scientific reports

OPEN

Effects of balance-based visual reaction time exercises on cognitive and physical performance in older adults: a randomized controlled trial

Fatma Kübra Çekok[1]✉ & Bahar Anaforoğlu[2]

Technological approaches that promote cognitive-motor abilities through visual information have recently become increasingly prevalent. This study aims to verify the effects of balance-based visual reaction time exercises on physical and cognitive performance in older adults. In this randomized controlled trial, 31 participants (aged 71.70 ± 5.67 years) were randomly allocated into two groups. The intervention group (*n* = 16) was enrolled in a balanced-based visual reaction exercise program, and the control group (*n* = 15) in a functional balance exercise program. The participants were assessed both prior to and following the intervention. Primary outcomes included global cognitive function, assessed using the Montreal Cognitive Assessment (MoCA); executive function, measured through the Stroop Test; and reaction time, evaluated using the BlazePod system and the New Test. Secondary outcomes focused on physical performance and included the Five Times Sit-to-Stand Test (FTSS), Timed Up and Go Test (TUG), Four Square Step Test (FSST), Short Physical Performance Battery (SPPB), and the Falls Efficacy Scale (FES) to assess fear of falling. At reassessment, the intervention group exhibited a significantly faster reaction time and made fewer mistakes on the Stroop test compared to the control group ($p < 0.05$). The intervention group also exhibited better physical performance and less fear of falling ($p < 0.05$). However, no significant improvements were observed in global cognitive function, as measured by the Montreal Cognitive Assessment (MoCA), or in Stroop Interference scores ($p > 0.05$). Two-model multiple linear regression analysis revealed that the changes in BlazePod reaction affected the improvement in TUG ($\beta = 0.006$, adjusted $R^2 = 0.24$) and FES ($\beta = 0.013$, adjusted $R^2 = 0.15$). In addition, the enhancement in FSST was influenced by changes in the BlazePod stroke ($\beta = -0.585$, Delta $R^2 = 0.22$). This study demonstrated that balance-based visual reaction time exercises significantly improved reaction time and physical performance in older adults, while no significant changes were observed in executive function measures. These findings highlight the potential of visually guided dual-task training as a feasible strategy to enhance functional outcomes in this population.

Keywords Older people, Reaction time, physical performance

Abbreviations

MMSE	Mini-mental scale
MOCA	Montreal cognitive assessment
10MW	10 m walking
TUG	Timed up and go test
TUG-C	Timed up go-cognition
FTSS	Five times sit-to-stand test
FSST	Four square step test
SFFB	Short physical performance battery
FES	Fall efficiency scale

[1]Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Tarsus University, Takbaş Mahallesi Kartaltepe Sokak Tarsus, Mersin 33400, Türkiye. [2]Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Ankara Yıldırım Beyazıt University, Ankara, Türkiye. ✉email: kubracekok@tarsus.edu.tr

The elderly population is increasing rapidly worldwide. Effective interventions are therefore needed to maintain and improve quality of life among older adults. One major public health priority is therefore to prevent and/or reduce the likelihood of physical and cognitive impairment[1].

Exercise is crucial for preventing health problems that can appear with age and for promoting a healthy lifestyle. Studies have indicated that older adults spend an average of 8.5–9 h a day sitting – 65%-80% of their waking time - and that older individuals have lower physical activity levels than the general population[2]. Prolonged physical inactivity may adversely affect cognitive performance, cardiometabolic health, physical capacity, and functional fitness[3].

Age-related physiological and neurological changes in older adults contribute to progressive declines in both physical and cognitive functions[4]. These changes negatively affect reaction time, balance, and overall physical performance, ultimately leading to reduced mobility, increased fall risk, and diminished independence in daily living activities. Importantly, a well-established association exists between cognitive impairment and fall risk, underscoring the need for interventions that target both cognitive and physical domains[5,6].

A growing body of research suggests a strong interconnection between motor and cognitive systems in aging populations. Executive functions such as attentional control, response inhibition, and cognitive flexibility are involved in postural regulation, adaptive gait, and decision-making during movement[7,8]. Slower reaction times considered sensitive indicators of central nervous system functioning have been consistently associated with a greater likelihood of falls and physical decline[9,10]. The combined deterioration of cognitive and physical ability not only restricts mobility and undermines independence in daily life[11]. This growing body of evidence highlights the urgent need for rehabilitation strategies that concurrently address physical deficits (e.g., balance, strength, reaction time) and cognitive decline to reduce fall risk and preserve autonomy among older adults[12,13]. Given the interconnected nature of the age- related declines, traditional physical rehabilitation may be insufficient on its own. As such, integrative approaches targeting that target both cognitive and motor functions are increasingly recommended.

New interventional methods include cognitive-motor and multi-domain training, particularly using modern technologies such as exergames[14], connected bikes[15], and video games[16]. These multi-domain interventions aim not only to enhance physical and cognitive performance but also to promote user engagement and enjoyment. Among these, visual-stimulus-based systems like BlazePod[17], Fitlight[18], and Witty SEM[19] represent promising tools due to their portability, standardization, and ability to replicate real-life cognitive-motor demands. Despite their increasing use, there remains limited empirical evidence regarding the effectiveness of balance-oriented visual reaction time exercises in older adults.

These technologies integrate visual stimuli to concurrently activate cognitive and motor systems, demanding real-time sensory processing, inhibition of irrelevant responses, and precise motor execution. In this context, reaction time is widely recognized as a sensitive indicator of central nervous system integrity and a critical predictor of fall risk in older populations[20] Such training protocols promote cognitive-motor integration by strengthening executive control networks, enhancing decision-making speed, and supporting more adaptive responses to unpredictable environmental stimuli. Neuroscientific evidence further supports this approach by highlighting that the visuo-spatial and motor systems operate concurrently[21,22]. while the cerebellum processes time and space through distinct pathways a system for when to act and a system for where to act[23]. These parallel systems reflect the dual or even multiple cognitive loads by such interventions on the aging brain[24], underscoring their relevance in targeting executive function, reaction time, and postural control. Consequently, these interventions show promise not only in improving motor function but also in reducing cognitive-related fall risks.

However, to the best of our knowledge, few studies[25] have implemented a visual balance-based reaction time exercise programs specifically for older adults. Given the limited research in this field and the increasing burden of fall-related injuries and healthcare costs[10], there is a pressing need for innovative and multidimensional rehabilitation strategies. Accordingly, the present study aimed to evaluate the effects of an 8-week balance-based visual reaction time exercise program designed to stimulate visual processing, motor reactivity, and postural control within a cognitively demanding framework. We hypothesized that such training would lead to measurable improvements in executive functions, reaction time, and physical performance in older adults.

Methods

Design and participants

The study was a single-blinded (assessor) randomized controlled clinical trial with an eight-week intervention period, conducted in a nursing home in Türkiye. The trial protocol was registered on 25/04/2024 at ClinicalTrials.gov (NCT06383676). The sample size was determined based on previous research by Phirom et al., who used cognitive performance data assessed via the Montreal Cognitive Assessment Scale[26]. To detect a significant difference between the post-training and final measurements in both groups, using Student's t test with a 95% confidence interval and 80% power, the required sample size was calculated to be 24 participants, 12 in each group, assuming an effect size of 1.24. Considering a 10% dropout rate, a total sample size of 28 participants was targeted.

Eligible participants were adults aged 65 years or older who residing in nursing homes. Inclusion criteria required participants to be able to walk without using a walking aid for at least 10 m and to step in multiple directions independently while ensuring their own safety. Exclusion criteria encompassed individuals with significant cognitive impairment (as indicated by a Mental State Examination score ≤ 23, adjusted for educational level) and individuals with a history of neurological disorders (such as stroke and Parkinson's disease), along with any health issues that affect the ability to walk (such as acute painful joint inflammation or mobility limitation), or visual impairments; or any other unstable health conditions that prevent activity. The study was performed in accordance with the principles of the Declaration of Helsinki. Before the experimental study, approval was obtained from the Ankara Yıldırım Beyazit University Faculty of Health Science Ethics Committee (protocol number 2023-03-125) prior to commencement. Informed written and verbal consent was obtained from the paticipants.

Participants were randomly assigned to either the intervention or control group using a stratified randomization procedure based on gender. An urn method designed for clinical trials[27] was implemented by an independent researcher who was not involved in recruitment, assessment, or intervention delivery. All outcome measures were collected by an independent physiotherapist who was blinded to participants' group assignments to ensure objectivity during follow-up assessments. This process ensured allocation concealment and minimized selection bias.

Training protocol

Older adults in the intervention group participated in a balance-based visual reaction time exercise program, engaging in physical, cognitive and motor functions. Each sessions lasted 40 min and conducted twice weekly for eight consecutive weeks. Balance-based visual reaction time exercises for older adults are performed with the BlazePod™ (Play Coyotta Ltd., Tel Aviv, Israel) reaction time panel, which consists of wireless light discs that can be controlled via an application compatible with a smart device[28].

The training program was designed as a choise reaction task, requiring participants to respond to visual stimuli presented on one to six wireless light disks, all participants were briefed on the test procedure and were instructed to execute rapid hand and foot movements to touch the disc surface and deactivate the lights.

All training sessions were conducted in a center-based setting and were supervised one-on-one by a licensed physiotherapist. The intervention was delivered individually rather than in group format. Participants were closely monitored throughout each session to ensure adherence to the protocol and to provide real-time feedback and safety control. Exercise progression was individualized and reassessed weekly based on participants' performance and tolerance. Exercises were conducted in a variety of positions, such as transitioning from sitting to standing, stepping forward and sideways, balancing on rigid and soft surfaces, and standing on one leg to simulate functional movements and progressively challenge postural control.

The protocol integrated balance training with visual reaction time tasks, targeting improvements in neuromuscular coordination and cognitive processing. Exercise difficulty was gradually increased throughout the 8-week program using predefined strategies embedded within each activity (Table 1). Progression criteria were based on participants' ability to perform each task effectively and safely. Adjustments included increasing target distance, modifying base of support (e.g., tandem stance, step height), altering posture, and incorporating more complex movement patterns or surfaces.

Participants progressed to the next level when they could complete a task with proper form and minimal errors across two consecutive sessions. A predefined safety protocol was followed, rest was allowed as needed, and all sessions were conducted in a controlled environment. No adverse events were reported.

The older adults in the control group also received a 16-session functional balance training program over the intervention period, with each session lasting 40 min. Exercises focused on functional balance activities such as maintaining a standing posture, transitioning from sitting to standing, walking, shifting weight using a Pilates ball, and standing on one leg.

Outcome measures

Cognitive outcomes

The Montreal Cognitive Assessment (MoCA) is a brief instrument designed to detect mild cognitive impairment. The Turkish-language version of the MoCA is valid and reliable (Cronbach's alpha = 0.66)[29]. Scores are

Training purpose	Training description
To enhance response time and speed of processing	In this exercise, older adults were instructed to touch the BlazePod™ panel while rotating their heads to the right, left, and upward, all while maintaining their balance
To improve reaction time and physical performance	The older adults were instructed to touch the BlazePod™ reaction time panel at different distances while transitioning from a seated to a standing position.
To improve reaction time and balance performance	The older adults were instructed to stand unsupported with their feet together and to touch the BlazePod™ reaction time panel at different distances.
To improve selective attention, visual attention, and balance ability	Older adults were instructed to tap the panels by performing left and right trunk rotations. To make the exercise more challenging, participants were encouraged to increase the range of their trunk rotations based on their individual abilities and to tap the BlazePod™ reaction time panels positioned at varying distances. (Fig. 1).
To enhance response time and physical performance	The older adults were instructed to reach for an object in various locations, including in front of them, behind them, to the sides, and beyond their arm's length. Increasing the distance while reaching out, changing the location of the object, and changing the individuals' posture (feet side by side, one foot in front of the other, one foot on the step, and tandem stance) were used to make this exercise more difficult
To enhance reaction time and physical performance	The older adults were instructed to take steps in multiple directions, including to the left, right, forward, and backward. In order to increase the exercise difficulty, they were asked to extend their step distance based on their individual ability levels, to perform the steps on a soft surface, to step over obstacles, and to tap the BlazePod™ reaction time panel.
To improve reaction time and physical performance	The older individuals were asked to maintain their balance with one foot on a step. In order to make the exercise more difficult, the step height was increased, and they were asked to touch the BlazePod™ reaction time panel while facing the wall.
To improve reaction time and physical performance	The older adults were instructed to walk in a figure-eight pattern between two chairs and to continue the movement by tapping the BlazePod™ reaction time panel placed on the floor.

Table 1. A summary of the balance-based visual reaction exercise training program.

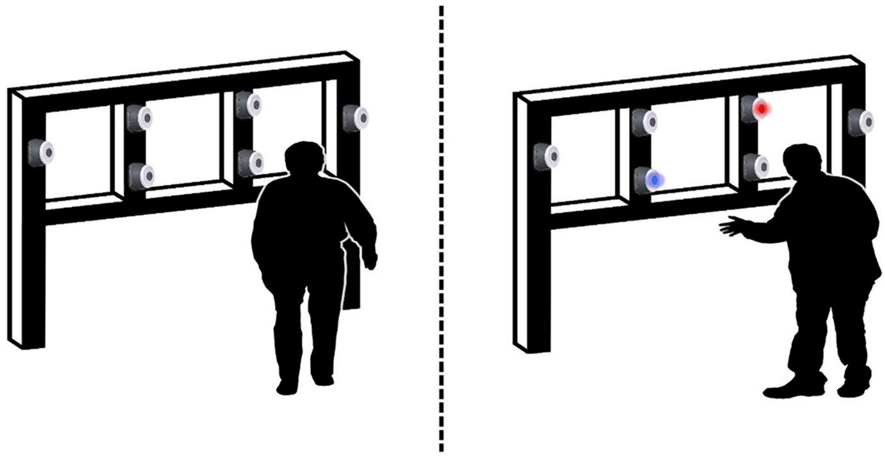

Fig. 1. An example of the balance-based visual reaction exercise training program training program.

calculated by summing the points earned for each activity completed, resulting in a range from 0 to 30. Higher scores indicate superior cognitive function. The MoCA was created to evaluate less severe types of cognitive impairment by examining a broad spectrum of cognitive abilities, including short-term memory, executive functions, visuospatial skills, language, attention, concentration, working memory, and temporal and spatial orientation. The test consists of a single page and typically takes 10–15 min to complete.

Stroop test

The Çapa version of the Stroop test consists of three com ponents: Stroop A, Stroop B, and Stroop C.

- Stroop A involves the rapid identification of the colors (i.e., red, green, and blue) of small rectangles presented sequentially from left to right. This subtest primarily assesses processing speed and visual attention.
- Stroop B requires participants to rapidly read color names printed in incongruent ink colors, thereby assessing selective attention and cognitive control over automatic reading responses.
- Stroop C asks participants to name the color of the ink used to print color words (e.g., red, green, or blue), rather than reading the words themselves. This task triggers the Stroop effect, requiring the inhibition of an automatic response (word reading) in favor of a less habitual one (color naming), thereby creating cognitive interference.

Performance on Stroop C reflects inhibitory control, cognitive flexibility, and broader executive functioning. Each subtest is timed in seconds using a chronometer and also recorded. In Stroop C, the number of errors and number of spontaneous corrections are also recorded. The score for "resistance to interference" (Stroop D) is calculated as the difference in response time between Stroop B and Stroop C. The Turkish version of the Stroop Test – Çapa Form has demonstrated acceptable validity and reliability in older adults, based on a normative study conducted in Turkey[30].

Reaction time outcomes

Lower extremity reaction time was measured using the BlazePod Trainer® (Play Coyotta Ltd, Tel Aviv, Israel), a sensor-based device that evaluates visual reaction speed during functional tasks. The system is Bluetooth-connected to a smartphone, with the "Random" mode was selected via the mobile application.

To ensure consistency and repeatability across all participants, all test procedures were standardized. Three BlazePod discs were placed on the floor, spaced 20 cm apart in a straight line. Participants stood upright position and were instructed to tap the illuminated pods with their dominant lower extremity as quickly as possible. The same verbal instructions were provided to each participant, and all tests were conducted under the same environmental conditions. Each test began with a "Start" command and ended with the "Finish" command at the 30-second mark. During the test, both the total number of hits (i.e., successful pod touch) and the average reaction time (i.e., mean latency across all responses) were recorded automatically by the application[28].

Upper extremity reaction time was assessed using the Newtest 1000 device (Newtest Oy, Oulu, Finland), which includes a digital display, stimulus light, and response button. Participants sat in a quiet environment with their tested arm resting on a table. The index finger of the testing side is placed 1 cm away from the device button. The participants were then asked to press the button whenever a visual or auditory input appeared. The mean score of the last five tests is further analyzed, and a total of 10 repetitions is recorded. Reaction time is recorded to 1/1,000 s sensitivity.

Physical performance outcomes

The Timed Up and Go (TUG) test was used to assess functional mobility and the risk of falling. The TUG test is frequently used as a screening instrument to assess the risk of falling in older adults. This validated was used to evaluate the risk of falls and has been reported to have an exceptional intraclass correlation coefficient (ICC

= 0.97–0.99)[31,32]. The time taken (in seconds) to rise from a chair with armrests, walk 3 m with usual assistive devices, turn around, return to the chair, and sit down again was recorded. The TUG-cognitive test, which included the task of counting backward in multiples of three from any number between 20 and 100 was also performed.

The Four Square Step Test (FSST) was used to assess dynamic balance in the elderly population. The test requires four single-point sticks (SPS) and a stopwatch. Participants began in one square and proceeds to each of the four squares by stepping in a single direction, using the sticks that are resting flat on the floor to form a cross[33]. After reaching the final square, the subject reverses direction and returns to the starting point.

The Five Times Sit-to-Stand Test (FTSS) is a standardized and reliable measure of lower extremity strength and balance, widely used in older adult populations[34]. Participants were seated on a 45 cm-high armless chair with their arms crossed over the chest. They were instructed to stand up and sit down five times as quickly as possible without using their hands. The total time (in seconds) from the initial seated position to the final seated position after the fifth stand was recorded using a stopwatch. A completion time of ≥ 10 s has been shown to predict the future risk of disability in community-dwelling older adult[35].

The Falls Efficacy Scale (FES) was frequently used to assess the social aspect of fear of falling and by focusing on simple daily activities[36]. Hwever, the scale may not fully capture the experiences of physically active older adults. The scoring system for each item is based on a four-point scale: 1 indicating no worry, 2 indicating slight concern, 3 indicating moderate concern, and 4 indicating a high level of concern. The total score is calculated by summing the scores of each item, resulting in a scale that ranges from 16 to 64 for the 16-item FES-I and from 7 to 28 for the seven-item FES-I. A low score signifies a decreased fear of falling.

The Short Physical Performance Battery (SPPB) is a validated tool used to assess lower extremity function and fall risk in older adults[37]. It consists of three components: balance, gait speed, and chair stand tests. Each component is scored on a 0 to 4 scale, with a total possible score ranging from 0 to 12, where higher scores indicate better physical performance. In this study, only the total SPPB score was used for analysis.

Statistical analysis

Statistical analyses were performed using IBM SPSS version 22.0 for Windows software (IBM Corporation, Armonk, NY, USA). The Shapiro–Wilk test was used to evaluate the normality of demographic data, the assessed parameters being presented as medians and interquartile ranges since the distribution was non-normal. The Mann-Whitney U test was used to compare parameters between the groups. Effect sizes (Cohen's d) were calculated to estimate the magnitude of differences between groups. To explore the relationship between improvements between improvements in physical performance parameters and changes in Blazepod reaction times, Blazepod Stroke, and New Test reaction time scores a multivariate linear regression analyses were performed. Only variables demonstrating a statistically significant difference between groups ($p < 0.05$) were included in regression analyses. In this analysis, the change in BlazePod reaction time constituted the first model as an independent variable. Delta values for the BlazePod reaction, BlazePod stroke test, and new test reaction were included in the second model. Prior to conducting regression analysis, the assumptions of multiple linear regression were assessed. Multicollinearity was evaluated using Variance Inflation Factor (VIF < 5) and tolerance values (> 0.2). Linearity, homoscedasticity, and normality of residuals were examined visually using scatterplot and histogram analyses. p values < 0.05 were regarded as statistically significant.

Results

Detailed information concerning screening, enrollment, and drop-outs is given in Fig. 2. One hundred fifty-five older adults were initially assessed for eligibility, whom 31 were recruited and randomly allocated to either the intervention group ($n = 16$) or the control group ($n = 15$). One member of the control group was unable to participate in the re-assessment owing to health issues that were not linked to the study. Thirty-one participants thus completed the study, an overall drop-out rate of 3.2%. There were no falls or other significant incidents during the balance-based visual reaction time exercises, and none of the major medical occurrences were directly or indirectly caused by the training. The participants' demographic characteristics are presented in Table 2. There were no significant differences between the groups in terms of any demographic characteristics at baseline.

No significant differences were observed between the groups' cognitive and physical outcome scores at baseline (Table 3). No significant differences were found between the intervention and control groups in any of the cognitive or physical performance measures at baseline (Table 3). After the 8-week intervention, both groups exhibited statistically significant improvements across multiple outcome domains. In the intervention group, MoCA scores increased significantly ($p < 0.001$), and all Stroop subtests—including A, B, C, interference score, and error rates showed notable improvements (all $p \leq 0.004$). Significant enhancements were also observed in reaction time parameters, including BlazePod average response time, number of strokes, and the new test (all $p \leq 0.001$). Furthermore, all physical performance measures—TUG, TUG-C, FTSS, FSST, SFFB, and FES—demonstrated significant post-intervention improvements (all $p < 0.001$). Similarly, the control group showed statistically significant changes in MoCA scores ($p = 0.006$), Stroop subtests (all $p \leq 0.002$), reaction time tests (all $p \leq 0.001$), and physical performance outcomes (all $p \leq 0.006$), though the magnitude of change was generally lower compared to the intervention group.

At eight weeks post-intervention, the intervention group demonstrated significantly greater improvements in Stroop A (Color board) (d = 0.63, $p = 0.003$), Stroop B (Word board) (d = 1.28, $p < 0.001$), and Stroop C (Color-word board) (d = 1.18, $p < 0.001$), as well as significantly fewer Stroop errors ($d = 1.25$, $p = 0.021$) compared to the control group. Significantly better outcomes were observed in the intervention group for reaction time (BlazePod: $d = 1.15$, $p = 0.004$; New Test: d = 0.96, $p < 0.001$), number of responses (BlazePod strokes: d = 2.44, $p = 0.014$), gait function and ability (TUG: $d = 1.27$, $p = 0.003$; TUG-C: $d = 0.60$, $p = 0.050$), functional strength (FTSS: d = 2.26, $p = 0.013$; SFFB: $d = 1.38$, $p = 0.050$), dynamic balance (FSST: d = 1.97, $p = 0.022$), and fear of falling (FES: d = 1.50,

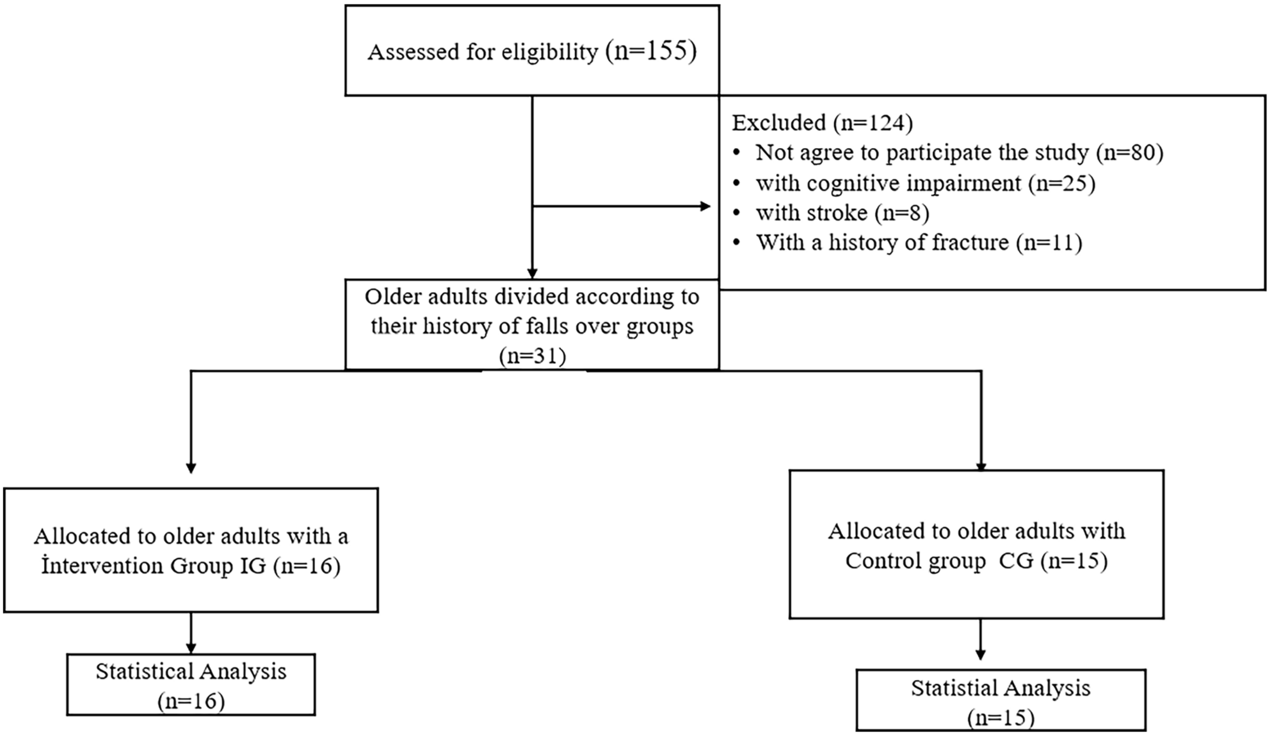

Fig. 2. Diagram of participant recruitment, enrollment, and completion of the randomized controlled trial.

Characteristics	Intervention Group ($n=16$)	Control Group ($n=15$)	p-Value
Age median [IQR]	70 [66–74]	71 [70–78]	0.520
Gender (male: female)	8:8	9:6	0.615
Height (m)	1.67 [1.58–1.70]	1.65 [1.5–1.70]	0.560
Mass (kg)	73 [60–79]	73 [66–76]	0.08
Education (years)	8 [8–12]	8 [8–12]	0.250
Falls in the past year (n)	0 [0–1]	0 [0–1]	0.640
MMSE	27 [26–28]	26 [24–28]	0.190

Table 2. The participants' demographic characteristics. *$p<0.05$ Values are expressed as numbers (n), medians, interquartile range [25%-75%] and percentages (%). MMSE: Mini-Mental Scale.

$p=0.022$) compared to the control group. In contrast, no significant between-group differences were found in MoCA scores (d = 0.43, $p=0.232$) or Stroop Interference scores (d = *0.28*, $p=0.429$) following the intervention (Table 4).

The assessment revealed excellent interobserver agreement across different reaction time measurement methods, indicating high reliability (Table 5). Specifically, intraclass correlation coefficients (ICCs) ranged from 0.94 to 0.96 across the New Test, standard BlazePod, and BlazePod Stroke protocols, with Cronbach's alpha values also exceeding 0.94. These findings support the consistency of reaction time measurements across different raters or sessions using both conventional and sensor-based systems.

In the regression analysis, the first model revealed that the delta change in BlazePod reaction after the training significantly affected TUG ($p=0.003$ adjusted R^2:0.24), FSST ($p=0.001$ adjusted R^2:-0.19), and FES ($p=0.018$, adjusted R^2: 0.15). In the second model, delta changes in BlazePod stroke from baseline to post-training had a significant effect on FTSS ($p=0.012$, $\Delta R^2=0.22$). In addition, delta change in BlazePod reaction time had also a significant change on TUG ($p=0.077$, $\Delta R^2=0.06$). However, the test reaction score did not appear to have a significant impact on the improvement in physical performance ($p>0.05$) (Table 6).

Discussion

This study investigated the effect of balance-based visual reaction time exercises on physical and cognitive performance in older adults. As hypothesized, participants in the intervention group exhibited a eaction time and better physical performance and a fear of falling. Exercise training has been suggested as a means of reducing the risk of falls by enhancing muscle strength, balance, and gait ability[38].

	Intervention group (TG) ($n=16$)	Control group (CG) ($n=15$)	p intergroup (baseline)
Cognitive outcome			
MOCA	Baseline: 25 [24-26.75] Post: 26.5 [26–28] p-intragroup: < 0.001*	Baseline: 25 [24–26] Post: 26 [25–27] p-intragroup: 0.006*	0.716
Executive Function			
Stroop A *Color board (n)*	Baseline: 53.29 [50.21–71.03] Post: 46.21 [41.17–54.01] p-intragroup: < 0.001*	Baseline: 70.12 [53-71.5] Post: 53.15 [50.15–70.25] p-intragroup: 0.001*	0.105
Stroop B *Word board (n)*	Baseline: 49.78 [45.90-67.29] Post:43.04 [38.36–47.59] p-intragroup: 0.001*	Baseline: 70.25 [59-71.33] Post:68.28 [50.25–71.18] p-intragroup: 0.002*	0.110
Stroop C *Color-word board (n)*	Baseline: 81.03 [72.73-109.72] Post: 66.17 [56.84–84.06] p-intragroup: < 0.001*	Baseline: 100.21 [90.08–112.2] Post: 106.12 [78.5-115.31] p-intragroup: 0.002*	0.114
Stroop Interference score (n)	Baseline: 29.89 [23.11–45.18] Post: 24.08 [11.20-35.53] p-intragroup:0.004*	Baseline: 29.96 [8.91–41.75] Post: 34.82 [10.95–46.98] p-intragroup: 0.023*	0.553
Stroop error	Baseline:3.5 [2.25–5.75] Post: 1 [0–2] p-intragroup: < 0.001*	Baseline: 4 [2–5] Post: 2 [2–3] p-intragroup: 0.002*	0.794
Reaction Time Measure			
Blazepod (avg-s)	Baseline: 1034 [989–1382] Post: 838 [762–970] p-intragroup: 0.001*	Baseline: 1230 [1109–1293] Post: 1068 [994–1300] p-intragroup: 0.001*	0.123
Blazepod number of stroke (n)	Baseline: 24 [19–26] Post: 30 [24–32] p-intragroup: < 0.001*	Baseline: 21[19–24] Post: 24 [21–25] p-intragroup: 0.001*	0.257
New test	Baseline: 2.12 [1.66–3.47] Post: 0.94 [0.70–1.25] p-intragroup:0.001*	Baseline: 2.25 [1.76–3.41] Post:1.90 [1.33–3.03] p-intragroup: 0.001*	0.477
Physical Performance			
TUG	Baseline: 12.24 [10-16.08] Post: 9.23 [8.07–10.61] p-intragroup: < 0.001*	Baseline: 14.55 [11.5-19.14] Post:12.49 [10.06–17.28] p-intragroup: 0.001*	0.260
TUG_C	Baseline: 17.95 [14.21-28] Post: 12.04 [9.33–19.61] p-intragroup: < 0.001*	Baseline: 17.25 [15.12-26] Post: 15.46 [15.12-26] p-intragroup: 0.003*	0.453
FTSS	Baseline: 14 [13.17–16.60] Post: 11.90 [10.92–13.32] p-intragroup: < 0.001*	Baseline: 14.12 [13.5–16] Post: 13.71 [10.25–20.30] p-intragroup: 0.001*	0.451
FSST	Baseline: 16 [10.63–18.59] Post: 10.48 [8.28–12.53] p-intragroup: < 0.001*	Baseline: 17.5 [12.09–20.45] Post: 13.71 [10.25–20.30] p-intragroup: 0.001*	0.441
SFFB	Baseline: 8 [7–9] Post: 10 [9–12] p-intragroup: < 0.001**	Baseline: 9 [7–9] Post: 9 [8–10] p-intragroup: 0.006	0.777
FES	Baseline: 34 [26–40] Post: 21.5 [16-27.25] p-intragroup: < 0.001*	Baseline: 32 [28–48] Post: 13.60 [12.90-15.01] p-intragroup: 0.005*	0.606

Table 3. The comparison of baseline and 8 weeks data of the groups (within intergroup and the groups). *$p < 0.05$ Values are expressed as median and interquartile range [25%-75%]. MOCA: Montreal Cognitive Assesment, TUG: Time Up and Go Test, FTSS: Five Times Sit To Stand Test, FSST: Four Square Step Test: SFFB: Short Physical Performance Battery, FES: Falls Efficacy Scale.

Nevertheless, while significant improvements were observed in Stroop A, B, C completion times and error rates, no significant changes were found in MoCA and Stroop Interference scores. These findings suggest that although the visual-based reaction training may enhance processing speed and attention-related performance, it might not be sufficient to elicit improvements in global cognitive function or executive control, likely due to the absence of specific cognitive training components within the program.

Reaction time, a physiological phenomenon that has been extensively investigated and identified as a contributing factor to the occurrence of falls in older adults[39]. Age-related changes in response times are inevitable for activities that involve complicated motor processes, rapid reflexes, and precise answers for the purpose of performing multiple tasks and walking. In addition, the improvement in reaction time as a result of the intervention is highly significant in relation to the ability to produce rapid muscle performance to prevent falls[40].

The eight-week intervention yielded positive outcomes in executive functioning and reaction time among participants in the intervention group. Intragroup comparisons revealed improvements in Stroop A, B, and C task completion times as well as reductions in error rates, suggesting enhanced cognitive processing speed and

	Intervention Group (n = 16)	Control Group (n = 15)	Cohens'd	p-value
Cognitive Outcomes				
Δ MOCA	1.0 [1.0–2.0]	1.0 [0.0–2.0]	0.43	0.232
Executive Function				
Δ Stroop A *Color board (n)*	-10.04 [-12.73– -1.94]	-2.85 [-5.02– -0.85]	0.63	0.003*
Δ Stroop B *Word board (n)*	-3.98 [-6.58– -2.42]	-0.41 [-2.97– -0.05]	1.28	< 0.001*
Δ Stroop C *Color-word board (n)*	-14.09 [-26.65 – -6.33]	-4.20 [-6.77 – -2.04]	1.18	< 0.001*
Δ Stroop Interference score (n)	23.13 [12.23–36.88]	34.82 [13.07–46.98]	0.28	0.429
Δ Stroop error	-3.0 [-3.0– -2.0]	-1.0 [-2.0– -1.0]	1.25	0.021*
Reaction Time				
Δ Blazepod (avg-s)	-1.13 [-1.24 – -0.78]	-0.40 [-0.50 – -0.24]	1.15	0.004*
Δ Blazepod number of stroke (n)	6.0 [4.25–8.0]	2.0 [2.0–3.0]	2.44	0.014*
Δ New test Score (avg-s)	-1.26 [-2.29– -0.77]	-0.43 [-1.2– -0.25]	0.96	< 0.001*
Physical Performance				
Δ TUG	-2.91 [-5.91– -2.44]	-1.86 [-2.49– -0.97]	1.27	0.003*
Δ TUG-C	-5.57 [-8.48– -1.96]	-2.14 [-3.94 –-1.86]	0.60	0.050*
Δ FTSS	-2.45 [-3.18 – -1.65]	-6.00 [-9.10 – -4.10]	2.26	0.013*
Δ FSST	-5.04 [-6.74– -2.53]	-1.33 [-3.01– -1.07]	1.97	0.022*
Δ SFFB	2.0 [2.0–2.75]	1.0 [0.0–1.0]	1.38	0.050*
Δ FES	-9.5 [-13.75– -6.0]	-3.0 [-4.0– -2.0]	1.50	0.022*

Table 4. Comparisons of the cognitive and physical performance outcomes between the intervention group and the control group. *$p < 0.05$ Values are expressed as median and interquartile range [25%-75%]. Δ: Differences between baseline and eight weeks later. MOCA: Montreal Cognitive Assesment, TUG: Time Up and Go Test, FTSS: Five Times Sit To Stand Test, FSST: Four Square Step Test: SFFB: Short Physical Performance Battery, FES: Falls Efficacy Scale.

Reaction Time	Cronbach's Alpha	ICC (95% CI)
New Test	0.96	0.960
BlazePod	0.97	0.94
BlazePod Stroke	0.94	0.96

Table 5. The interobserver reliability using intraclass correlation coefficient for measurements of reaction time. ICC: Intraclass Correlation Coefficient.

attentional control. However, no significant improvements were observed in MoCA scores or Stroop Interference performance. The Stroop Interference task looks at how well someone can control their impulses and ignore automatic reactions when faced with confusing information.

Similarly, the MoCA evaluates a broad range of cognitive domains, including memory, language, and abstraction, many of which were not directly addressed in the training protocol. While the intervention included visual-motor tasks with dual-task elements, its overall cognitive complexity may have been insufficient to elicit broader cognitive improvements. In particular, the absence of structured cognitive tasks such as working memory engagement, decision-making under pressure, or complex multitasking may explain the limited effect on higher-order executive functions and global cognition. Moreover, the progression in training was tailored to individual physical abilities, which may have further reduced cognitive load. The observed improvements in Stroop A, B, and C subtests likely reflect enhanced perceptual-motor integration rather than fundamental changes in executive control. In contrast, the lack of significant change in Stroop Interference scores may also reflect a persistent difficulty in managing cognitive conflict, a domain that typically requires more intensive and targeted cognitive engagement.

One possible explanation for this persistence is the robust semantic processing of language often observed in older adults. As suggested by Park et al.[41], memory for meaning and language-related skills generally stay constant or may even enhance with age, which might account for the increased word interference reported. Conversely, diminished inhibition of color-related stimuli may stem from age-related declines in retinal illuminance and contrast sensitivity[42]. These sensory limitations might further impair performance in tasks requiring visual-cognitive integration. Taken together, these findings highlight the specificity of training effects and the importance of developing multimodal interventions that simultaneously engage physical, perceptual, and cognitive domains. Incorporating elements such as color-coded visual stimuli into cognitive-motor training may help optimize both visual perception and cognitive performance in older adults.

Reaction time has been shown to be significantly correlated with a range of physical measures[43]. This is consistent with Patla et al.[44], who showed that both central (initiation time) and peripheral components (weight

	Δ TUG		Δ FSST		Δ 5XSST		Δ FES	
Model 1	**B (SE)**	***P***	**B (SE)**	***P***	**B (SE)**	***P***	**B (SE)**	***P***
Δ Blazepod Reaction (avg-s)	0.006 (0.002)	**0.003**	0.002 (0.003)	0.517	0.001 0.001)	0.279	0.013 (0.005)	**0.018**
Model 2								
Δ Blazepod Reaction avg-s	0.004 (0.002)	0.077	−0.004 (0.003)	0.290	−0.001 (0.001)	0.327	0.007 (0.006)	0.237
ΔBlazepod number of stroke	−0.134 (0.146)	0.367	−0.585 (0.217)	**0.012**	−0.249 (0.084)	0.006	−0.375 (391)	0.346
Δ New test (avg-s)	0.351 (0.411)	0.401	−0.059 (0.612)	0.923	0.144 (0.237)	0.550	0.866 (1.103)	0.439
Note	DW:1.332		DW:2.118		DW:1.339		DW:1.762	
	Model 1		**Model 1**		**Model 1**		**Model 1**	
	Constant:-1.55		Constant: -3.17		Constant:-1.31		Constant:-4.305	
	R^2:0.24		R^2: 0.19		R^2:0.07		R^2:0.15	
	Model 2		**Model 2**		**Model 2**		**Model 2**	
	Constant:-0.99		Constant:-1.95		Constant:-0.68		Constant:-2.839	
	ΔR^2:0.06		ΔR^2: 0.22		ΔR^2:0.29		ΔR^2:0.16	

Table 6. Two model multiple linear regression analyses showing the effect of changes in blazepod reaction times, blazepod Stroke, and new test reaction time scores on the improvement in physical performance. **Δ** differences between baseline and eight weeks later. DW: Durbin-Watson TUG: Time Up Go Test, FTSS: Five Times Sit To Stand Test, FSST: Four Square Step Test: SFFB: Short Physical Performance Battery, FES: Falls Efficacy Scale. B unstandardized coefficients, SE standard error, R2 adjusted R-squared.

transfer time) were important in lower extremity reaction time, and that both parameters revealed age-related decline. Effective step initiation requires adequate lower limb strength not only to stabilize the stance leg but also to enable rapid lift-off and movement of the stepping leg. This muscular strength contributes to rapid and efficient movement initiation, which is essential for improving reaction time. Simultaneously, balance control is a vital for maintaining coordination and postural stability throughout step initiation and execution. Thus, improved lower extremity strength and balance control act synergistically to enhance reaction time by enabling swift, stable, and precise motor responses[45,46].

In our study, gait function and mobility, assessed using the Timed Up and Go (TUG) and cognitive dual-task version (TUG-C), as well as functional lower limb strength was assessed via the Five Times Sit-to-Stand Test (FTSS), showed significant improvement in the intervention group following the 8-week training. Notably, significant gains were also observed in the Four Square Step Test (FSST) and the Short Physical Batary (SFB) test, supporting the effectiveness of the training approach. Moreover, multiple regression analysis revealed that improvements in reaction time were significantly associated with better scores on the TUG, FSST, and Falls Efficacy Scale (FES), suggesting that faster reaction times play a meaningful role in the enhancement of functional mobility and confidence in balance. These improvements are in line with previous studies on exercise programs incorporating balance-oriented components, such as dancing and Multi-System training programs [38,39].

The structured and individualized design of our program, which focused on functional tasks, balance challenges, and visual reaction stimuli, appears to have effectively contributed to enhancing both dynamic balance and physical performance capacities in older adult. The improvement in dynamic balance is in accordance with other exercise programs described earlier that include balance training, such as the dancing program and the Multi-System training programs[47,48]. Despite the relatively short duration of the program, two factors likely contributed to its effectiveness: (1) the inclusion of a targeted and progressively challenging balance-based training regimen, and (2) the adaptation of the program content to individual functional levels using the BlazePod system.

Previous research have shown that the duration of training programs is essential for achieving cognitive and physical enhancements in older adults. In the present study, the 8-week balance-based visual reaction time training resulted in improvements in reaction time and specific executive function components, such as selective attention and processing speed. Párraga-Montilla et al.[49] found that eight weeks of physical, cognitive, or dual-task training markedly enhanced both physical and cognitive functions in elderly individuals, indicating that these interventions may mitigate the adverse effects of aging. Similarly, a randomized controlled trial by Rodrigueset al.[50] showed that 8 weeks of combined physical and cognitive training improved dual-task walking and executive control. Nonetheless, extended training periods (12 to 24 weeks) seem to provide more significant and widespread cognitive advantages. For example, Patrict et al.[51] found that 6-month multicomponent physical exercise program—augmented with simultaneous cognitive training (verbal memory or VR dancing) yields greater cognitive benefits than physical training alone. Likewise, Kattenstroth et al.[52] found that 12 weeks of dance-based physical and cognitive training improved many cognitive domains, such as attention and cognitive flexibility. Taken together, these findings suggest that while an 8-week program may be sufficient to enhance processing efficiency and task-specific cognitive abilities, a longer duration and/or higher cognitive load may be necessary to elicit improvements in more global cognitive outcomes.

In our training program, participants were typically required to perform two tasks simultaneously, one visual and the other motor reflecting a dual-task approach that engaged both cognitive and physical domains. This integrated strategy not only supported cognitive stimulation but also served as an effective method to reduce fall risk in older adults by improving reaction time, motor coordination, reflexes, and movement precision. The use of BlazePod training tools specifically enhanced participants' responsiveness to visual stimuli, contributing to significant improvements in reaction time. Furthermore, the program's progressive structure from simple to complex tasks, along with corrective feedback, played a crucial role in maintaining motivation, enhancing learning, and increasing accuracy and concentration. The training sessions were of sufficient duration and intensity, and exercises were executed appropriately. Collectively, these factors may explain why the intervention group showed superior performance compared to the control group, suggesting that such multimodal training protocols can effectively support both cognitive and physical function in older adults. As an emerging training modality, visual reaction-based systems like BlazePod represent a promising approach for engaging multiple domains simultaneously and promoting functional improvements in aging populations. Although both groups demonstrated statistically significant improvements across cognitive and physical measures; however, the intervention group exhibited consistently greater gains. This pattern of results suggests that, beyond the potential effects of repeated assessments or general participation, the structured and targeted nature of the intervention played a key role in enhancing its overall efficacy.

The particular strength of this study is that a physical exercise program was designed to address the improvement of reaction time in a manner specific to older individuals. However, the study has several important limitations that should be acknowledged. First, the statistical power of the regression analyses was limited due to the small sample size, which restricts the robustness and generalizability of the findings to the broader older adult population. In addition, the non-normal distribution of several baseline characteristics and outcome parameters suggests sample heterogeneity, which may have introduced variability and potential confounding factors Second, the cognitive assessment was limited to only the MoCA and Stroop tests. This narrow scope may have overlooked other relevant cognitive domains such as memory, sustained attention, and planning. Including a more diverse battery of cognitive tests would allow for a more comprehensive evaluation of cognitive function and may reveal effects not captured by the current measures. Third, the absence of long-term follow-up assessments prevents conclusions regarding the durability and retention of the observed benefits over time. Without longitudinal data, it is unclear whether the cognitive and functional gains are sustained beyond the immediate post-intervention period. Taken together, these limitations suggest that the present findings should be interpreted as preliminary.

Conclusion

In summary, balance-based visual reaction exercises improved reaction time and functional ability in older adults. However, no significant changes were found in global cognition (MoCA) or Stroop interference, suggesting limited effects on higher-order executive functions. Integrating visual stimuli with balance training may offer synergistic benefits for physical function and quality of life. Future research should focus on validating these initial results using larger samples, more comprehensive cognitive assessments, and long-term follow-up to better understand the sustained and broader cognitive effects of such interventions. These findings also highlight the potential of visual reaction-based systems as an emerging training modality for promoting functional gains in older adults.

Data availability

The data underlying this study are available from the corresponding author upon reasonable request.

Received: 29 December 2024; Accepted: 15 September 2025
Published online: 01 October 2025

References

1. Winblad, B. et al. Defeating alzheimer's disease and other dementias: a priority for European science and society. *Lancet Neurol.* **15**, 455–532 (2016).
2. Wullems, J. A., Verschueren, S. M., Degens, H., Morse, C. I. & Onambélé, G. L. A review of the assessment and prevalence of sedentarism in older adults, its physiology/health impact and non-exercise mobility counter-measures. *Biogerontology* **17**, 547–565 (2016).
3. Herlofson, K. & Daatland, S. O. *Ageing, Intergenerational relations, Care Systems and Quality of life-an Introduction To the OASIS Project* (Oslo Metropolitan University-OsloMet: NOVA,, 2001).
4. Cooper, R. et al. Objective measures of physical capability and subsequent health: a systematic review. *Age Ageing.* **40**, 14–23 (2011).
5. Cooper, R., Kuh, D. & Hardy, R. Objectively measured physical capability levels and mortality: systematic review and meta-analysis. *BMJ* **341**, c4467 (2010).
6. Dewey, M. E. & Saz, P. Dementia, cognitive impairment and mortality in persons aged 65 and over living in the community: a systematic review of the literature. *Int. J. Geriatr. Psychiatry*. **16**, 751–761 (2001).
7. Cruikshank, L. C., Singhal, A., Hueppelsheuser, M. & Caplan, J. B. Theta oscillations reflect a putative neural mechanism for human sensorimotor integration. *J. Neurophysiol.* **107**, 65–77 (2012).
8. Ikkai, A. & Curtis, C. E. Common neural mechanisms supporting Spatial working memory, attention and motor intention. *Neuropsychologia* **49**, 1428–1434 (2011).
9. Lajoie, Y. & Gallagher, S. Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific balance confidence (ABC) scale for comparing fallers and non-fallers. *Arch. Gerontol. Geriatr.* **38**, 11–26 (2004).
10. Graveson, J., Bauermeister, S., McKeown, D. & Bunce, D. Intraindividual reaction time variability, falls, and gait in old age: a systematic review. *Journals Gerontol. Ser. B: Psychol. Sci. Social Sci.* **71**, 857–864 (2016).

11. Ikegami, S. et al. Physical performance reflects cognitive function, fall risk, and quality of life in community-dwelling older people. *Sci. Rep.* **9**, 12242 (2019).
12. Baniasadi, T., Namazizadeh, M. & Sheikh, M. Attentional focus can affect sway in postural and supra-postural tasks in community-dwelling older adults. *Ann. Appl. Sport Sci.* **6**, 31–37 (2018).
13. Marsh, A. P. & Geel, S. E. The effect of age on the attentional demands of postural control. *Gait Posture*. **12**, 105–113 (2000).
14. Béraud-Peigné, N., Maillot, P. & Perrot, A. The effects of a new immersive multidomain training on cognitive, dual-task and physical functions in older adults. *GeroScience* **46**, 1825–1841 (2024).
15. Barcelos, N. et al. Aerobic and cognitive exercise (ACE) pilot study for older adults: executive function improves with cognitive challenge while exergaming. *J. Int. Neuropsychol. Soc.* **21**, 768–779 (2015).
16. Perrot, A., Maillot, P. & Hartley, A. Cognitive training game versus action videogame: effects on cognitive functions in older adults. *Games Health J.* **8**, 35–40 (2019).
17. Ilin, D. & Kalron, A. Reproducibility and convergent validity of the blazepod stepping reaction test in older people. *Gait Posture*. **119**, 1–6. https://doi.org/10.1016/j.gaitpost.2025.02.015 (2025).
18. Koppelaar, H. et al. Proof of concept of novel visuo-spatial-motor fall prevention training for old people. *Geriatrics* **6**, 66 (2021).
19. Ružbarská, B., Kačúr, P., Vašková, M. & Chovanová, E. Age and gender differences in the level of motor docility, selected cognitive and motor-cognitive abilities of older school-age children. *J. Kinesiol. Exerc. Sci.* **33**, 28–37 (2023).
20. Okubo, Y., Schoene, D. & Lord, S. R. Step training improves reaction time, gait and balance and reduces falls in older people: a systematic review and meta-analysis. *Br. J. Sports Med.* **51**, 586–593. https://doi.org/10.1136/bjsports-2015-095452 (2017).
21. Classen, J., Gerloff, C., Honda, M. & Hallett, M. Integrative visuomotor behavior is associated with interregionally coherent oscillations in the human brain. *J. Neurophysiol.* **79**, 1567–1573 (1998).
22. Feng, G. Is there a common control mechanism for anti-saccades and reading eye movements? Evidence from distributional analyses. *Vision. Res.* **57**, 35–50 (2012).
23. Honda, T. et al. Tandem internal models execute motor learning in the cerebellum. *Proc. Natl. Acad. Sci.* **115**, 7428–7433 (2018).
24. Beauchet, O., Dubost, V., Aminian, K., Gonthier, R. & Kressig, R. W. Dual-task-related gait changes in the elderly: does the type of cognitive task matter? *J. Mot. Behav.* **37**, 259–264 (2005).
25. Béraud-Peigné, N., Perrot, A. & Maillot, P. Wireless lighting system: A new tool for assessing cognitive functions in the elderly. *Behav. Sci.* **13**, 943 (2023).
26. Phirom, K., Kamnardsiri, T. & Sungkarat, S. Beneficial effects of interactive physical-cognitive game-based training on fall risk and cognitive performance of older adults. *Int. J. Environ. Res. Public Health*. **17**, 6079 (2020).
27. Wei, L. J. A class of designs for sequential clinical trials. *J. Am. Stat. Assoc.* **72**, 382–386 (1977).
28. de-Oliveira, L. A., Matos, M. V., Fernandes, I. G., Nascimento, D. A. & da Silva-Grigoletto, M. E. Test-retest reliability of a visual-cognitive technology (BlazePod™) to measure response time. *J. Sports Sci. Med.* **20**, 179 (2021).
29. Ozdilek, B. & Kenangil, G. Validation of the Turkish version of the Montreal cognitive assessment scale (MoCA-TR) in patients with parkinson's disease. *Clin. Neuropsychol.* **28**, 333–343 (2014).
30. Emek-Savaş, D. D., Yerlikaya, D., Yener, G. G. & Tanör, Ö. Ö. Validity, reliability, and normative study of the Stroop Test Çapa Form. *Turk. J. Psychiatry* **31**, 9–21 (2020).
31. Shumway-Cook, A., Brauer, S. & Woollacott, M. Predicting the probability for falls in community-dwelling older adults using the timed up & go test. *Phys. Ther.* **80**, 896–903 (2000).
32. MS, T. Age-and gender-related test performance in community-dwelling elderly people: Six-Minutes walk test, Berg balance scale, timed up & go test, and gait speeds. *Phys. Ther.* **82**, 123–137 (2002).
33. Dite, W. & Temple, V. A. A clinical test of stepping and change of direction to identify multiple falling older adults. *Arch. Phys. Med. Rehabil.* **83**, 1566–1571 (2002).
34. Whitney, S. L. et al. Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the Five-Times-Sit-to-Stand test. *Phys. Ther.* **85**, 1034–1045 (2005).
35. Makizako, H. et al. Predictive cutoff values of the five-times sit-to-stand test and the timed up & go test for disability incidence in older people dwelling in the community. *Phys. Ther.* **97**, 417–424 (2017).
36. Ulus, Y. et al. Reliability and validity of the Turkish version of the falls efficacy scale international (FES-I) in community-dwelling older persons. *Arch. Gerontol. Geriatr.* **54**, 429–433 (2012).
37. Fisher, S., Ottenbacher, K. J., Goodwin, J. S., Graham, J. E. & Ostir, G. V. Short physical performance battery in hospitalized older adults. *Aging Clin. Exp. Res.* **21**, 445–452 (2009).
38. Cadore, E. L., Rodríguez-Mañas, L., Sinclair, A. & Izquierdo, M. Effects of different exercise interventions on risk of falls, gait ability, and balance in physically frail older adults: a systematic review. *Rejuven. Res.* **16**, 105–114 (2013).
39. Mercer, V. S., Hankins, C. C., Spinks, A. J. & Tedder, D. D. Reliability and validity of a clinical test of reaction time in older adults. *J. Geriatr. Phys. Ther.* **32**, 103–110 (2009).
40. Okubo, Y., Schoene, D. & Lord, S. R. Step training improves reaction time, gait and balance and reduces falls in older people: a systematic review and meta-analysis. *Br. J. Sports Med.* **51**, 586–593 (2017).
41. Park, D. C. et al. Models of visuospatial and verbal memory across the adult life span. *Psychol. Aging*. **17**, 299 (2002).
42. Haegerstrom-Portnoy, G., Schneck, M. E. & Brabyn, J. A. Seeing into old age: vision function beyond acuity. *Optom. Vis. Sci.* **76**, 141–158 (1999).
43. Vala, H., Padnani, R., Dave, S., Cheta, P. & Zalavadiya, G. A study to find out the correlation between physical activity, reaction time, and fall risk in the elderly. *Int. J. Health Sci. Res.* **13**, 43–48 (2023).
44. Patla, A. et al. Age-related changes in balance control system: initiation of stepping. *Clin. Biomech. Elsevier Ltd*. **8**, 179–184 (1993).
45. St George, R. J., Fitzpatrick, R. C., Rogers, M. W. & Lord, S. R. Choice stepping response and transfer times: effects of age, fall risk, and secondary tasks. *Journals Gerontol. Ser. A: Biol. Sci. Med. Sci.* **62**, 537–542 (2007).
46. Waddell, C. L., Mellifont, R. B. & Burkett, B. J. Improving balance in community-dwelling older people through a targeted mediolateral postural stability program. *J. Am. Geriatr. Soc.* **57**, 2380–2382 (2009).
47. Chittrakul, J., Siviroj, P., Sungkarat, S. & Sapbamrer, R. Multi-system physical exercise intervention for fall prevention and quality of life in pre-frail older adults: a randomized controlled trial. *Int. J. Environ. Res. Public Health*. **17**, 3102 (2020).
48. Santos, D. P. M. A., Queiroz, A. C., d., C. M., Menezes, R. L. & Bachion, M. M. Effectiveness of senior dance in the health of adults and elderly people: an integrative literature review. *Geriatr. Nurs.* **41**, 589–599 (2020).
49. Párraga-Montilla, J. A. et al. A randomized controlled trial protocol to test the efficacy of a Dual-Task multicomponent exercise program vs. a simple program on cognitive and fitness performance in elderly people. *Int. J. Environ. Res. Public. Health*. **18** https://doi.org/10.3390/ijerph18126507 (2021).
50. Rodrigues, L. et al. Effects of an 8-week training cessation period on cognition and functional capacity in older adults. *Exp. Gerontol.* **134**, 110890 (2020).
51. Eggenberger, P., Schumacher, V., Angst, M., Theill, N. & de Bruin, E. D. Does multicomponent physical exercise with simultaneous cognitive training boost cognitive performance in older adults? A 6-month randomized controlled trial with a 1-year follow-up. *Clin. Interv. Aging* **10**, 1335–1349 (2015).
52. Kattenstroth, J. C., Kalisch, T., Holt, S., Tegenthoff, M. & Dinse, H. R. Six months of dance intervention enhances postural, sensorimotor, and cognitive performance in elderly without affecting cardio-respiratory functions. *Front. Aging Neurosci.* **5**, 5 (2013).

Author contributions
F.K.Ç. wrote the main manuscript text, designed the study, prepared figures and performed statistical analyses. B.A. designed the study and wrote the main manuscript text. All authors critically revised the manuscript.

Funding
This work was supported by The Scientific and Technological Research Council of Turkiye under Grant 122C235.

Declarations

Competing interests
The authors declare no competing interests.

Additional information
Correspondence and requests for materials should be addressed to F.K.Ç.