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Cardiovascular responses and cybersickness induced by virtual reality in undergraduate medical students.

Respuestas cardiovasculares y cibermareo inducidos por la realidad virtual en estudiantes de medicina.

Peñúñuri Domínguez José Alfredo[1], González Flores Andrea[1], Alvarado Mena Ignacio[1], Hernández Albarrán Nadia Arleth[2], Ariana Cerón Apipilhuasco[3], Jorge Loria Castellano[4], Juan Rodrigo Mendoza Carrillo[5], Teodoro Vite Sergio[6], Fuertes Abascal Begoña[7], Iñigo Cabrejos Rubén Dario[7]

1 Médico General, Universidad Anáhuac México Norte; 2 Ingeniería Biomédica, Universidad Anáhuac México Norte; 3 Directora del Centro Anáhuac de Simulación Clínica, Universidad Anáhuac México. 4 Profesor, Centro Anáhuac de Simulación Clínica, Universidad Anáhuac México. 5 Médico General, Coordinador General del Comite de Residentes, RENASIM. 6 Doctor en Ciencia e Ingeniería en Computación. 7 Profesor Adjunto, Centro Anáhuac de Simulación Clínica, Universidad Anáhuac México.

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Abstract.

Introduction: Virtual reality (VR) is an emerging technological and educational resource that is increasingly being used in medical education for the development of technical skills through an immersive environment. VR has shown clinical benefits in reducing perioperative anxiety in patients and also allowing educational experiences to pregrade students on different topics like anatomy and basic life support training. Even though VR has benefits, adverse effects such as cybersickness have been reported, with limited evidence regarding the exposure time for onset and its physiological impact. Measuring and analyzing these parameters is important to establish safe exposure times for VR simulations. **Objective**: Evaluate changes in heart rate, blood pressure, and cybersickness symptoms after a 15-minute exposure to a VR environment (Anatomy and Physiology Lab on META Quest 2) in pre-graduate medical students, by comparing physiological parameters and applying the Simulator Sickness Questionnaire (SSQ) before and after immersion. **Methods**: Observational, descriptive, cross-sectional study in which vital signs (heart rate, respiratory rate, and blood pressure) were recorded before and after exposure to a VR environment. The qualitative data were analyzed using frequencies and percentages, and the quantitative data with medians and ranges. Chi-square and Student's t tests were applied to assess differences between time points. **Results**: No significant changes were found in heart rate ($p = 0.1754$). Respiratory rate increased after exposure ($p = 0.0017$), as did systolic blood pressure ($p = 0.0329$), while diastolic pressure remained unchanged ($p = 0.7025$). Regarding cybersickness, symptoms occurred in 20% of participants, with no association to VR experience ($p > 0.05$). **Conclusions**: VR exposure may increase respiratory rate and systolic blood pressure without affecting heart rate. Further research is needed to determine optimal immersion duration and predisposing factors that may contribute to adverse effects in order to ensure a safe and effective immersive experience in medical education.

Keywords: Immersive Learning, Medical Education, Virtual Reality, Augmented Reality, Cybersickness, Simulation

Resumen.

Introducción: La realidad virtual (RV) es una herramienta educativa innovadora en crecimiento dentro de la formación médica, que permite el desarrollo de habilidades técnicas mediante entornos inmersivos. Además, ha demostrado utilidad clínica en la reducción de la ansiedad perioperatoria en pacientes adultos y pediátricos. Sin embargo, la literatura también describe efectos adversos asociados a la exposición a RV, sin definir con claridad el tiempo de inmersión necesario para su aparición ni su impacto en los signos vitales. Evaluar estos parámetros es esencial para establecer umbrales seguros de exposición y promover su uso informado en programas académicos. **Objetivo**: Evaluar los cambios en frecuencia cardíaca, presión arterial y síntomas de cybersickness tras una exposición de 15 minutos a un entorno de RV —Anatomy and Physiology Lab en lentes META Quest 2— en estudiantes de medicina, mediante la comparación de los parámetros fisiológicos y la aplicación del Simulator Sickness Questionnaire (SSQ) antes y después de la inmersión. **Metodología**: Estudio observacional, descriptivo y transversal, aprobado por el comité de investigación. Se registraron signos vitales (frecuencia cardíaca, frecuencia respiratoria y tensión arterial) antes y después de la exposición. Las variables cualitativas se analizaron con frecuencias y porcentajes, y las cuantitativas con medianas y rangos. Se aplicó Chi cuadrada para diferencias de proporciones y prueba t de Student para comparar medias entre momentos. **Resultados**: No se observaron cambios significativos en la frecuencia cardíaca ($p = 0.1754$). La frecuencia respiratoria aumentó tras la exposición ($p = 0.0017$). Se registró un incremento en la presión arterial sistólica ($p = 0.0329$), sin cambios en la diastólica ($p = 0.7025$). El 20% de los participantes reportó síntomas de cybersickness, sin relación con la experiencia previa en RV ($p > 0.05$). **Conclusiones**: Una exposición breve a RV puede inducir aumentos en la frecuencia respiratoria y la presión arterial sistólica, sin modificar significativamente la frecuencia cardíaca. Se requieren estudios adicionales para determinar la duración óptima de inmersión y los factores predisponentes a efectos adversos, con el fin de garantizar una implementación segura en educación médica.

Palabras clave: Aprendizaje Inmersivo, Educación Médica, Realidad Virtual, Realidad Aumentada, Cybersickness, Simulación

1. Introduction

Virtual reality (VR) is a relatively new and cutting-edge learning educational resource that is currently expanding in the medical field. It is used in the educational context to train personnel in the development of specific technical skills through immersive scenarios (1). However, VR has also been used in clinical settings to help reduce perioperative anxiety in both adult and pediatric patients (2).

The origins of virtual reality (VR) date back to the 1920s, when Edward Link developed the Link Trainer, also known as the "Blue Box," a mechanical flight simulator used to train pilots in the U.S. military aviation sector. The link trainer enabled practicing in a well-controlled and safe environment. Years later, in 1957, Morton Heilig introduced the Sensorama, a machine that offered a multisensory experience using 3D images, sound, vibrations, and even scents, in order to create a total user immersion. Later in 1960, Heilig patented the Telesphere Mask, which is considered the first wearable display and also the precursor to VR headsets known today (5).

Virtual reality (VR) can be an immersive or non-immersive experience, depending on the degree of physical isolation from the real environment (1). This resource has been implemented in recent years in various areas such as medical education, as innovative teaching methods have gained particular relevance for both students and instructors (6-7). However, one of the most frequently documented adverse effects of VR use is cybersickness, which is a type of motion sickness caused mainly because of a mismatch between visual and vestibular stimuli due to the total immersion. Cybersickness can manifest symptoms like dizziness, nausea, blurred vision, cold sweating, and fatigue; the intensity of the latter symptoms varies according to exposure duration, virtual content, and individual user characteristics (4). It has been described in the literature that individuals with a present history of migraine, anxiety, or vestibular disorders show more susceptibility than patients with a negative present history to the latter conditions. Due to these facts, it is necessary to establish inclusion and exclusion criteria in research protocols using VR (8-9).

Vital signs are physiological parameters that reflect the general clinical state of the body, obtained through objective and punctual measurements (10-11). The vital signs described in the literature include heart rate, respiratory rate, blood pressure, oxygen saturation, temperature, and pulse. Each has normal parameters and a specific method of measurement. They are routinely recorded in healthcare since simple measurements can provide valuable information about a person's health status (12). However, vital signs can also be influenced by non-pathological conditions such as emotional experiences or daily activities (e.g., exercise, sleep, and eating). The sympathetic and parasympathetic nervous systems are responsible for the regulation of latter parameters using internal and external stimuli perception to maintain systemic equilibrium (18). This study focuses mainly on evaluating heart rate and blood pressure.

Despite the benefits of virtual reality, there are still some limitations, mainly because of the possible adverse effects that have been identified. These side effects are associated with prolonged use (4). Currently, the most frequently reported side effects in the literature are visual disturbances, disorientation, postural instability, nausea, and headache, collectively known as cybersickness.

Cybersickness is a term used to describe the adverse effects experienced while using virtual reality (VR). In 1995, the concept of cybersickness was introduced by Kay Stanney (13). As stated above, cybersickness symptoms may include headaches, nausea, postural desorientation, instability, dizziness, vomiting, drowsiness, general discomfort, visual fatigue, difficulty focusing, increased salivation, sweating, difficulty concentrating, lightheadedness, and blurred vision (14). The severity of cybersickness is measured using validated rating scales such as the Simulator Sickness Questionnaire (SSQ). Created in 1993, the SSQ is the most widely used tool for this purpose. It consists of 16 symptoms grouped into three domains: Nausea (SSQ-N), Oculomotor Symptoms (SSQ-O), and Disorientation (SSQ-D). Each symptom is rated on a Likert scale from 0 to 3 (0 = absent, 1 = slight, 2 = moderate, 3 = severe). Total SSQ scores range from 0 to 235.62, with higher scores indicating more severe disturbances. For each domain, scores between 5–10 indicate minimal symptoms, 10–15 significant, 15–20 concerning, and above 20 severe symptoms (15-16).

In the present study, the authors aimed to evaluate changes in heart rate, blood pressure, and cybersickness symptoms after a 15-minute exposure to a VR environment (Anatomy and Physiology Lab on META Quest 2) in pre-graduate medical students, by comparing physiological parameters and applying the Simulator Sickness Questionnaire (SSQ) before and after immersion. We hypothesize that a 15-minute exposure to a virtual reality immersive experience on an Anatomy and Physiology Lab (META Quest 2) will produce an effect in heart rate, blood pressure, and cybersickness symptoms, evidenced by measurable differences in physiological parameters and Simulator Sickness Questionnaire (SSQ) scores before and after immersion.

2. Methods

Following approval from the Ethics Committee of the Universidad Anáhuac México for educational research (Approval number: Folio 202538), a descriptive, cross-sectional observational study was conducted. We included only undergraduate medical students who were invited to participate after providing written informed consent and acknowledging a confidentiality agreement to protect personal data. During the study, the participants did not receive any compensation for participating, and sensitive data was not collected. Every participant could withdraw their participation at any point of the study, and in case it was related to cybersickness, the proper medical attention was provided.

Participants included students aged 18 to 30 years who were enrolled in the courses Anatomy or Clinical Anatomy. Our exclusion criteria were: a past or present history of any vestibular disorders (e.g., benign paroxysmal positional vertigo), any uncorrected visual impairments requiring corrective lenses, and refusal to sign the informed consent form. Any participant experiencing adverse effects during the procedure was withdrawn.

Our protocol was implemented in the Clinical Simulation Center, which was equipped with exploration rooms for measuring vital signs before and after VR exposure. These assessments were conducted by medical interns completing their social service at the simulation center before instructor supervision. For the virtual reality exposure, we used the commercial VR headset "Meta Quest 2." We used the application Anatomy and Physiology Lab, offering a 360-degree interactive experience focused on human anatomy, cardiac physiology, and skeletal structures. In order to evaluate pre-post-exposure responses, participants were asked to complete the Simulator Sickness Questionnaire (SSQ) via Google Forms based on the Spanish validated tool (15). The data we collected using the Google Forms was demographic information, vital signs before VR exposure, vital signs after VR exposure, pre-existing symptoms assessed via the SSQ and post-exposure symptoms reassessed using the SSQ.

Hemodynamic measurements were obtained using a Beurer PO30 digital pulse oximeter (61 × 36 × 32 mm) to assess oxygen saturation (SpO_2) and heart rate. Blood pressure was measured using a Welch Allyn WADS44-11 aneroid sphygmomanometer, with a certified accuracy of ±3 mmHg. Auscultation was performed with a 3M Littmann® Classic III stethoscope (acoustic rating of 7, 69 cm in length).

Participants first completed the demographic questionnaire—baseline vital signs, including heart rate, respiratory rate, and blood pressure. Each participant then experienced a 15-minute individual VR session using the Anatomy and Physiology Lab. During this time, a research team member guided them through anatomical content, helping identify structures such as bones, heart chambers, and the heart's electrical conduction system. Participants were also oriented on how to navigate the application's menus and tools. Once the academic session, participants were instructed to remove the headset carefully to minimize potential side effects such as dizziness, blurred vision, or diplopia. A second set of vital signs was recorded, and the final section of the SSQ form was completed.

The statistical analysis included a Student's t-test to assess changes in vital signs, a point-biserial correlation to examine relationships between blood pressure changes and VR exposure, and a chi-square test to explore associations between VR use and reported adverse effects. All analyses were conducted using Microsoft Excel.

3. Results

We recorded the vital signs of 80 participants who were analyzed before and after exposure to VR, including heart rate (HR), respiratory rate (RR), and blood pressure (BP). None of the participants presented any medical condition contraindicated VR exposure. Five participants were excluded because of elevated BP readings during the pre-exposure vital sign assessment. The final sample size for statistical analysis was 75 participants.

Demographic data showed that the mean age of participants was 26.5 years (SD = 9.22; range 21–76). Female participants represented 54.66% of the sample (n = 41), and Male participants represented 45.34% of the sample (n = 34). Additionally, 43.75% reported a history of corrective lens use (glasses or contact lenses) (n = 35).

The statistical analysis using the Student's t-test showed that the mean baseline HR was 73.09 beats per minute (bpm) (SD = 10.33), while the post-VR intervention mean HR was 74.72 bpm (SD = 11.74). No statistically significant difference was observed between the two measurements (p =

0.1754), suggesting that the VR intervention did not have a significant effect on this parameter with this kind of academic immersion.

The mean baseline RR was 14.21 breaths per minute (SD = 2.57), which increased to 15.5 breaths per minute (SD = 3.07) following VR exposure. The Student's t-test demonstrated a statistically significant difference ($p = 0.0017$), indicating that the intervention had an effect on this parameter.

On the other hand, for blood pressure, the baseline systolic and diastolic BP means were 113.53 mmHg (SD = 9.75) and 77.18 mmHg (SD = 8.12), respectively. After the intervention, the mean systolic BP increased to 116 mmHg (SD = 11.0), while the mean diastolic BP was 77.53 mmHg (SD = 7.5). Statistical analysis of systolic BP revealed a significant difference ($p = 0.0329$), whereas diastolic BP showed no significant change ($p = 0.70$) (figure 1).

A point biserial correlation test was used to evaluate the relationship between prior experience with VR and the difference in BP before and after the intervention. The biserial correlation coefficient (r) was 0.1510; this finding suggests a weak positive relationship between the two variables; however, this relationship was not statistically significant ($p = 0.31$).

Another variable we analyzed was the presence of symptoms following VR exposure. The majority of participants reported no symptoms (n = 65). Only 18.75% (n = 15) of participants reported any symptom associated with VR exposure. The most frequently reported symptoms were visual fatigue (n = 8) and dizziness (n = 7), as shown in table 1.

Table 1. SSQ Symptoms Cuestionnaire - General Overview of Symptoms Frequency.

Item	Symptom	Subscale	Participants (n)	Percentage
1	General Discomfort	N	7	8,75%
2	Warmth	N	0	0,00%
3	Nausea	N	0	0,00%
4	Stomach discomfort	N	0	0,00%
5	Sweating	N	0	0,00%
6	Head heaviness sensation	O	0	0,00%
7	Visual fatigue	O	8	10,00%
8	Difficulty focusing	O	0	0,00%
9	Headache	O	0	0,00%
10	Blurred vision	O	0	0,00%
11	Increased salivation	N	0	0,00%
12	Dizziness when moving the head	D	0	0,00%
13	Dizziness when moving the body	D	0	0,00%
14	Disorientation	D	0	0,00%
15	Postural instability	D	0	0,00%
16	Loss of balance	D	0	0,00%
17	No Symptoms	--	65	81,25%
				100,00%

A chi-square test was conducted to assess the relationship between prior VR experience and the occurrence of adverse effects. No statistically significant association was found between the two variables, $\chi^2(1, N = 75) = 0.47$, $p = 0.49$, indicating that prior experience with VR did not influence the likelihood of experiencing adverse effects during the intervention (figure 2).

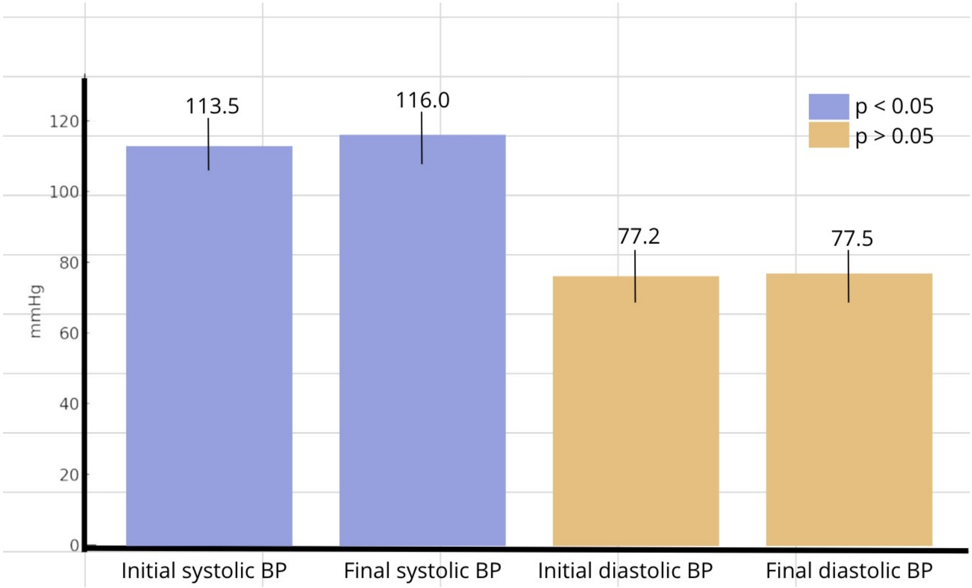

Figure 1. Comparison of Blood Pressure before and after the VR intervention.

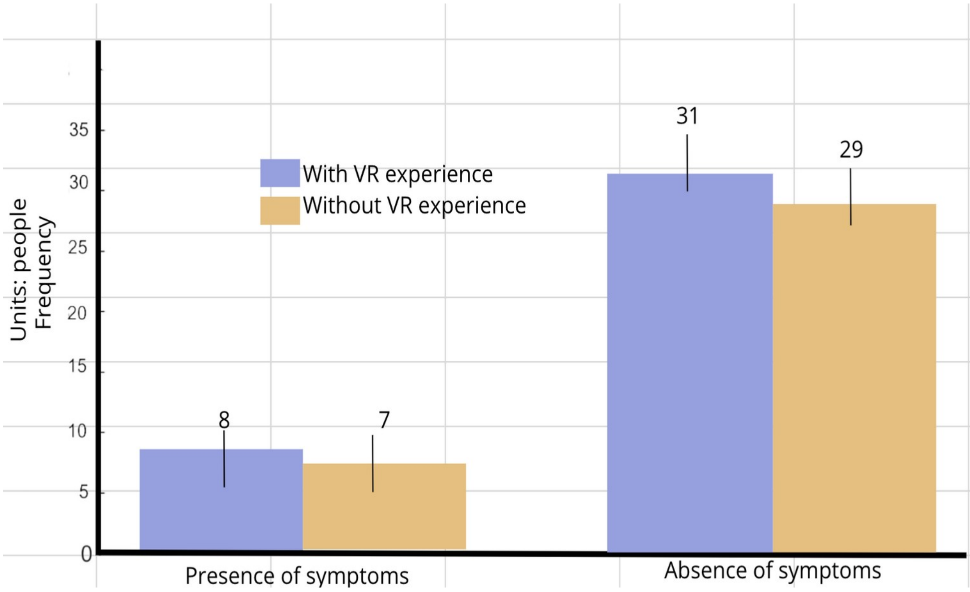

Figure 2. Frequency of symptoms associated with previous VR experience.

4. Discussion

Our findings align with those reported by Yoon Sang et al. (13), These authors investigated the physiological effects of cybersickness induced by Virtual Reality (VR) using head-mounted devices. However, their study involved the development of a VR experience specifically designed to provoke cybersickness, featuring a first-person view of an aircraft flying over a city on a fixed trajectory rather than academic immersion as we did. Their simulation included both translational and rotational movements, with an emphasis on the latter, particularly combined multi-axis rotation, due to prior evidence suggesting that such motions significantly increase dizziness. Yoon Sang et al study included 16 university students as participants (8 men and 8 women), all of whom were screened before the VR simulation to exclude any history of neurological, autonomic, or visual disorders. They considered that to reduce the likelihood of cybersickness, participants should get at least eight hours of sleep before the experiment. Their results confirmed that participants experienced notable cybersickness. Post-exposure SSQ scores increased significantly across all subscales, with disorientation as the main and most frequent symptom of cybersickness. This outcome mirrors findings from earlier studies, which have identified disorientation as a key symptom of visually induced motion sickness. Togenter with physiological disturbances, a statistically significant increase in heart rate was observed, with the average rising from 78.06 to 83.50 beats per minute. This response was interpreted as a stress reaction linked to the experience of cybersickness due to the kind of immersion the participants were exposed to. In contrast, both systolic and diastolic blood pressure decreased significantly, systolic dropping from 130.81 mmHg to 117.31 mmHg, and diastolic from 76.69 mmHg to 67.50 mmHg. Interestingly, this decline runs counter to typical stress-related cardiovascular responses, which usually involve concurrent elevations in both heart rate and blood pressure. Ultimately, they concluded that VR-induced disorientation can have measurable physiological effects, particularly on cardiovascular variables such as heart rate and blood pressure, reinforcing the importance of understanding cybersickness as a systemic physiological condition.

Regarding the cybersickness symptoms in VR users, Simón-Vicente et al published a systematic review (14). Across the ten included studies in the systematic review (416 participants), disorientation was the most frequent and severe adverse effect, followed by nausea and oculomotor disturbances. These findings align with the classical symptom clusters described in the foundational SSQ work by Kennedy et al. (16).

In our study, a 15-minute academic VR immersion using Meta Quest 2 was associated with a statistically significant increase in respiratory rate and systolic blood pressure, while heart rate remained unchanged, suggesting mild autonomic stimulation without clinically relevant cardiovascular instability symptoms. Cybersickness-related symptoms were reported only by a minority of participants (<20%), predominantly visual fatigue and dizziness, with no nausea or gastrointestinal complaints, indicating good tolerability of short educational VR exposure. These findings align with the exploratory comparative study by Taylor and Layland, in which 360-degree VR video produced no greater self-reported cybersickness symptoms than common non-VR simulation modalities (high-fidelity manikin, standardized patient, and video case study), supporting the notion that cybersickness may not represent a major barrier to VR adoption in undergraduate healthcare curricula. (17). Their results also indicated higher fatigue in non-VR conditions compared with VR, suggesting that immersive learning may be perceived as less fatiguing under certain pedagogical designs.

In addition to our results, these data support that the integration of structured, short-duration VR sessions into medical education are safe while also highlighting the value of combining subjective cybersickness assessment with objective physiological monitoring to better define exposure thresholds and identify susceptible subgroups. Recent evidence by Pawełczyk et al. using a comparable seated 15-minute Meta Quest 2 protocol reported significant yet predominantly mild cybersickness symptoms (notably eye strain, general discomfort, and headache), while maintaining moderate spatial presence and flow, suggesting that minor discomfort may coexist with an important engagement (17).

Limitations

This study presents limitations that should be considered. Although the sample size of 75 participants provides useful preliminary insights, it may still be insufficient to fully capture the variability in all the parameters we are discussing. There is a lack of group control; all individuals in the sample were evaluated using the same procedures.

The VR experience used in this study involved academic immersion rather than a simulation specifically designed to induce cybersickness. As a result, the intensity of sensory conflict may have been lower compared with other studies.

5. Conclusions

- With a total sample of 75 pre-grade students as participants, our analysis of vital signs revealed that respiratory rate showed a statistically significant change before and after VR exposure. Our findings also suggested a possible correlation with systolic blood pressure, which also demonstrated statistical significance.
- The post-experience symptoms support the hypothesis that VR does not produce major adverse effects beyond visual fatigue and dizziness after prolonged use. This states the need to develop longitudinal studies that could further determine the extent of physiological adaptation following repeated exposures to an immersive environment in adults and even children.
- VR technology is here to shape the new ways of creating educational environments; therefore, it is important to learn and measure how its use impacts our bodies and the adverse effects it might bring to people after long exposure. VR is an exceptional tool for education, not only because of the wide variety of immersions it can hold, but also because of its accessibility in comparison with normal high-fidelity simulation costs and the need of having a simulator center.
- To minimize the occurrence of cybersickness during VR-based academic activities, we make the following recommendations:
    - Gradual exposure and adaptation: students should be introduced to VR progressively, beginning with short sessions and gradually increasing exposure time.
    - Stable visual references and reducing visual-vestibular conflict.
    - Regular calibration of equipment is essential. We recommended using VR devices with high refresh rates, low latency, and good image resolution.
    - Short pauses every 10 to 15 minutes can help alleviate early symptoms.
    - Environmental adjustments: VR use should take place in quiet, well-ventilated rooms with enough space to move safely.

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