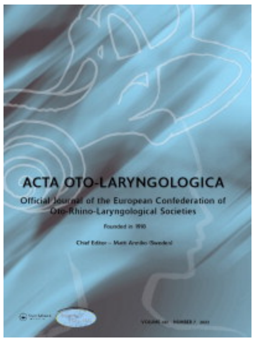

Acta Oto-Laryngologica

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ioto20

Subjective Visual Vertical test with the 3D virtual reality system: effective factors and cybersickness

Fazıl Necdet Ardıç, Ulaş Metin & Betül Ebrar Gökcan

To cite this article: Fazıl Necdet Ardıç, Ulaş Metin & Betül Ebrar Gökcan (2023) Subjective Visual Vertical test with the 3D virtual reality system: effective factors and cybersickness, Acta Oto-Laryngologica, 143:7, 570-575, DOI: 10.1080/00016489.2023.2238769

To link to this article: https://doi.org/10.1080/00016489.2023.2238769

Published online: 26 Jul 2023.

ACTA OTO-LARYNGOLOGICA
2023, VOL. 143, NO. 7, 570–575
https://doi.org/10.1080/00016489.2023.2238769

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

Subjective Visual Vertical test with the 3D virtual reality system: effective factors and cybersickness

Fazıl Necdet Ardıç, Ulaş Metin and Betül Ebrar Gökcan

Department of Otolaryngology, School of Medicine, Pamukkale University, Denizli, Turkey

ABSTRACT

Background: 3D Virtual Reality (VR) offers new opportunities in vestibular science. It also presents new challenges and problems.

Aims/objectives: The study aimed to evaluate the effective factors in the 3D VR Subjective Visual Vertical (SVV) test and the impact of cybersickness on the test results.

Material and methods: The effect of the foam surface, head position in the yaw axis, moving background, and arm position holding the controller was tested. Cybersickness was evaluated using the Simulator Sickness Questionnaire (SSQ).

Results: The head position and controller holding style significantly affected the results. The foam surface and the moving background did not have a significant effect. Although 61.4% of the patients fell into the bad category according to the symptoms of the SSQ score, cybersickness did not significantly affect the SVV results.

Conclusions and significance: In 3D VR SVV, additional factors should be considered: the headset's weight, head position, and how we hold the controller. The A-effect emerged when the head was 45 degrees turned on the yaw axis. A significant shift was detected in the test, with the arm holding the controller at 90 degrees. Most subjects felt cybersickness at a considerable level. Cybersickness should always be taken into account in VR when planning new applications.

ARTICLE HISTORY
Received 30 May 2023
Revised 12 July 2023
Accepted 13 July 2023

KEYWORDS
Subjective visual vertical; virtual reality; otolith; cybersickness

Introduction

Perceiving the gravity vector correctly is one of the important factors in maintaining our balance. Subjective visual vertical (SVV) primarily evaluates the function of the saccule and central graviceptive pathways. The otolith organs have previously been reported to be affected in both acute and chronic phases of vestibular disorders [1]. Therefore, SVV is a necessary test to monitor patients. However, it can be influenced by various factors, including age groups, sex, starting point, active or passive body inclination, and soft surfaces [2]. Various techniques have been proposed to measure SVV, from simple bucket tests to advanced virtual reality systems [3,4].

The test device used is also an important factor in normal values. In 3D systems, in addition to the classical bias factors, two different factors come into play: the first is the weight of the headset, which can be particularly effective on different head positions *via* neck proprioception, and the second is the effect of the proprioceptive sensation created by the controller in hand. In studies comparing SVV and subjective haptic vertical, it has been reported that haptic sensation reduces the bias created by visual sensation during central processing [5]. In addition to body posture, the condition of the arms has also been found to affect cervicocephalic kinesthesia [6].

With the increasing applications of virtual reality systems in both testing and rehabilitation, the issue of a negative side effect known as cybersickness has emerged. Cybersickness is similar to motion sickness, characterized by eye fatigue, headache, vision disturbances, and nausea. Unlike motion sickness, cybersickness can occur even without physical movement. The prevalence of cyber-sickness during or after VR applications has reached 80% [7,8].

This study was planned to clarify the daily problems we encountered while performing SVV (Subjective Visual Vertical) with a virtual reality system. During tests, we observed that patients preferred to stand in different positions and hold their arms in various ways. We aimed to investigate how this situation could potentially impact the test results. The first goal was to determine the normal values of the SVV tests performed using a VR headset under varying stress conditions while also exploring the potential impact of the weight of the headset and the controller usage methods on the test results. Second, it aims to assess whether cybersickness experienced during VR usage affects the test results.

Material and methods

This study was carried out in healthy volunteers aged >18 years. A total of 105 volunteers participated in the study.

CONTACT Fazıl Necdet Ardıç fnardic@pau.edu.tr Department of Otolaryngology, School of Medicine, Pamukkale University, 20070 Denizli, Turkey.

Patients with impaired cooperation, musculoskeletal or systemic diseases, previous ear diseases, symptoms of dizziness, central nervous system pathology, history of ototoxic drug use, and patients for whom the use of glasses could pose a problem (such as epilepsy, vision loss, etc.) were excluded from the study. Ethical approval for the study was obtained from the University Clinical Research Ethics Committee (08.06.2021/No: E-60116787-020-62626). All participants were informed about the procedure and written informed consent was obtained. The study was prospectively registered on Clinicaltrials.gov (NCT05069701).

The commercially available Virtualis® Physio VR system (Virtualis, France) was used for the Subjective Visual Vertical (SVV) test. The system consists of a headset, a computer, and a handheld controller. The headset is the HTC Vive Pro (HTC Corp., Taiwan). The weight of the headset worn by the patient is 1015 g and the weight of the handheld controller is 205 g (we weighed them) (Figure 1).

When patients wear the goggles, they can see an illuminated bar for the static SVV and illuminated dots rotating to the right or left on the background of the bar for the dynamic SVV on the screen (Figure 1). No light enters the goggles. Goggles have a sensor that detects the position of the head. The starting point of the bar can be randomly adjusted to different angles by the computer and the visual background can be rotated at a speed of ±30°/s for the dynamic test.

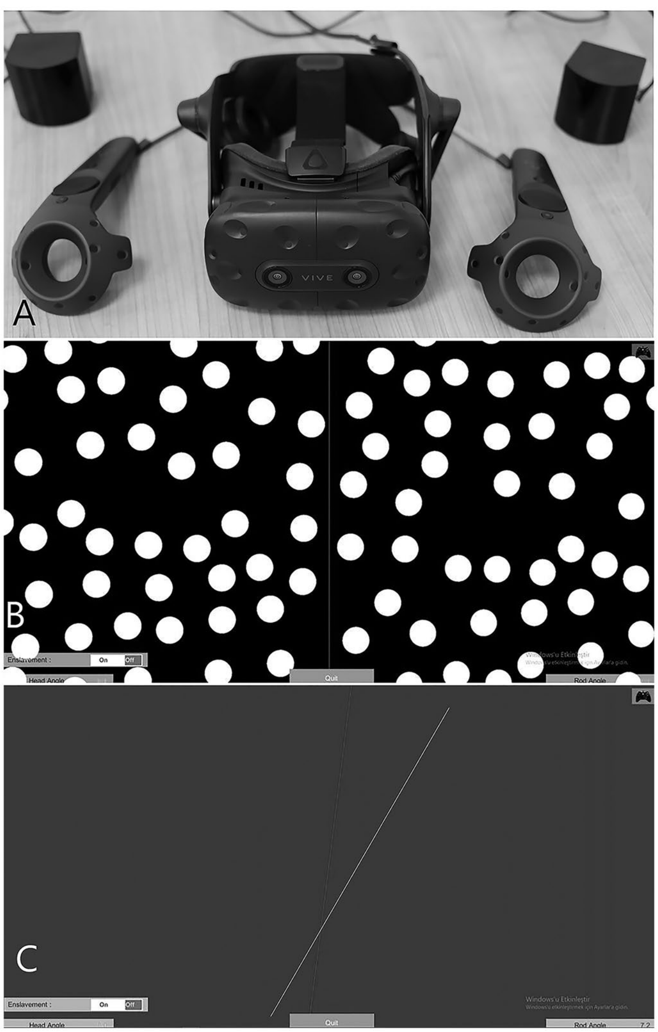

Figure 1. (A) Virtual SVV headset, hand controlers and speakers. (B) Illuminated dots rotating to the right or left on the background of the bar for the dynamic SVV on the screen. (C) Subjects can see an illuminated bar for the static SVV.

The participant adjusts the bar vertically using the left/right arrow signs on the controller. When verticality is confirmed by pressing the central button on the control unit, the computer records the bar's angle and the head's position. Each test was repeated three times at 5-s intervals. After the angles three times, the average value was recorded. SVV tests were carried out while sitting, standing on a firm and foam surface, head turned 45 degrees to the right and left on the yaw axis, the arm holding the controller at 90 degrees and 180 degrees (angle of the elbow), standing on a firm and foam surface with moving visual background (Figure 2).

After the tests, 57 patients completed the Simulator Sickness Questionnaire(SSQ). This questionnaire includes 16 questions that assess symptoms of movement illusion as described by Kennedy et al. [9]. Each question is rated on a scale ranging from 'none' to 'severe' (0–3). Individual scores for each item are then combined into three subscales: Nausea, Oculomotor and Disorientation. Each subscale score is multiplied by a specific constant recommended in the original study to calculate the final subscale scores. The total score is also obtained by adding the three raw scores and multiplying them by a different constant. It is hard to say the normal level of SSQ, but some studies have been conducted to assess VR systems, and the recommended levels were: none (< 5), minimal (5–10), significant (10–15), concerning (15–20) and bad (> 20) [10].

Data were analyzed using SPSS 25.0 (IBM SPSS Statistics 25, Armonk, NY: IBM Corp.). Continuous variables were expressed as mean ± standard deviation or median (minimum-maximum values). The normality of the data distribution was examined using the Shapiro-Wilk test. For the analysis of dependent group differences, if parametric test assumptions were met, the paired samples *t*-test was used; if the assumptions were not met, the Wilcoxon signed rank test was used. Furthermore, Pearson and Spearman correlation analyzes examined the relationships between continuous variables. In all analyzes, $p < .05$ was considered statistically significant.

Results

A total of 105 participants (54 females and 51 males) were included in this study. Three individuals could not complete the test, and one completed it with additional support. A person was excluded due to diplopia. One person voluntarily stopped the trial. The study population decreased to 99 subjects. All participants were subjected to 9 different test combinations. The average age of the participants was 38.68 ± 12.06 years. The test results and statistical comparisons are given in Table 1 and Figure 3.

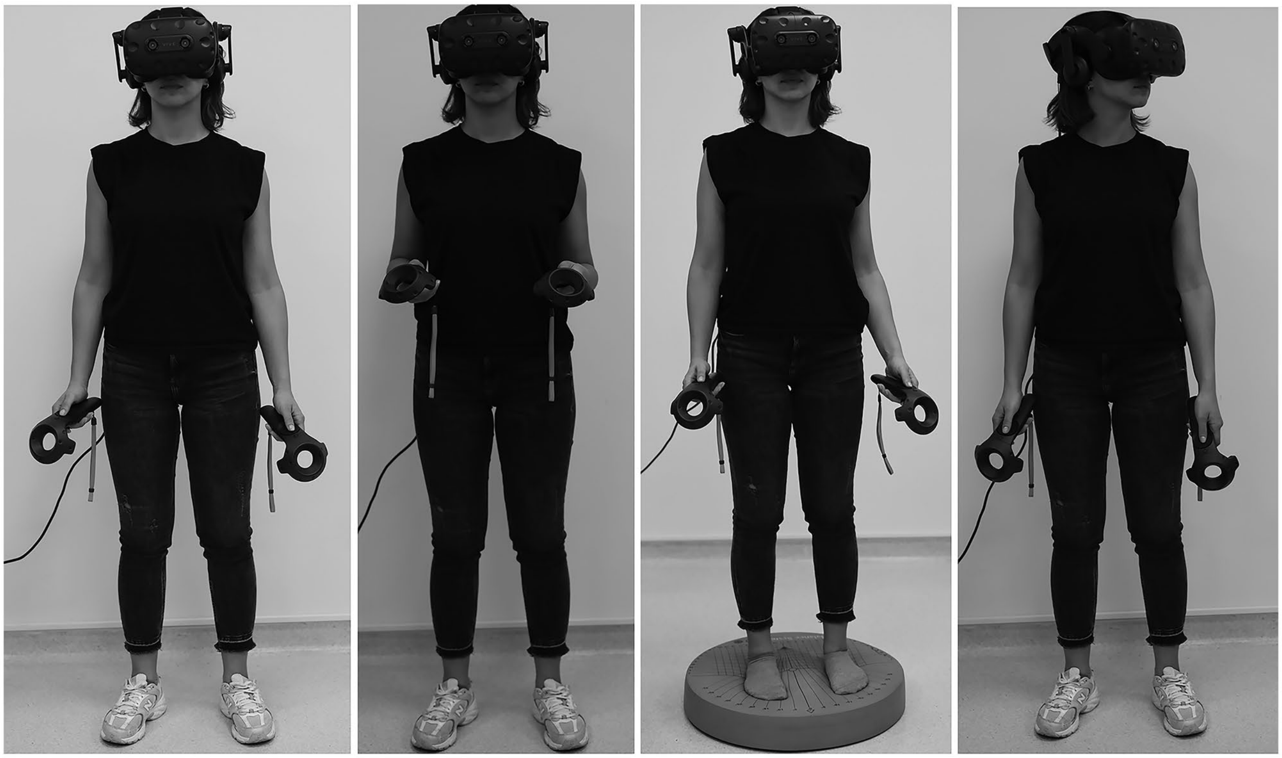

Figure 2. Test conditions: (A) Standing on a firm surface the arm holding the controller at 180 degrees, (B) standing on a firm surface the arm holding the controller at 90 degrees, (C) standing on a foam surface the arm holding the controller at 180 degrees, (D) standing on a firm surface the arm holding the controller at 180 degrees and head turned 45 degrees to the right and left on the yaw axis.

Table 1. Test results are plotted.

		Female	Male	*p* (F vs M)	Total	
	n	53	46		99	
	Age	37.01 ± 10.92	39.8 ± 13.09	0.232	38.31 ± 11.99	SVV comparisons
	SVV tests(m ± std)					
1	Sitting	−0.39 ± 2.04	−0.37 ± 1.47	0.362	−0.38 ± 1.79	Proprioceptive sense $p > .05$
	Standing firm (I)	−0.26 ± 1.69	−0.59 ± 1.72	0.334	−0.42 ± 1.7	
	Standing foam	−0.32 ± 2.02	−0.51 ± 1.87	0.394	−0.41 ± 1.95	
2	Head Neutral (II)	−0.26 ± 1.69	−0.59 ± 1.72	0.334	−0.41 ± 1.7	Head position $p < .01$
	Head right	0.65 ± 2.21	0.2 ± 2.31	0.33	0.44 ± 2.26	
	Head left	−1.32 ± 2.36	−0.92 ± 2.48	0.41	−1.14 ± 2.42	
3	Standing arm 180°	−0.47 ± 1.7	−0.63 ± 2.09	0.689	−0.55 ± 1.88	Arm position $p < .01$
	Standing arm 90°	−0.05 ± 1.92	−0.36 ± 1.91	0.287	−0.13 ± 1.92	
4	Standing firm (III)	−0.26 ± 1.69	−0.59 ± 1.72	0.334	−0.41 ± 1.7	Visual background $p > .05$
	Dinamik firm	−0.01 ± 2.1	−0.09 ± 1.97	0.833	−0.04 ± 2.03	
	Dinamik foam	0.07 ± 2.64	−0.73 ± 2.63	0.132	−0.3 ± 2.65	
	SSQ Scores(m ± std)					
	SSQ Nausea	30.05 ± 31.3	31.97 ± 36.48	0.843	31.29 ± 34.47	
	SSQ Occulomotor	33.35 ± 37.57	30.72 ± 32	0.782	31.64 ± 33.75	
	SSQ Disorientation	66.81 ± 66.46	64.7 ± 67.33	0.910	65.44 ± 55.44	
	SSQ Total	46.18 ± 46.46	45.08 ± 46.22	0.982	45.47 ± 45.89	

p: independent samples *t*-test; SSQ: Simulator sickness questionnaire; SVV: Subjective Visual Vertical.
There is no significant difference between males and females in any test condition. The four main comparisons are; (1) Tests performed while sitting and standing on foam and firm surfaces to change proprioceptive perception were compared. (2) Tests with the head turned 45° to the right and left on the yaw axis were compared with the neutral position. (3) Tests with two different arm positions that hold the controller against gravity. (4) Tests were carried out with a moving background. (Tests abbreviated by numbers I, II, and III are the same test).

Simulator Sickness Questionnaire (SSQ) was administered to 57 individuals (37 males (64.9%) and 20 females (35.1%)) to assess the symptoms experienced after the test. The average age of the participants evaluated for cybersickness was 39.17 ± 12.64. There was no significant correlation between SSQ scores and age, sex, or SVV test results ($p > .05$). Detailed SSQ scores and the distribution of participants according to categories are provided in Table 2. The total scores of the three participants who could not complete the test were 29, 79, and 89, respectively. The disorientation score was significantly higher than the other subscores ($p < .05$). Furthermore, % 70.2 of the subjects fall into the bad category on the disorientation subscore (Table 2).

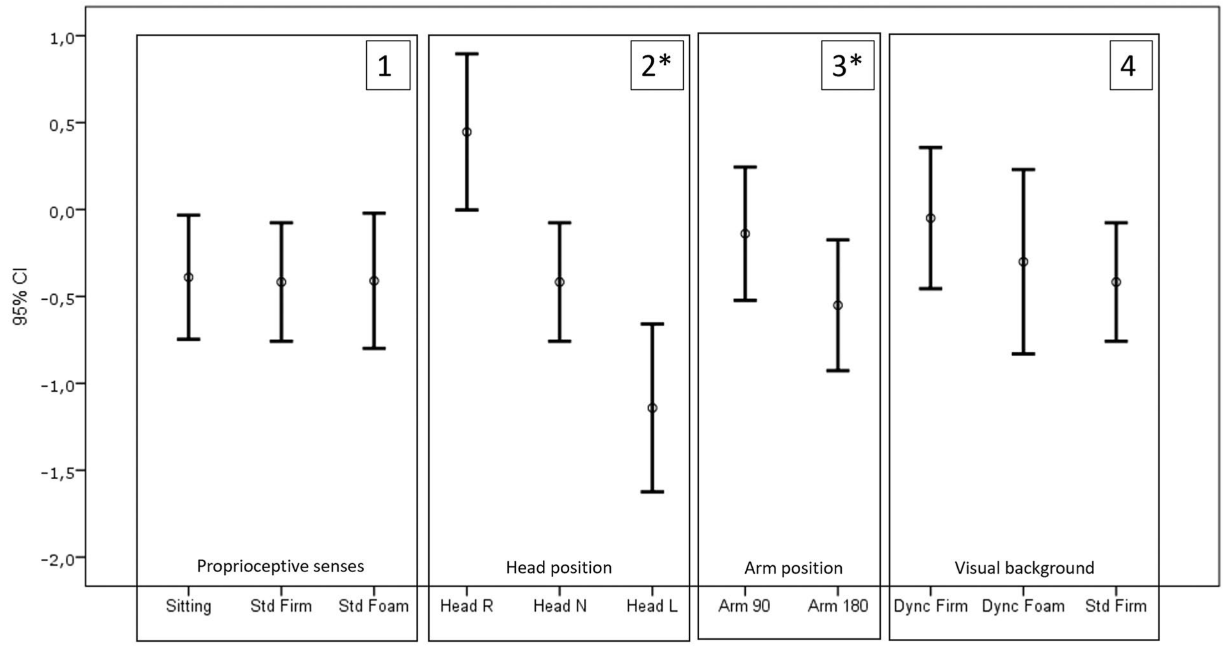

Figure 3. Mean and 95% confidence intervals of all tests. The tests compared are shown in squares together, and their numbers are identical to Table 1. Std: Standing head neutral; R: Right; L: Left; N: Neutral; Dync: Dynamic background; *: Statistically significant.

Table 2. The distribution of subjects into categories is shown in the Table.

	Categorization of SSQ scores (*n*(%))					
SSQ	Negligible (<5)	Minimal (5–10)	Significant (10–15)	Concerning (15–20)	Bad (>20)	*n*
Total score	12(%21.1)	2(%3.5)	5(%8.8)	3(%5.3)	35(%61.4)	57
Nausea	14(%24.6)	9(%15.8)	0	7(%12.3)	27(%47.4)	57
Disorientation	12(%21.1)	0	5(%8.8)	0	40(%70.2)	57
Oculomotor	14(%24.6)	7(%12.3)	0	7(%12.3)	29(%50.9)	57

SSQ: Simulator sickness questionnaire.
Disorientation was the main factor that contributed to the bad category. There was no significant correlation between the SSQ scores and the results of the SVV test. The disorientation score was significantly higher than the other subscores ($p < .05$).

Discussion

This study investigated factors that could affect the results of SVV tests carried out with a 3D virtual reality system. Furthermore, our objective was to determine the presence of symptoms during the test and whether they affected the results. In the standard test position (neutral head position, standing, firm ground), the normal deviation of the SVV is -0.41 ± 1.7. We observed increased deviation angles during the SVV tests with foam surface and dynamic background, but they did not create a statistically significant difference (Figure 1). The head turning on the yaw axis and the arm position holding the controller made a statistically significant difference in the results. There was no difference found between males and females in all tests. The test results did not correlate with age. SSQ scores showed that subjects were significantly affected by cybersickness. However, no correlation was found between the degree of this effect and the test results.

We conducted three tests; sitting position and standing on a firm or soft surface to evaluate proprioceptive stimuli on the plantar surface. We did not observe statistically significant differences among them. In a previous study we published, using a different brand of Virtual SVV, we reported that the deviation angle increased significantly on a soft surface [11]. This could be attributed to the difference in the foam used in both studies. The characteristics of the foam used have been shown to affect the results [12]. On the other hand, Foisy et al. claimed that stimulation of the entire plantar surface did not affect SVV [13]. They reported that only unilateral plantar stimulation affected SVV perception, while bilateral foam application did not affect perception. Furthermore, they found that this effect was absent in individuals with plantar exteroceptive inefficiency. Furthermore, the increase in neck proprioception due to headset weight could be considered a difference between the two studies.

It has long been known that in a structured environment, tilting our head or body on a roll axis at angles smaller than 60 degrees leads to an overestimation of gravity, causing a shift towards the opposite direction (E-effect). On the other hand, tilting at larger angles causes the vertical line to shift toward the bending side (underestimation, A-effect) [14]. Experiments have shown that during prolonged tilt, the E-effect decreases by up to 2 degrees, and the vertical line shifts according to the direction of the head tilt [15]. We used different setups with head tilt on the roll axis for SVV and found the same effect with VR or conventional settings

[1,11]. To our knowledge, there is no study by turning the head on the yaw axis. When wearing a VR headset, the head position can differ from the center position because the subject cannot see the environment. In this study, when the head turned to the left, the mean value was -1.14 ± 2.42; when the head turned to the right, it was 0.44 ± 2.26. This indicates that turning the head on the yaw axis causes the A-effect. This suggests that neck proprioception has an important impact on SVV. Also, the weight of the headset may strengthen this effect. Alghadir et al. designed an experiment to test the impact of body posture on cervicocephalic kinesthesia [6]. They reported that cervicocephalic kinesthesia improved in both the vertical and horizontal planes when the weight of the arms was lifted (with support under the arms while sitting). This indicates that the position of the head is the primary factor in cervicocephalic kinesthesia. In our study, we found that when we changed the holding position of the controller to 90 degrees, the mean test score shifted toward the side where the controller was held. This indicates that holding the controller in a way that allows us to feel its weight changes the proprioception of the neck.

In a study by Zaleski-King et al. significant increases in tilts were observed in SVV tests conducted with a dynamic background [3]. In our study, we observed that the dynamic background increased the deviation of the SVV, and the variability increased more when a soft surface was added. However, no statistically significant differences were observed whether the test was performed on a firm or foam surface.

As VR applications become more widespread, cybersickness emerges as an additional factor that needs to be considered. According to the total SSQ score, 61.4% of the patients reported experiencing symptoms in the SSQ category. The disorientation subscore contributed the most to this picture. No correlation was found between SVV scores, age, sex, and SSQ. The literature reports an average dropout rate of 15%. Four patients were unable to complete the SVV test in our setting. No difference was found between males and females. Cybersickness is distinctly different from motion sickness or simulator sickness, as the sub-scores indicate. Disorientation is the main subscore associated with cybersickness, as in our study [16]. Although SSQ is accepted as a standard measure for cybersickness, it includes disadvantages such as subjectivity and lack of real-time measurement. Therefore, methods using real-time eye and head tracking data have been developed and reported to be 83.4% accurate [17]. Using a neural network model to predict cybersickness even before it happens is possible [18]. Perhaps conducting a study using such methods can reveal the difference between those who have high scores but continue the test and those who quit.

The popularity of studies focused on reducing cybersickness in virtual reality is increasing. However, attempts such as field-of-view reduction, Depth of Field blurring, and adding a rest frame into the virtual environment have proven unsuccessful [19]. On the other hand, technical improvements, such as using 2k plus resolutions for the display or achieving a frame rate have shown promising results in reducing symptoms of cybersickness symptoms [20,21]. All these studies were conducted using complex game programs, whereas the SVV test is simple and typically takes less time compared to our research. The more significant impact of these improvements would be observed in more complex interventions such as rehabilitation programs.

Our goal was to involve healthy individuals as subjects for this study. However, our selection process relied solely on a basic examination and patient history, which could overlook subclinical vestibular issues. Therefore, the absence of comprehensive neurological examinations and vestibular tests posed a limitation in our investigation.

Conclusion

The standard VR SVV data were consistent with previously published normative SVV data. But when transferring the SVV test to a virtual reality environment, different factors should be considered: the headset's weight, head position, and how we hold the controller. A-effect emerged when the head was 45-degree turned to the left and right sides on the yaw axis. In the test carried out with the arm holding the controller at 90 degrees, a significant shift towards the side of the arm was detected. Most subjects felt cybersickness symptoms at a considerable level during the tests. Cybersickness should always be considered in VR studies when planning new applications.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The study registered on clinicaltrials.gov [NCT05069701].

ORCID

Fazıl Necdet Ardıç http://orcid.org/0000-0003-4230-3141
Ulaş Metin http://orcid.org/0000-0001-5517-628X
Betül Ebrar Gökcan http://orcid.org/0009-0008-7702-4111

References

[1] Pinar HŞ, Ardiç FN, Topuz B, et al. Subjective visual vertical and subjective visual horizontal measures in patients with chronic dizziness. J Otolaryngol. 2005;34(2):121–125. doi:10.2310/7070.2005.04014.

[2] Toupet M, Van Nechel C, Grayeli AB. Subjective visual vertical tilt attraction to the side of rod presentation: effects of age, sex, and vestibular disorders. Otol Neurotol. 2015;36(6):1074–1080. doi:10.1097/MAO.0000000000000771.

[3] Zaleski-King A, Pinto R, Lee G, et al. Use of commercial virtual reality technology to assess verticality perception in static and dynamic visual backgrounds. Ear Hear. 2020;41(1):125–135. doi:10.1097/AUD.0000000000000736.

[4] Negrillo-Cárdenas J, Rueda-Ruiz AJ, Ogayar-Anguita CJ, et al. A system for the measurement of the subjective visual vertical using a virtual reality device. J Med Syst. 2018;42(7):124. doi:10.1007/s10916-018-0981-y.

[5] Schuler JR, Bockisch CJ, Straumann D, et al. Precision and accuracy of the subjective haptic vertical in the roll plane. BMC Neurosci. 2010;11:83. doi:10.1186/1471-2202-11-83.

[6] Alghadir A, Zafar H, Iqbal Z, et al. Effect of sitting postures and shoulder position on the cervicocephalic kinesthesia in healthy young males. Somatosens Mot Res. 2016;33(2):93–98. doi:10.1080/08990220.2016.1189895.

[7] Yildirim C. Don't make me sick: investigating the incidence of cybersickness in commercial virtual reality headsets. Virtual Real. 2020;24(2):231–239. doi:10.1007/s10055-019-00401-0.

[8] Kim YY, Kim HJ, Kim EN, et al. Characteristic changes in the physiological components of cybersickness. Psychophysiology. 2005;42(5):616–625. doi:10.1111/j.1469-8986.2005.00349.x.

[9] Kennedy RS, Lane NE, Berbaum KS, et al. Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. Int J Aviat Psychol. 2009;3:203–220. doi:10.1207/s15327108ijap0303_3.

[10] Stanney KM, Kennedy RS, Drexler JM. Cybersickness is not simulator sickness. Proc Hum Factors Ergon Soc Annu Meet. 1997;2:1138–1141. doi:10.1177/107118139704100292.

[11] Ardıç FN, Şentürk M, Çil T. The effect of head roll and soft surface on virtual SVV in healthy subjects: a normalization study. ENT Updates. 2020;10:326–334. doi:10.32448/entupdates.743714.

[12] Patel M, Fransson PA, Lush D, et al. The effect of foam surface properties on postural stability assessment while standing. Gait Posture. 2008;28(4):649–656. doi:10.1016/j.gaitpost.2008.04.018.

[13] Foisy A, Kapoula Z. Plantar cutaneous afferents influence the perception of subjective visual vertical in quiet stance. Sci Rep. 2018;8(1):14939. doi:10.1038/s41598-018-33268-3.

[14] Bjasch D, Bockisch CJ, Straumann D, et al. Differential effects of visual feedback on subjective visual vertical accuracy and precision. PLoS One. 2012;7(11):e49311. doi:10.1371/journal.pone.0049311.

[15] Wade NJ. Effect of prlonged tilt on visual orientation. Q J Exp Psychol. 1970;22(3):423–439. doi:10.1080/14640747008401916.

[16] Saredakis D, Szpak A, Birckhead B, et al. Factors associated with virtual reality sickness in head-mounted displays: a systematic review and meta-analysis. Front Hum Neurosci. 2020;14:96. doi:10.3389/fnhum.2020.00096.

[17] Wang J, Liang H-N, Monteiro D, et al. Real-time prediction of simulator sickness in virtual reality games. IEEE Trans Games. 2023;15(2):252–261. doi:10.1109/TG.2022.3178539.

[18] Islam R, Desai K, Quarles J. Towards forecasting the onset of cybersickness by fusing physiological, head-tracking and eye-tracking with multimodal deep fusion network. In Conference Proceedings - 2022 IEEE International Symposium on Mixed and Augmented Reality, Singapore, Singapore, ISMAR 2022. 2022. p. 121–130.

[19] Shi R, Liang HN, Wu Y, et al. Virtual reality sickness mitigation methods. Proc ACM Comput Graph Interact Tech. 2021;4(1):1–16. doi:10.1145/3451255.

[20] Wang J, Shi R, Xiao Z, et al. Effect of render resolution on gameplay experience, performance, and simulator sickness in virtual reality games. Proc ACM Comput Graph Interact Tech. 2022;5(1):1–15. doi:10.1145/3522610.

[21] Wang J, Shi R, Zheng W, et al. Effect of frame rate on user experience, performance, and simulator sickness in virtual reality. IEEE Trans Vis Comput Graph. 2023;29:2478–2488. doi:10.1109/TVCG.2023.3247057.