Multimodal Cognitive Training Effects on Tablet-based Dual-Task Performance and Walking-while-Talking among Middle-aged Adults

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Author Contributions

S.H. contributed to the conceptualization, formal analysis, and developed the original draft. Y.L. and M.L. contributed to the conceptualization, formal analysis, and reviewed and edited the manuscript. X.L. reviewed and edited the manuscript. D.D.T., A.H., A.T., and M.P. contributed to data curation, revised and edited drafts of the manuscript. E.M. and A.F.K. contributed to the methodology, acquired funding, and reviewed and edited the manuscript. S.P.M. contributed to the conceptualization, acquired funding, developed the methodology, administered the project, provided resources, supervised the work, validated the results, wrote the original draft, and reviewed and edited the manuscript.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

Ethical Approval

All procedures performed in this study involving human participants were in accordance with the ethical standards of the University of Illinois at Urbana-Champaign's Office of Protection for Research Subjects' Biomedical Institutional Review Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

Statement on the Welfare of Animals

This article does not contain any studies with animals performed by any of the authors.

Transparency Statement

- Study Registration: The CORTEX-II trial was pre-registered on clinicaltrials.gov.
- Analytic Plan Registration: The analysis conducted in this study was not entirely detailed in preregistration.
- Availability of Data: The data used in this study is available on the Open Science Framework on PsyArXiv

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Significance Statement

As individuals age, the ability to effectively manage dual tasks—such as walking while talking—often diminishes, serving as an early indicator of neurocognitive decline. This study highlights the potential of cognitive training programs, specifically exergaming combined with stationary dual-task exercises, to improve dual-task performance (DTP) in middle-aged adults. By targeting cognitive and motor function simultaneously, these interventions may help counteract the early signs of cognitive aging and promote healthier aging trajectories. Our findings suggest that relatively short-term, digitally delivered cognitive training can lead to meaningful improvements in DTP, with potential long-term benefits for reducing the risk of age-related neurocognitive decline. These insights underscore the importance of cognitive training programs as preventative measures in the fight against aging-related cognitive decline.

Abstract

Objective: This study investigated the impact of a comprehensive cognitive training program on dual-task performance (DTP) in low -active but generally healthy middle-aged adults, with DTP serving as an indicator of aging and neurocognitive decline.

Methods: A total of 233 mid-life adults (average age = 46.73, 65.7% females) were randomly assigned to either the Games group (stationary dual-task training plus exergaming) or the Videos group (attention-control condition involving educational YouTube videos). The interventions were delivered in 10 sessions totaling 20 hours, both in-lab and at home. Performance improvement was assessed using a tablet-based dual-task and Walking-while-talking (WWT) test at baseline, month one post-intervention, and at a six-month follow-up.

Results: The Games group demonstrated a larger improvement in tablet-based dual-task response times compared to the Videos group, with a reduction in response times by 26 *ms* versus an increase by 74 *ms*. A minor improvement in dual-task cost of 18 *ms* was also observed in a longitudinal analysis from baseline to the 6-month follow-up. Regarding WWT performance, a path model indicated that the Games group showed marked improvement in dual-task speed (β=.15; R^2=.09; M diff=0.14 *m/s*) and error reduction (β=.20, R^2=.07; M diff=1.82), while single-task measures remained unchanged.

Discussion: The findings underscore the efficacy of cognitive interventions, like exergaming and stationary dual-tasks, in boosting DTP. The Games group demonstrated notable improvements in both tablet-based and WWT tasks, indicating dual-task specificity of our training. Such training could help counter neurocognitive decline and promote healthier aging. Further research is needed to confirm these findings and examine long-term impacts.

Introduction

Fewer than a quarter of adults in the United States meet the national physical activity guidelines to prevent disease (Bennie & Wiesner, 2022). Factors such as work-related stress (Stults-Kolehmainen & Sinha, 2014), disabilities (Martin Ginis et al., 2016), demographic disparities (Oates et al., 2017), and a lack of resources or education (Seefeldt et al., 2002) contribute to an increased risk of chronic disease (López-Bueno et al., 2020), functional impairment (Meisner et al., 2010) and worsening of comorbid conditions (Lee et al., 2012) among low active adults.

Self-regulatory capacity, or the ability to manage one's exercise behavior, is a key determinant of sustained participation in physical activity or exercise programs (McAuley et al., 2011). This cognitive control, important during mid-life, encompasses behaviors such as goal setting, planning, self-monitoring, and motivation and involves cognitive processes like attention, working memory, and executive function (Buckley et al., 2014). Research indicates a bidirectional relationship between exercise and cognitive functioning, with individuals demonstrating higher levels of cognitive control better able to maintain their exercise behavior, and regular exercise leading to cognitive improvements (Allan et al., 2016; Daly et al., 2015). Moreover, adherence rates and dropout are linked to brain structure and functioning (Gujral et al., 2018; Gürdere et al., 2023; McAuley et al., 2011; Szabo-Reed et al., 2023).

The dual-task paradigm, a measure of executive functioning, assesses an individual’s ability to manage two tasks simultaneously. This coordination could involve either two cognitive tasks, two motor tasks, or a combination of both. This assessment is pertinent in middle-aged and older adults, unmasking early signs of neurocognitive decline and associated risks such as falls or dementia (McCarley et al., 2004; Neider et al., 2011). When tasks are combined, such as having a conversation while street-crossing (McCarley et al., 2004; Neider et al., 2011), a decrement in performance is typically observed and can be referred to as the dual-task cost. Dual-task functioning tends to decline with neurocognitive aging and cardiovascular deconditioning (Colcombe et al., 2004). A study of 640 middle-aged adults, Zhou et al., (2023) found that decline in dual-task performance (DTP) began at age 54 and global cognitive functioning was predictive of individual variation in performance. Wong et al. (2015) suggests that this phenomenon may be a function of the capacity for activation of regions of the brain that are critical for executive functioning, a potentially mediating factor between cardiorespiratory fitness and cognitive performance during dual-tasking.

DTP, despite declining with neurocognitive aging and cardiovascular deconditioning (Colcombe et al., 2004; Zhou et al., 2023), can be improved through interventions, including computerized (Li et al., 2010; Lussier et al., 2012) and tablet-based tasks (Fraser et al., 2017; Lussier et al., 2021) that demonstrate greater sensitivity and ecological validity. Investigation into intervention effectiveness has extended to determining which intervention yields the best results (Kramer et al., 1999). For example, Kramer et al. (1999) found that dual-task training that emphasized frequent shifts in task priorities led to higher DTP in task mastery and transferability, compared to training where both tasks were given equal importance. This suggests that the sequence and emphasis of tasks may play a significant role in the effectiveness of dual-task training interventions.

Dual-task training, incorporating physical activity with cognitive tasks, such as exergaming, is a promising intervention to improve DTP (Chen et al., 2023; Gallou-Guyot et al., 2020). Exergaming has been linked with enhanced attention, processing speed, and executive function (Ogawa et al., 2016), and improved exercise enjoyment and self-efficacy (Bock et al., 2019), contributing to cognitive function and overall life quality improvements among those at risk or suffering from neurodegenerative conditions such as Parkinson’s Disease (Schaeffer et al., 2019). Chen et al. (2023) demonstrated that their exercise-cognitive dual-task program led to greater enhancements in verbal fluency, aerobic endurance, and muscular strength compared to the exercise and control groups in a sample of 70 older adults. Gallou-Guyot et al.'s (2020) recent review also offered strong evidence to support the beneficial effects of dual-task interventions within the limited research examining the effects of exergaming on physical and cognitive functioning.

This study investigated whether targeted, multimodal cognitive-motor training can lead to performance improvements in dual-task functioning, as assessed through a validated computerized, tablet-based task (Lussier et al., 2021), and a widely used walking-while-talking (WWT) paradigm (Holtzer et al., 2018, 2019; Lucas et al., 2019; St George et al., 2022). WWT metrics of interest included dual- and single-task velocities and the number of errors, measured at baseline and one month into the study. We hypothesized that participants in the multicomponent dual-task intervention would display a reduction in dual task interference (faster speeds) and faster dual-task walking speeds with fewer spoken errors, independent of any improvement in single-task velocity.

Method

Participants and Procedure

Participants (N = 233, women = 153, men = 80; mean age = 46.73 ± 8.20 years) were low-active middle-aged adults who volunteered to participate in the 12-month CORTEX-II study. Detailed recruitment procedures, full inclusion–exclusion criteria, and study specifics have been described elsewhere. Briefly, participants were recruited via local media outlets and online. Inclusion criteria pertinent to the present data included being low-active (i.e., less than three days of involvement in aerobic activity during the previous three months); having no medical conditions likely to be exacerbated by physical activity; and passing the Telephone

Interview Cognitive Survey (Brandt, Spencer, and Folstein, 1988). Participants who passed the pre-screening criteria were required to obtain physician consent for participation in the exercise program. Participants were recruited in six distinct waves starting from January 2017, with the final wave initiating their participation by May 2019. Each wave of participants completed baseline testing, and post-intervention follow-ups at one, six, and 12 months. For the purpose of our study, the most pertinent data were collected at baseline, and one- and six-month follow-ups for dual-task cognitive outcomes, and at baseline and one-month follow-ups for the WWT outcomes. Data processing and analysis were subsequently carried out from November 2022 through July 2023.

Upon signing informed consent, participants were emailed a baseline survey and subsequently received a Fitbit Charge 2, followed by communications to schedule physical and cognitive functioning assessments on two separate occasions. All testing took approximately two weeks to complete. After baseline data collection, participants were randomized into one of two conditions: a multimodal cognitive training (Gaming) group and an attentional control (Videos) group. Both interventions were digitally delivered using screens of the same size to control for potential differences in screen interaction. The timing (two-hour sessions, 20 total hours) and degree of social interaction were also equivalent across conditions. Five sessions were scheduled in the laboratory for the first two weeks, and five sessions were intended to be practiced at home without guidance or supervision. Post-testing was scheduled with at least 48 hours of delay, immediately following the month-long intervention period, and again at six-month follow-up (at least 48 hours after exercise). Participants were also given a yearlong fitness facility membership with daily opportunities to join group classes. They were asked to meet public health recommendations (U.S. Department of Health and Human Services, 2008, 2018) through a mix of facility-based or self-guided activities, primarily through moderate-intensity activity (a minimum of 150 minutes of aerobic training, two days per week of strength training).

Measures

Demographics. *Age* and *biolgical sex* at birth were self-reported at baseline. *Education level* was assessed on a self-reported 7-point scale: 1 = Less than one year of high school, 2 = High school graduate, 3 = Some college, 4 = Two-year college or technical degree, 5 = College/university graduate, 6 = Master's degree, and 7 = PhD/MD/Other. *Annual household income* was self-rated on an 8-point scale: 1 = Less than $24,999, 2 = $25,000–$39,999, 3 = $40,000–$59,999, 4 = $60,000–$79,999, 5 = $80,000–$99,000, 6 = $100,000–$124,999, 7 = $125,000–$149,000, and 8 = More than $150,000. Participants who selected "Prefer not to respond" or did not answer were coded as missing.

Body Mass Index (BMI) was assessed at baseline using a digital height and weight scale (Seneca). BMI was calculated as weight in kilograms divided by height in meters squared.

Cardiorespiratory Fitness (CRF). CRF was calculated using the Jurca et al. (2005) formula and expressed in METS. CRF was estimated based on gender, age, BMI, resting heart rate (RHR), and a self-reported physical activity (SRPA) index. RHR was measured after a 10-minute rest period using an automated Omron (10 series) device.

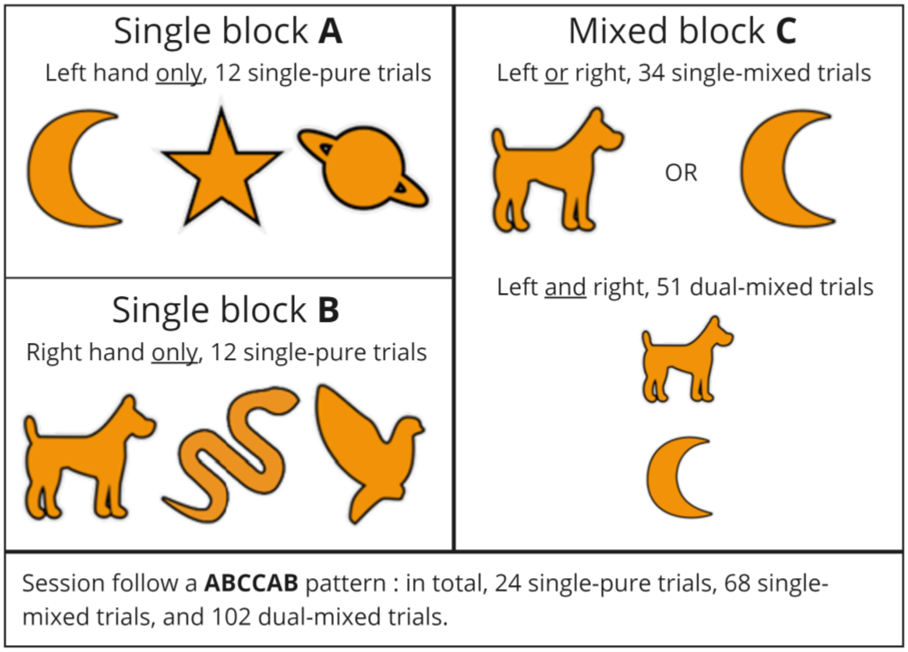
Timed Up and Go (TUG) Task. The TUG task was used to assess functional mobility. Participants were instructed to rise from a chair, walk three meters, turn around, walk back to the chair, and sit down. The total time to complete this task was recorded, with shorter times indicating better functional mobility.

Tablet-based dual task assessment. The tablet-based dual tasks introduced in this study are modifications of a computerized dual task that has been widely used in numerous studies involving older adults (Bherer et al., 2005, 2008; Bherer, Erickson, & Liu-Ambrose, 2013;

Lussier et al., 2017). The tablet version closely mirrors the original computerized version, with the primary difference being that participants are instructed to respond using their thumbs on the touchscreen, as opposed to using their index and ring fingers on a keyboard. The alterations do not compromise the task's validity and normative data have been published (Lussier et al 2021).

Stimuli: The dual-task paradigm requires participants to perform two discrimination tasks either separately or simultaneously. In one task, participants are required to identify animals (dog, snake, or bird) by pressing the corresponding button with their left thumb. In the other task, they are required to identify celestial bodies (moon, star, or planet) using their right thumb. The stimuli, measuring 150x150 pixels , are displayed in orange with a black and white border to enhance contrast against the dark blue background. The stimuli are randomly presented above or below the focus point where the fixation cross appears (approximately 3.17° from the cross at an arm's length), to prevent prioritizing one task over the other. The response buttons for the celestial bodies and the animal tasks are displayed in light blue and are arranged vertically on the left and right sides of the tablet. After the participant responds, the correct response button for that trial turns green for 500 ms to indicate the correct answer.

The Paradigm: The procedure follows an ABCCAB pattern. Initially, participants complete a single block of the animal task (A: 12 trials), followed by a single block of the celestial bodies task (B: 12 trials). Then, two mixed blocks, combining the two tasks (C: 85 trials each), are performed. Finally, the single blocks are repeated. Each first single block and mixed block are preceded by four practice trials. In the single condition, participants only respond to one type of task (animal task or celestial bodies). Trials within this condition are referred to as single-pure trials. In mixed blocks, participants either perform the two tasks simultaneously (dual-mixed trials) or just a single task at a time (single-mixed trials). Sixty percent of trials in the mixed condition are dual-mixed trials. The order of trials within all blocks is randomly generated and remains the same for all participants. In total, each participant responds to 48 single-pure trials, 68 single-mixed trials, and 102 dual-mixed trials. After appearing on the screen, stimuli remain until the participant responds. Once all stimuli are answered, they immediately disappear from the screen, leading to a one-second pause before the next trial appears. While the task itself utilized only symbols, the instructions were presented on the screen at the beginning to instruct the participant and were reinforced verbally by the test administrator. The reliability of computerized RT paradigms has been shown to be adequate if the task has enough trials (Saville et al., 2011). Although test–retest reliability could not be evaluated with the available data, the correlation between the first and the second half of the task design (i.e., ABCCAB) was over .85 for all trial types (simple-pure: .85, simple-mixed: .88, dual-mixed: .90). For more details, see Lussier et al. (2021). The task took approximately 15 minutes to complete. The difference in performance between single-pure and single-mixed trials represents task-set cost, which is thought to indicate the capacity to keep multiple response options in working memory while preparing for various tasks. Another key measure, dual-task cost, is determined by comparing performance on single-mixed and dual-mixed trials. Dual-task cost reflects the extra cognitive load of coordinating two simultaneous tasks, as originally suggested by Schumacher et al. (2001) This measure is frequently employed in dual-task research with older adults (Bherer et al., 2005, 2008; Lussier et al., 2017, 2017; Lussier, Gagnon, & Bherer, 2012; Strobach et al., 2012).



*Walking-while-talking paradigm. T*he WWT paradigm required participants to walk 40 ft (12.19m) first, without further instructions (single-task), and then with an added challenge (dual-task). For the single-task procedure, only one trial was conducted. Participants were instructed to walk with a typical gait to and from a mark on the ground 20 ft (6.10m) away from their starting point. As a given participant completed the task, the facilitator recorded the steps taken and time elapsed. Upon completion, participants transitioned to the dual-task process of which they completed two trials. The dual-task process was identical to the single-task; however, participants were instructed to recite alternating letters of the alphabet while paying equal attention to walking and talking. Testers recorded the steps taken and time elapsed once again, but also included errors in speaking.

Mobility functioning. To account for baseline variation in mobility, a timed Up and Go test was administered in which participants began by sitting in a standard, stationary chair. Participants were then instructed to, when prompted, rise, walk around a cone on the floor 8ft (2.44m) away, turn, and return to the chair and a seated position. Test administrators measured the duration from their initial instruction to when a given participant was once again seated.

Data Analysis

Data were analyzed using the R statistical software, maintaining a significance level of $p < .05$. Outlier values for both the dual-task cognitive outcome and values in the Walking-while-Talking (WWT) errors (WWTE), WWT dual-task velocity (WWTV), and WWT single-task velocity (WWTPV) were considered outliers with criteria of above quantile 3 + 3 x inter-quantile range or below quantile 1 - 3 x inter-quantile range. Two outliers were found for WWTE at baseline. The outliers were confirmed as accurate values. Because baseline WWTE was not used as a dependent variable in the subsequent analysis, mean imputation, instead of multiple imputation, was used to impute the two outliers (Gomila & Clark, 2022).

Analysis of the dual-task performance outcomes was performed using linear mixed-effects models and repeated measures ANOVA. The lmer function from the lmerTest package in R was employed to construct the mixed-effects model, defining response time (RT) as the dependent variable and Session, Condition, Type, and Hand as fixed effects, while accounting for random effects from the participants. Main and interaction effects, particularly the Session by Condition interaction, were of interest to understand within-subject training (practice) effects. Our trial's most critical secondary outcome target was to assess group intervention (between-subjects) effects.

Linear multiple regressions were used to test the intervention effect on WWTE, WWTV, and WWTPV at month one. Specifically, three separate baseline models were constructed, with each WWT variable (WWTE, WWTV, and WWTPV) at baseline, as well as other baseline covariates (education, injury/illness in the first month, baseline cardiorespiratory fitness, baseline Fitbit steps, and baseline timed Up and Go) to predict each WWT variable (WWTE, WWTV, and WWTPV) at month 1. Then, three separate models were built with the intervention variable added at baseline. An F test was used to compare the fit of the model with and without the intervention variable. A significant ($p < .05$) and positive change of the F value indicates intervention substantively improves model fit. For each regression model, Cohen's d statistic was presented as a standardized effect size measure, using the intervention variable for grouping. This provided an estimate of the average difference between the intervention and control groups in a standardized manner. Cohen's *d* may be interpreted as follows: 0.2 = small effect, 0.5 = medium effect, 0.8 = large effect.

The normality assumption of each dependent variable was assessed using Shapiro–Wilk test with a p-value larger than .05 indicating approximate normal distribution. WWTE at month 1 violated the normality test. We proceeded with multiple linear regression for WWTE at month 1 since research has shown the robustness of linear regression to the violation of normality assumption with a relatively large sample size (Knief & Forstmeier, 2021). Model diagnostic plots, including residuals versus fitted plot and qq plot, were used to assess linearity, homoscedasticity, and normality of the residuals. The linearity and homoscedasticity assumptions were met if there was no visually identifiable linear trend of the residuals, and the residuals were equally distributed along the $y = 0$ line. The normality assumption was met if the residuals fell close on the 45-degree reference line in the qq plot. For tablet-based DTP, we also analyzed the accuracy rate, and considered the inverse efficiency score (IES) and the coefficient of variation (CV) to ensure that the RT improvements were not due to riskier strategies that may have led to a drop in accuracy or larger variability.

Results

Preliminary analyses. Participant demographics and the means and standard deviations for all study outcomes are displayed in Table 1. There were no significant differences between groups at baseline for any of the variables included in the analysis, indicating that the groups were comparable at the start of the study.

Tablet-based dual-task performance. The analysis of our transfer task relied on a repeated measures ANOVA. We found a significant main effect of Session, $F(1,212) = 63.18$, $p < .001$, $\eta^2 = .23$, indicating a systematic change in response times over the sessions. Crucially, there was also a significant Session x Group interaction, $F(1,212) = 14.35$, $p < .001$, $\eta^2 = .06$, showing differential progress between the groups from baseline to one-month post-testing. Specifically, the Gaming group demonstrated a larger improvement (-74 ms) compared to the video group (-26 ms. Subsequent repeated contrast analyses indicated a significant reduction in dual-task cost by 33 *ms*, $F(1,212) = 14.99$, $p < .001$, $\eta^2 = .07$, but no significant change in task-set cost. However, the three-way Session x Group x Condition interaction failed to reach significance, suggesting that the observed improvement in dual-task cost was comparable across the two groups. The accuracy rate throughout the study remained exceptionally high at 98.87%, indicative of a ceiling effect that rendered further detailed analyses ineffective. There was no observable decrease in accuracy and even the application of an inverse efficiency score (IES) resulted in negligible changes to the response times. Similarly, the coefficient of variation (CV) remained stable and no significant Session effect was identified. Therefore, it can be affirmed that the improvement in response times cannot be attributed to riskier strategies resulting in decreased accuracy or larger variability.

A longitudinal analysis from Session 1 (baseline) to the 6-month follow-up revealed a small but significant main effect of Session, $F(1, 171) = 3.90$, $p < .05$, $\eta^2 = .02$. This change was characterized by a minor slowing down of responses by about 11 *ms* and was uniform across Conditions and Groups. Moreover, a significant Session x Condition interaction was detected, $F(2, 276) = 4.81$, $p < .05$, $\eta^2 = .03$. Repeated contrasts highlighted a minor improvement in dual-task cost of 18 *ms*, $F(1, 138) = 6.05$, $p < .05$, $\eta^2 = .04$, but not in task-set cost. Again, the three-way Session x Group x Condition interaction was not significant.

Walking-while-talking performance. Linear multiple regressions were used to test the intervention effect on dual-task velocity, errors, and single-task velocity change. Specific results of these analyses can be seen in Tables 2-4. The analysis revealed statistically significant effects ($p < .05$) of group on dual-task velocity ($\beta = 0.15$; $R^2 = 0.44$; $d = 0.35$) and errors ($\beta = -0.29$; $R^2 = 0.23$; $d = -0.60$), indicating significant improvement in performance in the intervention group compared to the control group. The mean dual-task velocity in the control group was 1.14 m/s, whereas the intervention group had a mean of 1.20 m/s. The mean number of errors in the control group was 2.13, while the intervention group had a mean of 1.17 errors. However, single-task velocity change did not yield a statistically significant effect ($p > .05$; $\beta = 0.02$; $R^2 = 0.50$; $d = 0.00$), indicating no significant difference in performance improvement between the intervention and control groups. The mean single-task velocity in the control group was 1.40 m/s, whereas the intervention group had a mean of 1.41 m/s.

Discussion

The present study examined the impact of a multi-modal cognitive training intervention on dual-task performance, both on a tablet-based task and a WWT paradigm. Our results affirm that the intervention positively influenced performance outcomes across both tasks, though the effects were particularly striking in the tablet-based task.

The accuracy rate remained exceptionally high throughout the study, with no observable decrease in accuracy. The stability in the coefficient of variation (CV) and the lack of a significant Session effect further affirm that the observed improvements in response times were not due to participants utilizing riskier strategies. This demonstrates the robustness of the intervention and its potential to effect real improvements without compromising accuracy or increasing variability. In contrast, the results of the WWT paradigm, though affirming the positive (transfer) effects of the intervention, showed more modest improvements. It is noteworthy that the gains in dual-task velocity were not due to an increased general walking speed, suggesting a decrease in dual-task cost among the intervention group. Longitudinally, from Session 1 (baseline) to the 6-month follow-up, a minor slowing down of responses was detected, which was uniform across conditions and groups. However, a minor improvement in dual-task cost was found. These findings suggest that the intervention's benefits have a certain degree of durability over time, though they might decrease somewhat.

Although our study sample is younger, the findings support those Bagheri et al. (2021) evaluating 60 adults aged 65 years and older. Upon comparing the effectiveness of videogaming versus a traditional motor-cognitive dual-task training protocol, Bagheri et al. (2021) concluded that both interventions were successful in enhancing DTP via a reduction in dual-task cost. While traditional dual-task training, video games, and multimodal interventions have shown potential in improving dual-task performance and related outcomes, it's worth emphasizing that our study is one of the few to specifically target a middle-aged demographic rather than older adults.

The implications of our findings are twofold. Firstly, they align with previous research highlighting the potential of motor-cognitive training, especially exergaming (Gallou-Guyot et al., 2020), to augment cognitive functioning among middle-aged to older adults (Chen et al., 2023). The utilization of exergames in our intervention, while not conclusively identified as the decisive factor, suggests its potential in enhancing dual-task performance (DTP). Secondly, the noticeable improvement in DTP within the intervention group infers that the cognitive benefits associated with exergaming may not be confined to gaming scenarios but could extend to other cognitively challenging motor tasks (Ogawa et al., 2016). This finding is particularly salient for older adults, where preserving cognitive abilities is paramount for maintaining independence, quality of life, and neurocognitive health.

The absence of a significant improvement in single-task velocity invites further exploration. Given the focus of our intervention was primarily on adding cognitive demands to tasks, it is plausible that the cognitive components may have overshadowed any potential physical conditioning effects. Alternatively, the duration of the intervention might not have been sufficient to generate perceptible changes in single-task speed. While our study did not primarily aim at inducing a 'fitness effect,' future research might consider extending the intervention periods and possibly incorporating more physically challenging components. Such adjustments could provide valuable insights into the interplay between physical fitness and cognitive enhancements in dual-task performance (Wong et al., 2015).

Despite the promising findings, certain limitations require acknowledgment. The intervention lasted for four weeks, which brings into question the longevity of the observed effects. The participants were also healthy adults aged 35 to 64 years, narrowing the applicability of our findings to older populations or those with cognitive or health impairments. Future research should aim to validate these results in more diverse and broader samples. Exploring the potential benefits of integrating more exergaming into cognitive training interventions to facilitate performance transfer to other cognitive domains such as attention and working memory could also be a promising avenue.

In conclusion, our study underscores the potential of multi-modal cognitive training interventions, particularly exergaming, in enhancing dual-task performance. The tablet-based tasks especially showed promising results, indicating a fruitful direction for future research. As the benefits of these interventions continue to emerge, our findings pave a potential path towards developing efficacious strategies to enhance cognitive function and support healthier aging trajectories.

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Table 1. Participant Demographics

Variables	Control		Intervention		Overall	
	Mean	SD	Mean	SD	Mean	SD
Continuous						
Age (years)	46.97	8.42	46.49	8.01	46.73	8.20
Annual household income	4.50	1.87	4.70	2.14	4.60	2.01
Education	3.19	0.94	3.20	1.11	3.20	1.03
Body mass index (kg/m, baseline)	32.66	7.72	32.88	7.99	32.77	7.84
Cardiorespiratory fitness (baseline)	9.74	2.48	9.83	2.39	9.78	2.43
Fitbit steps (7-day average, baseline)	7,703.89	2,732.69	7,662.16	2,688.90	7,682.76	2,704.83
Timed Up and Go (seconds, baseline)	5.62	0.89	5.62	0.89	5.57	0.91
WWT errors (number of times misspoken, baseline)	2.09	1.85	2.13	1.95	2.11	1.89
WWT errors (times misspoken, month 1)	2.78	1.88	1.71	1.67	2.24	1.85
WWT single-task velocity (m/s, baseline)	1.41	0.19	1.40	0.21	1.41	0.20
WWT single-task velocity (m/s, month 1)	1.41	0.19	1.41	0.18	1.41	0.18
WWT dual-task velocity (m/s, baseline)	1.12	0.29	1.14	0.25	1.13	0.27
WWT dual-task velocity (m/s, month 1)	1.11	0.26	1.20	0.23	1.15	0.25
Categorical	Count (n)	Percentage (%)	Count (n)	Percentage (%)	Count (n)	Percentage (%)
Gender						
Male						
	39	33.91	41	34.75	80	34.33

Categorical	76	66.09	77	65.25	153	65.67
Gender						
Male Female						
Race						
White	93	80.87	96	81.36	189	81.12
Black or African American	17	14.78	15	12.71	32	13.73
Asian	4	3.48	6	5.08	10	4.29
American Indian/ Alaska native	0	0.00	1	0.85	1	0.43
Native Hawaiian or other Pacific islander	1	0.87	0	0.00	1	0.43
Ethnicity						
Non-Hispanic/Latino	105	91.30	110	93.22	215	92.27
Hispanic/Latino	10	8.70	8	6.78	18	7.73
Employment						
Full time	90	78.26	96	81.36	186	79.83
Part time	10	8.70	12	10.17	22	9.44
Retired, working part time	5	4.35	4	3.39	9	3.86
Retired, not working at all	2	1.74	1	0.85	3	1.29
Laid off or unemployed	8	6.96	5	4.24	13	5.58
Injury/Illness						
0 = No	76	66.09	80	67.80	156	66.95
1 = Yes	39	33.91	38	32.20	77	33.05

Note: Income was measured on an 8-point scale: 1 = Less than \$24,999, 2 = \$25,000–\$39,999, 3 = \$40,000–\$59,999, 4 = \$60,000–\$79,999, 5 = \$80,000–\$99,000, 6 = \$100,000–\$124,999, 7 = \$125,000–\$149,000, and 8 = More than \$150,000. Participants who selected "Prefer not to respond" or did not answer were coded as missing. Education was reported on a 7-point scale: 1 = Less than one year of high school, 2 = High school graduate, 3 = Some college, 4 = Two-year college or technical degree, 5 = College/university graduate, 6 = Master’s degree, and 7

= PhD/MD/Other. Cardiorespiratory fitness (CRF) was calculated using the formula provided by Jurca et al. (2005) and expressed in METS. CRF was estimated from gender, age, body mass index (BMI), resting heart rate (RHR), and a self-reported physical activity (SRPA) index. CRF values ranged from 3.2 to 15.3 METS, where 10 METS is considered the maximal capacity for regularly active middle-aged men and women, 3–5 METS suggests a highly deconditioned individual, and 15+ METS indicates high endurance. WWT = walking while talking; SD = standard deviation.

Table 2. Regression results using walking-while-talking error at month 1 as the outcome

Predictor	**b**	**95% CI [LL, UL]**	**β**	**95% CI [LL, UL]**	**Fit**	**Difference**
Model 0					F(6, 226) = 6.273***	
(Intercept)	1.68	[-0.57, 3.93]				
WWT errors (number of times misspoken, baseline)	0.35**	[0.23, 0.47]	0.36	[0.24, 0.49]		
Education	-0.06	[-0.29, 0.16]	-0.04	[0.16, 0.09]		
Injury/Illness	0.18	[-0.30, 0.66]	0.05	[-0.08, 0.17]		
Cardiorespiratory fitness (baseline)	0.02	[-0.08, 0.12]	0.03	[-0.10, 0.16]		
Fitbit steps (7-day average, baseline)	-0.06	[-0.15, 0.03]	-0.09	[-0.22, 0.04]		
Timed Up and Go (seconds, baseline)	0.05	[-0.21, 0.32]	0.03	[-0.11, 0.16]	R^2 = .143**	95% CI [.05, .21]
Model 1					F(7, 225) = 9.519***	
(Intercept)	2.43*	[0.27, 4.59]				
Group	-1.08**	[-1.51, -0.66]	-0.29	[-0.41, -0.18]		
WWT errors (number of times misspoken, baseline)	0.36**	[0.24, 0.48]	0.37	[0.25, 0.49]		
Education	-0.07	[-0.28, 0.14]	-0.04	[-0.15, 0.08]		
Injury/Illness	0.16	[-0.30, 0.61]	0.04	[-0.08, 0.16]		
Cardiorespiratory fitness (baseline)	0.02	[-0.07, 0.12]	0.03	[-0.09, 0.16]		
Fitbit steps (7-day average, baseline)	-0.07	[-0.15, 0.02]	-0.10	[-0.22, 0.02]		
Timed Up and Go (seconds, baseline)	0.02	[-0.24, 0.27]	0.01	[-0.12, 0.13]	R^2 = .228**	ΔR^2 = .086
					95% CI [.12, .30]	ΔF(1,225) = 24.995***

Note: Model 0 represents the model with only covariates. Model 1 represents the model with both covariates and group. b represents unstandardized regression weights. β indicates the standardized regression weights. 95% CI represents 95% confidence interval. LL and UL indicate the lower and upper limits of a confidence interval, respectively. * indicates $p < .05$. ** indicates $p < .01$. *** indicates $p < .001$.

Table 3. Regression results using walking-while-talking dual-task velocity at month 1 as outcome

Predictor	**b**	**95% CI [LL, UL]**	**β**	**95% CI [LL, UL]**	**Fit**	**Difference**
Model 0					$F(6, 226)$ = 27.36***	
(Intercept)	0.33*	[0.04, 0.62]				
WWT-velocity (baseline)	0.55**	[0.46, 0.65]	0.59	[0.49, 0.69]		
Education	0.04**	[0.02, 0.07]	0.18	[0.08, 0.28]		
Injury/Illness	0.02	[-0.04, 0.07]	0.03	[-0.07, 0.13]		
Cardiorespiratory fitness (baseline)	0.01*	[0.00, 0.02]	0.11	[0.00, 0.22]		
Fitbit steps (7-day average, baseline)	-0.00	[-0.01, 0.01]	-0.02	[-0.13, 0.08]		
Timed Up and Go (seconds, baseline)	-0.01	[-0.04, 0.01]	-0.05	[-0.16, 0.05]	$R^2 = .421$**	95% CI [.31, .49]
Model 1					$F(7, 225)$ = 25.59***	
(Intercept)	0.28	[-0.00, 0.57]				
Group	0.07**	[0.03, 0.12]	0.15	[0.05, 0.25]		
WWT-dual task velocity (baseline)	0.55**	[0.45, 0.64]	0.59	[0.48, 0.69]		
Education	0.04**	[0.02, 0.07]	0.18	[0.08, 0.28]		
Injury/Illness	0.02	[-0.03, 0.07]	0.03	[-0.06, 0.13]		
Cardiorespiratory fitness (baseline)	0.01*	[0.00, 0.02]	0.11	[0.00, 0.21]		
Fitbit steps (7-day average, baseline)	-0.00	[-0.01, 0.01]	-0.02	[-0.12, 0.09]		
Timed Up and Go (seconds, baseline)	-0.01	[-0.04, 0.02]	-0.05	[-0.15, 0.06]	$R^2 = .443$**	$\Delta R^2 = .023$
					95% CI [.33, .51]	**$\Delta F(1,225)$ = 9.097

Note: Model 0 represents the model with only covariates. Model 1 represents the model with both covariates and group. b represents unstandardized regression weights. β indicates the standardized regression weights. 95% CI represents 95% confidence interval. LL and UL indicate the lower and upper limits of a confidence interval, respectively. * indicates $p < .05$. ** indicates $p < .01$. *** indicates $p < .001$.

Table 4. Regression results using walking-while-talking single-task velocity at month 1 as outcome

Predictor	b	95% CI [LL, UL]	β	95% CI [LL, UL]	Fit	Difference
Model 0					$F(6, 226) = 37.75$***	
(Intercept)	0.45**	[0.21, 0.68]				
WWT-velocity (baseline)	0.63**	[0.54, 0.72]	0.68	[0.58, 0.78]		
Education	0.02	[-0.00, 0.03]	0.09	[-0.00, 0.19]		
Injury/Illness	0.03	[-0.01, 0.07]	0.07	[-0.02, 0.17]		
Cardiorespiratory fitness (baseline)	0.00	[-0.00, 0.01]	0.04	[-0.06, 0.14]		
Fitbit steps (7-day average, baseline)	-0.00	[-0.01, 0.01]	-0.01	[-0.10, 0.09]		
Timed Up and Go (seconds, baseline)	-0.01	[-0.03, 0.02]	-0.03	[-0.13, 0.08]	$R^2 = .501$**	95% CI [.40, .56]
Model 1					$F(7, 225) = 32.25$***	
(Intercept)	0.44**	[0.20, 0.68]				
Group	0.01	[-0.03, 0.04]	0.02	[-0.08, 0.11]		
WWT-single task velocity (baseline)	0.63**	[0.54, 0.72]	0.68	[0.58, 0.78]		
Education	0.02	[-0.00, 0.03]	0.09	[-0.00, 0.19]		
Injury/Illness	0.03	[-0.01, 0.07]	0.07	[-0.02, 0.17]		
Cardiorespiratory fitness (baseline)	0.00	[-0.00, 0.01]	0.04	[-0.06, 0.14]		
Fitbit steps (7-day average, baseline)	-0.00	[-0.01, 0.01]	-0.01	[-0.10, 0.09]		
Timed Up and Go (seconds, baseline)	-0.00	[-0.03, 0.02]	-0.02	[-0.13, 0.08]	$R^2 = .501$**	$\Delta R^2 = .000$
					95% CI [.40, .56]	$\Delta F(1,225) = 0.115$

Note: Model 0 represents the model with only covariates. Model 1 represents the model with both covariates and group. b represents unstandardized regression weights. β indicates the standardized regression weights. 95% CI represents 95% confidence interval. LL and UL indicate the lower and upper limits of a confidence interval, respectively. * indicates $p < .05$. ** indicates $p < .01$. *** indicates $p < .001$.