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Research Article

Cybersickness Induced by Head-Mounted Virtual Reality Video Games

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Received: July 16, 2022; **Published:** August 23, 2022

Abstract

Background: Virtual reality head-mounted displays (VR-HMDs) are 3D displays with a large field of view and head tracking ability. They offer a sense of immersion into the game or movie. VR-HMDs also offer interacting features, which makes it an interesting activity among young adults. However, "Cybersickness" symptoms comprise a major drawback of VR-HMDs, which include nausea, vomiting, headache, eye strain, discomfort, and other symptoms.

Methods: The study was conducted between February to April 2020, and was held at Department of Optometry, College of Applied Medical Sciences, King Saud University. The Simulator Sickness Questionnaire (SSQ) was used in this study to assess cybersickness caused by VR-HMD video games before and after 45 minutes of playing interactive 3D video games with the VR-HMD system. The SSQ assesses three categories of symptoms, including ocular, disorientation, and nausea symptoms and also the total severity of symptoms. The study was completed by 26 young adults with normal vision.

Results: There was a significant increase in all three subscale scores and total scores of SSQ for the majority of participants, emphasizing the negative impact of VR-HMDs on users.

Discussion: Using the VR-HMD system to play 3D video games can clearly aggravate all sorts of cybersickness symptoms as determined by the SSQ. Therefore, a statement of manufacturer warning should be introduced to players before they start the game to reduce symptoms and disseminate knowledge.

Keywords: *Virtual Reality; Video Games; Head-Mounted Display; Cybersickness; Simulator Sickness Questionnaire*

Introduction

Virtual reality head-mounted display (VR-HMD) is a technology system that offers stereoscopic three-dimensional (3D) video games or movies [1]. According to the Oxford English Dictionary, virtual reality denotes "The computer-generated simulation of a 3D image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors" [2,3]. VR-HMDs are not a completely new concept; they have been in existence in several forms since the late 1960s [4]. However, they have recently become widely popular among young adults in industries devoted to film and leisure. Gaming and films are obvious virtual reality applications, but VR technology has numerous applications, including healthcare, education, military, sport, marketing and mass media [4]. The goal of virtual reality is to immerse the user in a real-time environment.

The VR-HMD system consists of software and hardware components that are required to interact with the virtual environment. The software components have the capacity to program the behavior of objects in a virtual environment. They provide the object's geometrical

construction, determine their visual properties, and manipulate their texture. Furthermore, the program may overlap and alter the sounds of objects within the virtual world [5]. The hardware components include computer workstations, head-mounted screens, helmets, wired clothing, 360° camera, gyroscope and motion-sensing gloves [5]. Typically, the VR-HMD system has a set of optical high-powered lenses and mirrors with a screen close to the eyes [6]. This optical setting provides a wide-angle view and enlarges the projected image [1]. VR-HMDs have the ability to track the head movement and maintain the orientation and position. All of these features provide the particular user with a perfect sensation of immersion inside this synthetic environment.

Cybersickness is a term that refers to an individual experiencing sickness and annoyance malaise symptoms after using virtual reality headsets [5]. VR-HMD users exhibit several symptoms, including general discomfort, headache, vertigo, disorientation, pallor, fatigue, vomiting, nausea, stomach awareness, eye strain, difficulty focusing, blurred vision, increased salivation, and sweating [5,7]. These symptoms following the VR-HMD experience can last for hours, and in some cases, they may last for a few days [7]. Therefore, cybersickness is a major drawback of VR-HMD headsets that needs to be evaluated.

Although previous studies have emphasized the detrimental impact of VR-HMDs on visual, vestibular, nonvisual and nonvestibular-related symptoms, the frequency and severity of symptoms varies amongst participants based on several variables, such as gender, age, anxiety, stress, the properties of the simulators themselves, and one's enjoyment in the course of the simulator itself. Lo and So reported that during a 20-minutes VR-HMD exposure, the intensity of nausea tends to increase linearly with time. Several other studies have reported significant increments in visual fatigue and discomfort after using VR-HMDs [8-10].

In previous studies that measured the number of symptoms after exposure to VR-HMDs, different methods and tools were used, and some of these methods depended on subjective responses from the participants using questionnaires and surveys. Moreover, some of these questionnaires may not reflect all types of symptoms of VR-HMD users because most of them focus on only certain types of symptoms. Furthermore, unvalidated questionnaires were used in some of the studies. Other studies used more objective measurements such as the blinking rate and eye movements to quantify symptoms [11,12]. The Simulator Sickness Questionnaire (SSQ), which was designed by Kennedy., *et al*. (1993), is a standard measure of cybersickness symptoms that assesses three types of 16 symptoms, including eye comfort, disorientation, and nausea [13].

Aim of the Study

This is a prospective study aimed to measure the subjective symptoms caused by playing interactive 3D video games using the VR-HMD system using the standardized SSQ.

Methods

Participants

The study was held at Department of Optometry, College of Applied Medical Sciences, King Saud University. All data were collected between February to April 2020. The study participants were students from the College of Applied Medical Sciences, King Saud University. All participants underwent preliminary clinical visual assessments to determine their participation eligibility. All participants had a corrected distance visual acuity of 6/6 in each eye, at least 60 seconds of arc stereoacuity at near, did not have distant or near ocular deviations, did not have amblyopia in one or both eyes, and did not have presbyopia. Participants with any ocular and/or neurological diseases were excluded from this study.

Procedures

To record baseline symptoms, participants were first asked to fill out the SSQ shown in table 1. The questionnaire was first published by Kennedy., *et al*. (1993) to assess three types of 16 symptoms, including eye comfort, disorientation, and nausea. The eye comfort or ocular

subscale (O) measures symptoms related to eye and visual discomfort such as eye strain, fatigue, concentrating difficulties, headache, and blurred vision. The disorientation subscale (D) reflects symptoms related to balance and vestibular functions such as dizziness and vertigo. The nausea subscale (N) reflects symptoms related to gastrointestinal issues such as stomachache, nausea, salivation, burping, and vomiting (Table 2).

SSQ symptoms	Rate			
	None	Slight	Moderate	Severe
1. General discomfort				
2. Fatigue				
3. Headache				
4. Eye strain				
5. Difficulty focusing				
6. Increased salivation				
7. Sweating				
8. Nausea				
9. Difficulty concentration				
10. Fullness of the head				
11. Blurred vision				
12. Dizzy (eye open)				
13. Dizzy (eye closed)				
14. Vertigo				
15. Stomach awareness				
16. Burping				

Table 1: *Simulator sickness questionnaire developed by Kennedy., et al. (1993).*

Of the 16 symptoms, 5 are involved in more than one category. For example, the score of blurred vision is used to evaluate the severity of ocular and disorientation subscales. That is why each category has seven symptoms. For each item of subscales, participants can rate their current feeling as none, slight, moderate, or severe, and these ratings are converted into numerical values ranging from 0 (none) to 3 (severe). The total score (TS) can also be calculated from the SSQ, which reflects the overall severity of cybersickness that is experienced by the participants after using the VR-HMD system. Each of the TS, O, D and N categories are assigned by weight (3.74, 7.58, 13.92 and 9.54 respectively). The score of each category equals the sum of its relevant symptom scores multiplied by its weight. Thus, O = [Sum of its symptom score] × 7.58, D = [Sum of its symptom score] × 13.92, N = [Sum of its symptom score] × 9.54, and TS = [O + D + N] × 3.74. As all three categories consist of seven symptoms, their score scale will range from 0 to 159.18 for the O subscale, from 0 to 292.32 for the D subscale, and from 0 to 200.34 for the N subscale. The scale of TS that consists of 16 symptoms will range from 0 to 179.52 (Table 2) [5,13].

SSQ Symptoms	SSQ Subscales		
	Nausea (N)	Oculomotor (O)	Disorientation (D)
1. General discomfort			
2. Fatigue			
3. Headache			
4. Eye strain			
5. Difficulty focusing			
6. Increased salivation			
7. Sweating			
8. Nausea			
9. Difficulty concentration			
10. Fullness of the head			
11. Blurred vision			
12. Dizzy (eye open)			
13. Dizzy (eye closed)			
14. Vertigo			
15. Stomach awareness			
16. Burping			
SUM	= [Sum of N symptom score] × 9.54	= [Sum of O symptom score] × 7.58	= [Sum of D symptom score] ×13.92
Total Score (TS)	= [O + D + N] × 3.74		

Table 2: *Simulator sickness questionnaire calculator method described by Kennedy., et al. (1993).*

Next, the participants played two interactive 3D video games using the PlayStation VR-HMD gaming system acquired from Sony (Figure 1). The first 3D video game is known as "ASTRO BOT Rescue Mission, SIE Japan Studio's ASOBI". This game involves a robot that has to move toward a certain direction, pass over obstacles, going up and down, and go to certain places at different distances from the screen plane. Players have to control the movement of the robot using their eyes, heads, and bodies all the time. Players have to spend 20 min on this game. In the second game, which is known as "President Evil 7: Biohazard, Capcom," the main character has to rescue his wife by solving some puzzles and fighting other characters. Again, the players have to control this main character using joysticks that sometimes require eye, head, and body movements. This game lasts for 25 minutes. The total duration of playing is 45 minutes. The order of game selection was the same for all participants. The two games were selected to maintain participants' awareness and motivation and to make them positively active for the entire session of the video game. Participants again rated their symptoms, but at this time point, they did so immediately after the VR-HMD playing session by refilling the SSQ. A total of 26 young adults aged 19 - 27 years (mean ± standard deviation: 22.5 ± 2 years) were enrolled in this study. Before participation, the participants received written informed permission. The study was carried out in accordance with the tenets of the Declaration of Helsinki and was approved by King Saud University Office of Research Ethics (IRB Approval Number E194298).

Figure 1: *Participant playing 3D video game using the virtual reality head-mounted display (VR-HMD) system acquired from Sony PlayStation.*

Data analysis

Data are presented as mean ± standard deviation and median for different subscale scores and TSs before and after the VR-HMD playing sessions (Table 3). The Wilcoxon signed-rank test was used to compare nonparametric measurements, which are the comparisons based on median values of subscale scores and TSs of SSQ before and after the VR-HMD playing session due to the abnormal distribution of SSQ scores. A P value < .05 was considered to be statistically significant. Data analysis was conducted using the IBM SPSS software (version 26).

Results

The majority of participants reported no symptoms at all before starting the VR-HMD playing sessions (based on median values of different subscale scores). After the VR-HMD playing sessions, there was a significant increase in subscale and TSs for all symptoms (Table 3). The largest change in symptoms was related to oculomotor symptoms. The score of ocular symptoms increased from 0 before the VR-HMD playing session to 34.11 after the VR-HMD playing session ($P < 0.001$). The nausea symptom score increased from 0 to 28.62 between the two sessions ($p < 0.001$), which was considered as the second largest change. The least change was related to disorientation symptoms, with the score increasing from 0 to 20.88 between the two sessions ($p = 0.001$). The total score increased from 3.74 before the VR-HMD playing session to 37.4 after the VR-HMD playing session ($p = 0.001$) (Table 3). The mean differences between the two playing sessions for each subscale score and the total score of SSQ are shown in figure 2.

SSQ Scores		Before VR-HMD playing Session	After VR-HMD playing Session	W Test, P Value
Nausea (N)	Mean	4.40	37.06	Wilcoxon signed-rank test value (W) = 3.893, P < 0.001
	Std. Deviation	6.17	33.7	
	Median	0	28.62	
Oculomotor (O)	Mean	8.45	39.65	Wilcoxon signed-rank test value (W) = 3.953, P < 0.001
	Std. Deviation	13.1	30.5	
	Median	0	34.11	
Disorientation (D)	Mean	5.35	36.41	Wilcoxon signed-rank test value (W) = 3.438, P = 0.001
	Std. Deviation	9.7	47.1	
	Median	0	20.88	
Total Score (TS)	Mean	35.82	44.45	Wilcoxon signed-rank test value (W) = 3.419, P = 0.001
	Std. Deviation	145.6	37.3	
	Median	3.74	37.40	

Table 3: *Mean, standard deviation, and median values of different subscale scores and total scores of the simulator sickness questionnaire (SSQ) before and after the VR-HMD playing sessions.*

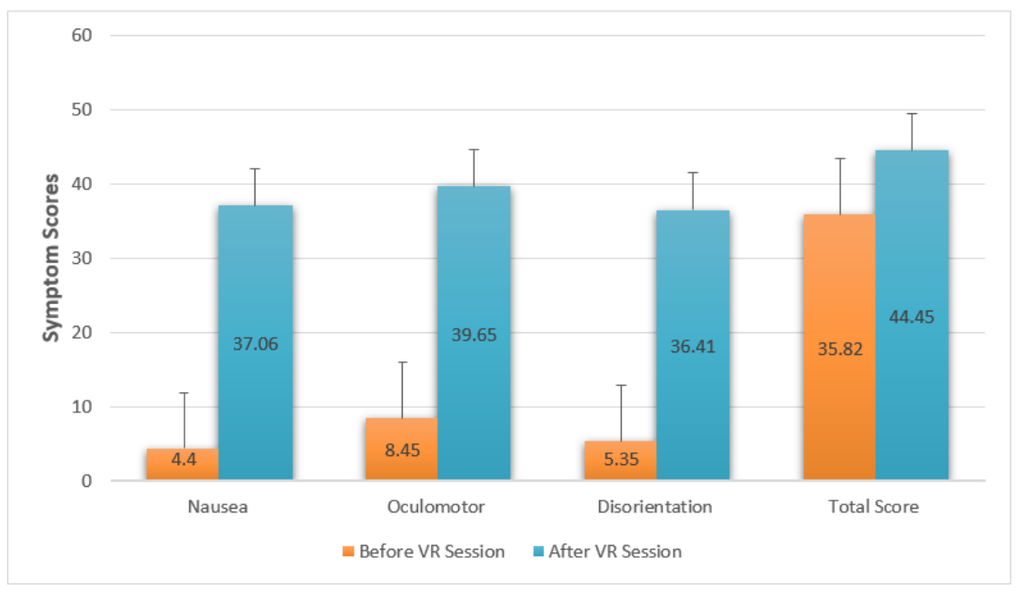

Figure 2: *The mean differences of simulator sickness questionnaire scores before and after VR-HMD playing sessions. Error bars indicate standard deviations.*

Discussion

This study evaluated the symptoms experienced by 3D video game players on the VR-HMD system using the standardized SSQ. The results revealed an increment in all SSQ scores that reflect the overall severity of cybersickness experienced by participants after the VR-HMD playing session. Symptoms related to eye and visual discomfort and symptoms related to gastrointestinal issues such as stomachache and vomiting increased to a larger extent than disorientation and balance symptoms.

Min., *et al*. (2004) conducted a study to assess the severity of various factors of simulator sickness, in which the study participants were asked to drive a car simulator for 60 minutes after taken SSQ. Physiological and SSQ evaluations were conducted orally at every 5 minutes of exposure to the car simulator. Participants reported nausea and disorientation-related symptoms after 10 minutes of simulator exposure. However, eye and vision-related symptoms were reported after 25 minutes. This observation highlights the effects of a car simulator even within a short period of time of 10 minutes [14]. In another study, William Stone (2017) found that cybersickness symptoms were limited when measured after the participants played 3D interactive VR-HMD video games for approximately 20 minutes. Games were classified into two separate categories in terms of controlling visual motion with and without corresponding to physical motion. Cybersickness symptoms induced by playing 3D video games with visual motion alone were less than those induced by playing 3D video games corresponding to physical motion. Different VR games may contribute to the differences between that study results and our study results [5]. In a recent study conducted by Ana Agić., *et al*. (2020), the authors evaluated how different variables may influence the level of cybersickness symptoms. They examined different variables such as the speed of movement in the virtual environment with function of age, gender, and state of participants. Their study findings suggested that age could have a significant relationship with vertigo-related symptoms at rapid speed. However, age, gender and state of participants did not have a significant impact on the total score of cybersickness symptoms [15].

The majority of previous studies, including our study, evaluated cybersickness symptoms after exposure to 3D images on the VR headset for a relatively short period of time (< 1h). This indicates that it is necessary to investigate the long-term cybersickness symptoms of playing interactive 3D video games using VR-HMDs. For instance, Polonen., *et al*. found that there were minor nausea and motion sickness symptoms after 2h of playing 3D video games in a sample of young children. However, they used video screens for the 3D video games [16]. Other study found that significant increases in both visual and nonvisual symptoms after 80 minutes of watching 3D videos using VR headsets compared to those after 30 minutes in the same subjects [17]. Furthermore, Ames., *et al*. (2003) reported that 50% of young adult participants could not view a 3D video content for more than 1 hour using VR headsets due to eye strain and visual fatigue [18].

Conclusion

In conclusion, playing 3D video games using the VR-HMD system induced nausea, oculomotor, and disorientation symptoms in the users even after a short period of time. This may contribute, for instance, to poorer efficiency at work or school, inability to adapt to cybersickness for long period of time, or changes in clinical measurements during a routine examination. Therefore, a clear statement of manufacturer warning should be introduced to players before they start the game to reduce or prevent symptoms and disseminate knowledge.

Acknowledgment

The authors would like to extend their sincere appreciation to the Deanship of Scientific Research and Research Center, College of Applied Medical Sciences at King Saud University for funding this work.

The authors thank the Deanship of Scientific Research and RSSU at King Saud University for their technical support.

Declaration of Conflicting Interests

The author(s) declare(s) that there is no conflict of interest.

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Volume 13 Issue 9 September 2022