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ARTIGO ORIGINAL

VIRTUAL REALITY IN GERONTECHNOLOGY: A CROSS-AGE COMPARATIVE STUDY USING HEAD-MOUNTED DISPLAYS

Uso da Realidade Virtual na Gerontecnologia: Um Estudo Comparativo entre Faixas Etárias Utilizando Head-Mounted Displays

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Abstract

As Gerontechnology integrates digital innovations into aging-related contexts, understanding its biological and physiological implications becomes important. This study aimed to analyze postural control in older adults and determine whether the impact of virtual reality is greater in this population than in young adults. A total of 50 participants were evaluated: 25 older (68.9 ± 7.3 years) and 25 young (22.4 ± 1.7 years) adults. All participants were exposed to an immersive 3D roller coaster simulation using a head-mounted display. Postural control assessments were performed before and during exposure. The variables analyzed were frontal and lateral sway, center of pressure sway area, and corresponding speeds. Repeated-measures analysis of variance revealed a significant main effect of group, indicating poorer postural control in older adults. A main effect of task was observed in both groups for lateral sway and center of pressure sway area. No significant group × task interaction was found, confirming a similar impact of virtual reality between older and young adults. The findings indicate that virtual reality is a promising tool in Gerontechnology. However, it should be used with caution because of its impact on postural control.

KEYWORDS

Aging. Virtual Reality. Motion Perception. Postural Balance. Biomechanical Phenomena. Digital Inclusion.

Resumo

À medida que a Gerontecnologia avança nas inovações digitais relacionados ao envelhecimento, torna-se importante compreender suas implicações biológicas e fisiológicas. Este estudo teve como objetivo analisar o controle postural de pessoas idosas e comparar se o impacto da realidade virtual é superior nessa população em relação aos jovens. Foram avaliados 50 participantes: 25 idosos (68,9 ± 7,3 anos) e 25 jovens (22,4 ± 1,7 anos). Todos os participantes foram expostos à simulação de montanha-russa 3D em realidade virtual por meio de um dispositivo de visualização imersiva acoplado à cabeça. As avaliações de controle postural ocorreram antes e durante a exposição da realidade virtual. As variáveis analisadas incluíram desequilíbrio frontal e lateral, área do centro de pressão e velocidades correspondentes. A análise de variância para medidas repetidas indicou efeito significativo para o fator grupo, evidenciando pior controle postural em idosos. O efeito da tarefa foi observado em ambos os grupos para desequilíbrio lateral e centro de pressão. Não houve interação significativa para grupo × tarefa, sugerindo impacto semelhante entre idosos e jovens. Os resutados indicam que a realidade virtual é uma ferramenta promissora da Gerontecnologia. Contudo, ela deve ser utilizada com cautela devido ao seu impacto no controle postural.

PALAVRAS-CHAVE

Envelhecimento. Realidade Virtual. Percepção de Movimento. Equilíbrio Postural. Fenômenos Biomecânicos. Inclusão Digital.

1 Introduction

Recent advances in medicine and healthcare have increased life expectancy and quality of life. Consequently, the profile of older adults in contemporary society has undergone substantial change. Aging has been previously associated with retirement and a more passive lifestyle centered on domestic activities and healthcare. Now, aging is characterized by active engagement in the social, cultural, and professional domains (Lee et al., 2020).

Gerontechnology has emerged as an interdisciplinary field that integrates age-related needs with technological innovations. It plays an important role in promoting independence, autonomy, and health-related quality of life in older adults (Moreno et al., 2024). From a multi-professional perspective, Gerontechnology offers solutions that support everyday activities, ranging from mobility assistance to cognitive stimulation and environmental adaptation (Jutai et al., 2024).

Despite all the Gerontechnologic advances, several biological and physiological changes accompanying aging may compromise functional capacity. Decreases in muscle strength, sensory processing, and motor coordination are common and contribute to postural instability and increased risk of falls (Kowalewska et al., 2026). Visual impairment, including reduced acuity and depth perception, may affect interactions with the environment (Avila-Villanueva et al., 2026). Cognitive functions, such as attention, memory, and executive control tend to decline, potentially impairing the integration of motor and cognitive demands required for safe mobility and balance (Christofoletti; Darling, 2024).

In addition to age-related changes, chronic and neurodegenerative diseases can intensify functional limitations. Alzheimer’s and Parkinson’s diseases are among the most prevalent disorders affecting the central nervous system in older adults. These diseases affect key neural structures, including the basal ganglia and hippocampus, leading to alterations in motor control, coordination, and postural regulation (Gnanalingham et al., 1997). Musculoskeletal disorders, such as osteoarthritis, contribute to pain, reduced mobility, and impaired motor performance (Guo et al., 2026).

Many older adults restrict their participation in daily activities, which may negatively affect their independence and social engagement. Age-related changes and perceived difficulties may create barriers to the adoption of new technologies. In this scenario, Gerontechnology plays an important role in working on the gap between technological innovations and older adults’ limitations, facilitating their integration into modern digital environments and enhancing their daily functioning (Comin et al., 2025).

Virtual reality (VR) has gained increasing attention among emerging technologies owing to its ability to create immersive and controlled environments for assessment, training, and rehabilitation. VR enables users to interact with simulated scenarios using head-mounted displays that can replicate real-life situations with high validity (Song et al., 2026).

VR has been applied to older adults in several contexts. This includes balance training, cognitive stimulation, fall prevention, and physical rehabilitation. However, exposure to immersive virtual environments may also alter sensory integration processes, particularly the interactions between the visual, vestibular, and somatosensory systems, potentially affecting postural control (Abayasiri et al., 2026).

Although previous studies have explored the use of VR in rehabilitation and functional training, there is still a lack of consensus regarding its immediate effects on postural control, especially when comparing young and older adults. Methodological variability across studies, including differences in exposure time, task demands, and outcome measures, limits the generalizability of the findings. Therefore, a better understanding of how immersive VR influences postural stability across different age groups is required (Kubota et al., 2026).

In this context, this study aimed to analyze postural control in young and older adults during VR exposure using a head-mounted display. The authors hypothesized that older adults would exhibit greater postural instability during VR exposure than young individuals, reflecting age-related differences in sensory integration and motor control, highlighting information processing conflicts common advanced ages.

2 Methods

This study recruited 50 participants (25 young and 25 older adults). Participants were recruited through a combination of direct contact with potential participants and social media platforms. This study was conducted in accordance with the STROBE statement checklist and principles of the Declaration of Helsinki. Ethical approval was obtained before the assessments (approval no.: 6,264,348). All the participants provided written informed consent.

Participants were eligible if they were either older (age ≥ 60 years) or young adults (age ≥ 18 years) of both sexes, and without neurological or musculoskeletal disorders. The exclusion criteria involved the use of antipsychotics or antidepressants, surgical procedures within the last six months, and inability to attend the Biomechanics Laboratory for assessment.

After providing informed consent, the participants completed a general questionnaire to obtain demographic and anthropometric data including sex, age, weight, height, and body mass index (BMI). Cognitive functions were assessed using the Mini-Mental State Examination (MMSE, Folstein et al., 1975). The MMSE is a widely known and recognized instrument that evaluates orientation, attention, memory, language, and visuo-constructive abilities. Its scores range from 0 to 30, with higher values indicating better cognitive performance.

Static upright postural control was assessed using a force platform consisting of a 500 mm^2 plate equipped with four load cells (BIOMEC 400_V4, EMG System, Brazil). All participants were assessed barefoot and instructed to stand upright on the platform for 180 seconds, maintaining a comfortable and natural posture without unnecessary movements.

In this study, the following variables were recorded: frontal and lateral sway (cm), center of pressure sway area (cm^2), and frontal and lateral speeds (cm/s). VR exposure was delivered using a 3D head-mounted display. The participants were evaluated with their eyes open under two conditions: a VR condition and a control condition without VR. Appendix A, presented at the end of this study, shows the VR interface used on the participants.

The participants were exposed to a 3-minute immersive 3D roller coaster simulation while maintaining a stationary upright posture during the VR condition. In the control condition, the participants stood quietly without VR stimulation for the same duration while maintaining a natural non-rigid posture. To minimize potential order effects, the sequence of conditions was randomized. A 5-min rest interval was provided between the conditions.

The statistical analysis was conducted in several steps. First, the data distribution was assessed to verify the parametric assumptions, which were confirmed by the Shapiro–Wilk and Levene tests. Continuous variables are expressed as mean ± standard deviation and categorical variables are expressed as absolute frequencies.

Second, chi-square (χ^2) tests were used to compare the sample size distribution, sex, and previous VR experience between groups. Independent Student's t-tests were used to compare age, weight, height, BMI, and MMSE scores between the young and older adults.

Third, repeated-measures analysis of variance was performed to examine the effects of VR on postural control, considering group (young × older), task (without × with VR), and the interaction (group × condition) effects.

Finally, the sociodemographic and cognitive variables that differed between the groups were included in a stepwise regression model to identify the factors associated with postural control variability during VR exposure. For all the analyses, significance was set at 5% ($p < 0.05$).

3 Results

Fifty participants were included: 25 older and 25 young adults. No significant differences in sex, weight, or BMI were observed between the groups. Older adults were older (as expected), had lower height, lower MMSE scores, and reported no prior VR experience compared with the young adult group. Table 1 summarizes the sociodemographic, cognitive, and functional characteristics of the participants.

Table 1 | Demographic, cognitive and functional characteristics of the participants

Variables	**Groups**		***p***
	Young adults	**Older adults**	
Sample size, n	25	25	0.999
Sex (male – female), n	12 – 13	10 – 15	0.569
Age, yrs	22.4 ± 1.7	68.9 ± 7,3	0.001
Weight, kg	71.8 ± 11.9	71.7 ± 13.9	0. 983
Height, m	1.7 ± 0.1	1.6 ± 0.1	0.005
BMI, kgm^2	25.2 ± 3.7	27.2 ± 4.6	0.100
MMSE, pts	29.6 ± 0.5	26.4 ± 2.7	0.001
VR exp. (yes – no)	8 – 17	0 – 25	0.002

Note: MMSE: Mini-Mental State Examination. VR exp. VR experience.

Table 2 presents the data for each variable measured on the force platform, and their respective analyses. Repeated-measures analysis of variance revealed a significant group effect for frontal sway, lateral sway, and lateral speed. A task effect was observed for the lateral sway and center of pressure sway area. No significant group × task interaction was found, confirming a similar effect between the older and the young adult groups.

Table 2 | Impact of 3D virtual reality on postural control.

Variables	**Groups**		***p***
	Young adults	**Older adults**	
Sample size, n	25	25	0.999
Sex (male – female), n	12 – 13	10 – 15	0.569
Age, yrs	22.4 ± 1.7	68.9 ± 7,3	0.001
Weight, kg	71.8 ± 11.9	71.7 ± 13.9	0. 983
Height, m	1.7 ± 0.1	1.6 ± 0.1	0.005
BMI, kgm^2	25.2 ± 3.7	27.2 ± 4.6	0.100
MMSE, pts	29.6 ± 0.5	26.4 ± 2.7	0.001
VR exp. (yes – no)	8 – 17	0 – 25	0.002

Note: $p_{(g)}$: p-value for the main effect of group; p(t): p-value for the main effect of task; p(g×t): p-value for the group × task interaction.

Figure 1 illustrates the correlation matrix among the postural control variables during VR exposure, allowing visualization of the relationships between frontal and lateral sway, center of pressure parameters, and frontal and lateral speed.

Figure 1 | Correlation matrix of postural control measures across VR conditions

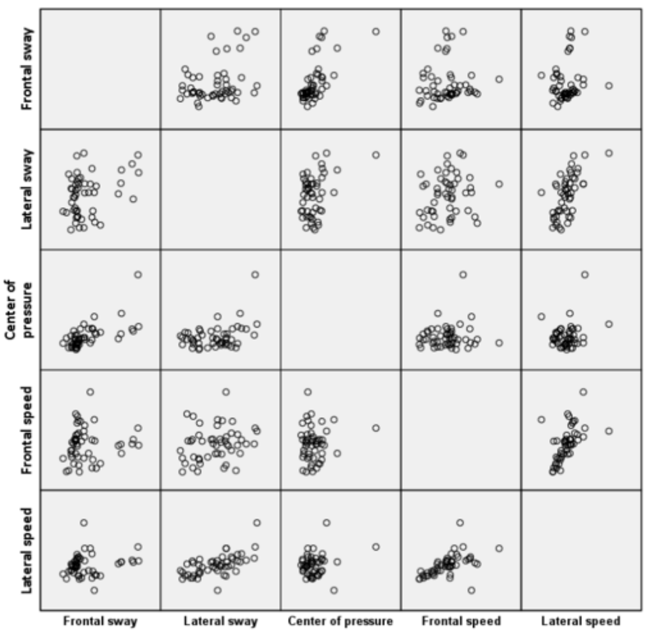

Table 3 presents the results of the stepwise regression model that examined whether age, height, MMSE score, and previous VR experience predicted the postural control performance during VR exposure.

Cognitive function explained 36.3% of the variability in frontal sway. Age explained 50.1% and 27.6% of the variability in the lateral sway and speed, respectively. Previous VR experience explained 10.5% of the variability in the frontal speed. None of the variables significantly predicted the variability of the center in the pressure sway area.

Table 3 | Stepwise regression models predicting motor performance in older and young adults during VR exposure

Variables	Models	β	R^2	*p*	*Durbin-Watson*
Frontal sway	MMSE	0.602	0.363	0.001	1.276
Lateral sway	Age	0.708	0.501	0.001	1.152
Center of pressure	None	---	---	---	---
Frontal speed	VR exp.	0.324	0.105	0.022	1.663
Lateral speed	Age	0.525	0.276	0.001	1.447

Note: MMSE: Mini-Mental State Examination. VR exp. VR experience.

Appendix B, presented at the end of this study, shows the correlation matrix between the demographic, cognitive, and functional variables. This supplementary analysis provides additional insights that may be of interest to readers seeking a more comprehensive understanding of the relationships between all the measures.

4 Discussion

This study investigated the effects of VR on postural control in older adults. Compared with young adults, older participants showed poorer motor performance under baseline conditions. VR affected specific postural control measures, and its impact was similar between groups. The results observed in our study support Abayasiri et al. (2026) and reinforce the need for appropriate safety measures during VR exposure.

Young participants exhibited postural control parameters within the normative ranges, whereas older adults exhibited reduced motor performance. This finding was expected because aging is associated with declines in postural control and increased risk of falls (Yang et al., 2026). Similar patterns observed in some motor variables may be explained by the preserved integration of visual, vestibular, and somatosensory inputs, which helps maintaining the overall postural stability (Thammachat et al., 2026). As these mechanisms were not directly assessed in our study, further investigations are needed to better clarify their contribution to postural control.

The correlation matrix revealed a significant association between frontal and lateral sway, center of pressure say area, and corresponding speed. Some variables were directly correlated, whereas others showed inverse relationships. These findings reinforce the multidimensional nature of postural control, which requires careful interpretation. Gerontechnology professionals should consider these interrelated parameters in association with gait and other cost-effective technologies, to ensure that older adults receive the appropriate and safe care (Zhong; Rau. 2020).

The groups were homogeneous in terms of sample size, sex distribution, weight, and BMI. These characteristics are relevant because they reduce the likelihood that anthropometric factors influence postural control outcomes. However, the groups differed in terms of age, height, cognitive performance, and prior VR experience. A multiple regression analysis using a stepwise entry method was performed to examine the influence of these variables on postural control.

The stepwise approach was considered appropriate because it allows the identification of the most relevant predictors by iteratively including only those variables that significantly contribute to the model (Whittingham et al., 2006). This is particularly useful in the presence of multiple, potentially correlated factors because it helps reduce model redundancy and minimizes overfitting risk, resulting in a more parsimonious and interpretable model. The Durbin–Watson test indicated no significant autocorrelation of residuals, supporting the adequacy of the regression model and the use of this analytical approach.

In the regression model, cognitive function emerged as a significant predictor of frontal sway, explaining 36.3% of its variability. This finding may be attributed to the contribution of attention, memory, and executive functions to the control of anterior–posterior stability, especially in tasks requiring continuous integration of sensory information and motor planning (Tait et al., 2026).

Age was associated with lateral sway and speed, explaining up to 50.1% of the variability in these parameters. This influence likely reflects age-related declines in neuromuscular control and mediolateral stabilty, which are essential for balance and tend to deteriorate with advancing age (Rasku et al., 2026).

Previous experience with VR influenced frontal speed, suggesting that familiarity with immersive environments may reduce cautious or rigid postural behaviors, allowing for more adaptive and efficient control strategies in the anterior–posterior direction. No predictors were retained in the model for center of pressure sway area. This may indicate that this parameter reflects a more global dimension of postural control arising from the interaction of multiple subsystems rather than being affected by isolated factors (Horak, 2006).

Supplementary material was included in the appendices to provide a comprehensive overview of the relationships among the variables, allowing readers to better understand how demographic and cognitive factors interact with postural control parameters (Deschamps et al., 2014). By presenting these associations, the appendix supports a more in-depth interpretation of the findings, particularly regarding the observed interdependence and complexity of the measures.

Limitations

This study has some limitations that should be acknowledged. First, the sample size was relatively small, which may limit the generalizability of the findings. Second, only one VR task was performed, which restricts the interpretation of the results to a specific type of exposure and does not allow conclusions about different VR environments or task demands. Therefore, further studies with larger samples and a wider range of VR protocols are needed to confirm and expand these findings.

Despite these limitations, this study contributes to the field of Gerontechnology by offering initial evidence on how demographic, cognitive, and experiential factors influence postural control during VR exposure. This information is important to support the safe and effective implementation of immersive technologies in older adults, guiding both clinical practice and the development of tailored interventions.

5 Conclusion

Aging significantly affects postural control, as evidenced by the observed poorer performance in older adults than in young individuals. Immersive VR exposure induced measurable changes in postural stability, particularly in the lateral sway and center of pressure sway area. The absence of a significant group × task interaction indicates that the magnitude of this effect is comparable across the groups.

Within the context of Gerontechnology, these findings support the feasibility of using VR in older populations and emphasize the need for careful implementation to ensure safety and minimize potential balance-related risks.

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Appendix

Appendix A | VR interface used in this study.

Appendix B | Correlation matrix of demographic, cognitive, and postural control variables during virtual reality exposure.