Passenger Anxiety About Virtual Driver Awareness During a Trip with a Virtual Autonomous Vehicle

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Abstract. A virtual reality study concerning participants' anxiety levels when immersed in a virtual reality interaction with an autonomous vehicle was conducted. Five conditions were tested. The examined conditions are based on awareness of the virtual character (driver). During the external awareness conditions the virtual character either focuses on the road traffic or does not. During the internal awareness conditions the virtual character either pays attention to the car or not. For the fifth condition, the virtual character is completely unaware; since a head-mounted display (HMD) was placed on his face. Results, implications, and limitations are discussed.

Keywords: Virtual reality · Virtual driver awareness · Autonomous vehicle · Cognitive anxiety · Somatic anxiety · Car passenger

1 Introduction

An autonomous vehicle, which is also known as a self-driving car, is capable of sensing the environment and the nearby obstacles in order to navigate itself without the need of a driver (i.e., human input) [33]. Autonomous vehicles enable hands-off-wheel and foot-off-pedal operation [2], and there is no need for the driver to fully focus on the internal operations of the car or on the external road traffic. Autonomous vehicles are becoming increasingly popular [32] and according to Calvert et al. [3], the production of autonomous vehicles will start to increase significantly from 2020. To make this happen, car manufacturing companies are trying to incorporate intelligent technologies to the cars to allow them to more precisely navigate autonomously without causing any issues to other cars, pedestrians, and of course the passengers [22]. To achieve this, a variety of techniques and hardware are combined [14].

Even if car manufacturing companies try to improve the reliability of the autonomous vehicle, many drivers and passengers remain skeptical about this new technology [15]. The car manufacturing companies need to gain consumer

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trust [35]. Therefore, it is imperative that both the transportation organizations and the car manufacturing companies understand the way car users (both drivers and passengers) interact with such cars. Measurements of anxiety and comfort levels along with passenger trust when the car is involved in difficult situations (e.g., a possible collision with another car) should be explored. In addition, the development of rules regarding driving behavior/habits of the autonomous vehicle should be refined in such a way that the behavior assigned to the car can accommodate the behavior of the passenger. Thus, considering that a human might become anxious when seated in an autonomous vehicle, a virtual reality (VR) study was conducted to explore this assumption by testing five conditions (see Fig. 1).

Fig. 1. The five conditions developed for this study concerning internal and external awareness of the driver.

2 Related Work

Research on interaction with autonomous vehicles is usually performed in simulators [20,23]. In such cases, VR technology is used to immerse participants into virtual environments and driving conditions that seem real. A number of studies have been conducted in the past with a variety of purposes such as the usability evaluation [28] of driving simulators, the physiological responses of participants when immersed in car simulators [7], and the differences between real and virtual driving experiences [25].

Concerning the interaction with autonomous vehicles in VR, the current research is mainly focused on the training process of the driver [31], the take-over control [10,11,30], the evaluation of driver reaction in critical situations [12], and the design of interfaces [5] that would allow the driver or pedestrians to more precisely interact with such cars [27]. It should be noted that most of the current research aims to evaluate the behavior of the drivers [23] and their cognition [16] during the take-over control process from car to driver.

Besides the plethora of studies aiming at trying to understand the way drivers interact with the autonomous vehicles, only limited research on the passengers of such cars has been conducted, despite the fact that such a study could provide important insight [21]. The internal environment of a car can be modified in such a way that the passenger can effectively support the driver [24]. Entertainment and multimedia systems can be developed to entertain the passengers without disturbing the driver. Finally, given the growth of autonomous vehicles, soon all people accommodated in the car will be considered passengers. Therefore, any information regarding the passengers and the way they interact with the car is useful in making autonomous vehicles more comfortable for everyone.

In most cases, studies that are concerned with car passengers usually focus on the way that the passenger can be an assistant to the driver [4]. On the other hand, design decisions can be made when conducting studies with passengers. Specifically, Wilfinger et al. [36] found that when designing UIs for the rear seat, it is important to focus on passenger experience. When car designers start taking into consideration passenger experience, they can then deploy the appropriate interface solutions. Meschtscherjakov et al. [24] conducted five research activities that explore the experience of passengers and argues that improving user experience in cars can best be done if all occupants are taken into account, including passengers. Finally, the ride comfort of passengers was investigated by Elbanhawi et al. [8].

As far as we are aware of, studies that examine the behavior of passengers when seated at the co-pilot seat in an autonomous vehicle have not been conducted yet. Therefore, the current study aims to understand how the behavior of VR car passengers' alternates when observing different behaviors of the driver.

3 Methodology and Implementation

3.1 Participants

All of the participants are students (both undergraduate and graduate) recruited by e-mail, in-class announcements, and posters placed in the department and the student center. All participants received a €5 voucher. In total, 82 people came to the lab in which the study was conducted but only 75 were able to fully complete the study ($M = 22.98$, $SD = 3.19$). Five of the participants that did not follow though the study expressed that they did not expect it would take so long. The other two participants expressed that they did not feel any difference in the conditions, and that they preferred to terminate the study early.

3.2 Conditions of the Study

Five conditions were developed for this study (see Fig. 1). The *Internal-External Awareness* (*IEA*) condition denotes the full awareness of the virtual character. The virtual character's hands hold the steering wheel and the virtual character's gaze is focused on the road traffic, which suggests that the virtual character pays attention to the internal and external parameters that influence the way the autonomous vehicle behaves, and the virtual character is ready to react if necessary, even if it is not the one driving the autonomous vehicle. The reason for placing the virtual character's hands on the steering wheel is based on Tesla's instructions that drivers should never take their hands off the steering wheel, even in autopilot mode [6].

The second and third condition denote partial awareness of the virtual character. In *Internal-No External Awareness* (*INEA*) condition, the virtual character is internally aware of the car i.e., the virtual character holds the steering wheel with his hands, but his gaze is not focused on the road; instead it is focused on the buildings and the pedestrians. In *No Internal-External Awareness* (*NIEA*) condition, the virtual character is externally aware since his gaze focuses on the road traffic. However, the virtual character taps his legs with his hands to the rhythm of a background radio song, which makes him unaware of the internal behavior of the car. Based on the second and third condition, it can be said that since the virtual character is not fully aware of the car and the road traffic, it might take longer to gain control of the car if an emergency arises; therefore, participants might feel more anxious.

In the *No Internal-No External Awareness* (*NINEA*) condition, the virtual character was designed to be both internally and externally unaware of the car and road traffic. In this condition, the gaze of the virtual character focuses again on the buildings and the pedestrians and the hands tap his legs following the rhythm of the background song. In the *Completely Unaware* (*CU*) condition, which is the last one developed for this study, the virtual character is also fully unaware. In this condition, the hands of the virtual character tap his legs, and the virtual character wears an HMD to entertain himself. It should be noted that there are cases of autonomous vehicle manufacturers providing modern entertainment systems and HMDs to entertain passengers and drivers during travel [9]. Though the fifth condition seems extreme, it is a potential reality in the near future. Based on the fourth and fifth conditions, it can be said that since the virtual character is not aware of the car or the road traffic, the virtual character might not be able to gain control of the car in an emergency; therefore, participants are likely to have the highest levels of anxiety.

We considered adding one more condition in which no virtual character is in the car, but we realized that the absence of a driver might provide different findings from the ones we were trying to investigate in this study, i.e., the anxiety of participants based on virtual character awareness. Therefore, we are planning to perform an additional study that will investigate the behavior of participants when they are seated as passengers in an autonomous vehicle with no virtual character seated next to them.

3.3 Study

The participants came in our lab and the research team informed them that they would be seated as passengers in a VR autonomous vehicle. They were also informed that they would be exposed to five conditions and that each condition would last four minutes. After the car reached its final position in the virtual environment the condition that was being examined would change, and the system would be ready to proceed with the next stage of the study.

Participants were told that they would have short breaks between the conditions. During the breaks, they would be asked to take off the HMD and respond to a number of questions in a computer-based questionnaire. It was mentioned that the research team would be there to assist them and control (start and stop) the VR application; however, unless a need arose, there would be no further communication throughout the study. The research team would inform the participants when the study was complete and would inform them they were free to leave and terminate the study at any time.

The order of the five conditions (see Sect. 3.2) was randomized for each participant. Before the beginning of the study participants were asked to provide written consent. This study was granted approval by the IRB of the Anonymous University. Figure 2 illustrates the study setup.

Fig. 2. A participant observing the VR scenario in the lab space in which the study was conducted.

3.4 Questionnaires

Two questionnaires were used in this study. The first asks questions related to their presence and is based on the SUS [29] questionnaire. The questionnaire on presence was used only once for each participant at the end of the first condition to which they were exposed. This part of the study had a between-group design with $N = 15$ participants in each group (condition of the study). The altered version [18] of the Anxiety Modality Questionnaire [34] was also used in this study. In both questionnaires, a seven-point Likert scale was used to capture the participants' responses. The Anxiety Modality Questionnaire initially was proposed with a five-point scale; however, a seven-point scale was used to make both questionnaires have the same anchors and avoid unwanted participant confusion.

3.5 Application and Equipment

The application was developed in Unity3D game engine. For the VR part of it, the Oculus Rift HMD and its associated SDK was used. Five scenes in Unity3D were developed, one for each condition. The virtual environment in which the driving simulation takes place was designed in Autodesk 3ds Max. All characters (pedestrians, driver, and self-avatar) used in this study were designed using Adobe's Fuse software.

The virtual character placed in the driver seat was assigned a simple idle animation and the FinalIK was used to make the hands of the virtual character move according to the rotation of the steering wheel. The hands of the virtual character were attached to the steering wheel only during the first and second conditions. For the gaze of the virtual character, the `LookAt` functionality of Unity3D was used to make the virtual character's head always focus on the buildings and pedestrians. To make the virtual character look realistic, the target positions were switched between the buildings and pedestrians, and the head of the driver was animated using the spherical linear interpolation (`Slerp`) function.

The rest of the animations used for the study were captured using a motion capture system. For the hand tapping animation of the driver character, a simple motion was captured in our motion capture lab and looped throughout the VR scenario. The hand tap animation was captured while the background song was playing. Synchronization between the song and hand tapping motion was performed afterwards manually. Thus, during the VR scenario the hand tapping motion was following the rhythm of the song. The pedestrians in the virtual environment were assigned a simple walking motion and a path finding method to make them move to different target positions. Additional pedestrians were assigned to reach the opposite sidewalk when traffic indicators forced the autonomous vehicle to stop. Finally, the virtual car was also pre-scripted to stop at a road crossing sign to allow pedestrians cross the road. Figure 3 shows the first-person view the participants had of the scene.

4 Results

For the questionnaire on presence, a between-group analysis of variance (ANOVA) was used because each participant was asked to respond to it once. It should be noted that an equal number of participants ($N = 15$) answered this questionnaire for each condition of the study. For the anxiety modality questionnaire one-way repeated-measures ANOVA was used. The post-hoc comparisons were performed using Bonferroni corrected estimates. The obtained results are shown in Fig. 4.

4.1 Presence

The effect of the participants' presence on the developed conditions of virtual character's awareness were examined. Based on the obtained results, we found

Fig. 3. First-person view of the VR scenario with an autonomous vehicle, during the *NINEA* condition. Car stopped to allow pedestrians to cross the road.

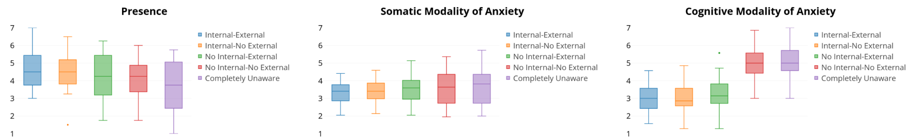

Fig. 4. The results on presence and anxiety (both somatic and cognitive) obtained from this study.

that there was not a significant effect across the five conditions of the study [$F(4, 70) = 0.92$, $p = 0.45$]. This means that for each of the five developed conditions, participants felt the same level of presence. Considering the mean values that participants assigned to presence, it can be said that this finding indicates that the developed scenario and VR application captivated the participants and made them feel part of the VR experience.

4.2 Anxiety

No significant effects were found regarding somatic anxiety [$\Lambda = 0.89$, $F(4, 71) = 2.07$, $p = 0.09$, $\eta_p^2 = 0.11$]. These were not the expected results; therefore, they need to be discussed. However, significant results were found when examining the cognitive anxiety [$\Lambda = 0.12$, $F(4, 71) = 127.39$, $p < 0.01$, $\eta_p^2 = 0.88$]. Post-hoc comparisons indicated that the *IEA* ($M = 2.98$, $SD = 0.73$), *INEA* ($M = 3.06$, $SD = 0.75$), and the *NIEA* ($M = 3.31$, $SD = 0.95$) were significantly lower than the *NINEA* ($M = 4.98$, $SD = 0.81$), and *CU* ($M = 5.08$, $SD = 1.84$) conditions. We partially expected these results. More specifically, we expected differences between the *IEA* and the partial awareness conditions in which the virtual character is not aware of the road traffic or the behavior of the car (*INEA* and *NIEA*). We also expected to find differences between the *NINEA* and *CU* conditions since in the latter condition, the virtual character is fully blind, does not know what might cause an unexpected event, and needs to perform an additional action with his hands to remove the HMD before taking the control of the car. Based on the cognitive anxiety, it can be said that the developed stimuli altered the behavior of participants, which means that participants are sensitive to the awareness of a virtual character when in a VR autonomous vehicle.

5 Discussion

Concerning participants' presence, the results from the analysis indicated that there is no difference in the five developed conditions. This result indicates that all participants felt that they were part of the VR scenario. Additionally, this result indicates that the way that the virtual character reacted did not influence their sense of being part of the virtual environment. The initial assumption was that when the virtual character is fully unaware of the road traffic and the behavior of the car, the participants might feel less present since this is an imaginary experience that contradicts prior knowledge of the way that a virtual character interacts with a car.

Based on the results that concern the somatic anxiety of participants, it can be said that regardless of the awareness of the virtual character, participant anxiety did not change at all, and it remained low. This result indicates that neither the VR technology used nor the developed stimulus had any influence on the somatic anxiety of participants. Specifically, the study was conducted by using a commodity VR headset and during the study participants sat in a desk chair, so no tactile feedback was given to them. The participants were aware of the way they experience the VR stimulus, so their somatic modality of anxiety did not respond as expected. A possible interpretation is that participants were not somatically present, which might have been a result of the low-cost VR setup that was used in this study.

Regarding the developed stimulus, it can be said that a rational/neutral driving condition was used. It seems that this behavior assigned to the autonomous vehicle, did not cause the participants any anxiety, so their responses were not influenced across the five conditions of the study. In case the stimulus was responsible for not causing any change in the participant's somatic anxiety, it can be said that this finding is in line with previous studies that examine the effects of neutral (in terms of speed) stimulus on user behavior [1]. However, to validate this assumption we would like to capture the physiological responses of participants in future studies.

The results concerns the cognitive part of participants' anxiety shown that participants' anxiety affected according to the observed awareness of the virtual character. Specifically, lower levels of anxiety were captured for the *IEA* and the partial awareness conditions (*INEA* and *NIEA*) compared to the condition (*NINEA* and *CU*) in which the virtual character is unaware of both the road traffic and the behavior of the car. It is worth mentioning that our study was limited by our focus on the behavior of the virtual character rather than the behavior of the car itself. In the current study, we made an implicit assumption that passengers would be more anxious about the virtual characters' behavior than the car's behavior. However, in Level-5 autonomous vehicles, one major issue is to make the virtual characters, passengers, and pedestrians confident in the behavior of the car.

Additionally, the driver was a virtual character with whom there was no interaction at all. According to discussions we had with a number of participants after the study, since there was no actual interaction with the virtual character, they felt that the virtual character was not highly realistic. Participants indicated that they were able to perceive occasional movements—as assigned by motion sequences—in the upper body of the virtual character. However, participants suggested that a virtual character who initiated a conversation by asking simple questions might enhance the realism of the developed VR scenarios.

In this study, the participant was seated as a passenger in an autonomous vehicle that moves in a virtual world. It is common that such VR scenarios can produce motion sickness to the participants [13]. This study did not consider thoroughly exploring the motion sickness of participants. Therefore, considering that severe motion sickness can possibly influence the study results, providing Simulator Sickness Questionnaire (SSQ) [17] may also help us understand what symptoms the subjects felt in the studies as well as how the obtained results altered by the motion sickness of participants.

6 Conclusions and Future Work

As the popularity of autonomous vehicles daily increases, the need to understand the way that passengers interact with them does also. To do so, user studies that place participants as passengers and ask them to interact with autonomous vehicles should be conducted. However, conducting such studies involves challenges that can be found in public roads and might compromise the safety of the participants. To avoid these issues, one possible solution is the use of expensive simulators. However, these simulators can be found only in a limited number of research centers and labs. Therefore, a possible alternative solution is the use of modern VR technologies that are cheaper than driving simulators and allow researchers to immerse participants in more sophisticated VR scenarios.

Understanding how passengers' behavior changes in different self-driving conditions is important to developing frameworks and regulations concerning the comfort of passengers [19]. However, there is a need to further investigate the behavior of passengers in autonomous vehicles, and many possible studies can be conducted to understand passenger behavior. For this reason, we plan to conduct additional studies. Among them we would like to examine participant anxiety based on different driving habits [18] instead of only developing a single neutral/rational driving habit that was assigned to the autonomous vehicle. Another interesting investigation is related to the sitting position of the passenger inside the car. In the current study, the participants were placed as passengers in the front seat. Investigating the behavioral changes of passengers that are placed in the back seat of the car would be also interesting and we plan to do so in the near future. Moreover, investigating the emotional reactivity [26] of passengers is another direction we are willing to explore.

In conclusion, the use of VR seems necessary for cases in which the real situation either would be too dangerous or not feasibly testable, given the current state of technology and legislation. However, more studies are needed to further understand the use of low-cost VR setups for conducting such studies. Finding the minimal feedback necessary to enhance the somatic and cognitive presence of participants, as well as to capture the anxiety or even mental disorders of the participants while experiencing VR scenarios, is essential for the use of VR as an efficient tool for understanding human behavior.

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