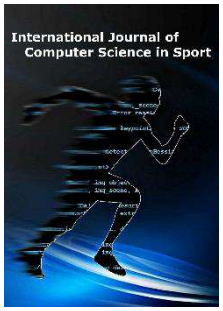
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Comparison between six-week exergaming, conventional balance and no exercise training program on older adults' balance and gait speed

Hashim, J.[1], Campelo, A.M.[1], Doyle-Baker, P.K.[2,3,4], Cossich, V.R.A.[1], Katz, L.[1]*

[1]Sport Technology Research Lab, Faculty of Kinesiology, University of Calgary, Calgary, Alberta, Canada

[2]Faculty of Kinesiology, University of Calgary, Canada

[3]School of Planning, Architecture, and Landscape, University of Calgary, Canada

[4]Alberta Children's Hospital Research Institute, University of Calgary, Canada

Abstract

We evaluated differences between a six-week exergame-training and a conventional balance training program on the balance and gait speed of older adults' (≥65 years). Forty-two healthy participants were recruited from independent living and community centers and randomized to one of three groups: exergaming balance training (EBT), conventional balance training (CBT), or control (no training). The participants completed two balance measurements (Fullerton Advanced Balance Scale (FAB) and center of pressure (COP) excursion), and gait speed at pre, post-intervention, and after a three-week follow-up. Both EBT and CBT groups improved their scores on the FAB, COP displacement, and gait speed post-intervention ($p<0.05$) and these changes were maintained and did not return to pre-training values after three weeks of detraining. The control group scores for FAB and gait velocity values declined ($p<0.001$) but not COP excursions during the study. This six-week exergame training program improved balance control and gait speed in community-dwelling seniors in a similar fashion to conventional training. Participants' physical abilities scores improved and were maintained following three weeks of detraining. Exergame-based training therefore may be considered as an intervention that can address balance control and gait speed in older adults. As well improved scores can be maintained with transient or sporadic activity.

KEYWORDS**:** SENIORS, EXERGAMES, ACTIVE VIDEO GAMES, NINTENDO WII FIT, DETRAINING.

Introduction

The world has experienced a rapid increase in life expectancy, and projections suggest a doubling of the older adult population by 2050, reaching a total of 2.1 billion seniors worldwide (Lutz et al., 2008; WHO, 2022). It is well-known that older adults experience biopsychosocial changes, which may include physical frailty, social isolation, and reduced levels of physical and cognitive functions (Briggs et al., 2016; Rossini et al., 2007). Apart from a general illness increase, older adults also face an increased risk of falls and fractures (Park, 2018; Thomas et al., 2019), which can lead to an increased functional dependence or even death (Kleiven, 2020; Mai et al., 2018).

Age-related physical impairments, such as poor balance control and gait disorders are considered to be multifactorial, including alterations in the neuromuscular system (e.g., sarcopenia, proprioception, and vestibular system impairments) and cognitive functions (Cuevas-Trisan, 2019; Manchester et al., 1989; Thomas et al., 2019). As we age, older adults tend to demonstrate more body sway – an increased center of pressure (COP) displacement – compared to their younger peers (Laughton et al., 2003; Manchester et al., 1989; Sundermier et al., 1996). Similarly, gait speed tends to decrease with aging (Atkinson et al., 2007; Callisaya et al., 2013; Hausdorff, 2007; Nascimento et al., 2022), which also may lead to increases in fall risk (Fritz & Lusardi, 2009; Middleton et al., 2015; Verghese et al., 2009). Thus, a sedentary lifestyle may contribute to accelerated age-related physical impairments (Buchner et al., 1992; Michel et al., 2016; Oliveira et al., 2022). Consequently, designing exercise programs to improve balance control and gait speed should be a priority for seniors (Ross et al., 2020).

Exercise programs to improve balance control – also known as balance control training – usually incorporate a combination of aerobic, strengthening, flexibility, and specific postural control exercises (Baker et al., 2007; Gillespie et al., 2012). Balance control training has been demonstrated to reduce the risk of falls in older adults (Lelard & Ahmaidi, 2015). However, besides the well-known benefits involved in regular physical activity practice – such as social interactions, prevention of chronic diseases, and reduction of general physical and cognitive impairments (Buchner et al., 1992; Ji et al., 2018; Lelard & Ahmaidi, 2015) – only 10-30% of older adults report engaging in exercise at recommended levels (Hallal et al., 2012; Sun et al., 2013). The most cited barriers for this population to avoid engagement in physical exercise are lack of time and motivation, physical disorders, the presence of chronic diseases, and fear of injuries (De Groot & Fagerström, 2011; Schutzer & Graves, 2004).

Due to the continued advances in technology, exergames – a term derived from the combination of "exercise" and "games", such as virtual reality games in which the players interact using their body movements – have emerged as a valuable tool to be incorporated into conventional exercise and rehabilitation programs (Caserman et al., 2020; Gallardo-Meza et al., 2022; Hasselmann et al., 2015; Martin-Niedecken & Götz, 2017; Ravenek et al., 2016; Sinclair et al., 2007). Exergame-based programs have been shown to be effective at improving older adults' physical capacity specifically balance control (Eckert et al., 2017; Van Diest et al., 2013), and as an assistive health technology (Tuena et al., 2020). Unlike conventional exercise programs, exergame-based programs may be perceived as an enjoyable, attractive, hobby-like practice (Campelo & Katz, 2020a; Rose et al., 2018; Yousefi Babadi & Daneshmandi, 2021). These perceptions might help to prevent boredom and increase adherence to exercise programs (Oesch et al., 2017; Rose et al., 2018).

A variety of interactive exergames has been introduced into healthcare environments. Among them, the Nintendo Wii Fit™ stands out as the prevailing exergame platform utilized for balance training (Hall et al., 2016; Lee et al., 2023). The Nintendo Wii Fit™ is a collection of exergames, such as aerobics, balance exercise, muscle exercise or yoga that can be played using the Wii

remote™ controls and/or the Wii Balance Board™ (WBB), which is similar to a force plate and captures the player's COP displacement (Clark et al., 2010). The Wii Fit™ games encourage users to achieve a designated target body position and provides real-time feedback by representing their center of gravity on the screen (Gil-Gómez et al., 2011). In particular, the balance games from Wii Fit involve four fundamental operations: maintaining balance on two legs; leaning the body in forward, backward, and side-to-side directions; rotating the hips clockwise and counterclockwise; and coordinating body movements to a rhythm.

Not surprisingly, the Nintendo Wii Fit™ and its accessories have been widely investigated as tools for balance assessment and training, especially for older adults (Agmon et al., 2011; Bieryla & Dold, 2013; Franco et al., 2012; Huang et al., 2022; Jorgensen et al., 2013; Lacourpaille et al., 2013; Williams et al., 2010; Young et al., 2011). In general, these studies reported an improvement in balance control and a decrease in fear of falling after regular exergaming practices (Afridi et al., 2021; Van Diest et al., 2013). However, few studies have included a control group (no exercise) when examining the effect of WBB-based balance training in healthy older adults (Fakhro et al., 2020; Merriman et al., 2015; Whyatt et al., 2015). To the best of our knowledge, no investigation has compared an exergame balance training (EBT) program using Wii Fit™ and its accessories to a conventional balance training (CBT) program with the inclusion of a no-exercise control group within the same sample.

Besides the physical, functional improvement promoted by exercise routines, it is important to understand the capacity to maintain such improvements (Grgic, 2022; Yang et al., 2022). Given that exergames can be used as a source of both leisure and structured physical activity (training or rehabilitation), understanding the detraining effects of using the technology is also relevant for health care professionals when designing exercise programs, and for informing end users.

The goal of this study was to evaluate the effects of a 6-week exergame-based program on older adults' balance control and gait speed, compared to a conventional balance training program and a control group (no training). We hypothesized that participants in EBT and CBT groups would experience similar enhancements in both balance control and gait velocity and both groups would demonstrate a gradual reduction in performance after three weeks of detraining.

Methods

Experimental Protocol

This single-blind randomized-controlled trial study was conducted at an independent-living center in Calgary, Alberta, Canada. The participants were randomly allocated to one of three study groups, exergame-based training, conventional training, or no training (control). We assessed the participants' dynamic and static balance control – Fullerton Advanced Balance Scale (FAB) and COP excursion – and the gait speed at pre-training (week 0), post-training (week 6), and after 3 weeks of detraining (week 9) (**Figure 1**). Each assessment session lasted for approximately 30 minutes.

Participants

Older adults were recruited from the local community and retirement centers. Participants aged 65 and older who spoke and read English and were able to ambulate without an assistive device were included. Those excluded had an inborn or acquired balance or neurological disorder(s) (e.g., stroke, traumatic brain injury, spinal cord injury, nerve injury, multiple sclerosis, or Parkinson's), and presented with vision and/or hearing skills incompatible with interacting with a videogame. Individuals that presented with acute/chronic disease (accessed by PAR-Q+) (Bredin et al., 2013; Thomas et al., 1992); failed to clear the Mini-Cog Test (score < 3) (Borson

et al., 2003); had taken part in a physical activity program within the last 3 months or, had more than 2 falling incidents in the previous year (self-reported) were also excluded. Initially, 74 older adults expressed interest resulting in 42 participants (27 females and 15 males) enrolled in the study (**Figure 1**). The participants were randomly assigned to one study group: exergame balance training (EBT, n=16), conventional balance training (CBT, n=15), or control (CTL, n=11). To maintain allocation concealment, randomized sequences were computer-generated (allocation ratio 5:5:3) by an individual that was not directly involved in the study. All participants read and signed the consent form, and the study was approved by the Research Ethics Board (#REB16-1633).

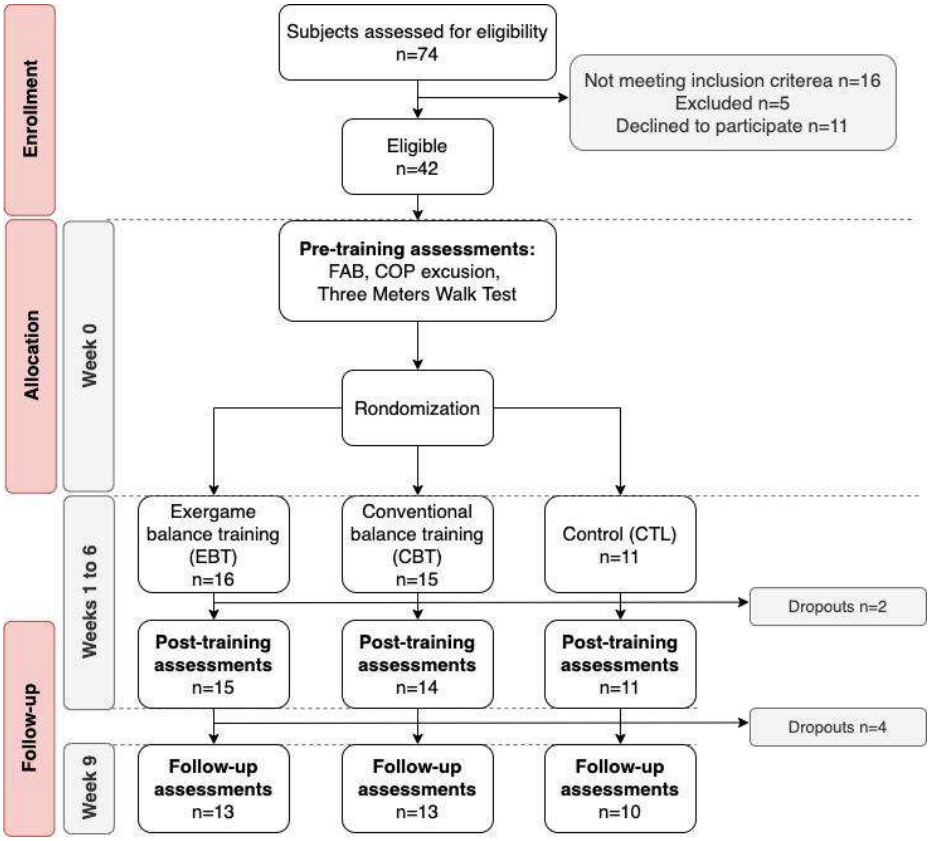


Figure 1. Recruitment and participant allocation.

Training Protocol

The EBT program included activities using the Nintendo Wii-U™ console (Nintendo®, Kyoto, Japan) to operate the Wii Fit-U™ games (Jorgensen et al., 2013). Participants used the Wii Balance Board™ and Wii Remote™ to control the games, while the CBT followed an adapted exercise program guideline (Kisner & Colby, 2012). Both the EBT (**Figure 2**) and CBT (**Table 1**) programs were designed to match the physical demands of the participants. The 6-week program (18 sessions) had a frequency of three times per week (Monday, Wednesday, and Friday) with a duration of approximately 50 minutes. The session included small groups of 4 to 5 participants and was conducted by the same instructor (a qualified physiotherapist), at the same location and time of the day. Although participants could interact with each other during the sessions, the exercises were performed individually. Training overloads (volume and intensity) were increased biweekly by increasing the number of plays and difficulties of the games, or the external loads – provided by elastic bands and ankle weights – for both EBT and CBT,

respectively. Participants allocated to the CTL were asked to not engage in any structured exercise program, but they were advised to maintain their usual daily routine.

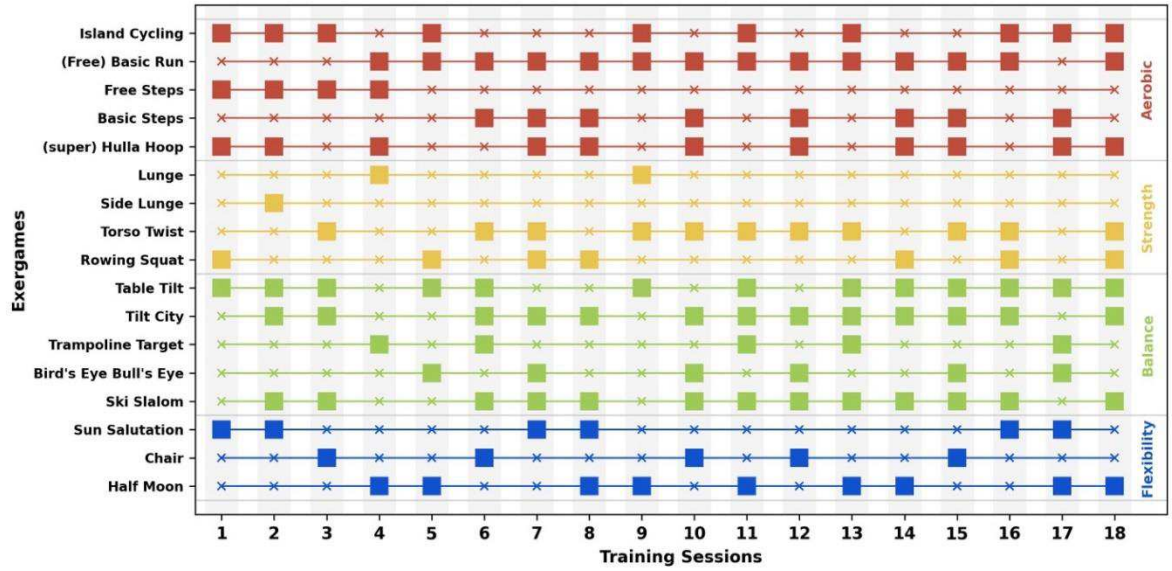


Figure 2. Exergames were used by category and training session. The Wii Fit-U™ games were categorized into four types: aerobics, strength, balance, and flexibility. The rectangles represent the sessions where the exergame was used. The average number of games played in the first two weeks was seven. In week three and four one-half of the sessions included seven games while the other half had eight games. During the last two weeks, the average number of games was 8, and the last session included nine games. Each session had different combinations of exercises, and those modifications were made to follow a progression to more difficult tasks and to keep participants involved with learning new skills.

Fullerton Advanced Balance Scale (FAB)

The FAB is a performance-based scale developed to identify subtle changes in balance control and to comprehensively assess the underlying cause of balance disorders. The test consists of ten evaluation items and each item is scored between 0 (unable to do) and 4 (totally able to do). A higher score indicates better balance control and a score below 25 indicates a higher risk of falling in older adults. The FAB has a high inter-rater (ICC=0.94-0.97), intra-rater (ICC=0.97-1.00), and test-retest reliability (Rose et al., 2006) when tested in the elderly.

Gait speed

The Three Meter Walk Test requires the participant to walk on an unobstructed flat surface at their own pace between the beginning and ending points marked out with cones and lines. The following standardized instructions were given: *''You will walk to the other end of the course at your usual speed, just as if you were walking down the street to go shopping. Walk all the way past the other end of the course before you stop. Ready…begin''*. Participants did not perform a practice walk but the appraiser demonstrated the test to each participant. One meter acceleration distance was added to the straight pathway. A total of two trials were performed and the faster time (measured with a stopwatch) was recorded as the gait speed (m/s). The gait speed of the individuals was used to classify them accordingly: (1) Household ambulatory: less than 0.4 m/sec; (2) Limited community ambulatory: 0.4 to 0.8 m/sec; (3) Community ambulatory: 0.8 to 1.2 m/sec; and (4) Able to cross streets safely: 1.2 m/sec and above (Middleton et al., 2015).

Table 1. Conventional Balance Training program.

Exercise	Volume
Aerobic	
• Static stepping	20 reps – 1 set
• Trunk rotation	12 reps – 2 sets
• Arm circles	12 reps – 1 set
• Wrist circles	12 reps – 1 set
• Arm scissors	12 reps – 1 set
• High knees marching	20 reps – 2 sets
Strength	
• Hip abduction (lateral decubitus - unilateral both sides)	12 reps – 2 sets
• Leg raises (dorsal decubitus - both unilateral sides)	12 reps – 2 sets
• Hip extension (standing - unilateral both sides)	12 reps – 2 sets
• Leg curls (upright - unilateral both sides)	12 reps – 2 sets
Balance	
• Bridging	10 reps – 2 sets (+10 seconds holding last rep)
• Bird-dog	2 reps – 10 seconds holding
• Sit to standing	12 reps – 2 sets
• Stepping out of the box (all directions - unilateral both sides)	1 rep – 3 sets
Flexibility	
• Hamstrings	
• Gluteus Maximus	
• Gastrocnemius and Soleus	1 rep – 2 sets (15 seconds holding)
• Lumbar Paraspinals	
• Shoulders	

The intensity was self-selected by the participant. However, the instructors tried to increase it biweekly for each continuous exercise overload across the program.

Statistical Analysis

The estimated sample of 30 participants (power = 0.80, effect size = 0.5, and type I error = 5%) was calculated assuming three independent groups with three longitudinal measures, using G*Power software V. 3.1.9.6 (Germany). The baseline differences in age, height, weight, and body mass index (BMI) across the groups were assessed using a one-way ANOVA. Generalized Estimating Equation (GEE) models were employed to determine the longitudinal effects on each of the dependent variables: FAB, AP and ML COP excursions, and gait speed. The ANOVA demonstrated that BMI was different between groups at baseline and then it was adjusted as a covariate in the GEE models. GEE models accounted for the groups (EBT, CBT, and CTL), moments (pre-intervention, post-intervention, and follow-up), and interaction effects. We adopted the GEE model because of correlated observations across study participants and an uneven number of observations (i.e., imbalanced). When necessary, we used a post hoc Bonferroni pairwise comparison test. The threshold for statistical significance was set as $p < 0.05$. All statistical analysis was completed using IBM® Statistical Package for the Social Sciences (SPSS) version 23.0. The images were produced using Python (version 3.7.4) and Matplotlib (version 3.5.3).

Results

Only BMI (p=0.03, **Table 2**) was statistically different among demographic data. During the first week of intervention two participants (one from EBT and the other from CBT) dropped out due to problems unrelated to the study (**Figure 1**). A total of 29 (EBT, 15; CBT, 14) participants completed the training and the post-training assessments (**Figure 1**). Four exercise participants (EBT, 2; CBT, 1), and one from the control group failed to complete the follow-up assessment (after detraining). The mean, (SD ±), training session attendance was 15 ± 3 (min = 13, max = 18) for EBT and 15 ± 2 (min = 12, max = 18) for CBT.

Table 2. Participant characteristics (mean; ± SD) by group and sex (male; female)

	EBT (n=15)		**CBT (n=14)**		**CTL (n=11)**		***p-value***
	M (n=6)	**F (n=9)**	**M (n=5)**	**F (n=9)**	**M (n=4)**	**F (n=7)**	
Age (yrs)	72 ±6	73 ± 9	70 ± 5	73 ± 5.	76 ± 10	72 ± 6	0.98
Height (cm)	171.8 ± 4.1	161.4 ± 7.3	173.6 ± 3.6	162.2 ± 3.9	173 ± 11.3	161.8 ± 4.5	0.72
Weight (kg)	97.0 ± 19.3	75.94 ± 12.3	92.4 ± 17.1	69.8 ± 10.0	80.1 ± 24.7	65.4 ± 5.9	0.06
BMI (kg/m^2)	32.8 ± 6.4	29.2 ± 5.0	30.5 ± 5.0	26.6 ± 4.2	26.4 ± 4.8	25.1 ± 2.9	**0.03***

Exergame balance training (EBT), conventional balance training (CBT), and control (CTL) groups. Body Mass Index (BMI). *EBT was significantly different from CBT and CTL (both, $p < 0.05$).

We observed a moment (Wald χ^2=6.48, p=0.039; **Figure 3A**) and a group-by-moment interaction effect (Wald χ^2=37.34, p<0.001; **Figure 3A**) in the FAB score. Significant improvements in FAB score were observed for both EBT and CBT (pre *vs.* post – p<0.001 and p=0.05; **Figure 3A**). The CTL score declined (pre *vs.* post – p<0.01; **Figure 3A**). A group significant effect was observed for AP (Wald χ^2=12.54, p=0.002; **Figure 3B**) and ML (Wald χ^2=9.786, p=0.007; **Figure 3C**) COP excursions (both, PRE > POST and POST = Follow-up). An improvement from the pre- to post-test and no changes to the follow-up test were observed for all groups on AP and ML body sway excursion, (**Figure 3B and C**). However, the pairwise comparisons (between moments) just reached marginal p-values.

A significant moment (Wald χ^2=8.76, p=0.012; **Figure 3D**) and interaction effects (Wald χ^2=30.94, p<0.001; **Figure 3D**) were observed in gait speed. Both EBT and CBT improved the gait speed after training (pre *vs.* post, both p<0.001; **Figure 3D**) and the follow-up speed remained different from the pre-value (both, p<0.001; **Figure 3D**). In the opposite direction, the CTL tended to decrease their gait speed across moments (**Figure 3D**).

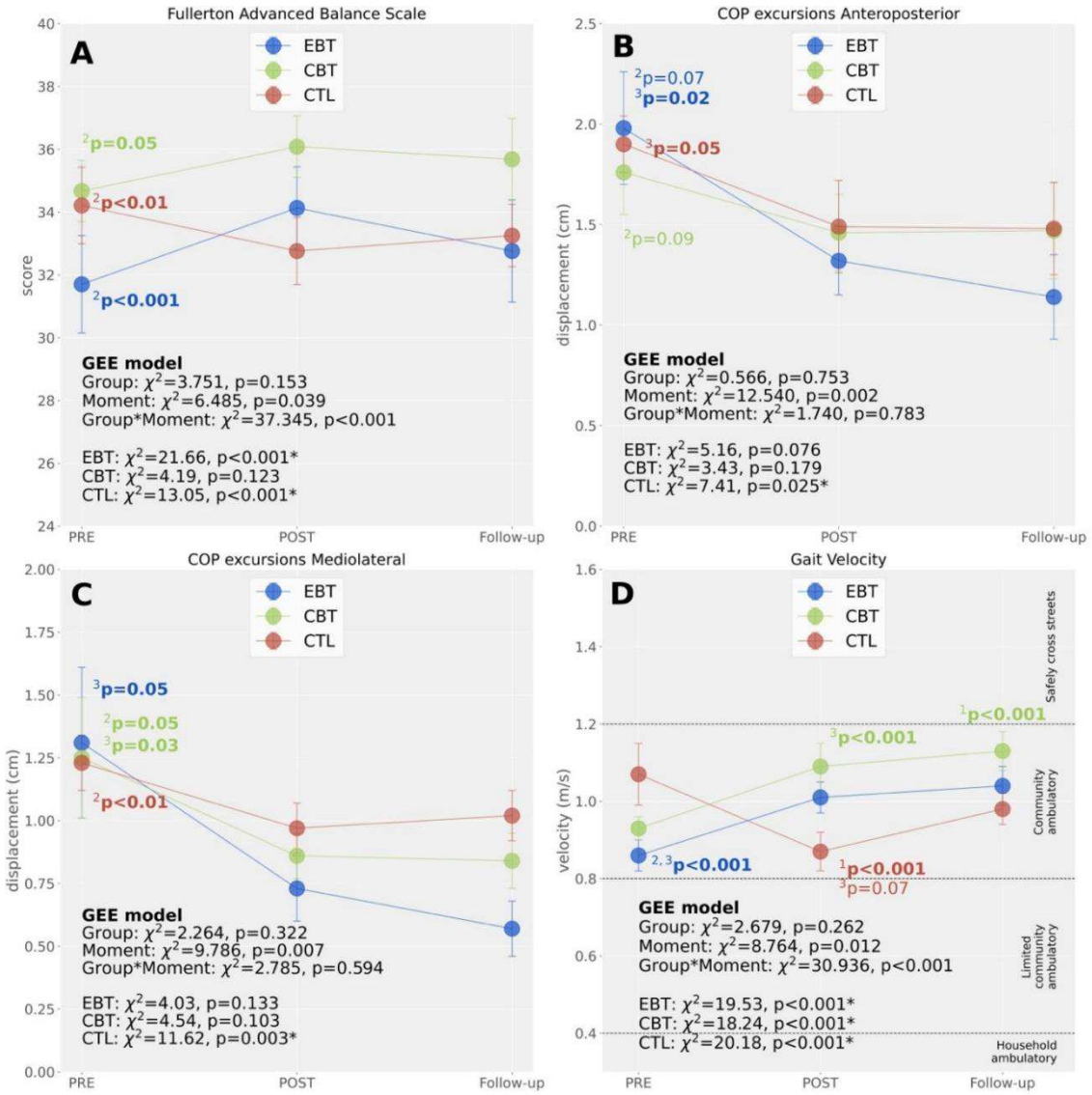


Figure 3. Fullerton Advanced Balance Scale, Anteroposterior and Mediolateral excursion, and Gait Velocity across moments for each group. Values are displayed as mean ± standard error. A) Fullerton Advanced Balance Scale, B) Anteroposterior COP excursion, 3) Mediolateral COP excursion, 4) Gait Velocity – the function level classification was based on (Middleton et al., 2015). Superscript numbers refer to the pairwise between moments comparison [1 = different from PRE, 2 = different from POST, and 3 = different from Follow-up]. Significant p-values were in bold. COP = center of pressure.

Discussion

The goal of this study was to evaluate the effects of a 6-week exergame-based and conventional training program on seniors' balance control and gait speed. The effects of 3-week detraining on the performance were also evaluated. As

hypothesized, both EBT and CBT groups improved the dynamic and static balance – measured by FAB and COP displacement, respectively – and gait speed after training. Interestingly, both training groups maintained improvements above the pre-training values after 3-weeks of detraining.

Recently, Fakhro et al. (2020) observed an improvement in balance – assessed by the Time To Up and Go score and COP ML displacement – after 8 weeks (3 times a week, 40-min per session)

in seniors with a fall history. Similarly, Padala et al. (2017) reported a balance control improvement – measured by Balance Berg Scale – in community-dwelling older veterans after an 8-week intervention (3 times a week, 45-min per session). These results are in line with previous studies that used the WBB and Wii Fit™ in the elderly (Agmon et al., 2011; Gallardo-Meza et al., 2022; Jorgensen et al., 2013; Williams et al., 2010; Young et al., 2011). However, Bieryla and Dold (2013) trained a small group of twelve seniors using the WBB and Wii Fit games for 3 weeks (3 times a week, ~30 min per session). They assessed balance performance using different tests – including the FAB scale –pre-intervention, after 1 week, and one month post-intervention. They found an improvement only in Berg Balance Scale scores after one month of follow-up. Based on those previous studies the volume of play (or training) can be related to the positive effects of balance control.

In the present study, six weeks of training improved both EBT and CBT dynamic balance, while the CTL group declined in performance during the study. Also, all groups reduced the COP displacement across the experiment. Although the EBT demonstrated a bigger percentual change post-training (anteroposterior: EBT = -33%, CBT = -17%, and CTL = -22%; mediolateral – EBT = -44%, CBT = -31%, and CTL = -21%), we cannot attribute those changes to the training program directly due to the changes observed in the CTL group. Although unexpected, it seems that the results append to a row of mixed findings involving COP and exergame literature. For example, Bainbridge et al. (2011) and Jorgensen et al. (2013) did not find significant differences in COP excursion and velocity after exergame-based training. However, Toulotte et al. (2012) observed a significant improvement in COP displacement after 20 weeks of training using Wii Fit™ and WBB. Whyatt et al. (2015) also reported a significant reduction in COP displacement after training (2 times a week – 10 weeks) using WBB and custom games. In the absence of a physiological explanation for the COP displacement results observed in the present study and witnessed by the improvement in FAB scores and gait speed only by EBT and CBT, the changes may be attributed to the participants' adaptability to the WBB (i.e., learning effect) after the first trials. Therefore, although the COP displacement serves as an objective and pragmatic balance outcome and the WBB is valid and reliable to measure the COP displacements (Clark et al., 2010, 2018; Lee et al., 2019; Llorens et al., 2016) extra trials might be included in future evaluation protocols to stabilize the measure better. Also, Park et al. (2018) suggested that more than a single assessment tool can be used in combination to maximize the characteristics and predictability of each test.

Although gait speed is a simple and quick option for measuring fall risk (Verghese et al., 2009) few researchers studied the effects of exergame-based balance training on gait speed (Agmon et al., 2011; Corregidor-Sánchez et al., 2020). Similar to the present findings, Agmon et al. (2011) observed an improvement in gait speed after playing Wii Fit™ games for 3 months (3 times a week, 30 min per session). Interestingly, we observed a consistent improvement in gait speed after just 6 weeks of training which suggests that older adults can demonstrate improvements in walking performance in shorter periods. It should be noted that even after improving their performances all groups remained classified as "Community Ambulatory" speed (Middleton et al., 2015) (see **Figure 3-D**). In order to display a higher functional level, longer periods of intervention may be needed.

The improvement obtained after six weeks (18 sessions) of training was maintained at post-training levels after a 3-week detrain. It is a relevant clinical finding, suggesting that even if the seniors experience intermittent training/activity they still can hold the benefits for a determined period. This result corroborates the findings from a recent systematic review by Modaberi et al. (2021), which demonstrated that performance retention after a balance control and fall prevention program can be held from 4 weeks to 6 months depending on the training volume and intensity.

In general, the present findings corroborate previous ones (Van Diest et al., 2013), and reinforce that older adults can use exergames to improve their functional capacity, specifically balance control and gait speed performance. Interestingly, the improvement in EBT was similar to the one experienced by CBT, suggesting that the exergame by itself can be a promising clinical intervention for enhancing seniors' balance control and gait speed performance. Despite its relevance, the generalizability cannot be extrapolated to the entire elderly population. In this study, the participants were considered healthy subjects, without recent fall history, and none of the participants were labelled as "faller risk" (FAB index < 25 points). Thus, when designing intervention programs for a group with different demographics, a variation in the training effects may be expected. Moreover, maintaining balance control involves a complex interplay between sensorimotor input, central processing, and motor output (Ganz et al., 2007). Consequently, clinical populations may need a constant challenge provided by the exercise programs. In this sense, the exergames can be used in combination with conventional balance exercises to maximize the gains and address the individual's response to the intervention. Also, future studies should investigate the use of newer off-the-shelf immersive virtual reality technologies (e.g., Oculus Quest™) when designing interventions for older adults to expand the current findings for the newest technologies.

Although the present results are interesting and support the use of exergames to promote improvements in seniors' physical health, one additional aspect that must be considered in the exergaming field is the game's dual mission, especially regarding the balance between effectiveness and attractiveness (Caserman et al., 2020; Martin-Niedecken & Götz, 2017; Sinclair et al., 2007). The effectiveness is evidenced by the positive changes in the main outcomes of this study: FAB scores, AP and ML COP excursions, and gait speed resulting from the exergame program. Although we did not objectively assess the game's attractiveness in the present study, participants regularly expressed interest in the technology. For example: *"I'm really glad that I got in the Wii group because it was way more fun than doing exercises"*, *"I like Wii Fit-U variants"*, and *"I might consider buying one [Nintendo Wii-U]"*, were common. These observations corroborate previous studies by our group (Campelo & Katz, 2018, 2020b; Donaldson, 2022), which have observed high levels of seniors' interest in both exergames and health trackers. Recent reviews have reinforced seniors' interest in exergames but highlighted that healthcare professionals should carefully conduct curation, including program design and game choice (Ismail et al., 2022; Yoong et al., 2024). We suggest that exergames be included as part of an exercise program. Professionals should be aware of the interesting fluctuations, which need to be continually checked so as to promote adequate measures to maintain seniors' interest levels and exercise engagement.

In conclusion, the 6-week exergame training presents a feasible way to improve balance control and gait speed in community-dwelling older adults. In addition, the training effects experienced by the EBT and CBT were similar improvements, reinforcing that the exergame-based training may be used as an intervention approach to address balance control and gait speed. Moreover, the participants were able to maintain their gains for three weeks (half of the intervention time), suggesting that transient or sporadic playing could provide physical abilities improvements to older adults.

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