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# Motion Sickness in Virtual Reality Environments

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## ABSTRACT

Virtual reality (VR) refers to a computer-simulated experience that mimics a variety of specific physical surroundings to immerse the user in a virtual environment (VRE). Although the use of VR has provided many benefits, this technology does carry potential adverse *physical* effects. VR sickness occurs when a person's exposure to a VRE causes symptoms similar to traditional motion sickness. These symptoms are normally present in most VREs but have shown to be more apparent in a horror VRE versus a pleasant VRE. Previous research observed adult heart rate and blood pressure were more elevated in a horror VRE versus a pleasant one. In this experiment motion sickness scores in adolescents were examined in a horror VR environment compared to a pleasant environment in 14 participants (11 female and 3 male, mean age 18) and confirmed through the measurement of heart rate (HR), blood pressure (BP), galvanic skin response (GSR), and a VR Presence survey. The experiment was split into two sessions; participants played both the pleasant VRE and the horror VRE with a 2–3-day time period between sessions. GSR, HR, BP, and symptoms of motion sickness were measured before and after VR play. A VR presence survey was given after play to ensure full participation in the VRE. Motion Sickness scores were higher in the Horror VRE ($p = 0.0001$). HR, BP, and GSR showed no significant differences. Results support the hypothesis that Motion Sickness scores would be higher in the Horror VRE versus the Pleasant VRE in adolescents.

## Virtual Reality

In its current form, virtual reality (VR) refers to a computer-simulated experience that mimics a variety of specific physical surroundings to immerse the user in a virtual environment (VRE). This is accomplished by using auditory cues, which enable the user's spatial awareness to be activated, as well as "pose tracking," which connects the user with their avatar in the VRE. With these, VR manages to divert its users from reality. The most common hardware used for VR is a head-mounted display (HMD) such as the Oculus Rift 2.

## Virtual Reality Industry

Up until 1990, the virtual reality industry primarily produced VR equipment for use in medical education, flight simulation, automobile design, and military training. However, the 1990s saw the launch of consumer headsets. Over the past three decades, the VR industry has grown significantly due to the universality of its use, expanding well beyond gaming into different modern industries such as healthcare, real estate, entertainment, and education. The use of Augmented Reality (AR), which is the integration of digital information with the user's environment in real time (Gillis 2022), as well as the use of VR without a headset has also increased significantly in the past 7 years. In 2023 alone, the VR industry reached about 171 million users worldwide, leading to a market value of 7.72 billion dollars (Kolmar 2023).

## Health Effects of VR

Although the use of VR has provided many remarkable benefits in several different areas, this technology does carry numerous potential adverse *physical* effects. In fact, most virtual reality systems come with consumer warnings about potentially serious side effects such as seizures, developmental issues in children, and tripping/falling (Oculus). Less serious short-term effects may include eye strain, headache, general physical discomfort, and motion sickness.

## Motion Sickness

Although there are several hypotheses regarding the pathophysiology of motion sickness occurring in both VRE and non-VRE environments, it is motion, whether actual or perceived, that is the underlying cause (Takov et al., 2019). Motion is normally both seen and felt. Motion sickness is caused by a conflict between signals arriving in the brain from the inner ear and eyes, which form the base of the vestibular system. This sensory apparatus deals with movement and balance and detects motion mechanically. The vestibular system is a complex set of structures and neural pathways that serve a wide variety of functions that contribute to our sense of proprioception and equilibrium. The centrally located vestibular system involves neural pathways in the brain that respond to afferent input from the peripheral vestibular system in the inner ear. (Casale et al., 2023). Our vestibular system enables us to determine body orientation, senses the direction and speed at which we are moving, and helps us maintain balance (Dunbar 2004). For example, if someone is looking at a stationary object within a vehicle, such as a magazine, their eyes will inform their brain that what they are viewing is not moving. This is an example of motion being felt but not seen. Their inner ears, however, will contradict this by sensing the motion of the vehicle. However, there are situations where motion is seen, but *not felt*. An example of this might be watching a movie where you are a passenger on a roller coaster. Another theory, called “defense against poisoning,” (Treisman 1977) suggests that some symptoms of motion sickness, such as nausea, fatigue, vertigo, and vomiting are caused by the brain drawing the conclusion that the visual and perceptual incongruity are due to hallucinations caused by ingesting poison. Thus, the brain reacts by inducing vomiting in order to get rid of the perceived toxin. Interestingly, aside from the appearance of symptoms, the onset and intensity of motion sickness can only be assessed indirectly, using objective measures of autonomic nervous system activation, such as heart rate, blood pressure and electrodermal activity (EDA) (Malmivuo et al., 1995).

## VR Sickness

Virtual reality sickness occurs when a person's exposure to a virtual environment causes symptoms that are similar to those seen in traditional motion sickness. On the other hand, simulator sickness is a subset of motion sickness that is typically experienced while playing video games from a first-person perspective. It was discovered in the context of aircraft pilots who undergo training for extended periods of time in flight simulators (Johnson 2005). Some symptoms of VR sickness are blurred vision, dizziness and vertigo (Katsigiannis et al., 2020). These symptoms commonly occur after using a VR device for extended periods of time (Jasper et al., 2020). Contemporary VR headsets have reported minimal to no motion sickness (Kourtesis et al., 2019), and gaming VR specialists argue that an individual will eventually become used to using head-mounted displays--relating it to “getting their sea legs". (Gahlinger 2000). It has been shown that women typically experience more VR sickness than men (Goncalves et al., 2018) and they do *not* develop their “VR legs” (Gahlinger 2000).

## VR Sickness Previous Research

Certain aspects of VR, such as change in speed, walking upstairs, and jumping can create virtual reality sickness in users (Evin et al., 2020). This is problematic because these types of movements are normal game functions in predominant gaming genres. Interestingly, some of these effects still occur even after VR play. Studies have shown that aftereffects of VR are cognitive effects including changes in decision times that may be related to alertness and attention; however, there is still a great need for further research to determine who is affected and why (Szpak et al., 2014). It has been shown that the risk of developing symptoms of motion sickness increases when the VR system does not have a high enough frame rate, or if there is a lag between the body's movement and the onscreen visual reaction to it (Caddy 2016). In addition, several studies have found a relationship between objective physiological changes and the motion sickness symptoms that may occur when exposed to a VRE. It has been found that heart rate (HR) increases with time spent in VREs (Dennison et al., 2021, Kim et al., 2005) although this is not always observed (Ramdhani et al., 2019). Galvanic skin response (GSR) also increases as time in a VRE increases (Dennison et al., 2021). VREs can also have an impact on VR sickness, most experiencing acute motion sickness in “horror” VREs versus “pleasant” ones (Chattha et al., 2020). They observed that total motion sickness scores, HR, and BP were higher in the “horror” VRE compared to the “pleasant” VRE in adults (Chattha et al., 2020).

## Statement of Intent

Because it has been shown that motion sickness scores, heart rate, and blood pressure have been higher in horror VREs versus pleasant VREs, it is expected that in this experiment motion sickness scores will be higher in a horror VR environment compared to a pleasant environment and will be confirmed though the measuring of GSR and a VR Presence survey. Previous research hasn’t explored physiological measurements such as HR, BP and GSR in different genres of VREs in adolescents. Most studies were conducted on adults, and only measured HR and/or GSR. This study will examine high school students playing two different genres of VREs while measuring their BP, HR and GSR as well as gauging their motion sickness and feeling of VR presence.

## Participants

This experiment took place at Shattuck-St. Mary’s School in Faribault, MN. Participants included 14 students grades 10-12 (3 males and 11 females) in a within-subject design. Experiments were conducted in a large school gymnasium that allowed for lots of space for VR play. All participants were informed about all parameters of the experiment including background, information and previous research, why the study is being done, and possible risks and discomforts. Participants gave their informed consent to participate in the study. Participants were tested individually.

## Virtual Reality Environments

Participants played two VREs total, one being a “pleasant” environment while another being “horror” environment. The pleasant VRE was the VR game GOLF+ Putt Pro, and the Putt Putt Practice feature of GOLF+. The first virtual environment that early participants played was Putt Pro golf, which takes place in a calm and peaceful atmosphere with a simple design--levels include Beach, Forest, and Peaks. Each environment has 9 levels. Not all subjects got to the 9th level of their environment. Each level plays nature ambient sounds while having simulated animals that the player cannot interact with in the background. The entire game takes place during the daytime and is on putt putt greens. In this game, the participant used one remote for their golf club (left or right depending on dominant hand). The second environment that the other remaining participants played in was the Putt Putt "Practice" feature of GOLF+, which takes place in a realistic golf course, surrounded by hills. The horror virtual environment was Face Your Fears 2. This game included a haunted house, jump scares, blood, and violence. The participants played the level "Shadows of the Past 2013". In this VRE, the game takes place during the nighttime. The level "Shadows of the Past" had participants roaming a Haunted house lot, and entering a shed where they must face several deadly spiders. The participant generally did not have enough time to finish the level, especially if they "died" and had to restart. The longer participants remained in the level, the more intense the fear-inducing stimuli became. In this game, both remotes were used.

### Subjective Measurements

Two different surveys were used in this experiment, starting with a pre-immersion Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993). The Kennedy et al., (1993) study, which included 1,119 military volunteers who participated in a range of Navy simulator training exercises, provided the basis for the factor structure of the SSQ. After the VR play, the same questionnaire was given. The other survey was only post-immersion and was a VR Presence Questionnaire (Witmer & Singer, 1998). Presence is the subjective feeling of being immersed in one environment, while actually being physically situated in another. Several factors that may be connected to this sense of presence have been identified (see Witmer & Singer, 1998). Control (degree, immediacy, anticipation, method, and physical or environmental modifiability) is one of these elements. Another factor connected to the sense of presence includes distraction which is a sense of how immersed a player is in their VRE. Sensory modality and environmental richness also impact a player's sense of place in a VRE as well as the realism of the VRE itself.

### Objective Measurements

The objective measurements in this experiment were HR and BP. Heart Rate and Blood pressure were taken with a wrist cuff, the MMIZOO Wrist Blood Pressure Monitor. The (systolic) upper value followed by the (diastolic) lower value was measured in units of millimeters of mercury (mmHg). Heart rate was measured as the number of beats per minute (bpm). Galvanic Skin Response (GSR) was also taken pre and post immersion for 2 minutes with the NeuLog galvanic skin response sensor NUL-217. The headset used in this study was the Oculus Rift 2 headset made by MetaQuest.

## Methods

This experiment was run in 2 sessions. The first step of the experimental protocol for Session 1 was to have participants fill out the pre-immersion Motion Sickness Questionnaire. Next, the Neulog Galvanic Skin Response Sensor was attached to the participant's proximal digits on the second and third fingers on their right hand. A two-minute baseline recording was taken. After baseline recording was taken, Neulog recording was stopped and saved but the device was not removed from participants. Blood Pressure and Heart rate were then taken and recorded in a spreadsheet. The Oculus headset was then placed on the participant's head, with the participant confirming comfort. Participants were shown how to use remotes for the headset. Participants were assigned at random the order in which they played the VREs, either the Horror VRE first and the Pleasant VRE second or vice versa. Participants would then play in the "pleasant" environment, a putt putt golf game (GOLF+) for 30 minutes. After 28 minutes of VR play, the Neulog device was turned on and another two-minute recording was taken. Once 30 minutes had passed, participants removed the VR headset and remotes. Once again BP and HR were measured and recorded. Finally, participants filled out a motion sickness questionnaire survey and VR Presence survey. Participants completed Session 2 approximately 2-4 days after Session 1. For Session 2, participants followed the exact same procedure, but instead played in the "horror" VRE, Face Your Fears 2. The averages of HR, BP, and GSR were calculated by taking the before and after measurements from each VRE and finding the difference between them. Statistical Analysis was a one tailed T-value of repeated measures (dependent) test.

## Results

**Table 1**. The change in heart rate, blood pressure, motion sickness, and galvanic skin response before and after VR play. The difference in the separate environments was calculated by taking the scores from AFTER VR play and then subtracting them from the scores BEFORE VR play.

| Measurements | VRE Genre | After Ave - Before Ave | t-value | p-value |
|---|---|---|---|---|
| **SSQ Scores** | Pleasant | 1.5 | 5.1 | **0.0001** |
| | Horror | 7.2 | | |
| **GSR** | Pleasant | 3.23 | 1.2 | 0.25 |
| | Horror | 4.22 | | |
| **Heart Rate (beats/min)** | Pleasant | 1.57 | -0.23 | 0.82 |
| | Horror | 0 | | |
| **Systolic BP** | Pleasant | -3.07 | -0.19 | 0.85 |
| | Horror | -5.21 | | |
| **Diastolic BP** | Pleasant | -2.14 | 0.13 | 0.9 |
| | Horror | -0.86 | | |

[1]All *p*-values in boldface are significant at better than the .05 level for a two-tailed test.

There was not a significant difference in average heart rate between the Pleasant VRE (1.57) and the Horror VRE (0) (p=0.82). There was also not a significant difference in average systolic blood pressure between the Pleasant VRE (-3.07) and the Horror VRE (-5.21) (p=0.85). This was also true for the average diastolic blood pressure between the Pleasant VRE (-2.14) and the Horror VRE (0.86) (p=0.90). However, there was a significant increase in the average of the motion sickness scores between the Pleasant VRE (1.5) compared to the Horror VRE (7.2) (p= 0.0001). There was no significant difference in GSR between the Pleasant VRE (3.23) and the Horror VRE (4.22) (p=0.25).

## Discussion

The results of this study indicate that HR, BP, and GSR were not significantly different from the Pleasant VRE to the Horror VRE. Motion Sickness, however, was significantly higher in the Horror VRE versus the Pleasant VRE. The lack of a significant difference in HR due to the VR environment is in contrast to the results of Dennison et al., (2021), who observed that HR increased with time spent in an "uncomfortable" VRE. Dennison et al., (2021) suggests that increased heart rate and decreased time between heart beats during HMD (head-mounted display, Oculus Rift) use was due to an increase in the sympathetic activity of the autonomic nervous system in response to an uncomfortable environment. In this experiment, however, participant's prior VR experience was not recorded. When casually asked but not measured, most had answered "no". Chattha, et al., (2020) also showed an increased HR in a VREs--the increase was much higher in the Horror VRE versus the Pleasant VRE.

Other research demonstrates a decrease in HR during VR use. Ramdhani et al., (2019) measured average HR at different points of VR play. Overall, HR and respiratory rates were shown to decrease as participants reached the peak of the experiment. An explanation for these decreases in HR could be the autonomic nervous system at work. When the body is confronted with danger, the sympathetic nervous system kicks in, and the "fight or flight" response is activated which increases HR. Over time, the body comes down from this when the parasympathetic nervous system kicks in, decreasing the heart rate back to normal. Changes in HR often go hand in hand with changes in BP, and Chattha et al., (2020) observed an increase in BP as well as HR during VR play. Chattha et al., (2020) found that BP increased during VR play a higher degree in the Horror VRE versus the Pleasant VRE, which contrasts this study's finding. In this experiment, however, participants were in each VRE for 30 minutes with HR and BP only being measured before and after play. Due to this data collection method, the possibility that in that time HR and BP could vary throughout VR play was created.

The results of this experiment for GSR were not statistically significant, which contradicts the results of Dennison et al., (2021), Kim et al., (2005), and Ramdhani et al., (2019). For example, Dennison et al., (2021) found that skin conductivity increased with more time spent in VR. They found that the longer participants spent in VR, higher levels of skin conductance were recorded. Subjects were allowed to quit within the allotted 10 minutes of play at any point when they felt sick, so subjects all spent varying amounts of time in the VRE. Kim et al., (2005) also found that skin conductivity increased as VR or HMD use went on; subjects played the entire duration in VR (9.5 minutes). Similarly, Ramdhani et al., (2019) found increased GSR scores with more time spent in VR but did not specify the length of time participants played. Two of these studies had a similar VR play time of ~10 minutes, while this study had a VR play time of 30 minutes. With this study's longer VR playtime, it was expected that GSR would be higher in the Horror VRE than what was recorded. One potential limitation of this study was its small sample size, which may account for the differences between our results and prior research on GSR in VREs. Other possible reasons for differences in GSR between these studies could be the devices used in each experiment. Dennison et al., (2021) and Ramdhani et al., (2019) as well as the present study measured skin conductance levels via electrodes on the fingertips. However, each study used different devices/software to record the GSR levels, which could cause small differences in data. Another potential limitation was how the post-VRE GSR was measured. Electrodes were connected back onto participant's pointer and ring finger with 2 minutes left in VR play, and measured GSR level while the participant played. This potentially could have affected the results, as participant play could interfere with the measuring process.

Motion Sickness was significantly higher in the Horror VRE versus the Pleasant VRE. Kim et al., (2005) observed high motion sickness scores, but did not use an uncomfortable environment, but rather a neutral navigational VRE. Image projections forming the virtual environment were presented through a multiple projector system with a theater-type concave screen. The generator displayed 3D objects such as trees, bridges, a road, a river, and buildings. The virtual reality room was equipped with a video camera and loudspeakers with electrical shielding. Users navigated the virtual environment using a steering wheel, a brake, and an accelerator. Despite having a neutral environment, Kim et al., (2005) found that forty-five subjects (78.9%; 24 women) among a total of 57 subjects reported cybersickness during the virtual navigation. In Dennison et al., (2021), participants viewed both a display monitor and HMD, observing that the participants viewing the display monitor had little to no motion sickness while those using the HMD overwhelmingly experienced motion sickness (19/20 participants experienced MS). The participants were subject to an "uncomfortable" environment in both the display monitor and HMD. Chattha et al., (2020) also observed an increase in Motion Sickness scores in both the Pleasant VRE and Horror VRE but observed higher levels of MS scores in the Horror VRE. Both Dennison et al., (2021) and Kim et al., (2005) had a VR playtime of about 10 minutes--while Chattha et al., (2020) had the participants play until they felt like stopping. This study had participants play for 30 minutes in each environment. Generally, the more time spent in a VRE, the more Motion Sickness will increase, which is supported by Dennison et al., (2021), Kim et al., (2005), and Chattha et al., (2020). It has been observed that women typically experience more motion sickness than men do (Goncalves 2018). The high post-VRE motion sickness scores could potentially be due to the fact that this present study had primarily female participants. Other potential limitations of the present study were the small participant group of only 14 subjects as well as the subjective nature of motion sickness and VR presence surveys. Participants ranked their own symptoms on the scale of “none” to “severe”. Participants also had different levels of VR experience, which could have potentially influenced their motion sickness scores as well as their physiological measurements.

## Conclusion

In conclusion, the average change of motion sickness scores significantly increased in the horror virtual environment versus the pleasant environment in adolescents.

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