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Comparative effects of cognitive and instability resistance training versus instability resistance training on balance and cognition in elderly women

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This study investigates the effects of integrated instability resistance training and cognitive training (IRCT) versus isolated instability resistance training (IRT) on balance, gait, muscle strength, and cognitive functions in elderly women.This randomized controlled trial included 36 participants, with 18 in the IRCT group and 18 in the IRT group. The sample size was estimated to achieve a statistical power of 0.95 with a large effect size (0.40; n = 12 each group). The closed-eye single-leg stand test was measured for static balance, the closed-eye stepping test, and the Timed Up and Go Test (TUGT) were measured for dynamic balance. Dual-task balance was assessed by combining the TUGT with cognitive tasks (TUGT-C) and motor tasks (TUGT-M). Gait performance was evaluated using a gait function system. Lower limb muscle strength was measured with the 30-Second Chair Stand Test. Cognitive function was assessed through the Trail Making Test (TMT), Digit Span Test (DST), Stroop Color and Word Test (Stroop), and Digit Symbol Substitution Test (DSST). Results IRCT group showed better improvements in both cognitive ($p < 0.001$) and motor ($p = 0.812$ for baseline; $p < 0.001$ for post-intervention) dual-task abilities, IRCT also experienced better enhancement in certain cognitive functions, particularly in the TMT ($p = 0.001$) and DSST ($p = 0.022$) compared to the IRT group. Both groups demonstrated enhancements in walking abilities as shown on selective markers of the gait performance test ($p < 0.05$) and leg muscle strength via 30-Second Chair ($p < 0.001$ for time main effect). These results suggest that combining cognitive exercises with physical training more effectively addresses the complex challenges associated with aging in women. The study highlights the potential of comprehensive training approaches in boosting health and quality of life for the elderly, with implications for developing tailored exercise programs focused on reducing fall risks and enhancing quality of life in this population.

Keywords Cognitive training, Dual-task performance, Randomized controlled trial, Older women, Gait

Falls among the elderly have escalated to a major global public health concern, posing significant threats to their well-being[1]. In real-life scenarios, seniors are often challenged to perform multiple tasks concurrently, such as walking while engaging in activities like buttoning a shirt, talking on the phone, or carrying objects. The complexity of these tasks can overwhelm their balance control, increasing the risk of instability or falls[2,3]. The ability to simultaneously perform motor tasks like walking alongside other motor or cognitive tasks is defined as dual-task balance. Studies have simulated real-life dual-task conditions to predict and mitigate fall risks in the elderly, yielding promising results[4]. However, those with compromised dual-task balance abilities remain particularly vulnerable to falls during dynamic or static activities[5,6].

To enhance dual-task balance capabilities in seniors, researchers have explored a wide range of interventions. Conventional single-modal physical exercise regimes, however, have proven insufficient in substantially improving dual-task balance in older adults, thereby not fully addressing practical daily needs[7]. As such, the effective enhancement of dual-task balance capabilities has become a critical research imperative. Balance is intricately connected to the functional integrity of the sensory, central nervous, and motor systems[8]. Therefore,

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some scholars have proposed and tested the combination of motor and cognitive training for elderly individuals, attaining noteworthy successes[9]. Motor-cognitive dual-task training, entailing the concurrent performance of a primary motor task and a secondary cognitive task, has thus emerged as a promising field of research. Nevertheless, the literature regarding comparing the effects of combined motor and cognitive training versus solely motor training on elderly balance abilities remain limited and inconclusive[10], thus further investigation is warranted.

Recently, the adoption of instability resistance training (IRT) has gained attention in practical applications, demonstrating its potential to exert stronger stimuli to the neuromuscular system compared to traditional training methods, resulting in enhanced muscle strength and balance[11]. Yet, integrative studies combining lower limb instability resistance training with cognitive training (IRCT) for elderly dual-task balance interventions remain scarce. Epidemiological findings indicate that older women are at a higher risk of falling compared to their male counterparts, identifying them as a vulnerable demographic[12]. Considering these factors, this study is directed towards examining the combined effect of lower limb IRCT vs. IRT alone, with a specific emphasis on the effects of such training modality on the dual-task balance skills in elderly women. The rationale for this study stems from the need to address the limitations of traditional resistance training in improving dual-task balance performance among elderly women. By integrating cognitive training with instability resistance exercises, this study aims to explore a more comprehensive approach that targets both motor and cognitive functions simultaneously. In addition, the research also aims to discern the composite impact of IRCT in comparison to standard IRT on various aspects including balance, gait stability, muscular strength, and cognitive abilities, particularly focusing on cognitive areas like attention, executive function, and adaptability, with the goal to provide insights into the differential effectiveness of these training modalities in improving balance among elderly women. We hypothesized that IRCT training will induce greater enhancement in overall physical and cognitive outcomes. The findings are expected to contribute valuable knowledge towards optimizing fall prevention strategies and improving overall balance, particularly in elderly women who face a heightened risk of falls.

Materials and methods

Participants

Sample size was estimated using G*Power 3.1.9 software[13]. Using variance analysis statistical methods, with $\alpha = 0.05$, to achieve a sufficient power ($1\text{-}\beta = 0.95$) under a large effect size (0.40), it was estimated that 12 individuals per group were needed. Considering the potential dropout during the intervention, a total of 36 participants were recruited for this study.

The inclusion criteria were: (1) elderly women aged 60 and above; (2) individuals without visual or auditory impairments and with normal understanding abilities; (3) no cognitive impairments, capable of independent walking and exercise; (4) elderly who have not engaged in strength training in the past six months; (5) no risks for exercise based on American Heart Association/American College of Sports Medicine health/fitness facility pre-participation screening questionnaire; (6) willing to participate in the study. The exclusion criteria were: (1) participants with known cardiovascular, metabolic or musculoskeletal diseases, or those who have recently recovered from an illness; (2) individuals with severe neurological diseases affecting balance, such as stroke; (3) those requiring walking aids. All methods were carried out in accordance with the Declaration of Helsinki and relevant regulations. This study was approved by the Institutional Review Board at Central China Normal University (NO.CCNU-IRB-202310027b). A written informed consent was obtained from all participants prior to any data collection.

Participants were randomly assigned to either the IRCT group ($N = 18$) or IRT group ($N = 18$). The IRCT group underwent lower limb instability resistance training combined with cognitive training, while the IRT group underwent lower limb instability resistance training only. The baseline characteristics of the subjects are shown in Table 1. After 8 weeks of intervention, one person in the IRCT group and one person in the IRT group dropped out. The experimental design is shown in Fig. 1.

Intervention

All subjects participated in an 8-week training program, training was carried out three times per week, with each session lasting 60 min (10 min of warm-up exercises, 40 min of training and 10 min of cool-down activities). The training content for the IRCT group included lower limb instability resistance training combined with cognitive training. The IRT group's training involved only lower limb instability resistance training.

For instability resistance training, training regime primarily involved overcoming body weight and elastic band (Thera band, Hygenic Corporation, Akron, Ohio) resistance, with a balance pad (Airex, Altenrhein, Switzerland,50*40*6 cm) used as the unstable support surface. The intervention plan for lower limb instability

	IRCT (*N* = 17)	**IRT (*N* = 17)**	***P***
Age (years)	66.65 ± 3.66	65.88 ± 2.96	0.507
Height(cm)	159.53 ± 4.27	159.41 ± 4.60	0.939
Weight(kg)	57.41 ± 4.30	56.18 ± 4.02	0.403
BMI (kg/m^2)	22.58 ± 1.83	22.08 ± 0.98	0.334

Table 1. Physical characteristics for all participants. IRCT, integrated instability resistance training and cognitive training group; IRT, instability resistance training only group.

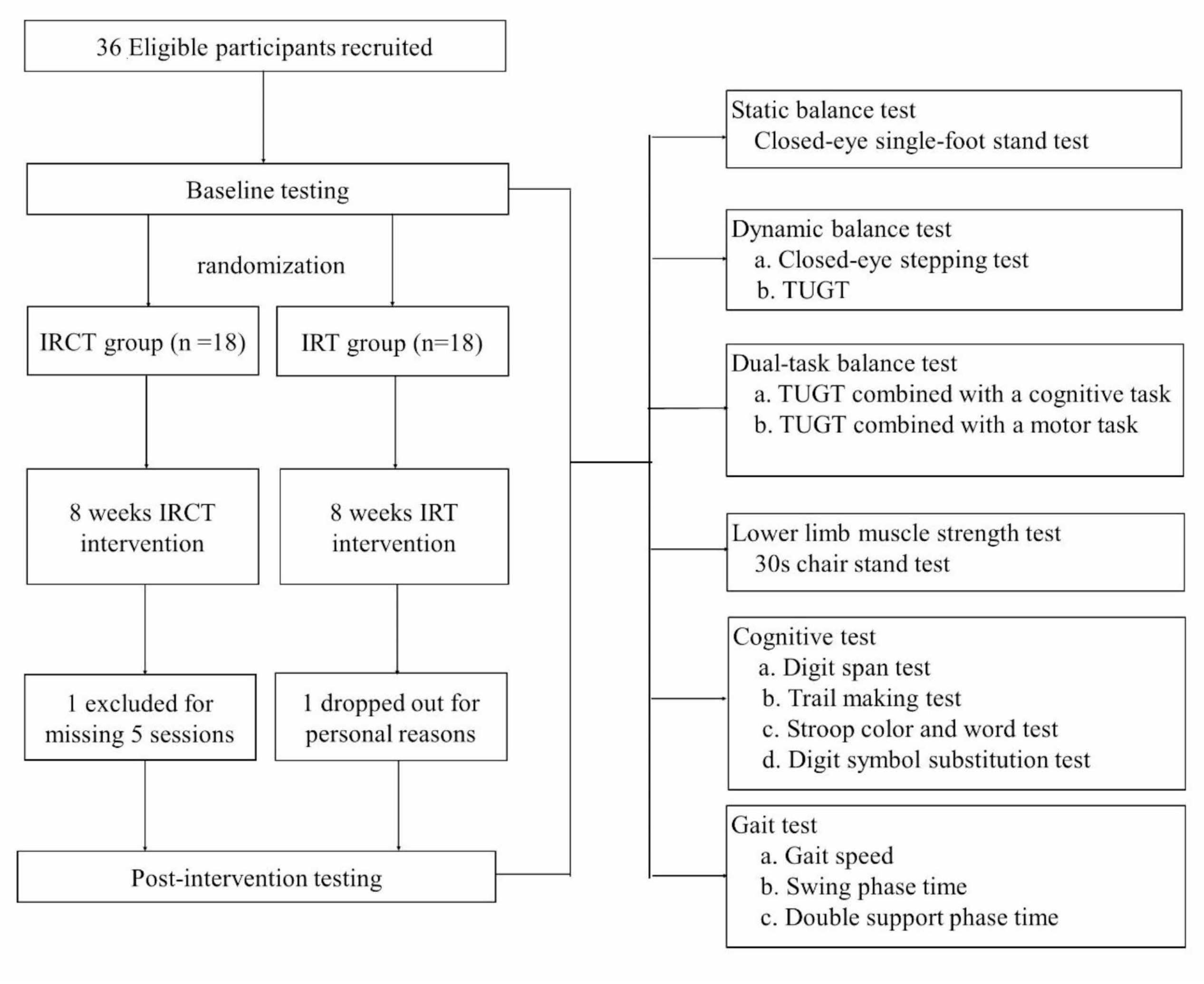

Fig. 1. Participants allocation and experimental design.

resistance training was formulated referencing the experimental designs of Colado et al. (2008) and Eckardt et al. (2016)[14,15]. The plan was dynamically adjusted according to the physical adaptability and training effects of the elderlies. Six types of movements, including hip extension, knee flexion, squatting, heel raise, forward lunge and lateral lunge squat were involved for the resistance training program. Each movement was completed for 2–4 sets, with 10–16 repetitions per set, maintaining each movement for 5 s as required, with 1–2 min of rest between sets. The choice of elastic band used was individually adjusted based on 10-repetition maximum method described by Valdés-Badilla et al.[16]. Participant was evaluated every 2 weeks to determine if the elastic band needs to be changed to the one with the next level of resistance. The training intensity was at a moderate or above-moderate level (OMNI-RES, slightly strenuous 5–8). Hence, the training becomes progressively more challenging, involving 5–8 major muscle groups of the lower limbs per session. As the elderly women mastered the training movements and adapted to the training intensity, the number of sets and repetitions for each training movement gradually increased.

The cognitive training involved two modes: variable tasks and fixed tasks, where a research personnel posed specific questions to the participants. In the fixed-task mode, participants underwent three sets of cognitive tasks—calculation tasks, Clock tasks, and word reverse recall training—in a fixed sequence. Each time, the type of task was announced before the question was posed. For example, in the calculation task, the difficulty progressively increased, beginning with two-digit calculations and advancing to three-digit calculations. The research personnel might ask, “What is 34 minus 5?” After the participant answered, the research personnel would repeat the question and provide the correct answer. In word reverse recall training, the research personnel would randomly present a word or idiom, and the participant had to recall it in reverse order. The complexity increased from simple two-character words to four-character idioms. For instance, if the research personnel said “三心二意”, the participant had to reverse it by saying “意二心三.” After the response, the questioner would repeat the phrase and confirm the correct answer. In the Clock task, participants were trained beforehand to understand the relative positions of the hour and minute hands on a clock. They were then asked to determine if the hands were on the same side of the clock based on a given time. For example, if the research personnel gave a time like "2:30," participants had to decide if the hour and minute hands were on the same side, responding with "yes" or "no." Questions avoided whole or half-hour times. The variable-task mode involved the random questioning of these same three cognitive tasks, but without prior announcement of the task type, thus requiring the participants to stay more mentally flexible and alert. The dual-task nature of the training was designed to improve participants' ability to allocate cognitive resources effectively during physical tasks, promote neuroplasticity, and enhance dual-task performance.

Balance

Single-Foot stand test under single-task conditions (closed-eye) was used to evaluate the static balance capabilities of older adults[17]. Participants are instructed to stand upright with arms placed neutrally at their sides. For safety, one evaluator is positioned adjacent to the participant for support, while another oversees the test, giving instructions and timing the performance. Participants are required to close their eyes and, upon receiving a start signal, lift one foot approximately 10 centimeters off the ground. The evaluators are tasked with ensuring that participants' eyes remain closed and that the lifted foot maintains the correct height and position. The timer is stopped if the lifted foot descends or if the supporting foot shifts. Two trials are conducted, and the best performance (longest time) is recorded. The duration for which the participant maintains balance under these conditions is indicative of their static balance proficiency; longer times suggest superior balance capabilities.

Two tests were used to assess dynamic balance. The first was the closed-eye stepping test using an optical gait testing system (OptoGait, Microgate, Bolzano, Italy)[18]. Participants stand within the designated area of the gait analysis device with eyes closed. A computer-generated beeping sound, set at a frequency of 120 beats per minute, guides the stepping rhythm. Upon the start signal, participants commence stepping for a duration of 30 s. The system calculates the mean deviation of the participant's foot movements. Lower deviation values are indicative of superior dynamic balance abilities. The second test used to assess dynamic balance was the timed up and go test (TUGT)[19]. The testing equipment included a chair with a backrest, a stopwatch, the gait analysis system, and cone-shaped markers. The test initiates with the participant seated in a chair. Participants are instructed to stand up without using the armrests or backrest for assistance and then walk to a marker placed 3 m away. Upon reaching this point, they turn around, ensuring both feet cross the line, and then return to the chair to sit down. Safety precautions are observed throughout the test. The gait analyzer records the time from the moment of the start signal. Two trials are conducted, and the shorter duration is noted. A reduced time in the TUGT correlates with enhanced balance capabilities.

Two tests were performed to assess dual-task balance ability in participants. The first is the TUGT combined with a cognitive task (TUGT-C)[20]. This variation of the TUGT includes a concurrent cognitive challenge, wherein participants perform arithmetic subtraction (starting from 100 and subtracting 3) while completing the physical task. Timing for each trial is recorded, with two attempts made, and the shortest duration noted[21]. The Dual-Task Effect (DTE-C) is calculated using the following formula: DTE = ((dual-task performance - single-task performance) / single-task performance) * 100%. In this context, a shorter completion time indicates better balance performance, thus a larger DTE value signifies greater dual-task demands. The second test is the TUGT combined with a motor task (TUGT-M) test. In this test, participants perform the TUGT while holding a disposable cup filled to 4/5th of its capacity with water, using their dominant hand. The objective is to complete the task without spilling the water. Timing for the task is recorded, with the procedure repeated twice and the shortest duration selected. The Motor Dual-Task Effect (DTE-M) is computed in a manner similar to DTE-C[22].

Cognitive function tests

The digit span test (DST) is a vital tool for assessing short-term memory capabilities in older adults. The test begins with the tester verbalizing a sequence of numbers, starting with two digits. The participant is required to repeat these numbers. The sequence length increases progressively upon each correct response. The test includes three variations: forward digit repetition, backward digit repetition, and numerical sorting tasks. The maximum number of digits that a participant can accurately repeat in each category is recorded. The aggregate of these numbers across all three tasks constitutes the participant's digit span. A larger digit span indicates stronger short-term memory abilities in the elderly[21].

Trail making test (TMT) was used to evaluate attentional capabilities in the elderly. Participants are presented with a sequence of numbers (1–25) on an A4 sheet. They are instructed to connect these numbers sequentially (i.e., 1 to 2 to 3, and so forth) until 25. The time taken to complete this task is recorded following the tester's start command. Shorter completion times are indicative of better-focused attention in older adults[21].

Stroop color and word test (Stroop) was used to assess the ability of elderly individuals to resist cognitive interference. An A4 sheet containing 45 Chinese characters, each with a color that may not correspond to its semantic meaning, is used. Participants are instructed to name the color of the word, disregarding its meaning. After an initial practice round with 10 words, the participant undergoes the formal test with 45 words, grouped by 15 words per color. The time taken to name all the colors is recorded, with shorter times indicating stronger interference resistance[23].

Digit symbol substitution test (DSST) was employed to evaluate learning abilities and information processing speed in the elderly. Participants are presented with an A4 sheet, the top of which displays a table correlating digits 1–9 with specific symbols. The lower part of the paper contains rows of random numbers. Participants are tasked with matching each number to its corresponding symbol as quickly as possible within a 90-second timeframe. The total number of correctly matched symbols is counted (errors are disregarded). A higher count reflects better cognitive flexibility[24].

These cognitive function tests are used as they are commonly employed methods for studying cognitive function in elderlies in literature, and they provide a comprehensive assessment of the cognitive functions most relevant to performing dual tasks in everyday life[25–28].

Lower limb muscle strength test

The lower limb muscle strength was evaluated with the 30-Second chair stand test using a chair with a backrest and a stopwatch. Participants sit in the chair with their arms crossed over their chest and without leaning against the backrest. On the tester's command, they repeatedly perform stand-sit actions for 30 s, aiming for speed under safe conditions. The test is conducted twice, and the maximum number of stands achieved in any single trial is recorded[29].

Gait performance

Gait performance was assessed using the gait analysis system in a quiet and bright environment. Markers were placed at the start and end points of the walk. Participant walked at her usual pace for 1 min as preparation before the test starts. During the actual test, participants walked straight for 10 m straight back and forth, and the effective system capture range was 3 m in the middle of the walkway. The test was carried out twice with 1-minute rest given between sets. Abnormal gait data were excluded, and the average values of all gait cycles within the 3-meter testing range in two gait tests were taken for analysis[30]. The parameters evaluated including stride length, gait speed, swing phase time and double support phase time[31]. Gait speed was calculated by dividing the total distance walked by the duration of the walk time (m/s). Swing phase refers to the phase in walking where the foot is continuously not in contact with the ground. It means the period from when the toes of one foot leave the ground to when the heel of the same foot touches down. This phase is essentially from the end of one support phase to the beginning of the next. Support phase is the sum of the time both feet are in support, indicating the phase in walking where the foot is always in contact with the ground.

Statistical analysis

Data processing was conducted using SPSS 27.0 statistical software. All measurement indicators are presented as mean (M) and standard deviation (SD). Normality of the data were checked by the Shapiro-Wilk test, and homogeneity of variance were checked using Levene's test. If all assumptions are met, repeated measures analysis of variance (ANOVA) was employed with Training method as a between-groups variable (IRCT vs. IRT, df = 1) and Time as a within-subjects variable (before vs. after training, df = 1), and added an interaction factor (Training method x Time) to compare changes in each indicator before and after the training intervention. Post-hoc Bonferroni correction was not made for repeated statistical evaluation, as there was only one comparison per dataset. When assumptions are not met, non-parametric tests are used (Mann-Whitney U test for independent comparisons, and Wilcoxon signed-rank test for repeated comparisons). Significance level was set at $p < 0.05$.

Results

Physical characteristics for all participants are shown in Table 1. Independent t-tests showed that none of the measured parameters was significantly different between IRCT and IRT groups at baseline.

Balance performance

For static balance measured by the closed-eye single-leg stand test, no between groups difference was detected for baseline measures ($p = 0.919$). Both groups exhibited improvement following training compared to baseline ($p = 0.001$ and 0.004 for IRCT and IRT, respectively) with no between groups difference ($p = 0.454$, Fig. 2A), according to nonparametric tests. Dynamic balance, assessed through closed-eye stepping and standing-walking tests, demonstrated significant interaction effects between time (baseline vs. post- training) and training method (IRCT vs. IRT) (stepping: F(1, 32) = 35.79, $p < 0.001$, $\eta p^2 = 0.78$, Fig. 2B; standing-walking: F(1, 32) = 5.594, $p = 0.024$, ηp2 = 0.149, Fig. 2C), indicating better performance in the IRCT group post-training. Cognitive dual-task balance ability showed significant improvements in the experimental group post-intervention (F(1, 32) = 24.848, $p < 0.001$, $\eta p^2 = 0.437$ for cognitive dual-task, Fig. 2D). Additionally, results for motor dual-task balance ability also suggested that IRCT group experienced better improvement ($p = 0.812$ for baseline; $p < 0.001$ for post-intervention comparison; $p < 0.001$ for IRCT within group comparison; $p = 0.019$ for IRT within group comparison, Fig. 2E), according to nonparametric tests Table 2.

Cognitive function and lower limb muscle strength

Cognitive function, assessed using DST, TMT, STOOP, and DSST, showed more significant improvements in the IRCT group in TMT and DSST, as indicated by a significant interaction effect (TMT F(1, 32) = 14.91, $p = 0.001$, $\eta p^2 = 0.318$; DSST F(1, 32) = 5.792, $p = 0.022$, $\eta p^2 = 0.153$). Similar improvement was seen in STOOP between two groups ($p = 0.919$ for baseline comparison; $p = 0.182$ for post-intervention comparison; $p < 0.001$ for IRCT within group comparison; $p = 0.007$ for IRT within group comparison) according to nonparametric tests. However, no significant changes were observed in the DST. Leg muscle strength, measured by the 30-second chair stand test, exhibited a significant main effect of time (F(1, 32) = 130.10, $p < 0.001$, $\eta p^2 = 0.803$), indicating increased strength post-intervention, with no significant interaction effect (F(1, 32) = 1.801, $p = 0.189$, $\eta p^2 = 0.053$, Table 3).

Gait performance

Gait performance was analyzed using support and swing phases, gait speed as well as stride length. The analysis revealed a significant main effect of time on the support phase (F(1,32) = 4.496, $p = 0.050$, $\eta p^2 = 0.219$), indicating

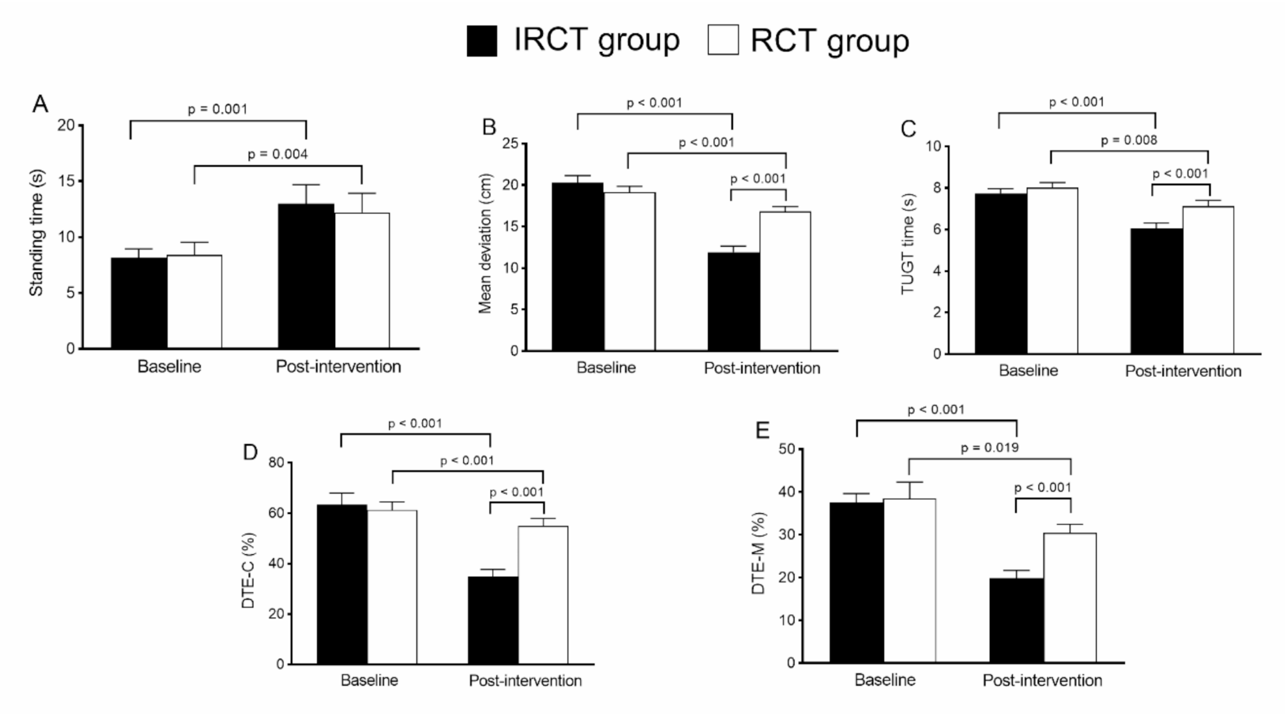

Fig. 2. Results of static, dynamic and dual-task balance. IRCT, instability resistance combined with cognitive training; IRT, instability resistance training only; TUGT, timed up and go test; DTE-C, dual-task effects for TUGT combined with a cognitive test; DTE-M, dual-task effects for TUGT combined with a motor test. (**A**) Static balance results as evaluated using closed-eye single-leg stand test, (**B**) dynamic balance results as evaluated using the 30s closed-eye stepping test, (**C**) dynamic balance results as evaluated using TUGT, (**D**) dual-task balance as evaluated using dual task effect for TUGT combined with a cognitive test, and (**E**) dual-task balance as evaluated using dual-task effect for TUGT combined with a motor test. *Significant difference.

	IRCT (*N*=17)		**IRT (*N*=17)**		***P***		
	Pre-intervention	**Post-intervention**	**Pre-intervention**	**Post-intervention**	**Time**	**groups**	**Interaction**
TMT (s)	38.68 ± 5.60 [35.80, 41.56]	28.88 ± 5.06[a,*] [26.27, 31.48]	37.43 ± 5.46 [34.43, 40.24]	34.48 ± 4.99 [31.91, 37.05]	0.001	0.178	0.001
DSST	32.00 ± 6.12 [28.85, 35.15]	43.23 ± 10.62 [a,*] [37.77, 48.70]	33.41 ± 6.11 [30.27, 36.56]	39.64 ± 9.30 [34.87, 44.43]	0.001	0.053	0.022
DST	12.76 ± 2.80 [11.33, 14.20]	12.94 ± 2.90 [11.45, 14.43]	13.00 ± 1.97 [11.99, 14.01]	13.24 ± 2.10 [12.15, 14.24]	0.171	0.053	0.843
Chair stand-up	24.65 ± 8.20 [20.43, 28.86]	31.35 ± 8.58[a] [26.94, 35.76]	24.82 ± 5.30 [22.20, 27.55]	30.12 ± 5.66 [27.21, 33.03]	0.001	0.825	0.189

Table 2. Results for cognitive and muscle strength performance parameters analyzed with ANOVA. IRCT, integrated instability resistance training and cognitive training group; IRT, instability resistance training only group. Data are presented as Mean ± SD and 95% confidence interval. TMT, Trail making test; DSST, digit symbol substitution test; DST,digit span test. [a]Significant main effect for time. *Significant interaction.

longer support times post-intervention, although the interaction effect was not significant (F(1,32) = 0.444, $p = 0.515$, $\eta p^2 = 0.027$). Similarly for swing phase, there was no baseline between groups difference ($p = 0.061$), however, IRCT groups showed increased swing phase time while IRT group showed decreased swing phase time ($p < 0.001$ and $p = 0.002$ for IRCT and IRT, respectively), according to nonparametric tests. No between group difference was detected post-training ($p = 0.196$). In addition, the stride length test time revealed a significant main effect (F(1,32) = 12.57, $p = 0.001$, $\eta p^2 = 0.295$), with post-hoc tests indicating a significantly longer stride length post-experiment compared to pre-experiment ($p < 0.001$). However, the main effect of group was not significant (F(1,32) = 0.058, $p = 0.811$, $\eta p^2 = 0.526$), and there was no significant interaction between test time and experimental group (F(1,32) = 0.031, $p = 0.861$, $\eta p^2 = 0.141$), implying that the changes in stride length were consistent across different groups (Table 4).

	IRCT (*N* = 17)		IRT (*N* = 17)		*P*		
	Pre-intervention	Post-intervention	Pre-intervention	Post-intervention	Time	groups	Interaction
Mean deviation (cm)	20.21 ± 3.57 [18.44,22.11]	11.91 ± 2.99 ^{a,*} [10.31,13.51]	19.13 ± 2.99 [17.59,20.67]	16.84 ± 2.29 [15.66,18.02]	0.001	0.044	0.001
TUGT(s)	7.77 ± 0.94 [7.25.8.22]	6.04 ± 1.10 ^{a,*} [5.48,6.61]	8.01 ± 1.02 [7.48,8.54]	7.12 ± 1.14 [6.54,7.72]	0.001	0.041	0.024
DTE-C(%)	63.28 ± 24.38 [53.34,73.22]	34.92 ± 11.16 ^{a,*} [32.87,42.03]	61.32 ± 20.70 [54.63,68.01]	54.93 ± 12.30 [30.45,46.53]	0.001	0.048	0.001

Table 3. Results for balance performance parameters analyzed with ANOVA. IRCT, integrated instability resistance training and cognitive training group; IRT, instability resistance training only group. Data are presented as Mean ± SD and 95% confidence interval. TUGT, timed up and go test; DTE-C, dual-task effects for TUGT combined with a cognitive test. ^{a}Significant main effect for time. *Significant interaction.

	IRCT (*N* = 17)		IRT (*N* = 17)		*P*		
	Pre-intervention	Post-intervention	Pre-intervention	Post-intervention	Time	Groups	Interaction
Stride length (cm)	58.20 ± 4.68 [55.71, 60.70]	61.12 ± 4.39^{a} [58.78, 63.46]	58.23 ± 5.21 [55.45, 61.01]	60.09 ± 4.73 [57.57, 62.61]	0.018	0.811	0.861
Support phase (s)	0.41 ± 0.03 [0.39, 0.43]	0.36 ± 0.02^{a} [0.35, 0.37]	0.40 ± 0.03 [0.38, 0.42]	0.36 ± 0.02 [0.35, 0.36]	0.050	0.343	0.515
Gait speed (m/s)	1.15 ± 0.09 [1.10, 1.19]	1.20 ± 0.14^{a} [1.12, 1.28]	1.15 ± 0.14 [1.06, 1.22]	1.19 ± 0.16 [1.11, 1.28]	0.042	0.908	0.876

Table 4. Results for gait parameters analyzed with ANOVA. IRCT, integrated instability resistance training and cognitive training group; IRT, instability resistance training only group. Data are presented as Mean ± SD and 95% confidence interval. ^{a}Significant main effect for time.

Discussion

The primary objective of this study was to investigate the effects of integrated instability resistance training combined with cognitive training (IRCT) versus isolated instability resistance training (IRT) on balance, gait, muscle strength, and cognitive functions in elderly women. The main findings indicate that while both training modalities improved walking abilities and leg muscle strength, the IRCT group experienced significantly greater enhancements in dual-task balance abilities and certain cognitive functions, particularly in attention and cognitive flexibility. This suggests that adding cognitive exercises to physical training can more effectively address the complex challenges associated with aging. Specifically, this combined approach seems to significantly enhance balance and cognitive skills, which are vital for decreasing the likelihood of falls and enhancing the overall well-being of older adults.

The most important finding of the current study is the more pronounced improvement in dual-task balance abilities in the IRCT group compared to IRT group, which suggests a synergistic effect of combining cognitive and physical training and is consistent with results from previous research[32,33]. This synergy likely stems from the enhanced neuroplasticity facilitated by the concurrent cognitive and motor challenges. Such neuroplastic changes are crucial for the elderly, as they contribute to the maintenance and improvement of motor and cognitive functions[34]. It's possible that cognitive challenges during physical tasks may stimulate the formation of new neural connections, improving the integration of sensory and motor processes essential for maintaining balance, which is an area that worth further exploration. This is substantiated by a recent study which indicate that combining traditional balance training with virtual reality could significantly improve balance ability in older men[35]. Furthermore, the cognitive aspect of the IRCT likely enhances proprioceptive feedback and motor control. The integration of cognitive tasks with physical exercises requires the participant to process multiple streams of information simultaneously, potentially leading to improved allocation of attentional resources and more effective response to balance-related tasks[33,36]. When engaging in dual-task training, the cognitive tasks occupy more attentional focus, which takes up resources originally used for balance control, affecting the body's ability to maintain balance. The participant must complete the cognitive task while resisting disturbances to maintain bodily stability, which reduces the attention allocated to the motor task. Prolonged dual-task training improves the elderly's ability to allocate cognitive resources. Simultaneously, the training can reduce the cognitive consumption required to complete the same task, thereby further enhancing the elderly's ability to perform dual tasks[37]. IRCT also yielded better dynamic but not static balance improvement compared to IRT only, which is likely through similar mechanisms. This improved cognitive processing and hence the balance could potentially contribute to a reduced risk of falls, especially in a dynamic or multi-tasking environment in this population.

Findings from this study demonstrate that both training methods effectively enhanced attention distribution, cognitive flexibility, and anti-interference ability. However, the IRCT exhibited a more substantial impact, especially in improving attention allocation and cognitive flexibility, suggesting its superiority over IRT. This enhanced effectiveness of IRCT is likely attributed to its dual-task nature, combining cognitive and physical exercises. This approach not only reorganizes attention distribution strategies but also accelerates the switching speed between multiple tasks, thereby refining cognitive agility[38,39]. Furthermore, IRCT showed a selective impact on cognitive function tests, enhancing certain cognitive aspects while not significantly improving short-term memory. The observed improvements in attention and cognitive flexibility may be attributed to the neuroplastic changes induced by the dual-task training, which likely stimulates the formation and strengthening of neural connections in brain regions responsible for executive functions and attentional control[40]. These findings align with previous research demonstrating the cognitive benefits of combined physical and cognitive training, particularly in enhancing domains crucial for multitasking and quick decision-making[41]. Clinically, these improvements are significant as they can enhance daily functioning and reduce the risk of cognitive decline in elderly populations. However, the absence of significant improvements in short-term memory suggests that the effects of such training may be domain-specific, possibly due to the nature of the cognitive tasks used. This selective effect indicates that while IRCT effectively targets specific cognitive domains, its influence varies across different cognitive functions[42]. The findings underscore the benefits of integrating cognitive exercises with physical training, particularly emphasizing dual-task training's role in improving cognitive functions in elderly women, as supported by a recent systematic review[43].

The improvement seen in walking abilities within both groups correspond with the well-documented advantages of resistance training in boosting muscle functionality and coordination, which are essential elements for proficient walking[44,45]. This is also partially substantiated by the similar strength improvement in both groups in the current study, which suggest that the primary driver of muscle strength enhancement is the physical training component. These findings are clinically relevant as they suggest that the training can lead to meaningful enhancements in gait stability and efficiency, which are crucial for reducing fall risk and improving mobility in elderly women. Improved gait performance can contribute directly to better functional independence and quality of life, making it an important outcome of this study. On the other hand, the outcome suggests that the cognitive component of the training may play a lesser role in the biomechanical changes to walking improvement. However, the cognitive load imposed by the dual-task training might still have implications for gait safety and efficiency, especially in more challenging walking environments. For instance, navigating uneven terrain or multitasking while walking could be better managed with the cognitive flexibility and attentional distribution skills honed through IRCT. Unfortunately, the gait analysis system utilized in the current study do not possess the capability of assessing gait under such circumstances. Future studies should consider incorporating more sensitive gait analysis tools to fully capture the impact of interventions on gait performance, especially in complicated environment.

Our research outcomes carry important implications for creating exercise programs tailored for older adults, especially those focusing on lowering the risk of falls and enhancing life quality. We demonstrated the feasibility of performing IRCT method in older women, which is an area that has been scarcely explored. The fact that IRCT yielded better results in balance and cognitive function than IRT alone suggests that elderly exercise routines would benefit significantly from integrating cognitive exercise. The practical implications of these findings are significant. The results suggest that incorporating cognitive elements into physical training programs could lead to more effective fall prevention strategies, especially in populations at high risk, such as elderly women. Health practitioners and exercise professionals can use these insights to design more holistic exercise programs that not only improve physical strength and balance but also enhance cognitive flexibility and attentional control. This approach could ultimately contribute to reducing fall rates, improving functional independence, and enhancing the overall quality of life for the elderly. Future studies should examine the enduring impacts of such combined training and assess its effectiveness across a diverse range of individuals, including men and those with varying initial levels of physical and cognitive abilities. Investigating which specific cognitive tasks and their intensity levels pair best with physical exercises could lead to more customized and efficient training plans for different groups of older adults. Additionally, it's crucial to explore how such combined training can counteract the decline in physical and cognitive faculties commonly associated with aging. Understanding how cognitive exercises influence physical performance, and the other way around, could shed light on the aging process and inform broader health strategies, including diet and lifestyle adjustments. Furthermore, the role of neuroinflammation, neurotrophic factors, and other biochemical changes in facilitating the improvements seen in IRCT should be considered in future studies. Previous studies suggest that physical exercise influences levels of brain-derived neurotrophic factor (BDNF), vital for brain adaptability and cognitive health[46]. Introducing cognitive challenges may further influence these biochemical pathways, amplifying their positive effects, which is an area the worth further exploration.

There are strengths of the study that should be mentioned. First is the comprehensive, multifaceted assessment tools employed, which enable a thorough evaluation of various aspects of balance, gait, muscle strength, and cognitive functions. This approach provides a detailed understanding of how the integrated training affects different dimensions of physical and cognitive performance, allowing for more nuanced insights into the intervention's effectiveness. Second, the exclusive inclusion of female participants allows the study to specifically address the unique physiological and functional challenges faced by elderly women, who are at a higher risk of falls. This focus provides targeted insights that can inform the development of gender-specific fall prevention programs.

While our study provides valuable insights, it is important to acknowledge several limitations. Firstly, the small sample size and focus on elderly women limit the generalizability of our findings to a broader population. The specific nature of the cognitive tasks used in the IRCT group may have influenced the results, therefore different cognitive exercises might yield varied outcomes. Future studies should consider recruiting a larger and more diverse sample to confirm these findings across broader populations. A larger sample size would enhance the study's external validity, allowing for a more comprehensive understanding of the intervention's effectiveness and allow for more detailed subgroup analyses, which could further elucidate the differential impacts of the training modalities based on individual characteristics such as age, baseline fitness level, or cognitive status. For example, the study participants were all cognitively healthy, which means that the findings may not fully extend to individuals with cognitive impairments, who might respond differently to the interventions. Future research should aim to replicate this study in individuals with varying levels of cognitive function, to determine whether the observed benefits of dual-task training can be generalized more broadly. Furthermore, the study's duration may not fully capture the long-term effects of the training, and the measures used to assess balance and cognitive functions might not encompass all aspects relevant to fall risk. Additionally, assessment performed after a period of time following intervention cessation could be informative regarding the long-term effects of the interventions Another limitation is the absence of a follow-up period to evaluate the retention of the training benefits. Long-term retention of improved balance and cognitive functions is critical for sustained fall prevention, and future studies should include longitudinal tracking to assess this aspect. Additionally, environmental cognitive factors that could affect balance, such as varying terrain and lighting conditions, were not accounted for in the study. Real-world scenarios often present more challenging conditions for balance, and future research should consider incorporating these factors to enhance the ecological validity of the findings. Lastly, the study did not control for other potential variables that could influence balance and cognitive functions, such as participants' nutritional status, or metabolic health. These factors can significantly impact the efficacy of the training program and should be considered in future research.

Conclusions

Our study highlights the benefits of combining physical and cognitive training for improving balance, walking abilities and cognitive functions in older women. This comprehensive training approach has the potential to significantly boost the health and well-being of the elderly. Future research should explore the long-term effects of such combined interventions and examine their applicability across different populations, including elderly men and those with varying baseline cognitive and physical abilities. Fall prevention programs should consider incorporating dual-task training to better address the complex challenges faced by elderly individuals in real-world scenarios. Future studies could also investigate the optimal intensity and types of cognitive tasks that best complement physical exercises for different subgroups within the elderly population.

Data availability

Data of this study are available upon contacting the corresponding author.

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Author contributions

YW was responsible for conception and design of study, data acquisition, analysis and interpretation of data, drafting and revising the manuscript. CZ was responsible for interpretation of data, drafting and revising the manuscript. BW was responsible for data analysis, drafting and revising the manuscript. DZ was responsible for data acquisition, analysis and interpretation of data. XS was responsible for conception and design of study, analysis and interpretation of data, drafting and revising the manuscript. All authors read and approved the final version.

Declarations

Competing interests

The authors declare that they have no competing interests.

Additional information

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