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Article

The Effectiveness of a Virtual Reality-Based Exergame Protocol in Improving Postural Balance in Older Adults During the COVID-19 Pandemic

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Abstract: Background: The COVID-19 pandemic significantly reduced physical activity levels, particularly among older people, negatively impacting their postural balance and increasing the risk of falls and hip fractures. This study aims to assess the effect of a virtual reality-based exergame physical activity protocol at home on improving postural balance in older people. Materials and Methods: A quasi-experimental design was employed with 10 older people (71 ± 9 years) who participated in a virtual reality-based exergame physical activity protocol consisting of eighteen 25 min sessions conducted at home. The protocol incorporated 3D movement tracking using a sensor attached to the participants' bodies to monitor postural sway in real time. Clinical measurements included the Timed Up and Go test and posturographic measures of center-of-pressure, including sway area, velocity, and standard deviation in the mediolateral and anteroposterior directions under four conditions: static with the eyes open and eyes closed and dynamic voluntary sway in the mediolateral direction following a 30 Hz metronome with the eyes open and eyes closed. Paired *t*-tests were used to compare pre- and post-intervention data. Results: The intervention led to significant improvements in postural balance as measured using both posturographic measures ($p < 0.05$) and the Timed Up and Go test ($p = 0.04$). Conclusion: The virtual reality-based exergame physical activity protocol conducted at home, comprising eighteen 25 min sessions, effectively improves postural balance in older people.

Keywords: physical activity; postural balance; older adults; COVID-19; home; virtual reality; 3D exergame

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1. Introduction

Older people (OP) are characterized by a progressive and natural deterioration in their motor skills due to non-pathological causes because of the normal physiological aging process, highlighting the loss of postural balance [1–3], leading to falls and traumatic events such as hip fracture [4]. Studies have shown that traditional physical activity (PA), such as balance and strength training, as well as Tai Chi, can help reduce fall risk by improving flexibility, standing, and walking performance and counteracting their age-related decline in neuromotor and somatosensory functions [5,6]. One of the tools commonly used for balance postural training is the Freeman and Bosu saucer [7]. However, they may be unsafe tools to apply given their difficulty in use and, in some cases, their use being risky in OP [8]. Adherence and continuity to these traditional PA programs is a challenge, since older adults consider them monotonous and boring to perform, which induces a regression in the results obtained toward previous levels of training when abandoning the program [9,10]. In addition to the above, the COVID-19 pandemic worldwide generated restrictions on travel and led to confinement for a large part of the population. OP had the highest risk of becoming infected, representing 80% of hospitalizations, with a 23 times higher risk of death than those under 65 years of age [11,12]. This disproportionate impact on older adults highlights the urgent need for scientific inquiry into their specific health challenges. For this reason, many older people feel safer being at home, negatively affecting their physical health because of little or no mobility, as well as their emotional and psychological health [13]. Therefore, the scientific community should prioritize research focused on developing and evaluating innovative interventions that can be safely and effectively delivered in home settings to address the physical, emotional, and psychological needs of OP, particularly in the context of public health crises that result in stay-at-home advice.

Exergame interventions have been implemented as a novel PA and rehabilitative strategy for those who have cognitive–motor impairments (e.g., Parkinson's and stroke) and have demonstrated great potential in enhancing balance control in older people [14,15]. Exergame interventions stimulate movements in different planes, even those in which the patient has difficulty, creating a demand that favors mobility and postural balance [14]. Commonly, 2D virtual environments use interfaces such as the Kinect and the Nintendo Wii with its peripheral balance board [8,16] to improve postural balance in older people and patients with Parkinson's, multiple sclerosis, and stroke [16–18]. They improve proprioception and activation of different receptors and provide a dynamic therapy that generates motivation and better adherence of its users in relation to conventional therapies [19,20]. However, the accessibility of entertainment interfaces is dependent on the commercial market, which in the case of the Nintendo Wii console was discontinued in 2014. To replace it, technological systems have been developed such as three-dimensional (3D) inertial sensors, which have a gyroscope and are widely used in human movement analysis laboratories [21,22]. These inertial sensors can be located in different areas of the body, allowing patients' movements to be measured during the practice of physical exercise or exergames [21]. Currently, it is possible to find low-cost inertial sensors with sophisticated technological implementation to measure patients' movements during therapeutic physical interventions, but there are no clinical investigations in OP worldwide that account for the effects of a protocol with 2D exergames carried out in their homes.

The aim of this research was to determine the effect of a home-based PA protocol using an exergame to improve postural balance in a population of OP from Chile, using a quasi-experimental design during the last quarter of the COVID-19 pandemic.

2. Materials and Methods

2.1. Participants and Study Design

All participants were contacted through a community club for senior citizens in central Chile during the last quarter of the COVID-19 pandemic. A total of fourteen OP were invited, four declined, and finally, ten older adults agreed to enroll in the PA protocol at home. Participants of both sexes between the ages of 62 and 80, with controlled comorbidities and immunized against SARS-CoV-2, were included (Figure 1). OP with a Mini-Mental State Examination score of less than 14 points, any condition affecting standing postural stability, and four or more reported falls in the last year were excluded. A quasi-experimental design was implemented.

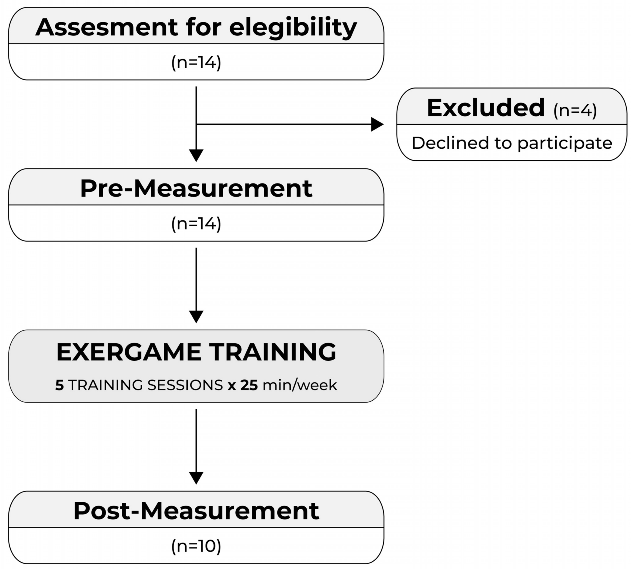

Figure 1. Quasi-experimental study; flowchart according to STROBE recommendations.

All participants voluntarily signed an informed consent form, with the research explained in detail both verbally and in writing. This document was previously approved by the ethics committee of the Universidad Mayor, Chile, in accordance with the ethical standards of the Helsinki Declaration (Folio No. 0190).

2.2. Measurements and Intervention

The technological device used for the exergame intervention was created by a mechatronic engineer, incorporating physiological and biomechanical aspects in its development. The sensor is attached at the trunk or abdominal level according to the participant's comfort. Figure 2 shows the interaction of the device with the LED screen.

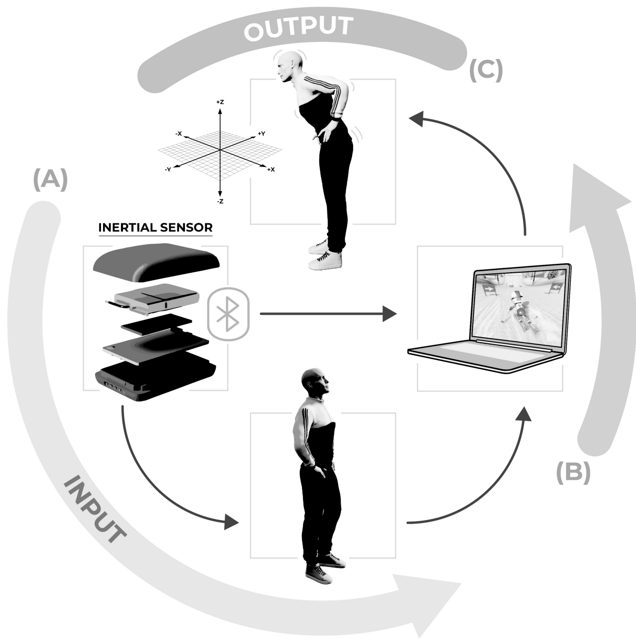

Figure 2. Diagram of interaction between the exergame and the elderly person at home: (**A**) inertial sensor on the body; (**B**) visual stimulus activates movement from the computer's LED screen; (**C**) movement in the sagittal, medial, or transverse plane depending on the exergame. Image credit: Luis Leiva-Cortez, designer. Unpublished figure, created in its original version for this publication.

The exergame intervention was carried out in the homes of the OP. Table 1 shows that the exergames applied in principle were based on a previous study, with four new exergames created to improve postural balance, covering the three planes of movement (sagittal, frontal, and transverse) [1,18]. The participants took part in eighteen sessions, each lasting 25 min with a frequency of five times a week (Monday to Friday), reaching a total of 3.5 weeks. The games were projected onto a personal computer, and the participants' movements were recorded using the device described above. In the first series, participants stood with their arms and hands at their sides, in a relaxed manner. In the second series, each game was repeated while the participants stood with their hands on their waist. In the third series, the participants kept their posture as relaxed as possible with their eyes open and subsequently with their eyes closed to encourage calm breathing (Table 1).

Table 1. Exergame protocol at home.

Exergame	Time (s)	Movement Axis
Skate	35	Sagittal axis
Donut	90	Mediolateral axis
Pizza	180	Transverse axis
Breathe	50	COM maintenance standing

2.3. Outcome

Measurements before and after the intervention were carried out. Clinical and posturographic measurements were performed at the Human Motor Control Laboratory of the Universidad de Talca, Chile.

For posturographic measurements, data were collected and recorded at 100 Hz using an AMTI OR6-7 force plate and AMTI-NetForce software (AMTI Inc., Boston, MA, USA). The intervention included four postural tasks that lasted 60 s each: (1) eyes open, (2) eyes closed, and mediolateral displacement of the body with a 30 Hertz auditory stimulus with (3) the eyes open and (4) the eyes closed. For clinical measurement, the Timed Up and Go (TUG) test was used as usual: the individual was seated on a chair, stood up, and walked three meters back and forth as quickly as possible before finishing by sitting down again. In addition, the baseline and demographic characteristics of the sample were considered (Table 2). Standing balance postural evaluation was completed within 5 min.

Table 2. Baseline and demographic characteristics of the study group.

Participants	Age (Years)	Sex	Weight (kg)	Height (m)	BMI (kg/m^2)
1	63	F	56.30	1.45	26.78
2	76	M	59.08	1.60	23.08
3	63	F	61.83	1.53	26.41
4	64	F	73.59	1.50	32.71
5	62	M	96.50	1.74	31.87
6	62	F	77.60	1.59	30.69
7	65	F	70.63	1.53	30.17
8	72	F	76.06	1.60	29.71
9	70	F	77.78	1.65	28.57
10	80	M	82.93	1.75	27.08

F: female; M: male; BMI: body mass index.

Postural balance was assessed using a force platform and the Timed Up and Go (TUG) test. Force platform data were processed using a custom Matlab R2012 script. Data were low-pass filtered using a second-order Butterworth filter with a 40 Hz cutoff frequency. Center of pressure (CoP) variables were calculated, including CoP sway area (CoPSway), the standard deviation of CoP displacement in the mediolateral (SDML) and anteroposterior (SDAP) directions, and CoP velocity in the mediolateral (VML) and anteroposterior (VAP) directions. CoPSway served as the primary outcome measure, with larger values indicative of poorer postural control. TUG performance was quantified by time (seconds) and speed (m/s). This approach combined laboratory-based (force platform) and clinical (TUG) measures for a comprehensive assessment of postural balance.

2.4. Statistical Analysis

The data were analyzed using SPSS 20.0 software (SPSS Inc., 233 South Wacker Drive, Chicago, IL 60606-6412, USA) for Windows. Inferential statistics were employed for the center of pressure parameters and clinical TUG test. The Shapiro–Wilk test was used to measure the normality of the data for each measurement variable. To analyze the differences in means, the paired *t*-test was conducted with a significance level of $p \leq 0.05$.

3. Results

3.1. Demographics

The demographic and clinical characteristics of the participants are presented in Table 2.

3.2. Variables

Ten participants completed the 18 training sessions of the home-based exergame protocol. All participants maintained standing balance during the posturographic assessment. The assumption of normality was tested using the Shapiro–Wilk test on the variables studied, allowing for the application of the paired *t*-test.

The home exergame protocol showed that time decreased and speed increased significantly for the TUG clinical test (Table 3). Likewise, significant changes were seen in postural tasks on a posturographic platform after the application of the home exergame protocol.

Table 3. Means and standard deviations for clinical assessments during the pre-intervention and post-intervention periods.

Clinical Assessments	Pre-Intervention	Post-Intervention	*p*-Value
TUG (s)	7.68 ± 0.64	7.42 ± 0.55	0.04
TUG (m/s)	0.78 ± 0.061	0.81 ± 0.062	0.04

TUG: Timed Up and Go.

A significant decrease was obtained in the main variable, COP area, in the four postural tasks, including those with the greatest demand in postural balance, mediolateral displacement with an auditory stimulus at 30 Hz both with closed eyes and with open eyes. The variability of the anteroposterior COP reflected a significant decrease in the motor response, thereby minimizing postural oscillations in this plane of movement (Table 4).

Table 4. Means and standard deviations for posturographic assessments during the pre-intervention and post-intervention periods.

CoP/Postural Task	Pre-Intervention	Post-Intervention	*p*-Value
CoP_{Sway}			
EO	1.71 ± 1.56	0.74 ± 0.28	0.042
EC	2.44 ± 2.34	0.88 ± 0.36	0.036
ML displacement—30 Hz sound—EO	67.10 ± 33.87	46.53 ± 20.77	0.003

Table 4. *Cont.*

CoP/Postural Task	Pre-Intervention	Post-Intervention	*p*-Value
ML displacement—30 Hz sound—EC	59.60 ± 22.13	45.20 ± 29.01	0.018
Velocity ML			
EO	0.06 ± 0.01	0.05 ± 0.01	0.02
EO	0.07 ± 0.03	0.06 ± 0.01	0.1
ML displacement—30 Hz sound—EO	0.93 ± 0.23	0.83 ± 0.28	0.03
ML displacement—30 Hz sound—EO	0.85 ± 0.22	0.70 ± 0.26	0.01
Velocity AP			
EO	0.12 ± 0.03	0.10 ± 0.02	0.02
EC	0.15 ± 0.07	0.13 ± 0.04	0.16
ML displacement—30 Hz sound—EO	0.19 ± 0.04	0.16 ± 0.03	0.005
ML displacement—30 Hz sound—EC	0.21 ± 0.07	0.20 ± 0.08	0.25
Standard deviation ML			
EO	0.02 ± 0.01	0.02 ± 0.01	0.133
EC	0.02 ± 0.01	0.02 ± 0.01	0.021
ML displacement—30 Hz sound—EO	0.63 ± 0.18	0.61 ± 0.22	0.269
ML displacement—30 Hz sound—EC	0.57 ± 0.17	0.50 ± 0.18	0.077
Standard deviation AP			
EO	0.05 ± 0.01	0.04 ± 0.01	0.02
EC	0.07 ± 0.03	0.04 ± 0.01	0.02
ML displacement—30 Hz sound—EO	0.08 ± 0.02	0.07 ± 0.01	0.01
ML displacement—30 Hz sound—EC	0.09 ± 0.02	0.07 ± 0.02	0.02

CoP: center of pressure; CoP_{Sway}: area of CoP sway; ML: mediolateral; AP: anteroposterior. EO: eyes open; EC: eyes closed. The CoP variables were expressed in cm^2; cm/sec and cm, respectively.

4. Discussion

The exergame PA protocol at home comprising eighteen 25 min sessions improves postural balance in OP. Exercise in general, including balance and combined exercise protocols, has been shown to be effective in reducing falls and fall-related injuries in OP [23]. Exergames, which combine physical exercise with interactive video games, have shown promise in improving balance and reducing fall risk among OP. A systematic review and meta-analysis indicated that motivational factors significantly influence the effectiveness of exergame interventions, suggesting that these factors should be considered when designing such programs [24]. Another study demonstrated that a tailored exergame program improved balance and reduced the fear of falling, with a significant reduction in fall rates compared to standard care [25]. This suggests that exergames can be a cost-effective strategy for fall prevention in older adults living in assisted facilities.

It should be noted that this research was conducted during the COVID-19 pandemic in OP who had been confined to their homes for more than 12 months as a measure to prevent contagion. During this period, it was impossible to go to neighborhood centers or community clubs for seniors, places where they usually carry out in-person PA systematically, at least three times a week, such as Tai Chi, Yoga, and entertaining dance, among others. Therefore, this OP population was eager to receive physical training guided by a trained professional and with it, the benefit of human interaction with people other than the family nucleus, directly contributing to their psycho-emotional state due to the known beneficial effects of physical exercise [16] and guided patient–health professional interaction at home [16–18]. Other studies conducted during the COVID-19 pandemic have reported low adherence levels, highlighting challenges in the uptake and sustainability of exercise protocols [26] and opportunities for home-based programs.

The average TUG score in Chile has been reported at 8.86 ± 3.56 s [27], with the OP analyzed in this study having an average of 7.68 ± 0.64, placing them at a low risk of falls. The minimum clinically important difference (MCID) in the TUG test, which indicates a clinically significant improvement, varies depending on the context and the population studied. In the context of patients undergoing surgery for lumbar degenerative disc disease, the MCID for the TUG test has been reported to range from 0.9 s to 3.0 s, with an average of approximately 2.1 s across different patient-reported outcome measures [28]. However, for those already performing in the low-risk segment, the focus might be better placed on maintaining overall functional mobility and addressing other potential risk factors for falls, such as muscle strength, balance, and environmental hazards, rather than solely aiming for further reductions in TUG time.

The greatest challenge of this research was to achieve the realization of a 2D exergame protocol to improve postural balance in the homes of the elderly, starting from simple and low-cost technological hardware, such as an inertial sensor (5 to 30 USD on the current market) to be placed on the person's body to read their movements [29] and transfer them via Bluetooth to a computer which projected the exergame. The avatar of the exergame protocol was led by software that allowed for the training of postural balance in the three planes of movement, following the principle of other authors [1,18] who used the Freeman and Bosu saucer.

Our exergame intervention applied in the homes of the elderly significantly reduced the principal variable area of CoP in the four postural tasks measured on a posturographic platform. This decrease in CoP resulted in better postural balance in the elderly, both in static conditions (EO and EC) and in dynamic conditions from the mediolateral displacement of the body to the rhythm of a sound at 30 Hz in EO and EC, respectively. There was also a significant decrease in diverse secondary variables of CoP, except ML variability with the eyes open and with a 30 Hz auditory stimulus with the eyes open and closed. Therefore, the velocity ML with the eyes open and velocity AP with the eyes closed were not significant. This variability of human motion according to the uncontrolled manifold theory does not always have a negative effect. Hence, although not significant, SD changes may still be within a range of functionality that allows for maintaining a stable CoP.

Therefore, it is important to highlight that this study included the reduction in laboratory measurements in the CoP_{sway} for the four postural tasks accompanied by decreases in the variables of speed and time in the TUG clinical test. Both aspects, laboratory and clinical measurements, are key to indicating that postural balance improved [18]. To our knowledge, this is the first study to improve postural balance based on a PA protocol with an exergame in the homes of OP.

The exergame intervention relies mainly on visual feedback when performing each of the games; hence, it is possible that there is an increased reliance on visual information after the intervention, which is reflected in improvements in posturographic measures during the postural tasks with EO. Most of the exergames utilized in this study challenge mediolateral balance by eliciting weight-shifting strategies to move interactive elements (i.e., avatars). The latter may not only challenge physical abilities but also the entire sensorimotor integration process since other input sources (i.e., proprioception) must be integrated into visual feedback during performance [14].

This study has several implications for clinical practice, particularly because exergame development provides a scalable and accessible option for fall prevention, which is particularly important in resource-limited environments [25]. The interactive nature of exergames can improve adherence to exercise programs among older adults, which is essential for achieving long-term benefits in muscle strength and balance [30]. Home-based interventions are accessible and convenient for OP because they can be integrated into daily activities [31] and can be particularly beneficial for those with mobility issues or those living in areas with limited access to exercise facilities [32]. Further research is required in older adult populations at high risk of falls or with higher levels of dependency. In addition, there is a need to elucidate the specific elements of exergames that contribute to improvements in balance and fall prevention, as well as to compare their effectiveness with conventional physical therapy. Finally, the current evidence is methodologically weak, with small sample sizes and non-randomized designs, highlighting the need for more robust studies to establish the effectiveness of exergames in these populations.

One of the limitations of this study is the small size and high homogeneity of the sample included in the study. A second limitation is the use of a pre–post-intervention study with no control group.

5. Conclusions

This study demonstrates that a home-based, VR-driven exergame intervention, incorporating 3D movement tracking, significantly improved postural balance in older adults. Comprising eighteen 25 min sessions, the VR exergame protocol offered a highly engaging and interactive approach to PA, even amidst the disruptions caused by the COVID-19 pandemic. This technology-enabled solution allowed older adults to maintain and enhance their balance in the comfort of their homes, overcoming the challenges posed by traditional in-person programs. The results emphasize the potential of VR and 3D exergames in promoting healthy aging, preventing falls, and providing accessible, effective PA options for older adults, regardless of their mobility or location.

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Informed Consent Statement: All participants voluntarily signed an informed consent form, with the research explained in detail both verbally and in writing.

Data Availability Statement: The data supporting the findings are available from the corresponding author upon request.

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Conflicts of Interest: The authors declare no conflicts of interest.

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