Effects of Exergaming on Cognition and Gait in Older Adults at Risk for Falling

ELISA F. OGAWA[1,2], HAIKUN HUANG[3], LAP-FAI YU[4], PHILIMON N. GONA[1], RICHARD K. FLEMING[1], SUZANNE G. LEVEILLE[5], and TONGJIAN YOU[1]

[1]Department of Exercise and Health Sciences, College of Nursing and Health Sciences, University of Massachusetts Boston, Boston, MA; [2]New England GRECC, VA Boston Healthcare System, Boston, MA; [3]Department of Computer Science, College of Science and Mathematics, University of Massachusetts Boston, Boston, MA; [4]Department of Computer Science, George Mason University, Fairfax, VA; and [5]Department of Nursing, College of Nursing and Health Sciences, University of Massachusetts Boston, Boston, MA

ABSTRACT

OGAWA, E. F., H. HUANG, L. YU, P. N. GONA, R. K. FLEMING, S. G. LEVEILLE, and T. YOU. Effects of Exergaming on Cognition and Gait in Older Adults at Risk for Falling. *Med. Sci. Sports Exerc.*, Vol. 52, No. 3, pp. 754–761, 2020. **Purpose:** To test whether an 8-wk exergaming (EG) program would improve cognition and gait characteristics compared with a traditional physical exercise (TPE) program in older adults at risk for falling. **Methods:** A pilot quasi-experimental study was conducted in adults age ≥65 yr at risk for falls, living in senior communities. Participants enrolled ($n = 35$) in either exercise program offered twice weekly for 8 wk. Cognition and single-task and dual-task gait characteristics were measured before and after the 8-wk exercise intervention. For each outcome, a repeated-measures ANCOVA adjusted for age, gender, and exercise intensity (ratings of perceived exertion, RPE) was used to examine the group–time interaction. **Results:** Twenty-nine participants (age, 77 ± 7 yr) completed either the EG program ($n = 15$) or the TPE program ($n = 14$). Statistically significant group–time interactions were observed in Trail Making Test Part A ($P < 0.05$) and single-task gait speed, stride length, swing time percentage, and double support percentage (all $P < 0.05$), and marginal group differences were observed in Mini-Mental State Examination ($P = 0.07$), all favoring the EG program. There were no statistically significant group differences in dual-task gait measurements except for swing time percentage and double support percentage, favoring the EG program. **Conclusions:** An 8-wk EG program for older adults at risk for falls contributed to modest improvements in a number of cognitive measures and single-task but limited improvements in dual-task gait measures, compared with TPE. These findings support the need for larger trials to determine cognitive and mobility benefits related to EG. **Key Words:** ACTIVE VIDEO GAMES, KINECT, GAIT, OLDER ADULTS

In the United States, more than one third of adults older than 65 yr fall at least once a year (1). Fall-related injuries, such as neck/head and pelvis/extremity injuries, can be a significant source of morbidity and mortality among older adults (2). The cost of treating fall-related injuries is substantial. In 2015, fatal and nonfatal fall-related medical costs were estimated to be US $50 billion (3) and are expected to increase considerably with population aging. Therefore, effective fall prevention programs are necessary to reduce fall-related concerns in the United States.

Considering most falls occur while walking, it is evident that gait dysfunction is a major cause of falls. Current evidence supports that gait dysfunction and falls are not only caused by mobility limitations from age-related decline in muscle strength, endurance, and power (4) but also due to declines in cognition (5), and dual-task mobility (6) among older adults. Cognition, such as executive function and attention, plays an important role in controlling gait (7), where decline in executive function and attention are associated with mobility limitation, falls, and progression to dementia (5). Dual-task mobility refers to the ability to perform two tasks simultaneously (e.g., walking while talking) and a decrease in dual-task mobility may be mediated by a decline in mobility performance and/or cognitive function (6).

Although it is well understood that regular physical activity reduces all-cause mortality, improves functional independence and also maintains cognition in older adults, levels of physical activity decrease with age (8). Thus, in addition to targeting appropriate fall risk factors, it is essential to find new approaches to successfully increase physical activity levels among older adults.

Exergaming (EG) is an increasingly popular form of exercise that combines physical exercise with video games. Accumulating evidence supports that EG improves older adults' balance, mobility, gait speed, and muscle strength (9) and may have

Address for correspondence: Tongjian You, Ph.D., Department of Exercise and Health Sciences, College of Nursing and Health Sciences, University of Massachusetts Boston, Boston, MA 02125; E-mail: tongjian.you@umb.edu.
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similar or slightly greater effect on cognition specifically on executive function compared with traditional exercise (10). However, based on our review, studies on benefits of EG for cognition and dual-task mobility in older adults are limited, with lack of active control groups for comparison (11). It is unclear whether EG has any additional benefits compared with traditional exercise, and which type of exergame may be more beneficial in reducing the risk of falls.

Several computer-based brain training programs have been shown to improve cognition, (12) and specific mind–body exercises (e.g., Tai Chi) have been shown to reduce the risk of falls (13). Thus, we developed exergames that combined a computer-based brain training program with modified Tai Chi movements (14). It is critical to examine the effects of exergames that have an appropriate cognitive stimulus and include an active control group with a comparable level of physical activity to determine possible incremental benefits related specifically to exergames designed to improve cognition and single-task and dual-task gait performance in older adults.

Therefore, the purpose of this study was to investigate the effects of an 8-wk EG program on interrelated pathways that are contributors to falls, specifically cognition and single-task and dual-task gait characteristics, compared with an 8-wk traditional physical exercise (TPE) program. We hypothesized that exergames designed to train dual-task function, integrating both physical and cognitive challenges, would lead to enhanced cognition and improved single-task and dual-task gait characteristics in older adults who are at risk of falling.

METHODS

Previously, we developed three Microsoft Kinect-based exergames that specifically train cognition and dual-task mobility for older adults at risk for falls (14). In the current study, we conducted the Project Motivating Older Adults via Exercise (Project MOVE), a pilot quasi-experimental study. Primary outcomes of this study were cognition and single-task and dual-task gait measures of an 8-wk EG program compared with TPE program among older adults at risk for falls. Secondary outcomes were mobility performance, fear of falling, fall frequency and program satisfaction. All study protocols and consent procedures were approved by the institutional review board of the University of Massachusetts Boston.

Recruitment/Eligibility

Participants were recruited from four senior living communities in the greater Boston area. For each senior living community, we advertised the study by hosting a launch event where we explained the study to interested residents. All potential candidates were screened initially over the phone. Inclusion criteria for participants were as follows: 65 yr or older, at risk for falling (reported at least one fall in the past year or reported any difficulty or task modification with walking a 0.5 mile or climbing 1 flight (10 steps) of stairs), and able to communicate in English. Exclusion criteria were: currently engaged in more than 40 min of moderate- to vigorous-intensity exercise per week, engaged in mind–body exercise for a total time of more than 1 yr in the past 10 yr, diagnosed with a degenerative neuromuscular disease, Parkinson's disease, terminal disease or dementing illness, or having assessed with moderate to severe cognitive impairment (Mini-Mental State Examination [MMSE] < 18) (15). We scheduled eligible participants for the baseline assessment visit at their senior living communities, which included the written informed consent, screening for cognitive impairment, health interview, as well as assessments for mobility performance, cognitive function, and single-task and dual-task gait mobility. All participants received a clearance from their primary care physician to participate in the study.

Intervention

The two supervised exercise programs, EG and TPE, were assigned to the senior living communities based on site and personnel availability. Four senior living communities were chosen for recruiting participants in the study. Two cohorts were hosted at two sites, where each site had a wave of the EG program (cohort 1, n = 6; cohort 2, n = 5) and the TPE program (cohort 1, n = 7; cohort 2, n = 4). One cohort was hosted at two other sites, where each site had the EG program (cohort 3, n = 5) or the TPE program (cohort 3, n = 8). Both exercise programs met for an hour twice a week for 8 wk. We designed the two exercise programs to have similar physical exercise time, break periods and incorporated preselected age-appropriate music. During the designated break periods, the exercise instructors led the health discussions (e.g., fluid intake, appropriate breakfast choices, healthy fruits, and vegetables). The only difference between the EG and TPE program was 30 min of EG (EG program) compared with 30 min of resistance and balance training (TPE program) (Table 1).

A detailed description of the developed exergames and methodology were reported previously (14). Briefly, we developed three exergames that combined computer-based brain training programs developed by Posit Science (San Francisco, CA): Target Tracker, Double Decision, and Visual Sweeps, that have been shown to improve cognitive function (12) with modified version of an exercise that has been shown to prevent falls, Tai Chi (13), which included slow and controlled dynamic

TABLE 1. Description of the EG program and the TPE program.

Time	EG	TPE
0–5	Housekeeping	Housekeeping
5–10	Warm up	Warm up
10–15	Walking	Walking
15–30	EG: Target tracker, double decision, visual sweeps (5 min each) [RPE 1]	Exercise 1: Lower-body resistance and balance training [RPE 1]
30–35	Break/Health Discussion (e.g., fluid intake, appropriate breakfast choices, healthy fruits and vegetables)	Break/Health Discussion (e.g., fluid intake, appropriate breakfast choices, healthy fruits and vegetables)
35–40	Walking	Walking
40–55	EG: Target tracker, double decision, visual sweeps (5 min each) [RPE 2]	Exercise 2: Upper-body resistance training [RPE 2]
55–60	Cool down (flexibility)	Cool down (flexibility)

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and static balance movements (see Video, Supplemental Digital Content 1, Description of the three exergames in the EG group: Target Tracker, Double Decision, Visual Sweeps (5 min each exergame × 2 for each session), http://links.lww.com/MSS/B769. Author: Elisa Ogawa. Videographer: Vanessa Law. Participants: William Butts, Shanice Milord. Length: 1 min 34 s. Size: 45.8 MB.] We modified the exergames based on participant's feedback from the previous study (14) for this EG intervention. For the EG intervention, two EG stations were created. Each EG station was equipped with a TV, a Microsoft Kinect, a laptop computer, and less than three participants were assigned to the station. Similar group EG approach was delivered successfully in an Tai Chi EG intervention in older adults (16). The TPE program's supervised resistance and balance training included free weights and body weight exercises in seated and standing positions (e.g., ankle dorsi/plantar flexion, heel/toe walks, body weight squats, hip flexion, extension, abduction, biceps curls, triceps kick-backs side/front raises).

Measurements

Study assessments were conducted on site at the housing communities before and after the 8-wk intervention period. At baseline, sociodemographic characteristics, including age, sex, race, and educational attainment and mobility performance and cognition, were collected. Physical activity levels were assessed using the validated physical activity questionnaire, Physical Activity Scale for the Elderly (17), and number of blocks walked in a week were recorded. Height was measured using a stadiometer and weight was measured using a digital scale. For those who refused to have their height and weight measured or were unable to stand on/stay on the scale, self-reported height and weight were recorded ($n = 11$). Post assessment, which was scheduled at least 48 h after the last exercise session, reassessed measures taken during the baseline assessment.

Cognitive function. Cognitive function in the domains of short-term memory, visuospatial, executive function, attention, concentration, working memory, language, and fluency task was assessed using the Montreal Cognitive Assessment (MoCA) (18). MoCA and MMSE, which was used in the eligibility screening, were used to assess global cognitive status (19). Composite scores were calculated for MMSE and MoCA. In addition, the Trail Making Test parts A (TMT-A) and B (TMT-B), and delta Trail Making Test (TMT-B minus TMT-A) were used to measure visual attention, simple sequencing, and executive function (20). Completion time in seconds was used to evaluate TMT.

Simple and choice standing reaction time tests were used to evaluate participants' standing foot reaction time. For each test, participants stood on a sensored gait mat (Protokinetics Inc. Havertown, PA) behind a colored tape with arms slightly resting on a walker. For the simple reaction time test, participants responded to a randomly intermittent light on the right side of the mat. For the choice reaction time test, participants responded to a randomly intermittent light on either side of the mat. Reaction time was determined by the time between appearance of the light and the initial movement in milliseconds. For both tests, participants completed three practice trials followed by 10 measured trials. Our protocol was modified from the Maintenance of Balance, Independent Living, and Zest in the Elderly Boston II Study (21).

Single-task and dual-task gait characteristic. Gait characteristics were examined under single-task and dual-task conditions. Participants walked back and forth on a sensored gait mat under three walking conditions in random order: one single-task (usual walking) and two dual-task conditions (category fluency dual-task and arithmetic dual-task). Participants' appropriate arithmetic dual-task was determined during a seated cognitive task assessment. Participants were asked to complete a counting backward or forward task, starting first with the most challenging (serial 3 s, serial 5 s, serial 1 s counting backward starting from 100; serial 1 s counting forward starting from 1 [easiest task]). All participants' recall dual-task was recalling items found in a supermarket aloud. Participants were instructed to walk at their normal pace under each condition (22). After one practice walk (3 passes), participants walked under three walking conditions (3 passes each) with a minute of break in-between. Gait characteristics such as gait speed, stride length, stride width, swing time (%), and double support time (%) were examined. The coefficient of variation (CV) was used as a measure of gait variability (SD/mean × 100). These gait measures have been validated and used in studying gait disorders in older adults (23). We also examined the dual-task decrement, which is the difference between single-task and dual-task for each of the gait parameter (24).

Secondary outcomes. Mobility performance was assessed using the Short Physical Performance Battery (SPPB), which measures three domains: balance, gait speed and chair stand (25). Fear of falling was assessed using the Tinetti Fall Efficacy Scale (26). Fall frequency was measured using fall calendars (27) during and up to 6-month after the intervention. Throughout the intervention, participants' attendance and exercise intensity (15-point Borg Scale for Perceived Exertion, RPE (28)) were recorded. At the beginning of the exercise program, each participant received instructions on how to rate their level of exertion. Participants were instructed to combine all sensations and feelings of physical stress, effort, and fatigue and not concern with any one factor such as pain (28). Participants reported their RPE to the exercise instructors after each EG/resistance and balance training portion of the exercise session (twice/session). Overall RPE represents the mean value of RPE over 8 wk. At the end of the post-assessment, we requested that participants complete a program satisfaction form and mail it back to the study office.

Sample Size

The sample size and power calculation were performed with G*Power (29). Previous meta-analysis indicated that effect size of physical activity on cognition among older adults was moderate (ES = 0.48) and combined training (e.g., aerobic with resistance training) yielded large effect size (ES = 0.59) especially in executive function (30). Similarly, previous dual-task training yield medium effect on dual-task gait speed

(ES = 0.46) (31). With a sample size of 16 in each group, repeated-measures ANOVA will have 82% power to detect interaction with an effect size of 0.46 at the 0.05 level of significance.

Statistical Analysis

Mean and standard deviations for continuous measures and percentages for categorical variables were calculated by exercise intervention group for baseline and week 8. Differences in baseline demographic, health characteristics, and study outcomes were compared between the EG program and TPE program using Wilcoxon rank-sum test. A repeated-measure ANCOVA adjusted for age, gender and differences in average RPE was used to determine the group difference for study outcomes. Two-time points were treated as the within-subject factor and the exercise groups were treated as the between-subject factor. Tests of simple main effects were calculated using Bonferroni correction for multiple comparisons. Considering the limited sample size of the study, a Wilcoxon rank-sum test was used to estimate between-group differences after 8-wk training period as secondary analyses. Fall frequency was examined by computing the incidence rate ratio using negative binomial regression model with an offset variable for log total days of reported days to investigate the effect of the exercise programs. All analyses were conducted with STATA SE 15.0 (College Station, TX), with two-sided tests at alpha = 0.05 significance level. Analyses of treatment effects were based on the intention-to-treat principle including all available values for participants.

RESULTS

We present our CONSORT diagram for screening, enrollment, and follow-up in Figure 1. Of a total of 65 older adults screened, 40 were eligible and 35 consented to participate, including 16 in the EG program and 19 in the TPE program. Of the 35 participants, 29 (82%) completed the post-intervention assessment, including 15 (93%) in the EG group and 14 (73%) in the TPE group. There were no differences in sociodemographic, health characteristics, and study outcomes between study participants who completed the study and participants who did not complete the study except for body mass index (BMI). Participants who did not complete the study had significantly lower BMI ($P < 0.05$) compared to those who completed the study. The reasons for dropping out of the study are shown in Figure 1.

The average age of the 29 participants who completed the study was 77 ± 7 yr (range, 65–94 yr). There were no statistically significant group differences in sociodemographic, health characteristics, and study outcomes between the two exercise groups. Overall exercise class attendance rate was 73%, with 79% for the EG group and 68% in the TPE group and there was no between-group difference. Both exercise programs were light in exercise intensity, with the TPE group having statistically significantly higher RPE (12.1 ± 1.7) compared to EG group (10.8 ± 1.4, $P < 0.05$, Table 2).

Cognitive function. We observed modest group–time interactions in visual attention and global cognition between the two exercise groups in their pre–post changes over the 8-wk

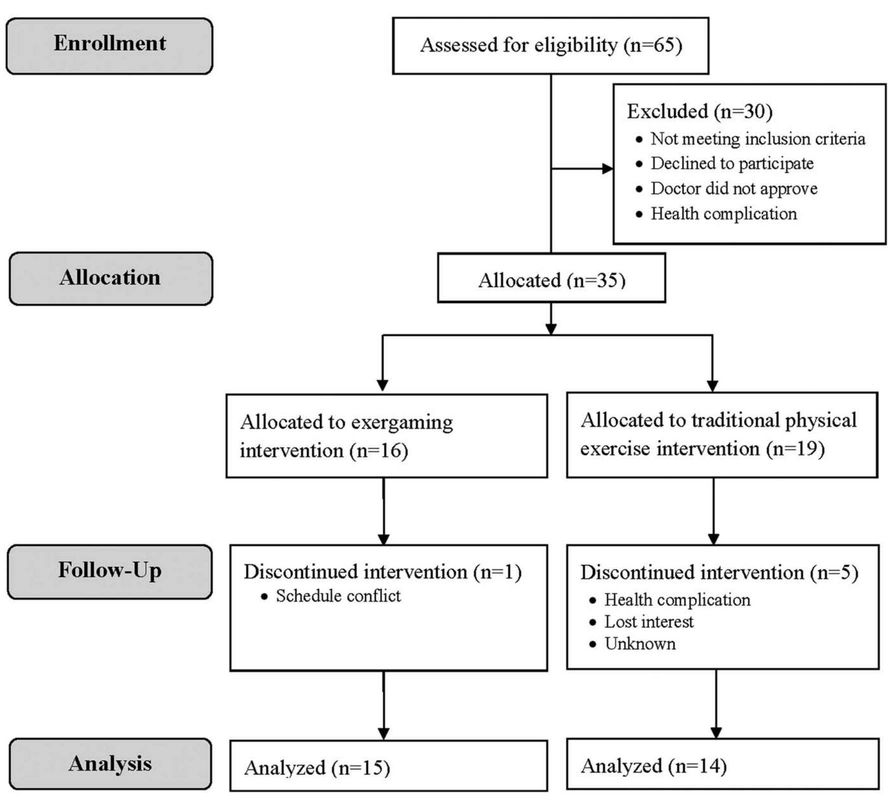

FIGURE 1—CONSORT flow diagram representing enrollment, randomization, and status in the study.

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TABLE 2. Baseline sociodemographic, health characteristics, and intervention measurements, 29 older adults, project MOVE.

Characteristics	Total (*N* = 29) Mean ± SD	EG (*n* = 15) Mean ± SD	TPE (*n* = 14) Mean ± SD
Age (yr)	76.97 ± 7.34	75.20 ± 7.31	78.85 ± 7.13
BMI (kg·m^{-2})	34.42 ± 7.17	34.83 ± 7.99	33.95 ± 6.37
MMSE	26.79 ± 2.40	27.00 ± 1.89	26.57 ± 2.90
PASE	78.82 ± 41.48	77.94 ± 50.53	79.76 ± 30.88
No. blocks walked per week	26.80 ± 48.50	19.90 ± 24.40	34.20 ± 65.66
Attendance rate	0.73 ± 0.23	0.79 ± 0.19	0.68 ± 0.27
RPE	11.40 ± 1.65	10.78 ± 1.42	12.06 ± 1.68*
	***n* (%)**	***n* (%)**	***n* (%)**
Gender			
Male	5 (17.24)	4 (26.67)	1 (7.14)
Female	24 (82.76)	11 (73.33)	13 (92.86)
Race			
Non-Hispanic white	18 (62.07)	8 (53.33)	10 (71.43)
Black or African American	5 (17.24)	3 (20.00)	2 (14.29)
Hispanic	1 (3.45)	1 (6.67)	0 (0)
Multiracial	5 (17.24)	3 (20.00)	2 (14.29)
Education			
≤High school graduate	6 (20.69)	3 (20.00)	3 (21.43)
Some college	6 (20.69)	4 (26.67)	2 (16.29)
College graduate	17 (58.62)	8 (53.33)	9 (64.29)
Fall in the past year			
No	13 (44.83)	7 (46.67)	6 (42.86)
Yes	16 (55.17)	8 (53.33)	8 (57.14)
Walking aid use			
No	15 (51.72)	10 (66.67)	5 (35.71)
Yes	14 (48.28)	5 (33.33)	9 (64.29)

PASE, Physical Activity Scale for the Elderly.
*Wilcoxon rank-sum test comparing pre–post changes between EG and TPE, *P* = 0.029.

intervention period. There was a significant group–time interaction in TMT-A time (*P* < 0.05); no pre–post changes were observed in TMT-A in the EG group, while the TPE group increased (worsened) their TMT-A time at follow-up compared with the baseline (−15%, *P* < 0.05). In addition, despite not observing significant group–time interaction in global cognitive assessment, MMSE score (*P* = 0.07), we observed a modest increase in the mean score of the EG group in MMSE scores (+4%, *P* < 0.01) compared with baseline while TPE group had no pre–post change. Both exercise groups decreased (improved) their TMT-B time, there was a significant pre–post change only within the EG group (*P* < 0.05), though no group–time effect was observed. In addition, both exercise groups significantly improved their executive function, delta TMT (*P* < 0.05) in their pre–post within-group comparisons (*P* < 0.05) and no significant group–time interactions were observed. We did not observe pre–post changes in other cognitive measures including overall MoCA score, simple reaction time, or choice reaction time (Table 3).

Single-task and dual-task gait characteristics. We observed statistically significant group–time interactions in several of the single-task gait characteristics over the 8-wk intervention period (Table 4). The TPE group significantly performed worse after the 8-wk intervention for the majority of single-task gait measurements (*P* < 0.05), while the EG group did not have any significant pre–post changes.

We did not observe any significant group–time interactions or within-group pre–post changes under the two dual-task conditions in either of the exercise groups except for swing time percentage in both dual-task conditions and double support percentage in arithmetic dual-task condition. Although no simple main effects were observed, EG increased (improved) their swing time percentage and decreased (improved) their double support percentage while TPE decreased (worsened) their swing time percentage and increased (worsened) their double support percentage. There were no statistically significant between-group or within-group differences observed in dual-task decrements (data not shown).

Secondary outcomes. We did not find group–time interactions in pre–post changes over the 8-wk intervention between the exercise groups for SPPB (F (1,24) = 0.78, P = 0.39), Falls Efficacy Scale (F (1,23) = 1.48, P = 0.235) or fall frequency (incidence rate ratio, 2.58; 95% confidence interval, 0.74–8.97; *P* = 0.14). Of the 29 participants who completed the study, 22 participants (75.9%) returned their program satisfaction form. There were no differences in how participants rated the overall quality, enjoyment, instructors, peers, and facility of the assigned exercise programs where both programs received positive feedback. Briefly, among those that completed the satisfaction form, 36% rated their assigned exercise program to be excellent, 50% very good, and 14% good. All participants who returned the program satisfaction form responded that they would recommend the program to others.

We observed qualitatively similar results using the Wilcoxon rank-sum test as the results using repeated-measures ANCOVA for both primary and secondary outcomes.

DISCUSSION

In this pilot quasi-experimental study, participation in the 8-wk EG program resulted in modest improvements in known

TABLE 3. Repeated-measures ANCOVA comparing changes in cognition in response to either EG or TPE group adjusted for age, sex, and RPE.

	EG (*n* = 15)		TPE (*n* = 14)		Group × Time
	Pre[a]	Post[a]	Pre[a]	Post[a]	*F* (1,24); *P*
MMSE	26.97 (0.70)	28.07 (0.62)*	26.61 (0.72)	26.42 (0.65)	3.67; 0.067
MoCA	23.78 (1.08)	24.01 (1.14)	22.17 (1.13)	22.99 (1.19)	0.39; 0.536
TMT-A (s)	51.69 (6.22)	46.26 (5.87)	49.11 (6.78)	59.28 (6.39)**	**6.87; 0.016**
TMT-B (s)	127.38 (14.81)	99.91 (10.29)**	125.19 (15.63)	107.10 (10.86)	0.23; 0.636
ΔTMT (s)	77.35 (8.47)	53.88 (8.66)**	76.42 (8.94)	51.84 (9.14)**	0.004; 0.949
SRT (ms)	295.14 (20.96)	285.66 (13.40)	324.97 (26.04)	299.19 (16.65)	0.346; 0.563
CRT (ms)	332.26 (18.74)	338.44 (16.46)	350.90 (23.29)	321.44 (20.45)	1.29; 0.269

[a]Adjusted mean and standard error based on repeated-measures ANCOVA controlling for age, gender, and RPE.
**P* < 0.01.
*Significant pre–post changes *P* < 0.05.
SRT, simple reaction time; CRT, choice reaction time.

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TABLE 4. Repeated-measures ANCOVA comparing changes in gait characteristics in response to either EG or TPE group adjusted for age, sex, and RPE.

	EG (n = 15)		TPE (n = 13)[a]		Group × Time
	Pre[b]	Post[b]	Pre[b]	Post[b]	F(1,23); P
Single-task					
Gait speed (m·s^{-1})	0.78 (0.05)	0.80 (0.06)	0.84 (0.06)	0.79 (0.06)*	**5.43; 0.029**
Stride length (cm)	95.55 (5.07)	97.52 (5.18)	99.64 (5.49)	93.59 (5.60)	**8.43; 0.008**
Stride width (cm)	10.68 (1.25)	10.49 (1.28)	10.52 (1.36)	12.01 (1.38)**	3.48; 0.075
Swing time (%)	31.38 (0.63)	31.54 (0.72)	31.53 (0.68)	30.20 (0.78)*	**6.86; 0.015**
Double support (%)	37.40 (1.26)	36.99 (1.46)	36.72 (1.37)	39.44 (1.58)*	**7.19; 0.013**
Stride length CV	4.25 (0.55)	4.36 (0.71)	4.42 (0.59)	5.00 (0.76)	0.32; 0.578
Swing time CV	8.63 (1.12)	6.41 (0.73)	6.30 (1.21)	6.99 (0.79)	3.80; 0.064
Category fluency dual-task					
Gait speed (m·s^{-1})	0.61 (0.06)	0.64 (0.06)	0.68 (0.07)	0.66 (0.06)	1.15; 0.295
Stride length (cm)	85.60 (5.34)	85.44 (5.57)	89.27 (5.78)	86.04 (6.03)	0.73; 0.403
Stride width (cm)	11.35 (1.40)	9.96 (1.66)	12.20 (1.51)	11.16 (1.80)	0.03; 0.871
Swing time (%)	29.13 (0.98)	29.59 (1.08)	29.40 (1.06)	28.09 (1.17)	**4.89; 0.037**
Double support (%)	41.68 (2.00)	40.88 (2.19)	41.40 (2.16)	43.72 (2.37)	3.62; 0.070
Stride length CV	6.03 (0.67)	5.55 (0.94)	5.40 (0.73)	6.17 (1.01)	2.47; 0.130
Swing time CV	12.41 (1.76)	9.67 (1.15)	8.74 (1.91)	8.80 (1.25)	1.20; 0.284
Arithmetic dual-task					
Gait speed (m·s^{-1})	0.57 (0.06)	0.60 (0.60)	0.65 (0.07)	0.60 (0.07)	2.24; 0.148
Stride length (cm)	85.08 (5.47)	84.09 (5.78)	87.14 (5.92)	82.41 (6.25)	1.08; 0.310
Stride width (cm)	11.48 (1.41)	11.30 (1.29)	12.41 (1.52)	12.26 (1.39)	0.001; 0.979
Swing time (%)	28.24 (1.30)	29.21 (1.35)	28.68 (1.40)	27.13 (1.46)	**8.39; 0.008**
Double support (%)	43.46 (2.63)	42.03 (2.76)	42.76 (2.84)	45.66 (2.99)	**5.77; 0.025**
Stride length CV	7.25 (1.00)	7.52 (1.05)	5.61 (1.08)	5.76 (1.13)	0.01; 0.928
Swing time CV	11.56 (1.57)	16.68 (3.17)	10.77 (1.70)	9.26 (3.44)	2.00; 0.171

[a]One participant in the TPE did not complete gait assessment.
[b]Adjusted mean and standard error based on repeated-measures ANCOVA controlling for age, gender, and RPE.
*Significant pre–post changes $P < 0.05$, **$P < 0.01$.

fall risk factors such as visual attention, global cognition, and gait characteristics. Older adults in senior living communities who participated in the newly developed EG program showed modest improvement in global cognitive status and protection against visual attention decline, and single-task gait decline compared with the TPE program. Contrary to our expectations, the improvements in dual-task gait measures were minimal in both exercise programs. Our results were similar to prior research studies which had mixed results pertaining to the effect of EG on cognition over and above an active control (32–34). We observed modest influence on selected cognitive measures including visual attention and global cognition. A possible explanation for the apparent cognitive benefits related to EG group compared with TPE could be that the cognitive portion of the developed exergames. Cognitive portion of the exergames was based on computerized cognitive training that was used in the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study (35,36). The ACTIVE study reported positive cognitive improvements and maintenance after 2 yr (35), and even 5 yr after the termination of the study, the training gains persisted, and there was less functional decline in the training group compared with the control group (36). Our novel approach of adapting the cognitive training used in the ACTIVE study for our exergames rather than using commercially available exergames could have resulted in the modest benefits we observed in the visual attention and global cognition.

Despite not being able to detect consistent changes in dual-task gait outcomes, significant group–time interactions in single-task gait and significant group–time interactions in dual-task swing time percentage and double support time percentage warrants future studies to investigate the effects of EG on dual-task gait characteristics. Since walking demands both cognitive and physical utilization among older adults (5), it is possible that with this relatively short 8-wk EG intervention, we were only able to observe an effect on regular walking as opposed to dual-task walking.

As previously hypothesized by researchers (32), possible mechanisms of EG's effect on cognition may be the compounding effect and/or the synergistic effect. The improvements seen in cognition from the EG could be from the added cognitive training (compounding effect), where EG's cognitive training improved participants' cognition. It also possible that the integration of motor and cognitive training led to greater improvement in cognition (synergistic effect). Thus, supporting the idea of dual-task training (e.g., EG) rather than separating mobility and cognitive training. The synergistic effect has been shown in other EG and non-EG studies (32,37). Giving the interconnection between gait and cognition, the compounding and/or synergistic effect of EG on cognition may modulate the effect of EG on gait characteristics.

Although the group differences were not statistically significant, the TPE group did have fewer falls during the intervention and 6-month follow-up despite increases in several fall risk factors such decline in cognitive measures and gait characteristics. Thus, it is still unclear whether interventions, such as EG that combine cognitive and mobility training are advantageous to lower older adults' fall risk in comparison to TPE.

It is well understood that various types of exercise programs can improve cognitive function in older adults (38). In a recent meta-analysis, investigators reported all types of exercise including aerobic, resistance training, and Tai Chi have demonstrated significant improvements in cognitive function. The authors also concluded that a duration of 45 to 60 min per session and moderate-intensity were associated with greater cognitive benefits (38). Among sedentary older adults who are at risk for falling, participating in moderate-intensity exercise could deter participants from adhering to the exercise program. Findings from this study support that cognitive benefits may be obtained even with light intensity training through exergames that combine physical and cognitive training. Further studies are needed to determine whether longer duration of the program, beyond 8 wk could lead to greater cognitive benefits.

The findings on worsening gait measurements in the TPE program need to be interpreted cautiously. Over an 8-wk period, the decline in gait measurements was unlikely due to aging. It is possible that some external factors such as pain contributed to the decline in gait measurements in the TPE group. A previous review indicated that multimodality interventions that combine cognitive and physical training such as dual-task training may have a positive impact on older adults' dual-task walking compared with regular exercise (39). Hence, we may not have observed the improvements in dual-task gait from our EG due to the short intervention term and small sample size, similar to other studies (33,34).

There are limitations to our study that need to be considered. The quasi-experimental study design lacked randomized group assignment. Since we assigned the program to the sites rather than randomizing older adults individually, it is possible that there were differences between the participating communities that could have accounted for the observed changes. Also, the assessor for the study was not blinded to the group assignment, which could have resulted in unintentional bias. However, we used structured protocols and objective measures of cognitive function and gait assessments to limit the potential for bias in the assessments. Since exercise intensity and duration have been found to impact cognition measures among older adults (38), we attempted to match the physical intensity of the two exercise programs. However, the average perceived exercise intensity, measured using the RPE, was higher in the TPE program compared to EG program. We statistically adjusted for the exercise intensity, however, these differences in perceived exercise intensity may have interfered with our ability to detect benefits of the light intensity EG intervention. In addition, previous studies have indicated that obesity (BMI >30 $kg \cdot m^{-2}$) is associated with an increased risk of cognitive decline and developing mild cognitive impairment, dementia, and Alzheimer's disease (40). Hence, change in weight status may have influenced the change in cognition. Although we recorded participants' anthropometric measurements, there were participants who self-reported their height and weight. Thus, we were unable to examine the relationship between change in weight status and cognition. Future large studies should further investigate whether improvements in cognition through EG is explained by change in weight status. Lastly, our sample size was relatively small which decreased the statistical power of the study. Furthermore, recruitment for this study was based on sample size estimates derived from power calculations for executive function and dual-task gait speed and no other measures of cognition or gait characteristics. Future research is needed with larger sample sizes and a longer intervention term to further investigate the effect of the exergames on dual-task mobility in older adults at increased risk for falls.

Despite these limitations, several strengths of this study are noteworthy. We developed an intervention, EG, that combined cognitive training that has been shown to improve cognition and mobility training that has shown to reduce risk of falls. We hypothesized greater reduction in fall risk factors from the EG intervention. This approach was novel, and the findings suggest potential benefits for using our EG program in community-living adults. Moreover, having an active control group allowed us to isolate the effect of physical exercise since it is well documented that exercise itself improves both cognition and mobility (8).

In conclusion, this study indicates an 8-wk EG program produces modest benefits to cognitive and gait performance compared with a TPE program. It also demonstrates that at-risk older adults are able to complete the EG intervention and also enjoy the program. Additional research is needed to determine optimal EG interventions for older adults at risk for falls. In addition to our two exercise programs, future research should include a computerized cognitive training group to further isolate the effects of cognitive training to examine the true combined effects of EG on fall risks. Moreover, with advances in technology, future studies could utilize machine learning and computational design technologies to generate personalized home-based EG programs.

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APPLIED SCIENCES

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