Neural Control of Movement

Additional acute effects of virtual reality head-mounted displays on balance outcomes in non-disabled individuals: a proof-of-concept study

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Abstract - Aim: This study aims to evaluate the additional acute effect of virtual reality (VR) head-mounted displays (HMD) when associated with balance exercises in balance outcomes in non-disabled individuals. **Methods:** Thirty individuals were randomized into two groups: balance exercise group (GBE; n = 15); and virtual reality + balance exercise group (GVR + BE; n = 15). The individuals were evaluated by static and dynamic balance using the tandem test (TT), single-leg stance (SLS), and Fukuda stepping test (FST). Both groups performed 30 min of balance exercises. The GVR + BE performed 8 additional minutes of virtual reality prior to balance exercises. A roller coaster application was used for the HMD. The Mann-Whitney test was used for intra-group and differences of inter-group analysis, considering a significance level of $p < 0.05$. **Results:** In the GBE group analysis, there was observed an increase of time in TT with closed eyes ($p = 0.025$) and SLS with closed eyes ($p = 0.003$). In the same way, the GVR + BE group increase TT with closed eyes ($p = 0.003$) and SLS with closed eyes ($p = 0.002$) after the intervention. In the intergroup analysis, the increase in the SLS with closed eyes was superior in the GVR + BE group when compared with GBE ($p = 0.006$; $d = 1.67$). **Conclusion:** The use of HMD in combination with balance exercise has an acute effect on increasing static balance in non-disabled individuals.

Keywords: balance, rehabilitation, physical therapy, virtual reality, non-disabled individuals.

Introduction

Postural control involves the coordination of sensory-motor strategies to stabilize the body mass center during postural instability[1,2] and can be altered by somatosensory demands[3,4]. The influence of sensory input or integration of multisensory inputs of postural control was widely investigated[5-8]. Chiba et al.[5] showed that the neural controller might regulate muscle control in a situation where one or several sensory inputs are inhibited to keep the balance during standing. Multisensory reweighting of visual, vestibular, and somatosensory inputs allows us to maintain balance as environmental conditions change[6]. Allison et al.[7] reported that sensory reweighting exercises by manipulating surface and visual conditions would benefit postural stability in adults[8].

One of the ways of reweighting multisensory inputs in non-disabled individuals is through the use of immersive virtual reality (VR) by somatosensory and visual conflict. VR is the name given for virtual experiences through head-mounted displays (HMD) and consoles with this kind of technology, which allow maximum interactions similar to real ones. VR with two-dimensional presentations is considered non-immersive. Three-dimensional presentations utilizing stereoscopic projections or displays with a fixed visual perspective are considered semi-immersive. Fully immersive systems allow for changing visual perspective with head movement[9-11].

Several authors discuss the use of balance training interventions using VR in a variety of populations. In a study on non-disabled participants, visual stimuli that produced a conflict with simultaneous somatosensory and vestibular signals generated by horizontal motion elicited more accurate postural corrections[12]. Streepey et al.[13] described an increased effect of visually simulated motion on postural responses when the subject base of support was decreased, making them more dependent on the erroneous, simulated visual information. However, negative results of using fully immersive systems were observed in some studies, such as nausea and dizziness in longer exposure[14] and motion sickness due to visual-vestibular conflict[15].

Virtual environments can manipulate the specificity and frequency of visual and auditory feedback and can affect motor, perceptual, and cognitive functions[16]. Thus, it provides a tool that can be used to harness the nervous system's capacity for sensorimotor adaptation. In addition to having real-time multisensory feedback, it provides great variation, progression, and repetitive and task-oriented training[15]. The environment provided by HMD can induce the reorganization of neural plasticity and improve motor abilities[16,17]. VR-HMD systems can offer ecologically valid scenarios to assess and train functional balance and can be used alone or in addition to other interventions[18]. However, the additional effects of VR-HMD on a specific balance exercise program are little explored in the literature. In addition, there is no minimum time established in the literature to avoid adverse effects, and at the same time to verify outcomes improvement in non-disabled individuals.

Therefore, this study aims to evaluate the additional acute effect of VR-HMD when associated with balance exercises in postural control in non-disabled individuals. The null hypothesis (H0) of this study is that the HMD associates with balance exercises will not modify the static and dynamic balance in the non-disabled individuals. However, the alternative hypothesis (H1) of the study is that HMD associated with balance exercise will modify static and dynamic balance in these individuals. Therefore, if it confirms the alternative hypothesis, it can be important as a therapeutic guide to clinical decision-making.

Methods

Study design, setting, and participants

This is a proof-of-concept study with two arms in 30 non-disabled individuals. The individuals were randomly assigned to the Center of Rehabilitation of Faculty of Human Talent and subjected to static and dynamic balance evaluation conditioned in three treatment groups: 1) GBE: treatment with conventional balance exercises (15 individuals); GVR + BE: treatment with HMD and conventional balance exercises (15 individuals). This research was approved by the Ethics Committee on Human Research at the Faculty of Human Talent (0023/2018), and written informed consent was obtained from the participants of this study.

Sample size calculation

Based on the sample size calculation, 30 individuals should be included, 15 in each group. The parameters used were test power 80%, the significance level of $p < 0.05$, and Cohen effect size 0.90. The sample size calculation was performed in G*Power 3.1 software.

Inclusion criteria

We included non-disabled individuals without vestibular dysfunction (absence of nystagmus in the Dix-Hallpike and supine roll tests); without cognitive alterations (Mini-Mental State Examination according to education); with ocular motility integrity; no visual sensory disturbances (>6 in the Snellen test); no auditory alterations (no alterations in the tuning fork tests); the bilateral presence of symmetrical tactile, thermal, and painful sensations in comparison to the two feet; and no history of lower limb fractures and lesions in the control system of balance, such as the brainstem and cerebellum.

Exclusion criteria

Subjects were excluded from participation if they had a known history of balance impairment (for any reason); peripheral neuropathy (clinically diagnosed or if they had symptoms of numbness/tingling in the lower extremities); orthopedic lower extremity or lumbosacral conditions requiring consultation with a health care professional (to include ligamentous injuries, osteoarthritis, or joint replacement); the pain of any level presenting simultaneously in both lower extremities; or unilateral lower extremity pain. Pregnant women were also excluded.

Randomization and blinding

The concealed randomization schedule was established using a computer-generated random number sequence and maintained by an off-site investigator who was neither involved with the enrollment nor with the assessment of study participants. A second research assistant then opened consecutively numbered, randomly ordered, opaque envelopes containing the group allocation (in a 1:1 ratio) after the baseline assessment.

Data sources/measurement

The following tests were used for static balance evaluation[19,20]:

Tandem test (TT)

The subject stood upright on a 60 × 60 × 7.5-cm piece of foam, which had a density of 28 kg/m^3 with one foot in front of the other forming a straight line, remaining in position for 30 s with eyes open (with visually focus on a dot marked 1.5 m away at eye level) and 30 s with eyes closed. A Technos Digital Quartz® chronometer was used to mark the time. The test was interrupted if the support base was changed. The individual had three opportunities to perform the test, with the highest time being chosen.

Single leg stance test (SLS)

In the upright position, the subject was placed in a single leg position with arms resting at their sides on a 60 × 60 × 7.5-cm piece of foam, which had a density of 28 kg/m^3, without letting their legs touch each other, remaining in position for 30 s with eyes open (with visually focus on a dot marked 1.5 m away at eye level) and 30 s with eyes closed. A Technos Digital Quartz® chronometer was used to mark the time. The test was discontinued if there was a change in the support base. The individual had three opportunities to perform the test, with the highest time being chosen.

To evaluate the dynamic balance, the following test was used:

Fukuda stepping test (FST)

Three concentric circles were drawn on the ground. These circles were divided into 12 equal parts by straight lines crossing the center, forming an angle of 30°. The patient performed a stationary gait, raising the knees approximately 45° without moving, running 50 steps (one per second) with the shoulder at 90°, and blindfolded. At the end of the test, the rotation angle was noted in degrees[21,22].

Interventions

Balance training was performed in only a single session, with an average duration of 30 min in all groups. The individual was subjected to an initial evaluation of the balance tests, and after the intervention, the tests were repeated for static and dynamic balance evaluation.

GBE

Treatment with conventional balance exercises for 30 min. The individuals performed two types of exercises: static and dynamic balance exercises, modified from Silsupadol et al.[10]. Static balance training consisted of the following: (a) standing with feet apart with eyes open, followed by placing feet together; (b) standing with feet apart with eyes closed; (c) standing with the dominant foot in front of the other foot (or tandem posture); (d) disturbance during the standing position; and (e) standing on a firm surface (e.g., wooden floor or cement) or unstable surface (e.g., foam, grass, or sand). The protocol under dynamic balance training conditions consisted of (a) the double support stance on a firm surface while holding a glass of water, (b) tandem posture while rotating hand quickly, and (c) playing and receiving a ball while standing. Two dynamic tasks, that is, reaching and throwing the ball, increased the balance function in the anteroposterior and mid-lateral directions. The subjects ended the training with a circuit with small obstacles, as well as balance activities (unipodal support and unipodal squatting) on the level and uneven surfaces.

GVR plus balance training

The intervention consisted of an immersive VR application, which utilized a VR box play (Shenzhen Ginotech Technology Co., Ltd) and earphones in a dark room. An iPhone 8 Plus was used in the VR box to perform the 3D SBS VR roller coaster game application. The game consists of high-flow images projected from a roller coaster in different directions. The environment was composed of roller coaster tracks, people in a grandstand, and natural vegetation. Each individual watched the simulation for 8 min in full HD VR in an upright position while standing on a 60 × 60 × 7.5-cm piece of foam, which had a density of 28 kg/m^3. The piece of foam (unstable surface) was used to increase the activation of the vestibular system. After VR applications, the balance exercises described above were applied for 30 min.

Static and dynamic balance evaluation was reassessed immediately after interventions.

Statistical methods

The data are presented as the average and standard deviation for the numerical data and percentage for categorical data. A normality test was performed using the Shapiro-Wilk test, assuming an asymmetric pattern. Non-Parametric tests were used to compare the groups. The Mann-Whitney test was used for intra-group analysis (before and after intervention in the same group). The differences of inter-group (after intervention values minus baseline values; ΔGBE x ΔGVR + BE) were performed by Mann Whitney test. The effect size was also calculated and defined as Cohen's D: small (0,20-0,49), moderate (0,50-0,79), and large (> 0,80). Data were analyzed using GraphPad Prism version 8 (La Jolla, CA, USA, www.graphpad.com) and were considered statistically significant at $p < 0.05$.

Results

Baseline data of included participants are shown in Table 1. No adverse events were reported in this study.

Table 2 showed the intra-group and inter-group balance outcomes analysis. In the GBE group analysis, we observed an increase of time in TT with closed eyes ($p = 0.025$) and SLS with closed eyes ($p = 0.003$). In the same way, the GVR + BE group increase TT with closed eyes ($p = 0.003$) and SLS with closed eyes ($p = 0.002$) after the intervention. In the intergroup analysis, the increase in the SLS with closed eyes was superior in the GVR + BE group when compared with GBE ($p = 0.006$; d = 1,67). In the TT with closed eyes, there was no difference between groups, but there was a large clinical superiority in the GVR + BE group when compared with GBE alone ($p = 0.269$; d = 1.22).

Table 1 - Baseline characteristics of included participants (n = 30).

	GBE (n = 15)	GVR + BE (n = 15)	p
Age (years)	28 (20-48)	24 (22-37)	0.875
Gender			
Male:female	8:7 (53.3%:46.7%)	7:8 (46.7%:53.3%)	1.000
Physical activity (h)	0 (0-5)	0 (0-5)	1.000
BMI (kg/m^2)	26.9 (19.2-38.9)	27.7 (22.2-31.9)	0.654
Static balance			
TT (s)			
Open eyes	30.0 (23.6 -30.0)	30.0 (25.5 -30.0)	0.455
Closed eyes	24.4 (19.72-30.0)	23.9 (11.3-30.0)	0.345
SLS (s)			
Open eyes	30.0 (18.9 -30.0)	30.0 (19.5 -30.0)	0.465
Closed eyes	14.6 (9.8-23.5)	16.4 (10.8-24.6)	0.375
Dynamic balance			
FST (°)	14.9 (7.7-18.0)	13.3 (9.3-17.2)	0.365

The values are presented in medians and intervals. Subtitles: TT: Tandem test; SLS, single-leg stance test; FST: Fukuda stepping test; BMI, body mass index.

Discussion

This study aimed to evaluate the immediate additional effect of HMD associated with balance exercises on static and dynamic balance in non-disabled individuals. The data suggest that the use of HMD additional to balance exercise had an acute improvement in the static balance with closed eyes when compared with balance exercise alone in a non-disabled population. The findings suggesting an acute improvement in the balance with the use of HMD can be explained by three mechanisms: (1) greater activation of the vestibular system, (2) activation of the mirror neuron system, (3) greater activation of the visual system to control the adaptation of moving objects in the retina, and (4) priming effect.

In the first mechanism, it is believed that dynamic balance exercises acutely increase the activity of the vestibular system by constant activation of the sensory receptors (utricle, saccule, and semicircular canals) that frequently inform the position of the body in space, generating greater balance reactions[23,24]. Coelho et al. (2020) observed that there was a decrease in ellipse area in conditions with eyes were closed after VR intervention. They hypothesized that VR HMD confounds the visual system, through distraction, and thus increases the activity in other systems, such as the vestibular and somatosensory systems, to maintain balance[25].

In the second mechanism, it is believed that VR activates the areas of the premotor and supplementary motor cortices, generating greater muscular activation for the musculature involved in the game. As a game related to constant changes in the environment (roller coaster) associated with inertial acceleration, greater activation of the

Table 2 - Analysis of outcomes between groups.

	GBE (n = 15)			GVR + BE (n = 15)						
	Before	After	p_1	Before	After	p_2	Δ_{GBE}	Δ_{GVR+BE}	p_3	D-Cohen
Static balance										
TT (s)										
Open eyes	30.0 (23.6-30.0)	30.0 (26.8-30.0)	0.182	30.0 (25.5-30.0)	30.0 (28.3-30.0)	0.310	0.02 ± 0.03	0.04 ± 0.08	0.294	0.55
Closed eyes	24.4 (19.72-30.0)	30.0 (25.1-30.0)	0.025*	23.9 (11.3-30.0)	30.0 (29.1-30.0)	0.003*	5.4 ± 1.45	6.1 ± 1.89	0.268	1.22*
SLS (s)										
Open eyes	30.0 (18.9-30.0)	30.0 (22.1-30.0)	0.456	30.0 (19.5-30.0)	30.0 (23.8-30.0)	0.298	0.02 ± 0.03	0.03 ± 0.04	0.245	0.55
Closed eyes	14.6 (9.8-23.5)	20.2 (13.4-22.0)	0.003*	16.4 (10.8-24.6)	24.3 (16.8-26.0)	0.002*	5.3 ± 1.56	7.9 ± 1.09	0.006*	1.67*
Dynamic balance										
FST (°)	14.9 (7.7-18.0)	11.9 (5.7-16.0)	0.08	13.3 (9.3-17.2)	10.4 (8.8-15.6)	0.05	-3.0 ± 6.71	-2.9 ± 5.16	0.269	-0.49

The values are presented in medians and intervals. Subtitles: TT: Tandem test; SLS, single-leg stance test; FST: Fukuda stepping test; BMI, body mass index.P1 - before and after intra-group (GBE).P2 - before and after intra-group (GVR + BE).P3 - Δ_{GBE} x $\Delta_{GVR + BE}$.D-Cohen: small (0,20-0,49); moderate (0,50-0,79); large (>0,80).

mirror neurons in the primary motor cortex could have occurred, thus increasing the activity of the antigravity and postural muscles, thereby increasing single leg control[26,27].

The third mechanism is that the use of dynamic visual information generates greater vestibular conflict due to the constant corrections of the extraocular musculature for fixation of the image in the retina, thus increasing the sensorial information for the vestibular nucleus in the brainstem, which in turn increases the responses of the vestibular system for correction (vestibule-ocular reflex) and adaptation of the balance[28-29]. In a systematic review, the authors showed that modifying visual information and increasing the complexity of VR protocol, regardless of their health status, showed overall improvements in vestibule-ocular reflex gain and posturography parameters[18].

The fourth mechanism refers to the priming effect. The priming effect is the phenomenon by which the exposure of a stimulus influences the subsequent response[30], and the VR-HMD techniques could influence the response of other techniques and the magnitude of the effect. Vourvopoulos et al.[31] suggest that VR with HMD can enhance the activation of brain patterns present during overt motor execution and concluded that immersive multimodal VR environment and motor priming can maximize the engagement of sensory-motor networks, due to the enhanced modulation of the same cortical areas that are activated during actual motor preparation and execution.

The limitations of this study are the small sample size and the non-blinding of the study evaluators. In terms of not affecting the performance tests of this study, the sample did not know any of the tests used. However, this is a low-cost study wherein, in a single VR session associated with balance exercises, we noted an acute improvement in the static balance in non-disabled individuals. Thus, this study can be replicated in any research center worldwide because it is a feasible, innovative, and playful tool for balance control. The main implication of the results obtained is that 8 min in full HD VR associated with balance exercises was sufficient to generate acute effects in static balance without adverse events, and this approach can be a model to future studies in disabled people.

Conclusion

It is concluded that the additional use of VRHMD before balance exercise has an acute improvement in static balance with eyes closed in non-disabled individuals.

References

1. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age and ageing. 2006;35(S2):7-11. doi
2. Horak FB. Clinical measurement of postural control in adults. Phys Ther. 1987;67(12):1881-5. doi
3. Ferrè ER, Walther LE, Haggard P. Multisensory interactions between vestibular, visual, and somatosensory signals. Plos One. 2015;10(4):e0124573. doi
4. Ferrè ER, Day BL, Bottini G, Haggard P. How the vestibular system interacts with somatosensory perception: a sham-controlled study with galvanic vestibular stimulation. Neurosci Lett. 2013;550:35-40. doi
5. Chiba R, Takakusaki K, Ota J, Yozu A, Haga N. Human upright posture control models based on multisensory inputs; in fast and slow dynamics. Neurosci Res. 2016;104:96-104. doi
6. Peterka RJ. Sensorimotor integration in human postural control. J Neuro-physiol. 2002;88(3):1097-1118. doi
7. Allison LK, Kiemel T, Jeka JJ. Sensory-challenge balance exercises improve multisensory reweighting in fall-prone older adults. J Neurol Phys Ther. 2018;42(2):84-93. doi
8. van Diest M, Lamoth CJ, Stegenga J, Verkerke GJ, Postema K. Exergaming for balance training of elderly: state of the art and future developments. J Neuroeng Rehabil. 2013;10 (101):1-12. doi
9. Silsupadol P, Siu KC, Shumway-Cook A, Woollacott MH. Training of balance under single- and dual-task conditions in older adults with balance impairment. Phys Ther. 2006;86 (2):269-81. doi
10. Ros M, Trives JV, Lonjon N. From stereoscopic recording to virtual reality headsets: designing a new way to learn surgery. Neurochirurgie. 2017;63(1):1-5. doi
11. Adamovich SV, Fluet GG, Tunik E, Merians AS. Sensorimotor training in virtual reality: a review. Neuro Rehabilitation. 2009;25(1):29-44. doi
12. Keshner EA, Kenyon RV, Langston J. Postural responses exhibit multisensory dependencies with discordant visual and support surface motion. J Vestib Res. 2004;14:307-19. doi
13. Streepey JW, Kenyon RV, Keshner EA. Visual motion combined with base of support width reveals variable field dependency in healthy young adults. Exp Brain Res. 2007;176:182-7. doi
14. Lampton DR, Kolasinski EM, Knerr BW, Bliss J. Side effects and aftereffects of immersion in virtual environments. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 1994;38(18):1154-1157. doi
15. Szpak A, Michalski SC, Loetscher T. Exergaming with beat saber: an Investigation of virtual reality aftereffects. J Med Internet Res. 2020;22(10):e19840. doi
16. Levin MF. Can virtual reality offer enriched environments for rehabilitation? Expert Rev Neurother. 2011;11:153-5. doi
17. Keshner, EA, Fung J. The quest to apply VR technology to rehabilitation: tribulations and treasures. J Vestib Res. 2017;27:1-5. doi
18. Soltani P, Andrade R. The influence of virtual reality head-mounted displays on balance outcomes and training paradigms: a systematic review. Front Sports Act Living. 2021;2:531-5. doi
19. Shumway-Cook A, Horak FB. Assessing the influence of sensory interaction on balance. Phys Ther. 1986;66:1548-50. doi
20. Fregly AR, Smith MJ, Graybiel A. Revised normative standards of performance of men on a quantitative ataxia test battery. Acta Otolaryngol (Stockh). 1973;75:10-6. doi

21. Honaker JA, Boismier TE, Shepard NP, Shepard NT. Fukuda stepping test: sensitivity and specificity. J Am Acad Audiol. 2009;20(5):311-4. doi
22. Bonanni M, Newton R. Test-retest reliability of the Fukuda stepping test. Physiother Res Int. 1998;3(1):58-68. doi
23. Feng H, Li C, Liu J, Wang L, Ma J, Li G, Gan L, Shang X, et al. Virtual reality rehabilitation versus conventional physical therapy for improving balance and gait in Parkinson's disease patients: a randomized controlled trial. Med Sci Monit. 2019;25:4186-92. doi
24. Fetsch CR, Turner AH, DeAngelis GC, Angelaki DE. Dynamic reweighting of visual and vestibular cues during self-motion perception. J Neurosci. 2009;29(49):15601-12. doi
25. Coelho TS, Neto EM, Bazan R, de Souza LAPS, Luvizutto GJ. Virtual reality immersion in healthy individuals: ellipse sway area of an electrical shuttle balance. J Mot Behav. 2021;53(3):343-50. doi
26. Garzorz IT, MacNeilage PR. Visual-vestibular conflict detection depends on fixation. Current Biol. 2017;27:2856-6. doi
27. Rizzolatti G, Craighero L. The mirror-neuron system. Annu Rev Neurosci. 2004;27:169-92. doi
28. Calabrò RS, Naro A, Russo M, Leo A, De Luca R, Balletta T, et al. The role of virtual reality in improving motor performance as revealed by EEG: a randomized clinical trial. J Neuroeng Rehabil. 2017;14(1):53. doi
29. Jurgens R, Becker W. Human spatial orientation in non-stationary environments: relation between self-turning perception and detection of surround motion. Exp Brain Res. 2011;215:327-44. doi
30. Schabrun SM, Chipchase LS. Priming the brain to learn: the future of therapy? Man Ther. 2012;17:184-6. doi
31. Vourvopoulos A, Bermúdez I Badia S. Motor priming in virtual reality can augment motor-imagery training efficacy in restorative brain-computer interaction: a within-subject analysis. J Neuroeng Rehabil. 2016;13(1):69. doi

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