The Effects of Driving Habits on Virtual Reality Car Passenger Anxiety

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Abstract. We developed an experiment to assess the anxiety of participants when asked to take a tour as passengers in a virtual reality car. For our study, five conditions were developed, based on driving habits (rational, speedy, slow, nervous, and distracted) and participants were exposed to two different virtual environments (urban and rural environments). The driving habits were applied to both the virtual driver and the car. During the experiment, participants were asked to wear the necessary virtual reality equipment and also to respond to a number of questions that concern the somatic and cognitive modality of anxiety. By analyzing the collected data, it was found that the participants' somatic anxiety did not differ significantly across the five driving habits in both virtual environments. Significant results concerning somatic anxiety were found only when comparing the distracted driving habit in the two different virtual environments. Contrarily, it was found that the participants' cognitive anxiety was significant across driving habits, but the levels of cognitive anxiety altered based on the environment to which they were exposed. Higher anxiety levels were found when participants were exposed to a crowded urban environment, when compared to a less crowded rural environment, especially for the speedy, nervous, and distracted driving habits. The obtained results are expected to provide insights when developing applications during which the users are seated as passengers in virtual reality cars. Limitations and future work directions are discussed.

Keywords: Virtual driver · Virtual trip · Somatic anxiety · Cognitive anxiety · Driving habits

1 Introduction

Interacting with cars is part of our daily routine, since we use them to move from one place to another. The use of a car can be characterized as active when we drive the car, or as passive when we are passengers in a car. A number of different

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aspects can influence the experience of passengers when interacting with cars and other transport-related services. According to Redman et al. [31], Schiefelbusch [33], and Stradling et al. [39], the passengers' anxiety, safety, and comfort have been identified as the most important factors when interacting with cars and are among the most important features of the car interaction experience.

According to the American Psychiatric Association [38], unwanted situations can lead to the arousal of anxiety accompanied with unpleasant feelings, which is a situation that we, as virtual reality developers, might not want to create for our users [25]. Examples include taking into account that when seated as passengers in a car, our anxiety might be altered due to the capabilities of the driver, especially when the habits of the driver do not match our personality or when the behaviors (driving habits) of other cars found on public roads induce insecurity. It is also known that virtual reality dominates our senses [18,30], and when we wear a head mounted display (HMD), we rely solely on the virtual information provided. An example of such a conflict, namely between the real world and the virtual reality experience, is the relationship between the passenger and the driving habit to which a user is exposed when in a virtual reality car. Given this, it can be said that when we are exposed to driving habits/conditions that deviate from what we consider as safe, our behavior might be altered, since we place ourselves in scenarios where we are aware of the contrast between what we see and what we know from real-world experiences.

As a result, considering that virtual reality users would like to feel comfortable when seated and immersed in virtual reality car scenarios, a study was conducted to investigate the anxiety, as psychological stress, of participants when being exposed to a number of different driving habits. Specifically, participant anxiety was based on a number of different situations that were defined as ambiguous, unpredictable, and difficult or impossible to manage [4]. This is true since each participant is simply placed in a car as a passenger and does not have the ability to control the car or the driving condition that it was assigned to.

Based on Fresco [16], self-reporting scales were used extensively in the past to measure a participant's level of anxiety when they were exposed to negative or uncontrolled stimuli. Thus, to measure the anxiety of participants, a questionnaire [43] that studies both the somatic and cognitive modality of anxiety was adopted and altered to match our experiment. We assumed that virtual reality studies which examine human-car interaction scenarios can be quite beneficial, since participants do not need to be exposed to real-life road traffic and driving habits. Thus, taking advantage of the recent development in virtual reality software and hardware, it is easy to simulate and control a number of driving conditions, while participants are also exposed to the same stimuli. This is quite important for virtual reality and psychological-related studies.

In order to investigate the anxiety levels of virtual reality car passengers, two different virtual environments (urban and rural) were designed for experimentation and five different driving habits (rational, speedy, slow, nervous, and distracted) were developed. Specifically, the first one is an urban environment

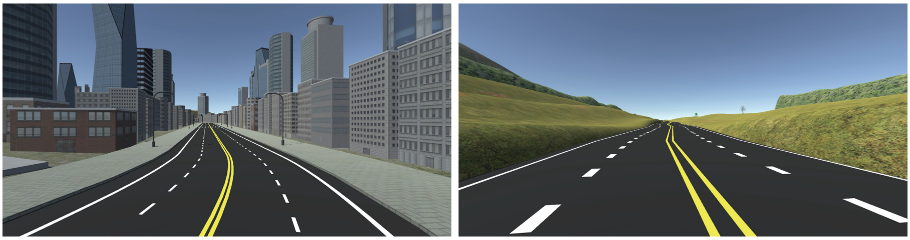

Fig. 1. The urban (left) and the rural (right) environments used for our study.

found in metropolitan cities and the second one is a less crowded rural environment (see Fig. 1). The driving habits that were simulated/developed (see Fig. 2) can be easily recognized when observing real-life driving patterns and are considered as common. More specifically, the following driving habits were broken into the following category of drivers:

– **Rational:** These can be acknowledged as the ideal drivers. They drive with appropriate speed, concentration and driving experience. They like to keep up with traffic, while maintaining a safe distance between cars.
– **Speedy:** Drivers who tend to exceed the speed limits. A common characteristic among these drivers is that the trip is taken with a sense of urgency. Such drivers often switch lanes quickly when they see an opportunity to go faster.
– **Slow:** There are cases where drivers believe that is always best to drive slowly. Driving slowly and carefully is appropriate in many situations, but not all slowness is necessary (e.g., especially on highways). Slow drivers can make passengers, or other car drivers, impatient and frustrated.
– **Nervous:** These drivers lack certainty in their driving capabilities and quite often become intimidated by the traffic and the high speeds of highways. In most cases they drive either at the specified speed limit or lower, without accelerating enough to merge safely with the traffic on highways. These drivers lack the ability to make split-second decisions when it comes to certain driving situations, such as when making a turn. Hesitation is a key characteristic of a nervous driver, along with panicking, which can in turn cause faulty or unsafe decisions on the road.
– **Distracted:** These drivers are mainly found interacting with a cell phone or chatting with other passengers. The distracted drivers forget to focus their attention on the road and, as a result, compromise the safety of their passengers and other motorists.

We assume that understanding the way that virtual reality participants perceive driving conditions would benefit the virtual reality community. The rationale behind our study is that an increasing number of virtual reality applications for entertainment, training, touristic and other purposes, place virtual reality users inside a car as passengers. Therefore, by studying the way that participant

Fig. 2. Example of the rational (left) and distracted (right) driving habit from the perspective of the passenger.

anxiety changes, based on the driving habits to which they are exposed, we can provide virtual reality developers with insight about the do's and don'ts they should take into account when developing such applications. The results would contribute to the development of virtual reality applications with which users would be able to comfortably interact, without suffering anxiety.

This paper is organized in the following sections. Related work on virtual reality and driving simulation is presented in Sect. 2. Section 3 covers the methodology and implementation details followed for the experiment. The results are presented in Sect. 4 and are discussed in Sect. 5. Finally, conclusions, limitations, and our plans for future work are presented in Sect. 6.

2 Related Work

In a car, besides the driver, a number of people (passengers) can be accommodated: in the case of a family/compact car, a small number of passengers can be carried, while in busses and other public transport services, a greater number of passengers can be transferred. Being seated in a car, either as driver or as passenger, is a complex activity, consisting of both psychological and physiological demands [3,24]. Among other psychological states, anxiety is identified as a reaction to potential future danger [2]. Anxiety can also be expressed as "a diffuse, objectless apprehension," chiefly, anticipatory [4]. People who experience anxiety are in a psychological state termed a "future-oriented mood." This state is related to the preparedness of people to interact with future uncontrollable or unpredictable situations [4]. This future-oriented state helps individuals handle future danger [36] while causing them at the same time emotional responses [37] and preparing them to encounter future danger, if necessary [9]. Thus, when being in a state of anxiety, the uncontrollability that people mainly experience, makes them think about all possible negative situations of future hazards, and therefore, people become anxious and ready for the worst-case scenario.

Until now, a number of studies that concern the psychological states of participants based on car driving scenarios have already been conducted. Examples, including the work of Dula and Geller [12], found that dangerous driving can be divided into subcategories including aggressive, risky, and emotional driving habits. Additional previously-conducted research [13] proposed that drivers with phobias tend to employ safer driving behaviors (e.g., slow, or nervous driving habits). However, our study is examining the general anxiety symptoms of virtual reality car passengers and not travel phobia specifically (nor any other type of specific anxiety disorder) that influence the behavior of the driver. Thus, considering that anxiety consumes cognitive resources [14,20], it was hypothesized that higher levels of anxiety would be mostly associated with an increased reporting of dangerous driving behaviors.

Virtual reality applications and studies that concern car driving have been developed and conducted in that respect. Since virtual reality experiments concerning participants are less risky, a great number of systems and software have developed in past decades that mimic real-world driving conditions and scenarios, while also providing the necessary tools for capturing the behavior of participants in a safe environment. Among them, driving simulators were developed to assess and understand car driving [40]. Such simulators have been used in a number of domains, including entertainment (games), engineering, medicine and psychology, and training. Examples of conducted studies include the validation studies conducted by Dols et al. [11], the analysis of the risk of older people driving when encountering motor vehicle crashes, conducted by Lee et al. [29], and finally, the use of driving simulators for clinical purposes, in order to either evaluate the sleepiness of drivers or to train drivers during a rehabilitation process after surgeries and stroke [1,8,17]. The Iowa Driving Simulator was developed by Cremer et al. [10], that deals with problems related to driving conditions and scene-generation for virtual reality car driving. A warning system for rear-end collisions was proposed by Bella et al. [6], to analyze the driver's behavior in order to define effective driver assistance systems, which can be readily accepted by the driver. Finally, Lang et al. [28], developed an optimization technique for generating personalized training programs that help drivers improve their driving habits.

Interestingly, researchers have also conducted experiments to understand how efficiently a driving simulator could be used and how close it is to real car driving. Thus, studies were also conducted that compared driving on a public road to driving through a simulator. Underwood et al. [42], conducted a study to understand hazard detection both when driving on a public road and when driving on a simulator. Speed comparisons were made by Godley et al. [19], and Bella et al. [5] in a variety of driving situations. They found that participants usually drove slightly faster through a driving simulator. Finally, the driving behaviors of participants in real and virtual tunnels were analyzed by Törnros et al. [41]. Based on the aforementioned studies, it can be concluded that driving simulators can be used for capturing and studying driving behaviors, since participants' driving behavior in simulators tend to be similar to the behavior they exhibit when driving in real road environment and conditions.

Besides the studies that have examined the physiological response of racing car drivers [22,23], there are no studies examining anxiety experienced when driving compact cars. Furthermore, apart from virtual reality studies concerning car drivers, limited research on passengers has been conducted, even though such studies could provide important insight not only for the virtual reality community, but also for the automotive industry [27]. For example, a vehicle can become more desirable and convenient by measuring the experience of passengers.

Considering that virtual reality passenger experiences have not been examined, a virtual reality study to assess the way that the anxiety (and consequently the comfort) of participants changes when being seated as a passenger in a virtual reality car, was conducted. The aims of this study were: (a) to examine the anxiety of participants on simulated driving habits, and (b) to examine whether the anxiety changed when participants were exposed to different types of environments. Moreover, studies that are related to car passenger anxiety in virtual reality, might provide insights to virtual reality developers and thus widen their view towards the psychological state of the user, including their safety and comfort. Therefore, applications developed in the future would enable users to experience, for example, virtual tours of remote cities, taken comfortably, as car passengers.

3 Method and Implementation Details

This section presents the background information of the developed experiment.

3.1 Participants

Before recruiting participants, we conducted an *a priori* power analysis to compute the required sample size using G*Power v3.1 [15] software. The calculation was based on one group with five repeated measures, a 95% power, a medium-effect size of 0.25 [7], a non-sphericity correction $\epsilon = 0.60$, and an $\alpha = 0.05$ were used. We determined the need for a minimum of 45 participants.

In this study, 45 college students took part. Of them, 32 were male (aged $M = 22.31$, $SD = 2.44$), and 13 were female (aged $M = 23.07$, $SD = 1.93$). Participants were recruited from in-class announcements, e-mails sent throughout the department, and posters placed in various locations in the department in which the experiment was conducted. All participants received extra credits.

3.2 Experiment Procedure

The virtual reality experiment was conducted in our lab space where the necessary equipment was installed. Once participants arrived, they were asked to complete a demographics section form, give written consent for taking part in the virtual reality experiment and also allowing us to use and analyze their responses. Participants were informed they were allowed to quit the experiment at any given point. In addition, participants were informed that the collected data will be used for the purpose of this project and after the project is published, the data will be destroyed/deleted. It should be noted that approval to conduct the experiment was granted by the Institutional Review Board (IRB) of the University of the Aegean.

Before the experiment started, the experimenter informed the participants about the general scope of the study. The conditions, including driver and car behavior, were not mentioned to the participants at all. Then, participants were asked to wear the HMD. Participants were seated in a desk chair the whole time during the experiment process. Figure 3 shows the experimental setup.

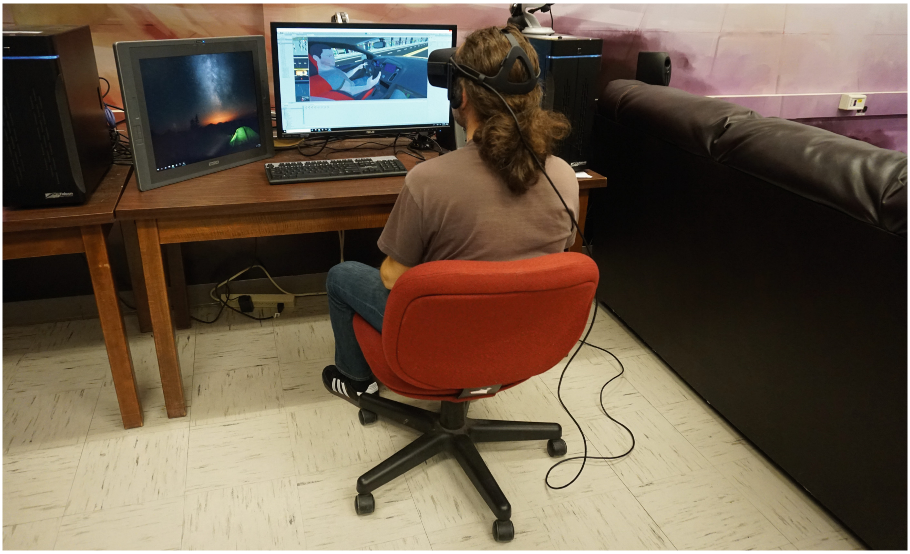

Fig. 3. A participant, during the experiment, observing the virtual reality stimulus in our lab space.

During the study, the experimenter was responsible for starting and stopping the condition (virtual reality application), as well as for providing instructions to the participants. We would also like to note that the developed conditions appeared in a randomized order. Each developed scene was pre-scripted to last for 3 min. Between the conditions of the experiment, a break was given to each participant. During that time, participants were asked to take off the HMD and answer the questionnaire by self-reporting their anxiety and presence. Questions were given to participants in a computer-based survey environment. Finally, it should be noted that the total duration of the experiment did not exceed 60 min.

3.3 Virtual Reality Application

A virtual reality application was developed to simulate: (a) the behavior of the virtual car, and (b) the behavior of the driver. Implementation details are provided in the next paragraphs.

For the rational condition, the driver was assumed to be concentrated and focused on road traffic. For that reason, a `LookAt` function (`transform.LookAt[target]`) was used to make driver's head always focus on the road. The car behavior was manipulated to never exceed the speed limits indicated on the side of the road and always keep a safe distance from the car in front of it. For the speedy condition, the virtual driver also concentrated on the road and traffic. However, the car behavior at all times exceeded the speed limit by 20 kph and was also pre-scripted to change lanes periodically. It should be noted that since we wanted to implement natural lane-change behavior, it was considered that the car should change lane randomly between 20 and 30 s.

For the slow condition, the driver was focused on the road and the traffic. Contrarily with the speedy condition, the car behavior was pre-scripted to move slower than the indicated speed limit by 20 kph. For the nervous condition, the virtual reality driver was programmed to stay focused on the road and traffic, and the car behavior was implemented to have variations in speed, ranging from the indicated speed limit to a 50% decrease. As before, since we wanted to develop a natural way that the speed limit would change, the speed values were computed randomly between 20 and 30 s. In addition, since nervous drivers do not decide fast enough, the inability of the driver to change lanes was implemented. Specifically, the driver turns the indicators on when there are no nearby cars, and after a short time period the driver decides to turn the indicators off and not change lanes. In addition, the head of the driver turns towards the target lane to ensure there are no cars approaching nearby.

The last developed condition is distracting. For this condition, a smartphone was attached to the right hand of the virtual driver and a `LookAt` functionality was implemented to make the driver's head periodically focus on the smartphone in a random order between 20 and 30 s, for 10 s. For the car behavior, it was decided that when the driver is distracted, the car should slightly increase its speed in order to closely approach the car in front of it.

Since we wanted to provide feedback to participants regarding the speed of the car, a digital speedometer was used to indicate the speed of the car at every time step. It should be noted that the speed limits, and the lane-changing behaviors adopted in our simulation, were empirically chosen by the authors of this paper. We understand that further investigation might be needed to study the impact that speed limits, lane changes and driver concentration have on the anxiety levels of participants.

To ensure that all participants would be exposed to the exact same stimuli, an initialization process of all the randomized parameters that were used in our simulation (lane change time, speed values, driver face `LookAt`, etc.), was applied. It was also believed that sound (car engine, car horn, etc.) relating to virtual content would enhance the participant's presence in our developed scenarios [21,32,34]. Therefore, the appropriate sound and sound effects (e.g., traffic sound, car engine, car horns, etc.) were also added to our scenarios. All sounds were controlled through the sound engine of Unity3D. The sound effects used in this implementation were downloaded from the freesound.org website, which is a collaborative sound database on which people from different disciplines share recorded sound clips under Creative Commons licenses.

The aforementioned developed conditions were studied in both an urban and rural environment. For both designed environments (urban and rural) a number of cars were also added to the scene, assigned with rational behavior and pre-scripted to a follow a predefined path. For the urban environment there were pedestrians on the pavements, moving in various directions (see Fig. 4). Pedestrians were generated and designed using the Adobe's Fuse. Their behavior and directions were randomly generated during the initialization for each condition of the experiment. It should be noted that the characters were pre-scripted to cross the road only when the road crossing light became green.

Fig. 4. The crowded by pedestrians and cars urban environment (left), and the less crowded by cars rural environment (right).

A human-like character was placed in the seat of the virtual driver and was assigned a simple idle animation and an inverse kinematics solution that attached its hands to the steering wheel. It should be noted that the steering wheel was animated by scripts to follow the path that the car follows, and the hands of the character followed the motion of the steering wheel, making the car look like it was controlled by the virtual driver. The path that the car should follow was pre-scripted for each condition and virtual environment. Similarly, the parameters of the scenes (e.g., traffic lights, car start-stop, etc.) were also pre-scripted. An additional virtual character that represents the user was placed to sit next to the virtual driver in the front seat of the car. A virtual camera was attached to the head of the self-avatar. This camera was used to provide visual feedback from the passenger perspective to participants. The self-avatar was chosen to be the same gender with the participant, and the adaptation of the gender was made based on the demographics questionnaire that participants had filled out once they entered the lab space in which the experiment was to be conducted. Figure 2 shows, from a first-person view, the way that participants were observing both the rational and the distracted condition of the virtual reality application.

For the implementation of the virtual reality application, the Unity3D game engine was used. The project was implemented in C# and a 3.4 GHz i7-6700 Processor Quad Core desktop with 16 GB of CPU memory, with a GeForce GTX 1060 GPU with 6 GB of memory. Finally, it should be noted that in total, ten scenes (five for each environment) were developed and used for this study.

3.4 Questionnaire

Two different questionnaires were used in this study. The first questionnaire (see Table 1) asks the participants questions related to their presence in the virtual environment. This one is based on the Slater-Usoh-Steed (SUS) [35] standard questionnaire of presence and was altered to fit the purposes of this experiment. To measure the anxiety of participants, the Anxiety Modality Questionnaire, developed by Van Gerwen et al. [43], was adopted and altered to match our experiment (passenger anxiety based on virtual reality driving habits). It should be noted that the questionnaire (see Table 2) included eighteen items and is divided into two parts. The first part includes eleven items that measured the somatic modality of anxiety and the second part included seven items that measured the cognitive modality of anxiety. A five-point scale was used, initially proposed by the authors of this questionnaire, with the following anchors of the scale: 1 stands for No Anxiety, 2 stands for Slight Anxiety, 3 stands for Moderate Anxiety, 4 stands for Considerable Anxiety, and finally 5 stands for Overwhelming Anxiety. However, to keep consistency with the 7-point scale used for the questionnaire on presence, the scale of the questionnaire on anxiety was altered so that 1 would indicate "Not at All," and 7 would indicate "Totally." For both questionnaires (presence and anxiety) used in the current study, a within-group design was used to allow participants to make direct comparisons among the different conditions of the experiment. It should be noted that the somatic and cognitive modality of anxiety questionnaires were treated separately in order to understand the individual impact of the virtual reality stimulus on the participant's anxiety.

Table 1. The altered questionnaire on presence that was used in this experiment.

Label	Question
PQ1	Please rate your sense of being in the virtual car. (1 indicates not at all, 7 indicates totally)
PQ2	To what extent were there times during the experience when the virtual trip with the car was reality for you? (1 indicates not at all, 7 indicates all the time)
PQ3	During the time of the experience, which was strongest on the whole; your sense of being in a virtual car or of being in the real world? (1 indicates being in the real world, 7 indicates being in the virtual car)
PQ4	During the time of the experience, did you often think to yourself that you were actually just sitting in a room wearing an HMD or did the virtual reality overwhelm you? (1 indicates sitting in a room, 7 indicates virtual reality overwhelm you)

Table 2. The Anxiety Modality Questionnaire that was altered to match the purpose of this study and used in this experiment. For all questions: 1 indicates not at all, and 7 indicates totally. The questionnaire includes eighteen items and is divided into two parts. The first part includes eleven items (AQ1–AQ11) that measure the somatic modality of anxiety, and the second part includes seven items (AQ12–AQ18) that measure the cognitive modality of anxiety.

Label	Question
AQ1	I felt I was short of breath
AQ2	I felt dizzy or I had the feeling that I was going to faint
AQ3	I had the feeling that I was going to choke
AQ4	I thought that I would faint from fear
AQ5	The tension made me clumsy and things fell out of my hands
AQ6	I noticed numbness in my limbs
AQ7	I felt pain in the region of my chest
AQ8	I felt palpitations of the heart or a quicker heartbeat
AQ9	I felt suddenly warm or cold
AQ10	My limbs were tense and cramped, so I felt the urge to move or walk
AQ11	I had a dry mouth
AQ12	I thought the particular car I was in would crash
AQ13	I paid attention to every sound or movement of the car and wondered whether everything was ok
AQ14	I continuously paid attention to the face and behavior of the driver
AQ15	The idea that something would go wrong was constantly on my mind
AQ16	I couldn't concentrate because I was preoccupied with thoughts of horrible car crash situations
AQ17	I had a fear of dying
AQ18	I couldn't tell what was going to happen and that made me feel very anxious

4 Results

In this section, we present the results obtained from the conducted user study. To analyze our data, we used a one-way repeated-measures analysis of variance (ANOVA), with Greenhouse-Geisser corrected estimates of sphericity (if necessary), using the five developed conditions as our independent variable, and using the results obtained from the questionnaires (presence and anxiety) as our dependent variables. Paired-samples t-tests were also used to assess the impact of the virtual environment that participants exhibited. Specifically, each driving habit (rational, speedy, slow, nervous, and distracted) for each of the two environments (urban and rural) was used as our independent variable and the results obtained from the questionnaires were used as our dependent variables (e.g., rational driving habit in urban environment versus rational driving habit in rural environment).

4.1 Presence

We compared the effects of the presence across the five developed conditions for both virtual environments that participants experienced. Based on the obtained results (see Fig. 5), we found that the driving habits did not have a significant effect on participants' level of presence for either the urban [$F(4, 41) = 1.43$, $p = 0.25$, $\eta_p^2 = 0.16$] or rural [$F(4, 41) = 0.71$, $p = 0.59$, $\eta_p^2 = 0.09$] environment.

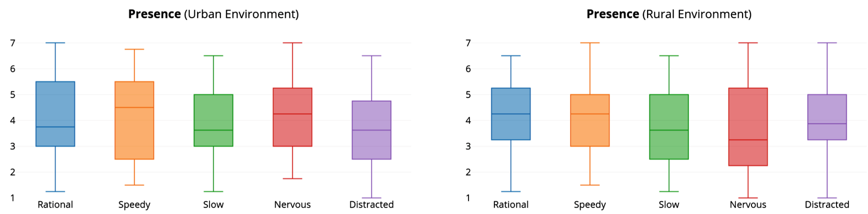

Fig. 5. Participant's presence in both designed environments (urban and rural).

Additionally, to further understand the presence of participants, the two virtual environments were used as independent variables, and the composite scores from the five driving habits were used as dependent variables. We decided to use the composite scores, since we wanted to understand in a general way, the impact of the virtual environment on participants' presence (presence in urban versus presence in rural environment). A paired-samples t-test was conducted to compare participants' presence in urban and rural environments. According to the obtained results, there was not a significant difference in the scores for urban ($M = 3.98$, $SD = 0.66$) and rural ($M = 3.89$, $SD = 0.78$) environments; $t(44) = 0.39$, $p = 0.70$. Taken together, these results indicate that no matter the environment and the driving habits to which the participants were exposed, their levels of presence were the same.

4.2 Driving Habits in Urban Environment

A crowded urban environment was designed to examine the anxiety levels of participants when being exposed to different driving habits. The obtained results (see Fig. 6) indicate that there was no significant effect for the five conditions of the experiment, when examining the somatic modality of anxiety [$F(4, 41) = 3.17$, $p = 0.27$, $\eta_p^2 = 0.29$]. This was not an expected result and needs to be discussed. Contrarily, when examining the cognitive modality of anxiety, significant results were obtained [$F(4, 41) = 52.75$, $p < 0.01$, $\eta_p^2 = 0.88$]. Post-hoc comparisons for the cognitive modality of anxiety indicated that the mean score for the rational ($M = 3.66$, $SD = 0.86$) and the slow ($M = 3.89$, $SD = 0.72$) driving habits, were significantly lower ($p < 0.05$) than were the speedy ($M = 5.57$, $SD = 1.28$), nervous ($M = 5.84$, $SD = 1.27$), and distracted ($M = 5.90$, $SD = 0.99$) driving habits. Taken together, these results suggest that the cognitive aspect of participants' anxiety changes, based on the virtual reality driving habit to which they were exposed.

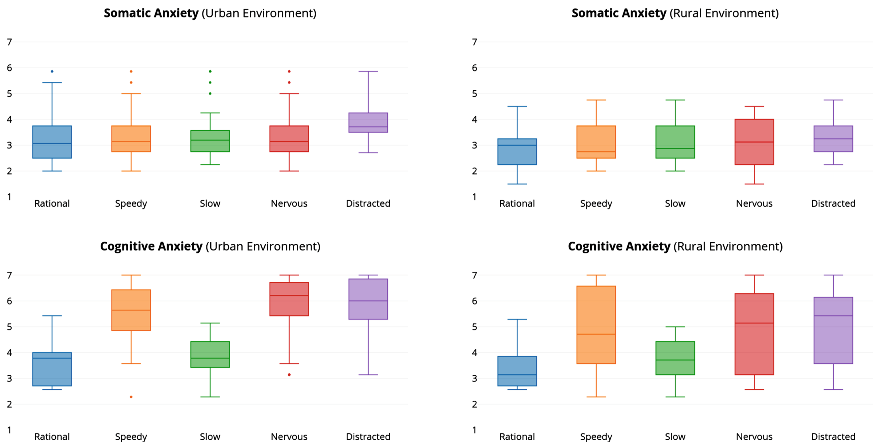

Fig. 6. Participant's somatic (top) and cognitive (bottom) anxiety in both designed environments (urban and rural).

4.3 Driving Habits in Rural Environment

A rural environment was also used to assess the anxiety levels of participants when being exposed to the five different driving habits. Similar to the urban environment, the obtained results (see Fig. 6) concerning the somatic modality of anxiety, did not indicate any significant difference across the five conditions of the experiment [$F(4, 41) = 1.16$, $p = 0.35$, $\eta_p^2 = 0.13$]. Contrarily, when examining the cognitive modality of anxiety, significant results were obtained [$F(4, 41) = 16.37$, $p < 0.01$, $\eta_p^2 = 0.69$]. Post-hoc comparisons for the cognitive modality of anxiety indicated that the mean score for the rational ($M = 3.39$, $SD = 0.82$) and the slow ($M = 3.71$, $SD = 0.76$) driving habits were significantly lower ($p < 0.05$), as compared to the speedy ($M = 4.82$, $SD = 1.67$), nervous ($M = 4.85$, $SD = 1.65$), and distracted ($M = 5.06$, $SD = 1.53$) driving habits. Taken together, these results suggest that the cognitive aspect of participants' anxiety changes based on the virtual reality driving habit to which they were exposed.

4.4 Impact of the Virtual Environment

To examine the impact of the environment to which the participants were exposed, additional analyses were conducted. For the presented analyses paired-samples t-tests were used to compare participants' anxiety in urban and rural environments. For the somatic modality of anxiety, there was a significant difference in the scores during the distracted driving habit between the urban ($M = 3.86$, $SD = 0.76$) and rural ($M = 3.31$, $SD = 0.68$) environments; $t(44) = 3.09$, $p = 0.004$.

For the cognitive modality of anxiety, there was a significant difference in the scores during the speedy driving habit between the urban ($M = 5.56$, $SD = 1.28$) and rural ($M = 4.82$, $SD = 1.67$) environments; $t(44) = 2.23$, $p = 0.033$. Significant difference was also found during the nervous driving habit between the urban ($M = 5.85$, $SD = 1.27$) and rural ($M = 4.84$, $SD = 1.65$) environments; $t(44) = 2.71$, $p = 0.011$. Finally, significant difference was also found during the distracted driving habit between the urban ($M = 5.06$, $SD = 1.53$) and rural ($M = 3.93$, $SD = 1.40$) environments; $t(44) = 3.07$, $p = 0.004$.

As can be observed from the obtained results, lower levels of anxiety were found when participants were exposed to rural virtual environment, which is an environment less crowded by cars and pedestrians. Taken together, these results indicate that the virtual environment to which participants were exposed, alters the somatic and cognitive anxiety of participants, especially for driving habits that can be characterized as dangerous.

5 Discussion

This study was conducted to assess the anxiety of virtual reality car passengers when they were exposed to five different driving habits (rational, speedy, slow, nervous, and distracted). The simulated habits were studied in two different virtual environments: a crowded urban environment, and a less-crowded rural environment. To assess the anxiety of participants, a questionnaire was developed that divided the anxiety in two parts: somatic anxiety and cognitive anxiety. In our study, each part of the questionnaire was treated individually, in order to investigate both the somatic and cognitive anxiety of participants when they are exposed to the developed stimuli. Here, we would like to note that, to the best of our knowledge, this is the first study that assesses the anxiety of virtual reality car passengers.

According to the results concerning the somatic anxiety of participants, we found that no matter the virtual environments (urban or rural) to which they were exposed, no significant effects were found for all five conditions of the experiment. This is an interesting result that indicates that participants' somatic anxiety was not influenced by the driving habits. Since participants' anxiety was kept in low levels, as well as given the self-reported results on presence, it can be said that they were not fully immersed into the virtual environments and the driving habits.

Based on the cognitive anxiety, we found that in both examined environments, participants indicated that the driving habits had significant effects on them. Specifically, lower levels of anxiety were found for the rational and slow driving habits, as compared to the speedy, nervous and distracted ones. These are very interesting findings and indicate that participants are less anxious (feel more comfortable) when being exposed to the rational and slow driving conditions, as compared to the other conditions. The authors assume that such a finding would be of interest not only to the research community, but also to virtual reality developers who develop applications that place virtual reality users as passengers in cars. For example, when developing virtual reality applications where the users take a virtual tour in a city and are placed as passengers in virtual reality cars, the developer should take into account that in order to reduce the anxiety of users and consequently to increase their comfortability, the virtual car and the driver should be assigned to either rational or slow behaviors.

The final analyses that were conducted, concern the impact that the virtual environments have on the five developed driving habits. Our results concerning the somatic modality of anxiety indicated that the anxiety of participants between an urban and rural environment changed when they were exposed to the distracted driving habit, with higher levels of somatic anxiety being found in the urban environment. This finding can be interpreted as follows. When participants are exposed to an environment crowded with cars and pedestrians, it can be said that participants became more aware about a possible event that might happen e.g., a possible accident with other cars or pedestrians. It can also be said that the inability of participants to control (stop before it happens) a possible event, might also affect the levels of their somatic anxiety. After taking into consideration that this change of participants' behavior happened only during the distracted condition of the experiment, it can be said that further experimentation is needed to conclude more accurate statements. It should be noted that the somatic anxiety of participants during the distracted driving habit in both virtual environments remained at low levels.

Regarding the cognitive modality of participants' anxiety, we found that participants' anxiety levels changed during the speedy, nervous, and distracted driving habits, with higher levels of cognitive anxiety being found in the urban environment. These can be considered as expected results. For all these three habits, it can be said that participants were more anxious about the possibility of an unwanted effect happening (e.g., collision with another car) when in an urban environment, as compared to a rural one, where a smaller number of cars were used for our simulations. Therefore, it can be said that since participants do not have control of the exposed situation, their level of anxiety increases. Moreover, when participants are exposed to a crowded environment, they may not only be concerned about their own safety but also about the safety of pedestrians and the other cars and drivers who take part in the simulation.

Even if the conducted experiment can provide a lot of interesting insights about the anxiety levels of participants, some limitations should be mentioned to help future researchers to develop similar experiments more efficiently. The most obvious limitation of our current experimental setup is the missing tactile feedback that should be provided to participants. More specifically, in our study, all participants were seated in a simple desk chair. As we would like to enhance the immersion and the believability of such an experiment, using a virtual reality car simulator would be ideal. It is assumed that by putting the participants in a simulator, their presence and their anxiety level, both somatic and cognitive, will have higher fluctuations among the five developed conditions. However, given the high cost of such a simulator, it can be said that our results can also provide interesting insights about the way that participants' anxiety can be altered.

Another limitation that should be mentioned relates to the virtual driver and the animations assigned to him. Specifically, a simple idle motion was assigned to the upper-body of the virtual character, therefore the character was moving occasionally, providing to the participants the impression that he was not a motionless character. According to discussions we had with a number of participants after the end of the experiment, they told us that they could sense that the character had been assigned a looped motion, which made them realize that the character was not the driver of the virtual car. Additionally, participants also mentioned that the virtual character looked unrealistic because of his face. More specifically, since no facial animation/expression had been assigned to the virtual driver's face, participants told us that they felt that the virtual driver was acting like a marionette. Participants told us that since the driver's face lacked an expression, they "felt scary and weird" especially during the distracted condition. Participants suggested that all of the driving habits would look more realistic if the character blinked his eyes. They also suggested us that some simple animation combined with speech would make the driver look more realistic, and therefore participants might be able to feel that the virtual driver is actually driving the car, and not controlled by scripts.

Concluding this section, we would like to mention that such virtual reality experiments and the associated developed conditions concerning real-life experiences cannot fully represent the reality to which participants are exposed in their daily life. This is especially true for example when considering that tactile feedback is not provided to participants; which in turn means that participants are not fully immersed into the examined conditions of the experiment. Thus, even for participants who were anxious in some conditions, there are cases in which they might be more or less anxious in real conditions. However, this experiment was conducted to provide us with some insight into the way virtual reality users perceive driving habits, how these habits can influence their levels of anxiety, and also to provide insight to developers of virtual reality car driving scenarios in which users are seated as passengers and take a trip with a virtual car.

6 Conclusions and Future Work

Virtual reality technology is slowly becoming a part of our daily life. Modern virtual reality technologies provide a number of capabilities for interaction within virtual environments. Thus, taking the advantage of modern virtual reality technology, this study was developed and conducted to investigate the way that the anxiety levels of participants change when they were placed as passengers into a virtual reality car, while also being immersed into a virtual environment. In our study, five different driving habits were developed/simulated, and two environments were designed for experimentation. Questionnaires that captured the presence and both the somatic and cognitive anxiety of participants were used.

By analyzing the collected self-reported answers of participants, we found that only the cognitive anxiety levels of participants changed across the five driving habits to which participants were exposed. However, the intensity of the anxiety depends both on the driving habit and the virtual environment that participants experienced. This is an interesting finding, since it indicated that we can use virtual reality technology to assess a real-life experience, such as the simulated driving scenario presented in this paper. Using virtual reality to understand human behavior on a number of different scenarios, that we are also exposed to in our real-life, can be quite beneficial since there is no need for the participants to face real challenges found in real life and no need for risks to be taken.

There are a number of other scenarios of human-car interaction that can be examined using virtual reality simulated environments and conditions. Among others, in our future work we would like to examine more complex driving habits, not only from the perspective of a virtual reality car passenger, but also from the perspective of a pedestrian, and from the perspective of a driver and passenger of another car. In addition, instead of using only questionnaires to assess anxiety, we would also like in the future to conduct experiments in which the physiological signals of participants would be captured. This would help us observe whether the somatic anxiety of participants changes when they are exposed to human-car interaction scenarios. Moreover, we would like to develop experiments to understand the way that participants' (in this case, placed as pedestrians in the virtual environment) anxiety changes when realizing that there is a car with a particular driving habit approaching them. Examples include participants walking on a pavement and when crossing roads.

Finally, since self-driving cars are becoming more and more popular and our interaction with them will soon become an everyday scene, we would also like to examine the way that the behavior of passengers in such cars changes based on a number of different simulated scenarios [26]. As already mentioned, it is difficult to develop and simulate the exact same experience that a car passenger has when being inside a real car. However, we can benefit from the advances that virtual reality provides in order to get some insights and understand the way that participants interact with cars in a less risky and much safer environment.

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