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The Effectiveness of Home-Based Exergames Training on Cognition and Balance in Older Adults: A Comparative Quasi-Randomized Study of Two Exergame Interventions

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Abstract

Background and Objectives: The effectiveness of exergames on fall risk and related physical and cognitive function in older adults is still unclear, with conflicting findings. The discrepancy in these results could be due to the different components and task-specific demands of individual exergame interventions. This open-label quasi-randomized study aimed to compare the efficacy of 2 different home-based dual-task exergame treatments on cognition, mobility, and balance in older people.

Research Design and Methods: Fifty older adults (65–85 years of age) were allocated to one of two 8-week exergame interventions: Cognitive-Intensive Exergame Training (CIT) or Physical-Intensive Exergame Training (PIT). Cognitive functions, balance, and mobility were assessed at baseline and after 8 weeks. Group × time interaction was measured by repeated-measure ANOVA, and both intention-to-treat (ITT) and per-protocol (PP) analyses were performed to assess the effectiveness of exergame interventions.

Results: ITT analyses showed that improvement in visual processing speed and visuospatial working memory was greater in the CIT group, with a medium effect size ($p = .04$; $\eta^2 = 0.09$ and $p = .01$; $\eta^2 = 0.12$). The improvement in verbal memory and attention was significant within both groups ($p < .05$), but this improvement was not different between the groups ($p > .05$). A significant improvement in balance was also observed in the PIT group, with a medium effect size ($p = .04$; $\eta^2 = 0.09$). Although mobility improved significantly in both groups ($p < .01$), there was no significant difference between groups ($p = .08$). These results were largely supported by the PP analysis.

Discussion and Implications: Dual-task exergame training can improve mobility and cognition in older adults. However, the different cognitive and physical demands of these interventions may have varying impacts on fall risk and related physical or cognitive functions. Therefore, a training program that includes both cognitive and physical domains with appropriate intensity is essential for the development of tailored exergame interventions to reduce fall risk in older adults.

Translational Significance: This study addresses the problem of conflicting findings regarding the effectiveness of exergames on fall risk and related physical and cognitive function in older adults. The findings suggest that tailored exergame interventions combining cognitive and physical domains can effectively improve outcomes related to fall risk in older adults, highlighting the need for comprehensive training programs in this population. By providing evidence-based recommendations, this research has implications for developing targeted interventions and reducing fall risk among older individuals, thereby enhancing their independence, safety, overall well-being, and quality of life.

Keywords: Aging, Dual task, Exercise, Exergaming, Fall

Background and Objectives

Aging is characterized by rapidly increasing cellular damage, onset and progression of age-related disease decreasing functional capacity, and accompanying cognitive decline (Luo et al., 2020). Degradation of the neuromusculoskeletal system, weakening of physical function, and impaired cognitive functions all significantly increase the risk of falling in older people (Jahn et al., 2019; Shur et al., 2021). Falls might cause serious injuries, even death, and often result in long-term hospitalization and high care needs accompanied by high healthcare costs (Bohl et al., 2010; Montero-Odasso, 2019).

The risk of falling is much higher in people with cognitive impairment and is almost doubled in people with dementia (Montero-Odasso & Speechley, 2018). Cognitive functions, such as attention, visuospatial functions, processing speed, and memory, are associated with functional mobility and

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thereby could play an active role in fall risks (Fernando et al., 2017; Jayakody et al., 2022; Zhang et al., 2019). Therefore, considering the role of cognitive functions in gait and balance, improving cognition might be effective in reducing the risk of falling in older adults (Chan et al., 2015). Although many fall prevention programs have focused on balance and gait (Delbaere et al., 2021; Thomas et al., 2019), interest in interventions that include both cognitive and physical domains related to balance, gait, and strength has increased recently (Guimarães et al., 2018; Rosado et al., 2021).

Evidence has shown that exercise can significantly reduce fall risk in older adults (Sherrington et al., 2020). Gallou-Guyot et al. (2020) suggested that especially motor-cognitive dual-task exercises and exergames might be more effective in improving both physical and cognitive functions than traditional exercises focusing only on physical improvements. As such motor-cognitive tasks could be more efficient in reducing fall risk. In this vein, previous reviews reported that some exergame interventions may be more effective on cognition and mobility than single-task exercises, as they contain both cognitive and physical demands (Chen et al., 2021; Choi et al., 2017). Exergames are also known as video games that require simultaneous involvement of both physical activity and cognitive tasks (Larsen et al., 2013). However, although some studies suggest that exergaming is more effective than an inactive control group in reducing fall risk by improving the above-mentioned outcomes in older adults (Park et al., 2015; Wu et al., 2015), there are also studies reporting that this innovative intervention is not superior to traditional single-task balance training (Hsieh et al., 2014; Singh et al., 2012). A recent review of systematic reviews by Gallou-Guyot et al. (2020) reported that exergames are effective in improving cognitive functions, but their effectiveness in also improving physical function is unclear. However, another umbrella review reported that exergames significantly improved balance and gait (Reis et al., 2019). These conflicting results could be due to particular exergame components and task-specificity. The optimal amount of cognitive and physical demands provided in an exercise intervention and how this could affect fall risk in older adults is still unclear. Moreover, although exergaming has been proposed as a potentially safe and feasible intervention (Alhagbani & Williams, 2021), interventions in studies conducted to date have almost always examined the effects of a supervised intervention in a research setting (Ge et al., 2022). Although it is emphasized that this treatment can be performed unsupervised at home, its impact and potential risks (e.g., of falls in vulnerable older adults with cognitive impairment or dementia) are also still unknown (Gallou-Guyot et al., 2020).

The aim of this study was to compare the efficacy of two different home-based exergame treatments involving different cognitive and physical domains on cognition and balance, which are closely related to fall risk in older people. Based on the specific tasks designed for the exergames and their therapeutic objectives, our hypothesis suggests that exergame training with increased cognitive demands would have a stronger influence on cognitive functions related to fall risk. Conversely, we propose that exergames emphasizing balance training would primarily enhance mobility and balance although having a limited effect on cognitive functions.

Research Design and Methods

Study Design

The present study was an open-label and quasi-randomized trial with two active groups (1:1 allocation ratio). The trial was registered in the Clinical Trial Registry (ID: NCT05395676). The study protocol was approved by the Loughborough University Ethics Committee (2021-5832-5089). Written informed consent was obtained from each participant before enrolling in the study. The CONSORT checklist was used to report this study (see Online Supplementary Material, Section 1).

Participants

Participants were recruited through local community centers in Loughborough and via online advertisements using Be Part of Research and Join Dementia Research websites from May 2022 to November 2022. Self-referrals were also accepted. The inclusion criteria were set as follows: eligible participants had to (a) be older adults aged from 65 to 85 years, (b) be physically able to stand for at least 5 min without assistance, and (c) be capable of performing a full range of upper limb movements against gravity. Participants with neurological conditions, such as vestibular deficits, stroke, Parkinson's disease, and dementia or other forms of cognitive impairment, severe cardiovascular and/or metabolic diseases, and orthopedic injuries obtained within the last 12 months that could affect the performance of the proposed activities were all excluded from the study ($n = 25$). Eligible participants were asked not to participate in another exercise program until they completed the study.

Considering previous meta-analysis results showing small (0.22–0.29) sized effects of exercise on cognitive functions in the elderly, the ES was estimated as 0.25 (Zhu et al., 2016). The sample size was thus based on a small ES ($f = 0.25$), with 80% power at a two-tailed 0.05 significance level with a repeated-measures ANOVA (Cohen, 2013). The power was calculated using G-Power software (Erdfelder et al., 1996), yielding a minimum of 34 participants (17 in each group). Considering the coronavirus disease (COVID) period (Bender et al., 2022; Dejvajara et al., 2022), performing exercises at home with technological devices that older adults might not be interested in, or found them challenging to use (Nawaz et al., 2016), with high drop-out rate (>20 %) in experimental studies including older adults (Drazich et al., 2020; Santen et al., 2022), a total of 50 (25 in each group) participants were initially included in the study.

Intervention

The participants were allocated to one of either treatment groups using an alternate allocation method, with participants assigned alternatively to either cognitive-intensive training (CIT) or physical-intensive training (PIT) in sequential order of enrollment in the study (Davidson & Hillier, 2002). Specifically, the first five participants were assigned to CIT, followed by the next five participants assigned to PIT, and so on, until all participants were allocated to one of the groups. Complete randomization was not feasible in this study due to time constraints and practical considerations related to limited resources for participant recruitment.

Both groups were asked to complete a moderate-intensity exercise program (30 min, 3 days/week for 8 weeks). Moderate-intensity exercise interventions have been found effective in improving cognition and physical ability in previous reviews (Fang et al., 2020; Ismail et al., 2022). The chosen programs were expected to be feasible and not too demanding for older adults, thus improving adherence and reducing drop-out rates (Swinnen et al., 2021). Following the initial baseline assessment, the participant underwent training that covered various aspects such as device setup, game selection, recommended repetition counts and intervals, as well as instructions on how to effectively engage with the chosen games. The first training session was supervised by an experienced physiotherapist. When the participants felt confident enough, they were then asked to complete the 24 sessions in their own homes, following the frequency, duration, and time of engagement with the exercise program agreed upon. Participants were also asked to keep a record of each exercise session they performed through a diary provided. A guide was also provided that clearly explained and illustrated what and how exercises should be carried out to support the process until the participants became familiar with the devices. Remote support was provided to solve technical problems that the participants might experience and to answer any questions. In addition, follow-ups were made at regular intervals (fortnightly) to encourage the participants to do the exercises regularly.

Cognitive-Intensive Exergame Training

The Cognitive-Intensive Exergame Training (CIT) group was trained with the Xbox device that provided dual-task activities including task aspects with a high cognitive demand. The Xbox Kinect system (XBOX 360, Microsoft Inc.), a commercial video game technology, provides control of the body movements of virtual characters through a camera sensor that detects the user's movements and provides feedback (Kamel Boulos, 2012). This 30-min intervention included five games in which physical movements and high-level cognitive processes had to be managed simultaneously. It took participants between 20 and 40 min to complete all tasks. Details of the five games selected from Dr Kawashima's Body and Brain exercise package are provided in Supplementary Material Section 2 (Kawashima, 2008). For the user's movements to be perceived smoothly and the camera sensor not to be distracted by external factors, the participants were asked to perform their exercises in a quiet and isolated environment.

Physical-Intensive Exergame Training

The Physical-Intensive Exergame Training (PIT) group was trained with another commercial video game technology called Wii Fit Plus (Nintendo Co.; Meldrum et al., 2012). Five games with more physical involvement due to the need to maintain balance on the balance board and with lower cognitive processing task demands (than in the Xbox games, see above) were performed. Each exercise session took approximately 30 min. The details of the motor and cognitive demands of both games are provided in Supplementary Material Section 2.

Adherence Rate and Safety

The progress of exercise, and adherence to the programs, were closely monitored through the use of the exergame systems records, and this was compared with the attendance checklist which was completed by the participants. A threshold for a successful level of adherence was set as compliance that was greater than 80% (Mehrabi et al., 2022; Van Beek et al., 2019). Participants were instructed to report any adverse events that might be caused by the training and were advised to cease training in the event of sharp pain, severe fatigue, shortness of breath, or chest discomfort. Additionally, participants were requested to document any technical or managerial issues that arose during the training process.

Outcome Measures

Cognitive functions, mobility, and balance stability were assessed by two experienced assessors before and after the exercise program. Before each assessment, the familiarization sessions were performed to minimize the learning effect on test performance during data collection.

Cognitive Functions

The computerized test battery consisting of the Visual sensitivity Test (VST), Corsi-Block-tapping Test (CBT), Stroop Task (ST), and Hopkins Verbal Learning Test (HVLT) were administered to assess cognitive functions (Hogervorst et al., 2008).

The VST assesses complex visual processing speed and reaction time (Hogervorst et al., 2008). Participants were instructed to touch the screen as soon as they detected a triangle formed from constantly moving dots. In the test including 40 complex-level stimuli, green moving random dots covering the entire black screen served as background distractors. New target triangles were initially drawn with only a few visible dots on each line, and the intensity of these dots increased linearly over time until the response of tapping on that triangle was recorded. After each response, new targets appeared with random delays of at least 500 ms. The mean and standard deviation reaction time (RT in ms) were recorded.

The CBT is one of the most commonly used tests to measure visuospatial short-term working memory (Kessels et al., 2000). This computerized test consisted of nine cubical blocks positioned on the screen. The blocks were tapped in a specific sequence (the color of the tapped blocks changes). Participants were asked to remember and tap these blocks in the same sequence as shown on the screen. Initially, the sequences involved three blocks, but the task became incrementally more difficult, with more blocks presented in the later stages depending on the participants' performance. The results were recorded as the best span (longest sequence reached at least twice) and would normally vary between 3 and 7.

The ST assesses selective attention and sensitivity to interference (Scarpina & Tagini, 2017). The test consists of 40 stimuli. Each colored word was placed on the center of the screen with a target and a distractor presented on the left or right side of the stimulus word. The participants were asked to press the left or right arrow key as quickly as possible to indicate the position of the target word. Reaction time (in msec) and accuracy of responses were recorded.

The HVLT measures the ability to recall items immediately and verbal learning using a 12-item word list of three semantic categories (Benedict et al., 1998; Hogervorst et al., 2014). The participants were instructed to listen carefully as the assessor read the word list and to try to memorize the words. The word list was then read to the participant at a rate of about one word every 2 s, with a 1 s interstimulus interval. The participants' free recall of the list was recorded. The same procedure was performed twice more, and participants were asked to also name the words they had recalled at the earlier trial. After the third learning attempt, the total number of immediately recalled words was noted.

Mobility

The Timed Up and Go Test (TUG) is used to assess functional mobility and fall risk (Podsiadlo & Richardson, 1991). The participants were required to stand up from a standard armchair, walk to a marker located 3 m away from the chair, turn around the marker, walk back to the chair, and sit down again. The time to complete the task in seconds was recorded.

Balance Stability

The Functional Reach Test (FRT) is a widely used clinical test to measure the limit of stability of reaching forward while standing (Duncan et al., 1990; Thomas & Lane, 2005). While the participants were standing with a position of 90° shoulder flexion and closed fist, the position of the 3rd metacarpal on the wall was marked. Then the participants were asked to reach as far as they could forward without taking a step. The distance between the start and end points was recorded (in cm). This was repeated three times and distances reached in the last two attempts were averaged.

Data Analyses

Descriptive statistics were performed using the independent *t*-test for normally distributed continuous variables, Mann–Whitney *U* test for ordinal or continuous data without a normal distribution and the Chi^2 test for nominal data. Analyses were carried out to show baseline intergroup differences following normality testing using the Shapiro–Wilk test. Two-way ANOVA with repeated measures was used to determine the main effects of interaction (group × time). Pre–post differences within groups were analyzed using the paired *t*-test. The study's primary analysis was conducted based on an intention-to-treat (ITT) approach, using multiple imputations of five databases to address missing data. The quality of the imputation technique was assessed based on the fraction of missing information (fmi) and relative efficiency. On average, the fmi was 0.13 (ranging from 0.02 to 0.25), indicating that the sample variance due to the missing data was 13%. The evaluation of imputation was carried out using multinomial logistic, and no significant difference was found between the complete and imputed data ($p > .05$). The imputed data exhibited a more than 95% relative efficiency. A per-protocol (PP) analysis was also conducted. The effect size (ES) was computed using eta-squared (η^2) and interpreted as $\eta^2 \le 0.05$ corresponding to a small effect, $0.05 < \eta^2 \le 0.13$ to a medium effect, and $\eta^2 > 0.14$ to a large effect, according to the criteria established by Rosenthal (1994). All statistical analyses were performed using SPSS version 26 (SPSS for Windows. Chicago, SPSS Inc.), with a significance level set at 5% ($p < .05$).

Results

A total of 87 participants were screened, and 50 eligible participants were assigned to either the CIT or PIT groups, 25 each (Figure 1). Three participants were excluded from the ITT analysis ($n = 24$ in the CIT and $n = 23$ in the PIT) as they expressed their unwillingness to complete the baseline assessments owing to their perceived difficulty. The baseline demographics of participants are provided in Table 1. Ten additional participants did not complete the study due to various reasons (Figure 1). Therefore, 36 participants ($n = 18$ in the CIT and $n = 18$ in the PIT) completed the exercise sessions and were included in PP analyses. The baseline demographics of participants included in PP analyses are also provided as supplementary materials (Supplementary Material Section 3).

The characteristics of the participants showed that there was a similar distribution of participants between the two groups regarding gender, with the number of female participants in both groups (71% and 70%, respectively) more than double that of male participants (Table 1). Additionally, both groups had a comparable mean age (73.4 vs 73.1 years, respectively) and BMI (27.9 and 26.4, respectively). The majority of participants (more than 90%) in both groups reported engaging in physical activity for at least 30 min of moderate-intensity on at least 3 days per week for a minimum of 3 months. However, two participants in each group had a history of falling. A 7-item questionnaire, which is a shorter version of the fall efficacy scale (FES), was used to evaluate the participants' concerns about falling (Kempen et al., 2008). Results indicated that there was no significant difference between the two groups in terms of fear of falling. Likewise, the baseline outcome assessments did not demonstrate any statistically significant differences between the two groups (Table 1). There is no significant difference observed between the characteristics of participants who dropped out of the treatment and those who adhered to it at baseline.

The results of the ITT analysis showed that 8 weeks of exergame interventions significantly improved all evaluated cognitive functions in both groups ($p < .05$, Table 2), except ST accuracy in CIT ($p = .26$). While the improvement in HVLT and ST (RT) was not significantly different between the groups ($F(1,45) = 0.87$; $p = .36$; $\eta^2 = 0.02$ and $F(1,45) = 3.44$; $p = .07$; $\eta^2 = 0.07$, respectively), visual processing speed and visuospatial working memory improved more in CIT with a medium ES ($F(1,45) = 4.35$; $p = .04$; $\eta^2 = 0.09$ and $F(1,45) = 6.15$; $p = .01$; $\eta^2 = 0.12$, respectively). However, the PP analysis results demonstrated a greater improvement in CIT across all cognitive tests, with a large ES ranging from 0.15 to 0.59 (Table 3).

The ITT analysis showed that although both interventions significantly improved mobility ($p < .05$), this improvement was not significantly different between groups ($F(1,45) = 0.06$; $p = .08$; $\eta^2 = 0.01$), a finding that was supported by PP analysis ($F(1,34) = 0.42$; $p = .52$; $\eta^2 = 0.01$). The CIT intervention program showed no significant differences between baseline and the end of the exergame training on FRT ($p = .53$), whereas there was a significant improvement in dynamic balance in PIT ($p < .001$), which showed significant time-group interactions, with a medium ES ($F(1,45) = 4.14$; $p = .04$; $\eta^2 = 0.09$). Conversely, the PP results demonstrated a significant improvement in both groups ($p < .05$), but no significant difference was seen between groups ($F(1,34) = 1.27$; $p = .26$; $\eta^2 = 0.04$).

The adherence rate to the interventions was defined as the proportion of attended sessions. The self-reported adherence rate of participants who completed postintervention assessments was slightly higher in CIT (89%) with a mean training duration of 641.1 min compared with the PIT (85%) with a mean training duration of 613.5 min. However, the adherence rates of participants included in the PP analysis were comparable between groups, with rates of 93.9% and 94.6% for CIT and PIT, respectively. There were no reported adverse

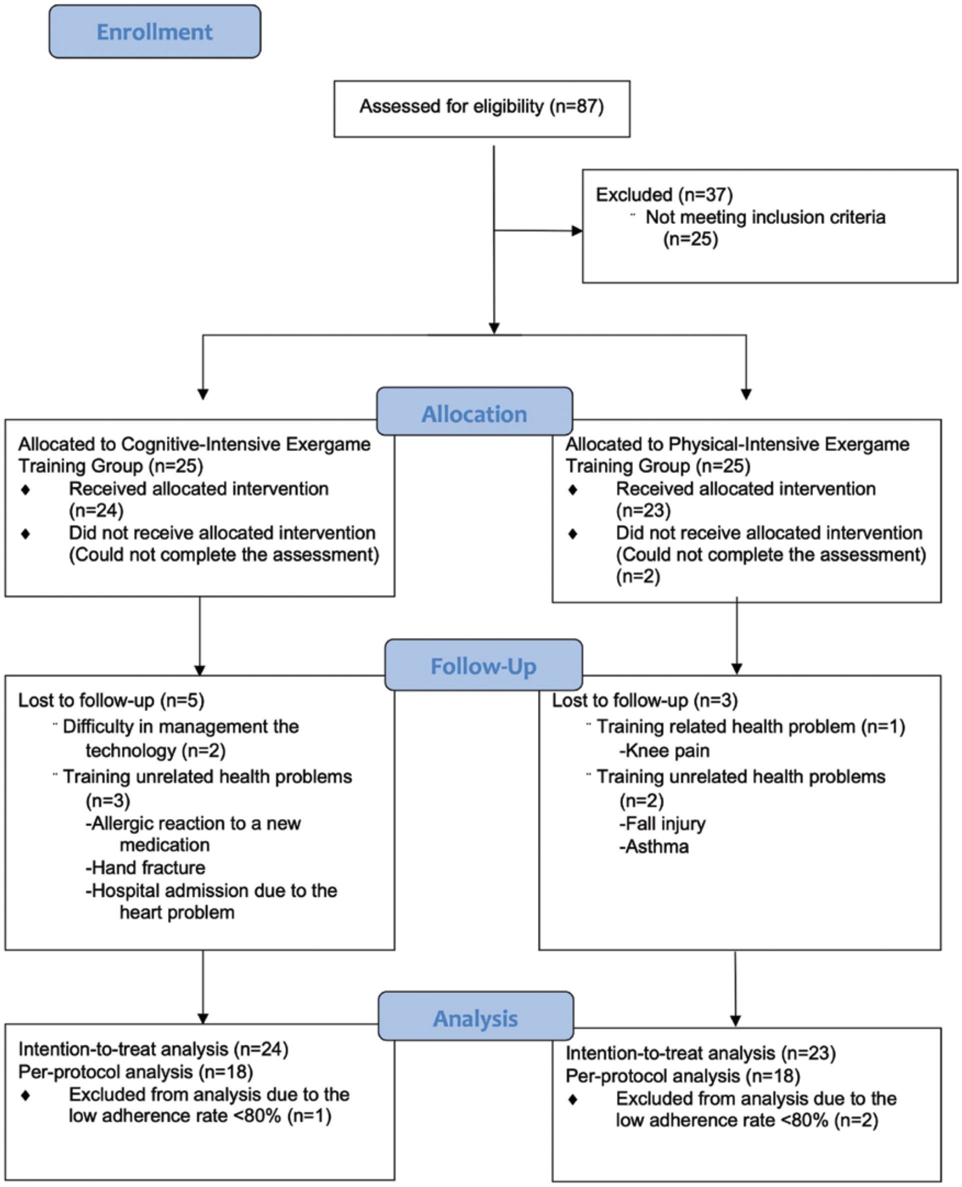

Figure 1. Study flowchart.

events associated with CIT/Xbox training, whereas a mild adverse event, specifically knee pain, was observed in one participant doing PIT/Wii training.

Discussion and Implications

This study compared two exergames to gain insight into how the interplay between cognitive and physical demands influences exergame effectiveness by examining their differential effects on cognition and mobility in older adults. Due to the combination of both physical and cognitive components in both interventions, positive effects were observed in both domains. Nevertheless, it is worth noting that the differing intensities of cognitive and physical aspects within the interventions may account for the variance in effects observed in these respective outcomes.

With regards to physical improvements, walking time in TUG decreased significantly in both groups. However, it is challenging to determine whether the improvement in the TUG test, which is a critical clinical mediator of fall risk, was caused by the intervention, as there was no significant difference between the groups. The lack of a control group thus complicates the interpretation of the results. The improvement on the TUG test in CIT might be due to the fact that both visual processing speed and visual-spatial working memory were more improved, allowing individuals to quickly perceive and interpret obstacles or cues during the TUG test, enabling faster reaction times and smoother navigation through the task, leading to better overall performance (Mirelman et al., 2014). In addition, this improvement is not clinically meaningful as the minimal clinically important difference (MCID) for the TUG test is considered to be 3.4–3.5 s, as reported by Vaz et al. (2022), although the MCID may vary depending on factors such as population, age, and other demographics. As expected, physical-intensive exergame training improved balance more than cognitive-intensive exergame training and balance was the only outcome that did not improve in

Table 1. Participants' Characteristics at Baseline (ITT)

Variables	Sub-category	Xbox group (*n* = 24)	Wii fit group (*n* = 23)	*p*
Age in years, mean (*SD*)		73.4 (5.6)	73.1 (4.8)	.85
Gender, *n* (%)	Male	7 (29)	7 (30)	.92
	Female	17 (71)	16 (70)	
BMI (kg/m²), mean (SD)		27.9 (4.9)	26.4 (3.4)	.19
Physically active, *n* (%)		23 (96)	21 (91)	.52
Fall history, *n* (%)		2 (8)	2 (9)	.96
Comorbidity, *n* (%)	Asthma	2 (8)	4 (17)	.35
	Diabetes	1 (4)	1 (4)	.98
	Head injury	1 (4)	3 (13)	.28
	Heart problems	2 (8)	1 (4)	.58
	Musculoskeletal problems	9 (38)	13 (57)	.19
	Vision problems	1 (4)	1 (4)	.98
	Hearing problems	5 (21)	8 (35)	.28
	High blood pressure	8 (33)	5 (22)	.37
	Multiple comorbidities	5 (21)	11 (48)	.51
Fall efficacy scale, median (IQR)		8 (2)	7 (1)	.39
Functional reach test, cm	Ankle	15.8 (3.8)	16.2 (3.5)	.73
	Hip	24.2 (6.1)	24.3 (5.8)	.96
Timed up and go test, s		11 (2)	10 (1.8)	.09
Hopkins verbal learning test		27.8 (4)	27.7 (3.5)	.90
Visual sensitivity test	RT (mean)	1,737.3 (237)	1,674.8 (176.4)	.31
	SD (mean)	427.7 (148)	393.9 (174.6)	.48
Corsi-block-tapping test		4.9 (1)	5 (0.6)	.86
Stroop task	Number of error	0.9 (1.3)	1.4 (1.4)	.24
	Reaction time (mean)	1,430.9 (236.9)	1,434.5 (248.8)	.96

Notes: BMI = body mass index; IQR = xxx; ITT = intention-to-treat; RT = xxx; *SD* = standard deviation.

the cognitive-intensive exergame training group based on ITT analysis.

On the other hand, some cognitive domains improved more in CIT. The cognitive-intensive exercise training group exhibited greater improvement in visual processing speed and visuospatial working memory, which are important factors associated with fall risk. This may be because the exergames utilized in this group contained games that specifically facilitated these cognitive outcomes. Unexpectedly, although the balloon game in the cognitive-intensive intervention also aimed to improve selective attention, there was no significant difference in improvement in ST in the CIT group compared with the PIT group. This might be due to similar games facilitating attentional abilities also included in PIT. Similarly, there was no significant difference in improvement in verbal memory between the two groups. These findings make it difficult to determine whether the significant improvement in pre–post values is due to both interventions equally improving these functions or due to a learning effect with repeated exposure to these tests. Although participants were given practice trials before the assessment to reduce learning effects, it is still challenging to eliminate these entirely, highlighting the importance of a cautious interpretation of these results (Daly-Smith et al., 2018; Goldberg et al., 2015). It could be argued that only the visually demanding tests (VST, CBT) improved in the CIT as this program had higher visual demands rather than the type of executive inhibition of overlearned responses, such as the ST assesses. As such, improvement was not global cognitive-affecting other cognitive functions associated with fall risks and dementia but rather in improving CIT program-specific functions included. Future dual-task programs should perhaps include task elements that also demand verbal learning and higher-order executive function or related task elements that have been found to improve these functions (Ten Brinke et al., 2020; Wilcockson et al., 2019). However, PP analysis showed that verbal memory and selective attention, in addition to other cognitive functions, also improved more in the cognitive-intensive treatment group.

This difference in results between ITT and PP analysis may be due to several reasons. Nonadherence to the treatment may have contributed to this difference (Mostazir et al., 2021; Murray et al., 2021). It is well-established that exercise duration and intensity are crucial determinants of the effectiveness of any exercise intervention, and adequate adherence (>80%) to exercise training is necessary to significantly improve the intended outcomes (Collado-Mateo et al., 2021; Tiedemann et al., 2011). Thus, differences in adherence and completion rates could have contributed to the observed differences between the ITT and PP analyses. In addition, missing data could be another potential explanation for the differences between the two analyses. As the number of missing data in this study was greater than 10%, multiple imputations were performed separately for both groups to address this issue, as recommended but this could have affected differences in analyses (Hamzah et al., 2020; Madley-Dowd et al., 2019). Despite these potential explanations, the similarity of baseline characteristics of the participants included in both the ITT and PP analyses could suggest that systematic confounding

Table 2. ITT Analysis of Between-Group Intervention Effects

Variables	Sub-category	Cognitive-intensive exergame group ($n = 24$)		Physical-intensive exergame group ($n = 23$)		Interaction effects (time × group)			Practical relevance
		Change from baseline to 2 months Mean (95% CI)	p Value	Change from baseline to 2 months Mean (95% CI)	p Value	F value	p Value	Effect size (η^2)	
Timed up and go test, s		−0.9 (-1.4 to −0.3)	<.01*	−0.8 (−1.4 to −0.2)	.01*	0.06	.08	0.01	Small effect
Functional reach test, cm	Ankle	0.2 (−1.3 to 1.6)	.8	1.3 (0 to 2.7)	.06	1.43	.23	0.03	Small effect
	Hip	0.8 (−1.7 to 3.2)	.53	3.8 (1.9 to 5.7)	<.001**	4.14	.04*	0.09	Medium effect
Hopkins verbal learning test		2.7 (1.5 to 3.9)	<.001**	1.9 (0.6 to 3.1)	<.01*	0.87	.36	0.02	Small effect
Visual sensitivity test	RT (Mean)	−232.2 (−342.7 to −121.6)	<.001**	−105.3 (−162.3 to −48.3)	<.01*	4.35	.04*	0.09	Medium effect
	SD	−144.5 (−206.1 to −83)	<.001**	−74.9 (−134.2 to −15.6)	.02	2.84	.09	0.06	Medium effect
Corsi-block-tapping test		1.3 (0.8 to 1.7)	<.001**	0.6 (0.3 to 0.9)	<.01*	6.15	.01*	0.12	Medium effect
Stroop Task	Number of error	−0.3 (−0.9 to 0.2)	.26	−0.7 (−1.1 to −0.4)	<.001**	1.92	.17	0.04	Small effect
	Reaction time (mean)	−178.7 (−260.2 to −97.3)	<.001**	−87.8 (−147.0 to −28.6)	<.01*	3.44	.07	0.07	Medium effect

Notes: CI = confidence interval; ITT = intention-to-treat; RT = xxx; *SD* = standard deviation.
$^{*}p < .05$. $^{**}p < .001$.

Table 3. PP Analysis of Between-Group Intervention Effects

Variables	Sub-category	Xbox group ($n = 18$)		Wii fit group ($n = 18$)		Interaction effects (time × group)			Practical relevance
		Change from baseline to 2 months Mean (95% CI)	p value	Change from baseline to 2 months Mean (95% CI)	p value	F value	p value	Effect size (η^2)	
Timed up and go test, s		−0.5 (−0.9 to −0.1)	.03*	−0.7 (−1.3 to −0.2)	.01*	0.42	.52	0.01	Small effect
Functional reach test, cm	Ankle	0.8 (−1.5 to 1.7)	.91	1.9 (0.4 to 3.4)	.02*	3.01	.09	0.08	Medium effect
	Hip	0.82.5 (0.6 to 4.5)	.02*	4.1 (1.9 to 6.2)	<.001**	1.27	.26	0.04	Small effect
Hopkins verbal learning test		3.4 (2.3 to 4.6)	<.001**	1.9 (1.4 to 2.5)	<.01*	5.97	.02*	0.15	Large effect
Visual sensitivity test	RT (Mean)	−220.6 (−278.1 to −163)	<.001**	−72.7 (−116.8 to −28.5)	<.01*	18.5	<.001**	0.35	Large effect
	SD	−145.2 (−213.2 to −77)	<.001**	−42.4 (−83.1 to −1.7)	.04*	7.51	.01*	0.18	Large effect
Corsi-block-tapping test		1.7 (1.4 to 2)	<.001**	0.4 (0.2 to 0.7)	<.01*	49.69	<.001**	0.59	Large effect
Stroop task	Number of error	−0.8 (−1.3 to −0.3)	<.01*	−0.5 (−0.8 to −0.3)	<.001**	0.64	.43	0.02	Small effect
	Reaction time (mean)	−164.4 (−216.2 to −112.6)	<.001**	−35.1 (−49.7 to −20.4)	<.001**	25.71	<.001**	0.43	Large effect

Notes: CI = XXX; PP = per-protocol; RT = xxx; *SD* = standard deviation.
$^{*}p < .05$. $^{**}p < .001$.

factors did not contribute to the observed differences. Future studies should include a third arm with a proper control condition and full computer algorithm-assisted randomization.

The findings of the present study indicate that regardless of the content of the technology providing the training and the task-specificity of the games, unsupervised home-based cognitive-motor dual-task exergame training can improve cognitive and physical functions, which are important factors for fall risk. There were no huge adverse effects or risks, or issues in setting the games up, especially with the Xbox training. However, it should be noted that the degree of improvement was related to the type of exergame. This can reveal the importance of different games and devices that target specific functions in the development of person-centered exercise programs based on detailed assessments of an individual's physical and mental capacity. If cognition is to be improved, it must include a sufficient level of intensive cognitive task demands.

Our results are consistent with previous studies. Gschwind et al. (2015) combined data from two separate clinical trials where the effects of two different exergames on fall risk in older adults were compared. While one of the unsupervised home-based exergames focused on improving muscle strength and balance, the other aimed to develop cognitive functions associated with fall risk. After 16 weeks of exergame training, it was found that both interventions significantly decreased the risk of falls, but reaction time and selective attention improved more in the cognitive training group. In a more recent pilot study of 23 older adults, the effectiveness of Kinect and Wii were compared (Li et al., 2021). Although both interventions, including the same games, significantly improved physical fitness and psychological perception, the authors stated that the Wii might be more effective in improving physical fitness, whereas the Kinect may be more advantageous in improving psychological perception. Li et al. (2021) also reported that both groups were willing to play exergames, but they preferred the Kinect due to reported difficulties in controlling the Wii.

On the contrary, our observations and feedback from the participants showed that the Xbox required more hand-eye coordination and the internal management of the system was more complicated than the Wii. The potential reason for these contrasting findings could be the presence of unsupervised training in our study. This could be supported by the fact that technology management-related dropouts were found only in the Xbox group and most of the reported technical problems were from this intervention group. The drop-out rate during the trial (12% and 20%, Figure 1) was similar to that of previous home-based exergame studies (Adcock et al., 2020; Gschwind et al., 2015).

Another noteworthy observation was that participants who had no prior experience with such technologies found it more challenging to adapt to the technology, and their willingness to use this technology was comparatively lower. We found that less interest in such technology was seen among single people, women, and those with no access to technology (Begde et al., 2023). These are the groups that need the most focus to introduce such technology to, as these are also the groups most at risk for dementia and frailty. Although interactive and enjoyable, these interventions may be challenging for older adults, particularly those with cognitive impairment, when used unsupervised. Therefore, producing simpler and more straightforward devices to target different physical and cognitive tasks and their dissemination among both healthy and cognitively impaired people might improve their willingness to use this type of technology. Although this experiment simulated a real-life exposure with the need to install and control such equipment at home without supervision, future studies should use other technology to provide better support when setting up and controlling this to respond to the comments and drop-outs.

Our study showed that both interventions could be safely performed at home. Although Xbox was more difficult to manage compared with the Wii, no adverse events were reported in this group. In the Wii group, a participant reported feeling a sharp pain in their knee during training, which subsided with rest. This mild adverse event was most likely caused by the weight-shifting control of the games on the Wii and thus the forces exerted by the body weight and motion on the knee. Although the participant had no history of musculoskeletal problems, it is difficult to ascertain whether this triggered a preexisting issue or whether engaging in the game was the primary cause. A recent systematic review also highlighted that these interventions can be safely performed at home (Alhagbani & Williams, 2021). However, whether this is also the case in older and frail individuals remains to be seen.

Dual-task exergame training can be provided to older adults to decrease later fall risk, thereby reducing the high cost of fall-related injuries (Gallou-Guyot et al., 2020; Uematsu et al., 2023). As such intervention might be more motivating and engaging and can be more interesting for older people. Additionally, this type of exercise can be a good option for individuals' physical activities when outdoor activities are limited due to unexpected conditions, such as COVID-19-related enforced lockdowns and bad weather conditions. Engagement with exergame can potentially prevent aging-related cognitive impairment and frailty by improving both cognitive and physical functions. Previous research showed that multicomponent exercise training including cognitive and physical exercises or dual-task exercise training might be more effective than single-task exercise training to reduce cognitive impairment/dementia risk (Begde et al., 2022). To ensure the practical implementation of this intervention and the successful adaptation of older individuals to technology, arrangements that facilitate and expand access to such technologies should be made by the industry in providing more support during set-up and control of the games, and by health care facilities and policymakers to promote and help fund these. Although the cost-effectiveness of exergame interventions was not analyzed in this study, it has been previously reported that exergaming is cost-effective in U.K. older adults, with an incremental cost-effectiveness ratio of £15,209.80 per quality-adjusted life year (Stanmore et al., 2019).

To better interpret the results of this study, it is important to acknowledge its limitations and strengths which have been mentioned earlier. To our knowledge, this is the first study to examine the effects of unsupervised home-based cognitive-intensive and physical-intensive exergaming on cognition and balance in older adults. The comparability of baseline characteristics and adherence rates of the two groups allowed the results to be analyzed and interpreted without the need for the control of confounders. However, this study was not completely randomized and was open-labeled, which may have caused bias and impacted the internal validity of the study. Additionally, the lack of a control group means that it is difficult to determine whether the observed pre–post changes were due to the intervention or simply a result of learning effects. The fact that most of the participants were women (70%) and physically active (over 90%) makes it difficult to generalize the results to the whole population. Another limitation affecting the external validity of the study was that no sub-group analysis was performed. Given the age range of the participants (65–85) and the potential for changes in physical and cognitive functions within this range, a sub-group analysis could have provided valuable insights into the specific population being studied. Earlier work has also shown that women responded better to exercise on cognitive tests (Clifford et al., 2009). However, the study size did not allow this analysis. Considering the limitations of the current study, it is recommended that future research prioritize the implementation of high-quality randomized controlled trials. Additionally, it would be valuable to include individuals with mild cognitive impairment and dementia in such studies, as this population faces an increased risk of falls, which could be essential in developing technology-based exercise programs at home to reduce fall risk for this vulnerable population.

The study findings indicate that both interventions involving dual-task exergames can be safely performed in a home setting without additional supervision. We found that these interventions, which involved varying degrees of cognitive and physical demands and task-specificity, had positive impacts on improving cognitive and physical factors related to fall risk among older people. Given their diverse effects on mobility and cognition, the provision of sufficient cognitive and physical-intensive programs may be essential for person-centered exercise programs.

Supplementary Material

Supplementary data are available at *Innovation in Aging* online.

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Conflict of Interest

None.

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Author Contributions

G. Blenkinsop, M.T.G. Pain, E. Hogervorst, A. Alqurafi, and A. Begde designed the research. A. Begde and A. Alqurafi contributed to data collection. A. Begde, A. Alqurafi, T. Wilcockson, and E. Hogervorst analyzed the data. A. Begde wrote the manuscript. All authors critically revised the article for important intellectual content and approved the final version.

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