Pfleging, "Preparing Drivers for Planned Control Transitions in Automated Cars," in *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia*, New York, NY, USA, Nov. 2018, pp. 83–92, doi: 10.1145/3282894.3282928.

[12] P. Bazilinskyy, S. m. Petermeijer, V. Petrovych, D. Dodou, and J. c. f. de Winter, "Take-over requests in highly automated driving: A crowdsourcing survey on auditory, vibrotactile, and visual displays," *Transp. Res. Part F Psychol. Behav.*, vol. 56, pp. 82–98, Jul. 2018, doi: 10.1016/j.trf.2018.04.001.

[13] Jingyan Wan and Changxu Wu, "The Effects of Lead Time of Take-Over Request and Nondriving Tasks on Taking-Over Control of Automated Vehicles," *IEEE Trans.*

Hum.-Mach. Syst. Hum.-Mach. Syst. IEEE Trans. IEEE Trans Hum.-Mach Syst, vol. 48, no. 6, pp. 582–591, Dec. 2018, doi: 10.1109/THMS.2018.2844251.

[14] B. Zou, Z. Xiao, and M. Liu, "Driving Behavior Recognition Based on EEG Data From a Driver Taking Over Experiment on a Simulated Autonomous Vehicle," *J. Phys. Conf. Ser.*, vol. 1550, p. 042046, May 2020, doi: 10.1088/1742-6596/1550/4/042046.

[15] J. Lee and J. H. Yang, "Analysis of Driver's EEG Given Take-Over Alarm in SAE Level 3 Automated Driving in a Simulated Environment," *Int. J. Automot. Technol.*, vol. 21, no. 3, pp. 719–728, Jun. 2020, doi: 10.1007/s12239-020-0070-3.

[16] B. Wandtner, N. Schömig, and G. Schmidt, "Secondary task engagement and disengagement in the context of highly automated driving," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 58, pp. 253–263, Oct. 2018, doi: 10.1016/j.trf.2018.06.001.

[17] K. Zeeb, A. Buchner, and M. Schrauf, "Is take-over time all that matters? The impact of visual-cognitive load on driver take-over quality after conditionally automated driving," *Accid. Anal. Prev.*, vol. 92, pp. 230–239, Jul. 2016, doi: 10.1016/j.aap.2016.04.002.

[18] V. V. Dixit, S. Chand, and D. J. Nair, "Autonomous Vehicles: Disengagements, Accidents and Reaction Times," *PLoS ONE*, vol. 11, no. 12, pp. 1–14, Dec. 2016, doi: 10.1371/journal.pone.0168054.

[19] "The 6 Levels of Vehicle Autonomy Explained | Synopsys Automotive." https://www.synopsys.com/automotive/autonomous-driving-levels.html (accessed Apr. 27, 2021).

[20] R. M s, A. S. S, R. Buyya, V. K r, S. S. Iyengar, and L. M. Patnaik, "Dynamic Management of Traffic Signals through Social IoT," *Procedia Comput. Sci.*, vol. 171, pp. 1908–1916, Jan. 2020, doi: 10.1016/j.procs.2020.04.204.

[21] A. Arslanyilmaz, S. A. Matouq, and D. V. Doner, "Driver Readiness in Autonomous Vehicle Take-Overs," *Int. J. Transp. Veh. Eng.*, vol. 14, no. 8, pp. 558–563, Jul. 2020, Accessed: Apr. 13, 2021. [Online]. Available: https://publications.waset.org/10011354/driver-readiness-in-autonomous-vehicle-take-overs.

[22] C. M. Tyng, H. U. Amin, M. N. M. Saad, and A. S. Malik, "The Influences of Emotion on Learning and Memory," *Front. Psychol.*, vol. 8, Aug. 2017, doi: 10.3389/fpsyg.2017.01454.

[23] N. Merat, A. H. Jamson, F. C. H. Lai, and O. Carsten, "Highly automated driving, secondary task performance, and driver state," *Hum. Factors*, vol. 54, no. 5, pp. 762–771, Oct. 2012, doi: 10.1177/0018720812442087.

[24] N. Merat, A. H. Jamson, F. C. H. Lai, M. Daly, and O. M. J. Carsten, "Transition to manual: Driver behaviour when resuming control from a highly automated vehicle," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 27, no. Part B, pp. 274–282, Nov. 2014, doi: 10.1016/j.trf.2014.09.005.

[25] O. Carsten, F. C. H. Lai, Y. Barnard, A. H. Jamson, and N. Merat, "Control task substitution in semiautomated driving: Does it matter what aspects are automated?," *Hum. Factors*, vol. 54, no. 5, pp. 747–761, Oct. 2012, doi: 10.1177/0018720812460246.

[26] M. Cunningham and M. Regan, “Autonomous Vehicles: Human Factors Issues and Future Research,” Sep. 2015.
[27] R. Fernandez and R. W. Picard, “Modeling drivers’ speech under stress,” *Speech Commun.*, vol. 40, no. 1–2, pp. 145–159, Apr. 2003, doi: 10.1016/S0167-6393(02)00080-8.
[28] K. Ihme, C. Dömeland, M. Jipp, and M. Freese, “Frustration in the face of the driver: A simulator study on facial muscle activity during frustrated driving,” *Interact. Stud.*, vol. 19, no. 3, pp. 488–499, Sep. 2018, doi: 10.1075/is.17005.ihm.
[29] J. Radlmayr, C. Gold, L. Lorenz, M. Farid, and K. Bengler, “How Traffic Situations and Non-Driving Related Tasks Affect the Take-Over Quality in Highly Automated Driving,” *Proc. Hum. Factors Ergon. Soc. Annu. Meet.*, vol. 58, no. 1, pp. 2063–2067, Sep. 2014.
[30] D. Choi, T. Sato, T. Ando, T. Abe, M. Akamatsu, and S. Kitazaki, “Effects of cognitive and visual loads on driving performance after take-over request (TOR) in automated driving,” *Appl. Ergon.*, vol. 85, May 2020, doi: 10.1016/j.apergo.2020.103074.
[31] J. Becker, M.-B. A. Colas, S. Nordbruch, and M. Fausten, “Bosch’s Vision and Roadmap Toward Fully Autonomous Driving,” in *Road Vehicle Automation*, G. Meyer and S. Beiker, Eds. Cham: Springer International Publishing, 2014, pp. 49–59.
[32] G. Prabhakar, A. Mukhopadhyay, L. Murthy, M. Modiksha, D. Sachin, and P. Biswas, “Cognitive load estimation using ocular parameters in automotive,” *Transp. Eng.*, vol. 2, p. 100008, Dec. 2020, doi: 10.1016/j.treng.2020.100008.
[33] A.-C. Hensch *et al.*, “Effects of secondary tasks and display position on glance behavior during partially automated driving,” *Transp. Res. Part F Psychol. Behav.*, vol. 68, pp. 23–32, Jan. 2020, doi: 10.1016/j.trf.2019.11.014.
[34] C. Gold, M. Körber, D. Lechner, and K. Bengler, “Taking over control from highly automated vehicles in complex traffic situations: The role of traffic density,” *Hum. Factors*, vol. 58, no. 4, pp. 642–652, Jun. 2016, doi: 10.1177/0018720816634226.
[35] S. Mattes and A. Hallen, *Surrogate Distraction Measurement Techniques: The Lane Change Test*. 2009.
[36] J. Beller, M. Heesen, and M. Vollrath, “Improving the Driver-Automation Interaction: An Approach Using Automation Uncertainty,” *HUMAN FACTORS - NEW YORK THEN SANTA MONICA*-, no. 6, SAGE, United States, p. 1130, 2013.
[37] C. Gold, D. Damböck, L. Lorenz, and K. Bengler, “‘Take over!’ How long does it take to get the driver back into the loop?,” *Proc. Hum. Factors Ergon. Soc. Annu. Meet.*, vol. 57, no. 1, pp. 1938–1942, Sep. 2013.
[38] P. Kerschbaum, L. Lorenz, and K. Bengler, “Highly Automated Driving With a Decoupled Steering Wheel,” 2014, p. 1686.
[39] H. Boril, S. O. Sadjadi, T. Kleinschmidt, and J. H. L. Hansen, “Analysis and Detection of Cognitive Load and Frustration in Drivers’ Speech,” p. 5.
[40] A. Martí-Belda, J. C. Pastor, L. Montoro, P. Bosó, and J. Roca, “Persistent Traffic Offenders: Alcohol Consumption and Personality as Predictors of Driving Disqualification,” *Eur. J. Psychol. Appl. Leg. Context*, vol. 11, no. 2, pp. 81–92, Jul. 2019, doi: 10.5093/ejpalc2019a3.

[41] C. Han, X. Sun, Y. Yang, Y. Che, and Y. Qin, "Brain Complex Network Characteristic Analysis of Fatigue during Simulated Driving Based on Electroencephalogram Signals," *Entropy*, vol. 21, no. 4, pp. 353–353, Apr. 2019, doi: 10.3390/e21040353.

[42] SangWoo Hahm and Hyungwoo Park, "Drowsiness Driving Prevention System using Bone Conduction Device," *KSII Trans. Internet Inf. Syst.*, vol. 13, no. 9, pp. 4518–4540, Sep. 2019, doi: 10.3837/tiis.2019.09.011.

[43] J. L. Deffenbacher, R. S. Lynch, L. B. Filetti, E. R. Dahlen, and E. R. Oetting, "Anger, aggression, risky behavior, and crash-related outcomes in three groups of drivers.," *Behav. Res. Ther.*, 2003, doi: 10.1016/S0005-7967(02)00014-1.

[44] J. L. Deffenbacher, R. S. Lynch, E. R. Oetting, and R. C. Swaim, "The Driving Anger Expression Inventory: a measure of how people express their anger on the road," *Behav. Res. Ther.*, vol. 40, no. 6, pp. 717–737, Jun. 2002, doi: 10.1016/S0005-7967(01)00063-8.

[45] E. Portouli, E. Bekiaris, V. Papakostopoulos, and N. Maglaveras, "On-road experiment for collecting driving behavioural data of sleepy drivers," *Fahrversuch Zum Erfassen Von Verhal. Bei Schläfrigen Fahrzeugführern*, vol. 11, no. 4, pp. 259–267, Nov. 2007, doi: 10.1007/s11818-007-0319-3.

[46] C.-T. Lin, L.-W. Ko, and T.-K. Shen, "Computational intelligent brain computer interaction and its applications on driving cognition," *IEEE Comput. Intell. Mag.*, vol. 4, no. 4, pp. 32–46, Nov. 2009, doi: 10.1109/MCI.2009.934559.

[47] T.-Y. Kim, H. Ko, and S.-H. Kim, "Data Analysis for Emotion Classification Based on Bio-Information in Self-Driving Vehicles," *J. Adv. Transp.*, pp. 1–12, Jan. 2020, doi: 10.1155/2020/8167295.

[48] M. A. S. Boksem, T. F. Meijman, and M. M. Lorist, "Effects of mental fatigue on attention: An ERP study," *Cogn. Brain Res.*, vol. 25, no. 1, pp. 107–116, Sep. 2005, doi: 10.1016/j.cogbrainres.2005.04.011.

[49] Marvin. McCallum, J. L. Brown, C. M. Richard, J. L. Campbell, Battelle Center for Human Performance and Safety., and United States. National Highway Traffic Safety Administration., "Crash warning system interfaces," 2007.

[50] S. Lemonnier, R. Brémond, and T. Baccino, "Gaze behavior when approaching an intersection: Dwell time distribution and comparison with a quantitative prediction," *Transp. Res. Part F Psychol. Behav.*, vol. 35, pp. 60–74, Nov. 2015, doi: 10.1016/j.trf.2015.10.015.

[51] A. L. Matouq and S. M, "Investigating the Impact of Buffer Time on Driving Behavior in Autonomous Intersections," Youngstown State University, 2020.

[52] "EMOTIV EPOC+ 14-Channel Wireless EEG Headset," *EMOTIV*. https://www.emotiv.com/epoc/ (accessed Mar. 05, 2020).

[53] T. Harrison, "The Emotiv mind: Investigating the accuracy of the Emotiv EPOC in identifying emotions and its use in an Intelligent Tutoring System," p. 59.

[54] S. Petermeijer, P. Bazilinskyy, K. Bengler, and J. de Winter, "Take-over again: Investigating multimodal and directional TORs to get the driver back into the loop," *Appl. Ergon.*, vol. 62, pp. 204–215, Jul. 2017, doi: 10.1016/j.apergo.2017.02.023.

[55] M. Kuehn, T. Vogelpohl, and M. Vollrath, "Takeover Times in Highly Automated Driving (Level 3)," *undefined*, 2017. /paper/Takeover-Times-in-Highly-

Automated-Driving-(Level-Kuehn-Vogelpohl/cf2e0a6d63d3425f2f86e7138f20cf5fa0c30682 (accessed Nov. 30, 2020).

[56] F. Naujoks, C. Mai, and A. Neukum, "The Effect of Urgency of Take-Over Requests During Highly Automated Driving Under Distraction Conditions," Jul. 2014, vol. 7.