Clinical Interventions in Aging

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CLINICAL TRIAL REPORT

Incorporated vs Additional Dual-Task Training in Community-Dwelling Older Adults

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Background: Aging involves declines in cognitive and physical functions, raising risks of falls, loss of independence, and poorer quality of life. Dual-task training, integrating cognitive and motor activities, has shown benefits, but direct comparisons of additional dual-task training (ADT), which embeds cognitive demands within motor tasks, and incorporated dual-task training (IDT), which requires concurrent yet independent cognitive tasks, are limited.

Purpose: This study compared the effects of ADT and IDT on cognitive function, physical performance, instrumental activities of daily living (IADL), and quality of life in community-dwelling older adults.

Patients and Methods: Seventy-four participants (≥60 years) were randomized to ADT (n = 34) or IDT (n = 40) and completed a 12-week group program. Cognitive outcomes were measured with the Montreal Cognitive Assessment, Digit Symbol Substitution Test, Wechsler Memory Scale-III Word List, and Stroop Color Word Test; motor outcomes with the Box and Block Test, Timed Up and Go, and dual-task indices (BBT-SST, BBT-FD); functional outcomes with the Lawton IADL and Community Integration Questionnaire (CIQ).

Results: A significant group × time effect was found for BBT-SST number scores (p =0.002), with IDT yielding greater dual-task cognitive gains. Both groups improved in global cognition, processing speed, and working memory, while only IDT enhanced motor performance and motor-cognitive coordination. No significant changes were observed in TUG, dual-task cost, IADL, or CIQ.

Conclusion: IDT showed superior benefits for dual-task cognition and coordination, suggesting greater ecological validity, more efficient resource allocation, and closer alignment with real-world demands. Future studies should investigate electroencephalography (EEG) based neural mechanisms and develop VR approaches for at-risk older adults.

Keywords: incorporated dual-task training, additional dual-task training, cognitive function, motor performance

Introduction

Aging is characterized by a wide range of physical and cognitive declines, which markedly increase the risk of falls and cognitive impairment. These changes substantially compromise the independence and overall quality of life of older adults.[1] Given the rising prevalence of cognitive deterioration and functional limitations in aging populations worldwide, there is an urgent need for effective interventions that simultaneously target both cognitive and physical domains. Such integrative approaches are essential for maintaining functional autonomy and improving well-being in older individuals.[2,3]

Motor-cognitive training, which combines physical activity with cognitive training, can be classified into sequential and simultaneous approaches. In sequential motor-cognitive training, physical and cognitive tasks are performed separately, while in simultaneous motor-cognitive training, they are carried out concurrently—commonly referred to as dual-task training.[4] Although both approaches have been shown to improve physical and cognitive functions in community-dwelling older adults,[5,6] systematic reviews suggest that simultaneous training may be more effective than

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sequential training or physical exercise alone in enhancing cognitive outcomes in both healthy and cognitively impaired older adults.[6,7]

Dual-task training is particularly relevant because many daily activities—such as walking while conversing or navigating a store while planning purchases—require the concurrent use of cognitive and motor skills. Training under such conditions has been shown to improve key cognitive functions, including global cognition, executive function, attention, inhibitory control, and processing speed. Simultaneously, it enhances physical outcomes such as gait and balance, contributing to fall prevention and better quality of life.[8,9] Moreover, these benefits have also been observed in populations with neurological conditions, such as Parkinson's disease and stroke.[10,11] These benefits are thought to be partly attributable to neuroplasticity mechanisms, as dual-task training induces adaptive structural and functional brain changes that facilitate more efficient cognitive–motor integration and support healthier aging.[7,12]

According to the nature of the cognitive demands, simultaneous motor-cognitive training can be further classified into two distinct forms: additional dual-task training and incorporated dual-task training.[4] In additional dual-task training, often described as "thinking while moving," a cognitively demanding task is added that is unrelated to the motor task—typically acting as a distractor. Examples include walking while solving math problems, stepping while memorizing words, or cycling while playing a maze game. Studies have shown that this form of training can significantly enhance executive function, attention, memory, processing speed, and global cognition.[8] Additionally, when resistance training is combined with cognitive tasks, it can provide comparable physical benefits to resistance training alone, while also yielding superior cognitive outcomes, possibly supported by neuroplastic adaptations such as increased brain-derived neurotrophic factor (BDNF) and enhanced activation of cognitive control networks.[7,12] Improvements in cognitive performance and quality of life have also been reported in older women following additional dual-task interventions.[13]

In contrast, incorporated dual-task training, or "moving while thinking," embeds the cognitive task within the structure of the motor activity in a way that is essential for its successful completion. Examples include dancing, practicing Tai Chi, or navigating a traditional market while mentally comparing prices or remembering shopping items. These tasks are ecologically valid, closely mimicking real-world cognitive-motor demands.[4] Incorporated dual-task activities often require the integration of memory, spatial awareness, and precise motor coordination. Interventions involving such activities have been shown to enhance functional connectivity in key brain networks and improve both cognitive and physical performance, suggesting that such motor-cognitive integration may further promote neuroplastic adaptations by strengthening links between cognitive and motor systems.[14] For instance, Tai Chi has been found to improve memory more effectively than brisk walking,[15] while dance-based video games can enhance foot placement and walking ability under dual-task conditions.[16] Additionally, these types of interventions have demonstrated benefits in quality of life and physical functioning.[17,18] Emerging technologies such as exergames and virtual reality (VR)-based training, which integrate cognitive and motor tasks in immersive settings, further support the feasibility and effectiveness of incorporated dual-task training in older adults.[19,20]

Both additional and incorporated dual-task training have demonstrated beneficial effects on cognitive and physical functions in older adults.[4,8] However, differences in cognitive demands may lead to varying implications for real-world applicability, while clear evidence confirming distinct underlying mechanisms between the two forms is still lacking.[4,21] In additional dual-task training, ie., thinking while moving, the cognitive task serves as a distractor, which can interfere with motor performance—even in relatively automatic activities such as walking.[21] By contrast, incorporated dual-task training, ie., moving while thinking, embeds cognitive demands within the motor task itself, thereby reducing competition for attentional resources and minimizing task interference.[4] This integral cognitive-motor interaction may be more meaningful and relevant to daily activities, enhancing motivation and adherence. Furthermore, when cognitive tasks are embedded within functionally relevant contexts—for example, incorporating spatial memory into activities targeting visuospatial deficits—interventions may yield stronger benefits. From a neuroscientific perspective, different cognitive demands may recruit partially distinct neural pathways or resources, although clear evidence confirming mechanistic differences between the two training forms is lacking. Taken together, dual-task training represents a promising approach for promoting neuroplasticity through the integration of physical and cognitive challenges, although the precise mechanisms remain to be fully elucidated.[22]

Previous research has emphasized the general effectiveness of dual-task training, yet direct comparisons between additional and incorporated dual-task modalities remain scarce. Only a few studies, such as those involving dance-based video games, suggest that incorporated approaches may yield superior and longer-lasting improvements in executive functions and global cognition compared to additional tasks.[23,24] Despite the increasing recognition of these training forms, most studies have focused on comparing sequential versus simultaneous training, without addressing the distinctions within simultaneous paradigms. This represents a critical gap in the literature, limiting our understanding of which dual-task format offers greater cognitive and functional benefits for older adults. Although dual-task training has been shown to improve cognitive and physical functions, evidence of its transfer to daily activities and social participation is scarce; these domains were therefore included to determine its broader functional relevance to aging.

The present study aims to compare the effects of incorporated versus additional dual-task training on cognitive, physical, daily function, and social integration in community-dwelling older adults. By systematically contrasting these two training modalities under matched conditions, the study seeks to identify the relative advantages of integrated versus non-integrated cognitive-motor task designs, and to inform the development of effective and functionally relevant interventions for cognitive aging. We hypothesized that incorporated dual-task training would yield greater improvements in cognitive, physical, daily function, and social integration compared to additional dual-task training These superior effects were expected to arise from the inherent features of incorporated dual-task training, including reduced dual-task interference, greater contextual relevance to daily life activities, and enhanced neurocognitive engagement driven by the integration of cognitive demands within motor tasks.

Material and Methods

Participants

The study protocol for this intervention was approved by the local institutional review board and registered at ClinicalTrials.gov (Identifier: NCT04689776, 29/12/2020).

The inclusion criteria were (1) age ≥ 60 years, (2) the ability to follow instructions (≥20 points on the Mini-Mental State Examination), (3) > 20 points on the Montreal Cognitive Assessment (MoCA), (4) no difficulty with basic activities of daily living, and (5) no diagnosis with dementia by a neurologist. Individuals with self-reported diagnoses of neurological disorders or unstable medical conditions (eg., recent myocardial infarction, heart failure, recent heart surgery, or severe asthma) were excluded from this study.

Procedure

All participants were recruited from local community facilities and elderly day care centers. After participants provided written informed consent, they participated in intervention programs and completed measures before and after programs. Research assistants were responsible for all measures in this study. To minimize potential confounding effect, the pre- and post- measurement of the participants were implemented by the same assistant. Cluster randomization was applied to minimize potential contamination, with clusters defined as local community facilities and elderly day-care centers. A research assistant employed a freely available online randomization tool (http://www.randomizer.org/) to generate site-stratified random tables which were used to determine group allocation for newly enrolled participants. Using a 1:1 allocation ratio, eight clusters (a total of 83 participants) were randomly assigned to one of two training programs: additional dual-task training (ADT) or incorporated dual-task training (IDT). Due to variations in cluster size, the number of participants in each group was not equal after randomization. The research assistant subsequently informed the therapists of the group assignments to administer the respective interventions. During the study, 9 participants withdrew, leaving 74 participants who completed all training sessions (Figure 1).

Interventions

The intervention program spanned 12 weeks, with one session per week, each lasting 120 minutes and delivered in a group-based format. Each session commenced with 15 minutes of motor exercise, followed by 15 minutes of cognitive

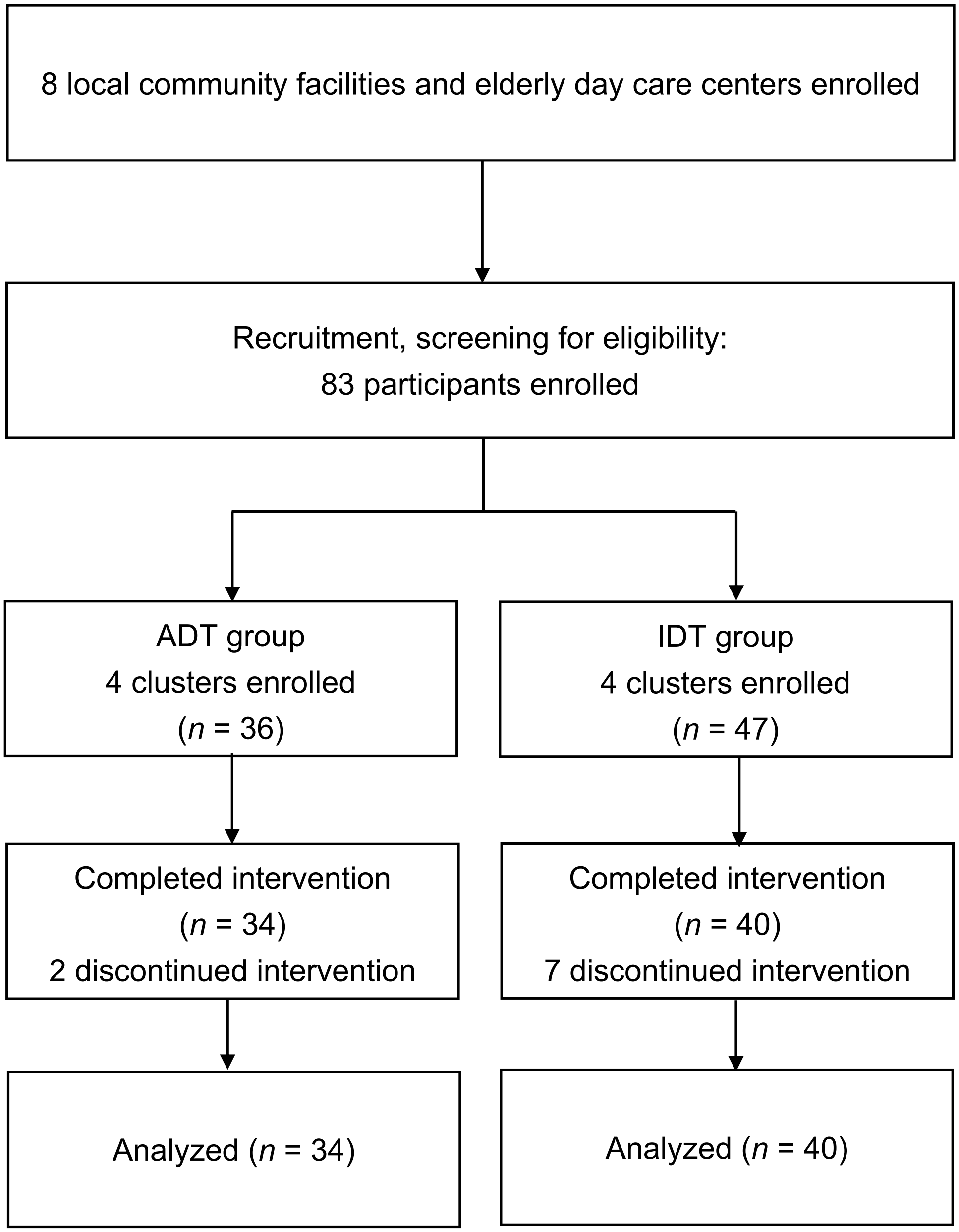

Figure 1 Flowchart of participants.
Abbreviations: ADT, additional dual-task training; IDT, incorporated dual-task training.

task practice, and subsequently 90 minutes of simultaneous motor-cognitive training. The study comprised two groups: the additional dual-task training group (ADT) and the incorporated dual-task training group (IDT).

In the ADT group, the cognitive task was performed concurrently but independently from the motor task, functioning as a distractor rather than a necessary prerequisite for task completion. Examples included performing lower limb strength exercises while solving arithmetic problems or reciting memorized items while stepping. Conversely, in the IDT group, the cognitive task was integrated within the motor task and was essential for successful completion of the combined motor-cognitive activity. Examples included memorizing and executing movement sequences akin to dancing or completing ladder stepping patterns in a predetermined order.

Every training session was led and supervised by a qualified occupational therapist. Program instructors received specific training on the dual-task intervention, which consisted of both theoretical lectures and practical workshops, to ensure the quality and fidelity of the intervention.

The motor training component included stretching, aerobic exercise, strength training, and balance exercises. Exercise intensity was gradually increased to a moderate level (50–70% of participants' maximum heart rate) using low-impact modalities to minimize injury risk and was adjusted according to individual physical condition throughout the intervention. Warm-up and cool-down periods involved whole-body muscle stretching. Aerobic exercises consisted of walking, marching in place, high knee lifts, kicking motions, leg curls, touchdown steps, and box steps, combining upper and lower limb movements to produce rhythmic and repetitive patterns. Strength training comprised squats, lunges, chair sit-to-stands, weightlifting using water-filled bottles, farmer's walks, and elastic band exercises targeting both upper and lower limbs. Balance exercises included single-leg stands, heel-to-toe walking, ball kicking, and cross-stepping.

The cognitive training targeted domains such as attention, language, memory, calculation, and processing speed. Each session incorporated one or more cognitive domains. Attention tasks involved responding to visual or auditory cues, spotting differences in quantity, size, color, direction, or shape, and identifying specific objects within cluttered environments. Language tasks included naming fruits, animals, and vegetables, playing word solitaire, engaging in word association, constructing sentences, spelling, reading, and picture-based storytelling. Calculation tasks required solving arithmetic problems or calculating shopping list costs. Processing speed activities involved timely responses to questions, such as number comparisons. Memory tasks focused on recalling numbers, symbols, words, or daily items after presentation, as well as remembering spatial locations, shopping lists, or informational content from brochures and images.

Outcome Measures

The participants were assessed before and immediately after the training programs. According to previous study shows that exercise and cognitive training could improve cognition, physical performance, mood, quality of life and IADL function.[3,8,13] We used reliable and valid assessments, including the Montreal Cognitive Assessment (MoCA), Digit Symbol Substitution Test (DSST) of the Wechsler Adult Intelligence Scale (WAIS), Word List (WL) of the Wechsler Memory Scale–third edition (WMS-III), and the Stroop Color Word Test (SCWT), to assess cognition in older adults. Time up and Go (TUG) to access the mobility and balance. The Geriatric Depression Scale (GDS) is used to assess the mood status of older adults. The Lawton Instrumental Activities of Daily Living (IADL), to assess the ADL function. The Community Integration Questionnaire (CIQ), to assess the level of social participation. In the current study, we designed two dual tasks for evaluated the dual tasks performance.

Montreal Cognitive Assessment (MoCA)

The MoCA is a sensitive and validated tool to evaluate individual's global cognition and detecting the cognition change.[25] In this study, we used a certified Chinese paper version (MoCA-T) with well reliability and validity.[26] It consists of 12 items that assess the orientation to time and place, executive functions, visuospatial abilities, language, short-term memory, attention, concentration and working memory. The total score is 30 points, and higher scores represent better global cognitive function. Individual education level is taken into account, 12 or less of education years were added one more score.

Digit Symbol Substitution Test (DSST)

The DSST, a subtest of Wechsler Adult Intelligence Scale (WAIS), was used to assess information processing speed. It is sensitive to detect cognitive impairment and changes in cognitive function.[27] Participants are required to match symbols to corresponding numbers and copy the symbols into designated spaces within 120 seconds. The DSST score is the total number of correct symbols, with higher scores indicating better information processing speed. The DSST demonstrates excellent test-retest reliability ($r = 0.89$) and good concurrent validity with other cognitive processing measures.[27]

Word List (WL)

The Word List (WL) subtest from the Chinese version of the Wechsler Memory Scale–Third Edition (WMS-III) is a standardized and reliable measure of working memory.[28] This study utilized WL Part I (WL-I), where participants are verbally presented with a list of 12 unrelated words over four trials and asked to recall the words immediately after each trial. Raw scores represent the total number of correct recalls across trials and are converted into age-adjusted scaled scores. Higher scores reflect better memory performance. The WL-WMS has demonstrated strong internal consistency (Cronbach's alpha > 0.80) and high construct validity across diverse populations.[28]

Stroop Color Word Test (SCWT)

The Stroop Color and Word Test (SCWT) was used to examine inhibitory control (MacLeod, 1991).[29] The primary measure used was the time difference (in seconds) between the congruent and incongruent conditions. Smaller differences indicate better inhibitory control. The Stroop test has shown high test-retest reliability (ranging between 0.70 and 0.91) and convergent validity with other executive function measures.[29]

Timed Up and Go (TUG)

The TUG is a widely used screening tool to assess mobility and balance in community-dwelling older adults and to identify individuals at risk of falling.[30] Faster completion times indicate better functional mobility. The TUG demonstrates excellent inter-rater and test-retest reliability (ICC > 0.90) and good predictive validity regarding fall risk.[30]

Community Integration Questionnaire (CIQ)

The CIQ assesses individuals' integration into social networks and engagement in productive activities such as employment, education, or volunteer work.[31] Higher scores indicate great level of social integration. It has shown good internal consistency (Cronbach's alpha approximately 0.70–0.80) and acceptable construct validity.[31]

Lawton Instrumental Activities of Daily Living (Lawton IADL)

The Lawton IADL Scale is a valid tool designed to evaluate the ability to perform tasks and detect early functional decline. It is a reliable and valid tool commonly used for evaluating older adults with cognitive impairment.[32] The scale measures tasks such as using a telephone, shopping, food preparation, housekeeping, laundry, transportation, medication management, and financial management. Higher scores indicate greater independence in IADLs.

Geriatric Depression Scale (GDS)

The Geriatric Depression Scale (GDS), originally developed in 1988,[33] has been extensively validated and widely applied among older populations. It is regarded as a sensitive and specific instrument for detecting depressive symptoms. In the present study, the short form of the GDS was employed. Both the long and short forms have been shown to effectively differentiate between depressed and non-depressed adults, with a strong correlation reported (r =0.84, p <0.001).[34] Higher scores indicate more depressive mood.

Box and Block Test (BBT)

The Box and Block Test (BBT) assesses gross manual dexterity.[35] Participants move wooden blocks from one box compartment to another within 60 seconds. The number of blocks that are moved from one compartment to another compartment is recorded. The more blocks means the better gross manual dexterity. The BBT shows excellent test-retest reliability (ICC = 0.95) and strong validity for manual dexterity evaluation in older adults and clinical populations.[35,36]

Serial Sevens Test (SST)

The Serial Sevens Test (SST) evaluates working memory via serial subtraction by sevens.[37] Correct and incorrect responses to SST are recorded, and the corrected number which is the difference between correct and incorrect responses is calculated. The more corrected numbers means the better working memory. While specific reliability data is limited, SST performance correlates moderately to strongly with other working memory and attention tasks, suggesting acceptable construct validity.[37]

Frequency Discrimination (FD)

The frequency discrimination (FD) assesses sustained attention by requiring participants to distinguish between high and low auditory pitches.[38,39] Participants discriminated between high (1000 Hz) and low (500 Hz) pitches and reported their answers in 18 trials conducted in 60 seconds. There was a total of 18 trials conducted in 60s. Specifically, there were nine trials each for high- and low-pitch sounds, presented in random order with intervals of 1 to 4 seconds. Correct and incorrect responses to FD are recorded, and the corrected number which is the difference between correct and incorrect responses is calculated. Higher scores indicate better sustained attention. The task shows acceptable test-retest reliability and construct validity within auditory attention paradigms.[38]

Dual-Tasks

We designed two dual tasks for current study: (1) Serial Seven Test (SST) and Box and Block Test (BBT); SST and BBT performed concurrently for 60s. Participants moved blocks from one compartment to another, one at a time, while simultaneously performing serial subtraction by sevens, starting from 300. (2) frequency discrimination (FD) and BBT (FD and BBT performed currently for 60s. Participants moved blocks from one compartment to another, one at a time, while simultaneously while identifying and reporting the pitch (high or low) of 18 trials for 60 seconds. These dual-task measures were adopted following the methodology established by Chen et al[40] This study[40] validated the responsiveness and minimal clinically important differences (MCIDs) of these protocols, thereby supporting their use as robust and clinically significant tools for assessing dual-task performance.

Dual Task: Box and Block Test - Serial Sevens Test (BBT-SST)

Participants asked to conduct the BBT and SST concurrently for 60s. Participants moved blocks from one compartment to another, one at a time, while simultaneously performing serial subtraction by sevens, starting from 300.

Dual Task: Box and Block Test - Frequency Discrimination (BBT-FD)

Participants asked to conduct the BBT and FD concurrently for 60s. Participants moved blocks from one compartment to another, one at a time, while simultaneously while identifying and reporting the pitch (high or low) of 18 trials for 60 seconds.

Dual-Task Cost

We use the formula to calculate the dual task cost: single task BBT minus dual-task BBT, divided by single task BBT, and then multiplied by 100. Formula (%) = 100 *(single task BBT – dual task BBT)/single task BBT. It's a commonly used approach to quantify performance change under dual-task conditions.[41] Lower dual-task costs indicate better performance. In this study, dual-task costs were calculated for both SST and FD conditions. The use of the Box and Block Test (BBT) in dual-task paradigms has been reported in previous studies investigating upper extremity cognitive–motor interference.[35,42] Increased costs reflect greater difficulty managing simultaneous tasks.[43]

Statistical Analysis

Baseline variables among the groups were compared with χ^2 and independent *t* test. Mixed ANOVA was applied on the outcome measures to compare the training effects for the two groups, where the within-subject factor was the time (before and after interventions) and the between-subject factor was the two intervention groups. The baseline characteristic variables were treated as covariates if they significantly differed between groups at baseline, and an additional within-subject analysis of covariance was then performed to evaluate effects involving the covariates. The effect size η^2 was calculated to determine the magnitude of interaction and main effects. Effect sizes (η^2) greater than 0.138 are classified as large effects, η^2 values between 0.138 and 0.059 are considered moderate effects, and η^2 values between 0.01 and 0.059 are regarded as small effects.[44] We used the paired *t*-test to determine the difference on change scores within groups between baseline and post-intervention. The significant statistical level was set at 0.05 for all statistical tests. We used the Cohen's d as the effect size to represent the magnitude of changes from baseline to post-intervention. Effect size (Cohen's d) values of 0.2 are commonly interpreted as small effects, values of 0.5 are considered moderate effects and values of 0.8 are considered large effects. The baseline characteristic variables were treated as covariates if they significantly differed between groups at baseline, and an additional within-subject analysis of covariance was then performed to evaluate effects involving the covariates.[45] Data were analyzed using SPSS version 22.

Results

Demographic and Clinical Data at Baseline

Demographic and baseline clinical data for the two groups are presented in Table 1. No significant between-group differences were observed in age, $t(72) = 1.092$, $p = 0.278$, or MMSE scores, $t(72) = -0.211$, $p = 0.833$. However,

Table 1 The Demographic and Clinical Data at Baseline

Variables	**Additional (n=34) ADT** *M (SD)*	**Incorporated (n=40) IDT** *M (SD)*	***p***
Demographic and clinical parameters			
Female, n (%)	33 (1)	32 (8)	
Age, years	74.30 (5.29)	72.72 (6.89)	0.278
Education years	9.26 (3.45)	12.15 (3.75)	0.001
MMSE	27.68 (2.14)	27.78 (1.87)	0.833
Outcome measures			
MoCA	26.12 (2.90)	26.38 (2.68)	0.693
DSST	50.76 (20.76)	59.20 (19.47)	0.076
WL	26.24 (7.91)	29.65 (7.93)	0.069
Stroop	20.27 (10.50)	18.03 (11.41)	0.387
TUG	9.67 (1.50)	10.08 (3.51)	0.513
BBT	63.44 (11.65)	58.28 (9.80)	0.042
BBT-SST	50.00 (15.61)	46.48 (12.10)	0.278
BBT-SST-Number	6.82 (4.66)	8.50 (4.22)	0.109
Cost-SST	21.89 (15.56)	20.34 (15.46)	0.670
BBT-FD	61.35 (12.24)	56.13 (10.92)	0.056
BBT-FD Number	16.50 (2.77)	15.78 (2.29)	0.059
Cost-FD	2.72 (11.86)	3.37 (12.62)	0.822
IADL	30.18 (1.00)	29.80 (3.23)	0.516
CIQ	19.73 (3.98)	18.11 (4.89)	0.128
GDS	2.18 (1.80)	2.35 (2.71)	0.751

Abbreviations: ADT, Additional training group; IDT, Incorporated training group; MoCA, Montreal Cognitive Assessment; DSST, Digit Symbol Substitution Test; WL, Word List Test; Stoop, Stroop Color Word Test, SCWT; TUG, Time up and Go; BBT-SST, BBT performance while dual task of BBT and SST; BBT-SST-Number, the correct numbers of SST while dual task of BBT and SST; Cost-SST, the cost while dual task of BBT and SST; BBT-FD, BBT performance while dual task of BBT and FD; BBT-FD-Number, the correct numbers of SST while dual task of BBT and FD; Cost-FD, the cost while dual task of BBT and FD; IADL, Lawton instrumental activities of daily living scale; CIQ, Community Integration Questionnaire; GDS, Geriatric Depression Scale.

significant differences were found in gender distribution, $\chi^2(1) = 5.006$, $p = 0.025$, education level, $t(72) = -3.424$, $p < 0.001$, and BBT scores, $t(72) = 2.072$, $p = 0.042$. The IDT group had significantly higher educational levels and lower BBT scores compared to the ADT group. Consequently, education level and BBT scores were included as covariates in subsequent analyses using analysis of covariance (ANCOVA).

Tests of regression homogeneity indicated that the relationship between education level and dependent variables did not violate the homogeneity assumption ($p = 0.104$ to 0.767). When BBT was included as a covariate, homogeneity was maintained for variables including MoCA, Stroop, DSST, BBT-SST number, Cost-SST, BBT-FD, and Cost-FD. However, homogeneity was violated for WL ($p = 0.024$), TUG ($p < 0.001$), BBT-SST ($p = 0.024$), BBT-FD number ($p = 0.047$), IADL ($p = 0.033$), and CIQ ($p = 0.017$). Therefore, Welch's test was applied for these variables to accommodate the violation.

Main Effects

Significant main effects of time were found for BBT-SST, *F* (1, 70) = 5.896, *p* = 0.018, η^2=0.078 (Table 2). However, no significant main effects of group were found for any outcome measures.

Table 2 Results of the Two-Way Mixed-Analysis of Covariance

Variable	Time	Group	Time x Group
MoCA			
F (1,70)	0.022	0.171	0.048
p	0.882	0.681	0.528
η^2	0.000	0.002	0.001
DSST			
F (1,70)	0.683	1.090	0.077
p	0.411	0.300	0.782
η^2	0.010	0.015	0.001
WL			
F (1,70)	0.033	1.513	0.016
p	0.857	0.223	0.901
η^2	0.000	0.021	0.000
Stroop			
F (1,70)	0.172	0.081	0.238
p	0.679	0.777	0.627
η^2	0.002	0.001	0.003
TUG			
F (1,70)	0.518	0.002	2.089
p	0.474	0.964	0.153
η^2	0.007	0.000	0.029
BBT-SST			
F (1,70)	5.896	0.341	0.007
p	0.018	0.561	0.936
η^2	0.078	0.005	0.000
BBT-SST-Number			
F (1,70)	0.315	2.148	4.552
p	0.576	0.147	0.036
η^2	0.004	0.030	0.061

(*Continued*)

Table 2 (Continued).

Variable	Time	Group	Time x Group
Cost-SST			
F (1,70)	1.319	0.119	0.614
p	0.255	0.731	0.436
η^2	0.018	0.002	0.009
BBT-FD			
F (1,70)	3.683	0.190	0.095
p	0.059	0.664	0.759
η^2	0.050	0.003	0.001
BBT-FD-Number			
F (1,70)	1.018	1.535	0.694
p	0.316	0.219	0.408
η^2	0.014	0.021	0.010
Cost-FD			
F (1,70)	0.105	1.220	0.249
p	0.746	0.271	0.619
η^2	0.002	0.017	0.004
IADL			
F (1,70)	0.001	1.021	1.387
p	0.978	0.316	0.243
η^2	0.000	0.014	0.019
CIQ			
F (1,70)	0.001	0.615	3.931
p	0.974	0.436	0.051
η^2	0.000	0.009	0.053
GDS			
F (1,70)	0.306	0.359	3.633
p	0.582	0.551	0.061
η^2	0.004	0.005	0.049

Interaction Effects

A significant group-by-time interaction was observed for BBT-SST number score, Welch F (1, 70.047) = 10.0725, $p = 0.002$, $\eta^2 = 0.061$. Post hoc analyses revealed significant improvements from pre- to post-training in the IDT group, $t(39) = -2.790$, $p = 0.008$, but not in the ADT group, $t(33) = -0.410$, $p = 0.685$. Both groups demonstrated significant improvement from pre- to post-training in MoCA (ADT: $t(33) = -3.316$, $p = 0.002$, $d = 0.407$, 95% CI: −1.85 – −0.44; IDT: $t(39) = -3.509$, $p = 0.001$, $d = 0.451$, 95% CI: −1.89 – −0.51), DSST (ADT: $t(33) = -2.159$, $p = 0.038$, $d = 0.119$,

Table 3 Results of the Within-Group Differences

	ADT (n=34)				**IDT (n=40)**			
	M (SD)				***M (SD)***			
	Pre	**Post**	***p***	***d (95% CI)***	**Pre**	**Post**	***p***	***d (95% CI)***
MoCA	26.12 (2.90)	27.26 (2.71)	**0.002***	0.407 (−1.85 – −0.44)	26.38 (2.68)	27.58 (2.65)	**0.001***	0.451 (−1.89– −0.51)
Stroop	20.27 (10.50)	17.48 (7.74)	0.122	0.297 (−0.79–6.35)	18.03 (11.41)	16.56 (11.13)	0.246	0.131 (−1.44– −0.11)
DSST	50.76 (20.76)	53.29 (21.47)	**0.038***	0.119 (−4.91– −0.15)	59.20 (19.47)	62.48 (21.17)	**0.043***	0.159 (−6.44– −0.11)
WL	26.24 (7.91)	29.44 (6.73)	**0.001***	0.428 (−5.03– −1.38)	29.65 (7.93)	32.10 (9.54)	**0.009***	0.270 (−4.27– −0.64)
TUG	9.67 (1.50)	9.98 (2.00)	0.268	0.167 (−0.86–0.25)	10.08 (3.51)	9.81 (3.30)	0.120	0.185 (−0.07–0.59)
BBT	63.44 (11.65)	63.74 (9.39)	0.846	0.027 (−3.36–2.77)	58.28 (9.80)	62.30 (12.06)	**0.000***	0.240 (−6.09– −1.96)
BBT-SST	50.00 (15.61)	49.91 (12.93)	0.965	0.006 (−4.02–4.19)	46.48 (12.10)	50.08 (13.54)	**0.022***	0.317 (−6.64– − 0.56)
BBT-SST-Number	6.82 (4.66)	6.41 (4.84)	0.536	0.087 (−0.93–1.75)	8.50 (4.22)	10.03 (4.83)	**0.008***	0.332 (−2.63– −0.42)
Cost-SST	21.89 (15.62)	21.96 (15.18)	0.975	0.005 (−4.53–4.39)	20.34 (15.46)	19.45 (15.71)	0.684	0.057 (−3.49–5.27)
BBT-FD	61.35 (12.24)	62.81 (9.15)	0.397	0.131 (−4.93–2.00)	56.13 (10.92)	58.45 (14.05)	0.116	0.176 (−5.25–0.60)
BBT-FD-Number	16.50 (2.77)	16.71 (1.86)	0.685	0.090 (−1.27–0.85)	15.78 (2.29)	16.70 (1.67)	**0.013***	0.454 (−1.64– −0.21)
Cost-FD	2.72 (11.86)	1.52 (10.31)	0.639	0.108 (−3.95–6.34)	3.37 (12.62)	5.86 (15.67)	0.213	0.172 (−6.48–1.49)
IADL	30.18 (1.00)	30.38 (1.13)	0.214	0.192 (−0.54–0.12)	29.80 (3.23)	29.73 (3.30)	0.815	0.023 (−0.57–0.72)
CIQ	19.73 (3.98)	19.53 (4.18)	0.630	0.049 (0.63–1.03)	18.11 (4.89)	19.16 (4.95)	0.091	0.212 (−2.26–0.17)
GDS	2.18 (1.80)	2.85 (2.18)	0.076	0.336 (−1.43–0.08)	2.35 (2.71)	2.08 (2.49)	0.393	0.105 (−0.37–0.92)

Note: Values are presented as mean (standard deviation). Pre and post indicate measurements before and after the intervention. Statistically significant within-group differences are indicated in bold (*$p < 0.05$). Effect sizes are reported as Cohen's d.
Abbreviation: CI, confidence interval.

95% CI: −4.91 – −0.15; IDT: $t(39) = -2.091$, $p = 0.043$, $d = 0.159$, 95% CI: −6.44 – −0.11) and WL (ADT: $t(33) = -3.576$, $p = 0.001$, $d = 0.428$, 95% CI: −5.03 – −1.38; IDT: $t(39) = -2.728$, $p = 0.009$, $d = 0.270$, 95% CI: −4.27 – −0.64).

Within-Group Improvements

Significant improvements from pre- to post-training were observed only in the IDT group for BBT, BBT-SST, BBT-SST number, and BBT-FD number scores (all $p < 0.05$), whereas no significant changes were found in the ADT group (see Table 3 for details).

Non-Significant Findings

No significant pre-to post-training improvements were observed in Stroop, TUG, Cost-SST, BBT-FD, Cost-FD, IADL, CIQ, or GDS scores in either the ADT or IDT groups.

Correlations

Significant correlations were observed between baseline MoCA scores and changes in MoCA scores ($r = -0.424$, $p < 0.001$), BBT-SST performance ($r = 0.340$, $p = 0.003$), and Cost-SST ($r = -0.269$, $p = 0.021$).

No significant correlations were observed between baseline MoCA and change scores for Stroop ($r = 0.114$, $p = 0.331$), DSST ($r = -0.018$, $p = 0.881$), WL ($r = 0.009$, $p = 0.940$), TUG ($r = 0.003$, $p = 0.979$), BBT ($r = 0.185$, $p = 0.115$), BBT-SST number ($r = 0.062$, $p = 0.599$), BBT-FD ($r = 0.236$, $p = 0.043$), BBT-FD number ($r = -0.049$, $p = 0.676$), Cost-FD ($r = -0.079$, $p = 0.505$), IADL ($r = 0.086$, $p = 0.467$), or CIQ ($r = 0.024$, $p = 0.837$).

Discussion

The present study aimed to compare the effects of two types of dual-task training—incorporated dual-task (IDT) and additional dual-task (ADT)—on cognitive and physical functions in community-dwelling older adults. To our knowledge, this is the first study to directly examine the differential outcomes of these two simultaneous training approaches under a community-based group setting. The findings revealed a significant interaction effect between group and time for the BBT-SST-N, indicating that the IDT group showed greater improvement in the cognitive performance component of dual-tasking compared to the ADT group. In terms of within-group changes, both groups demonstrated significant improvements in global cognitive functioning, processing speed, and working memory, as reflected by gains in MoCA, DSST, and WL scores. However, significant enhancements in motor performance under both single-task (BBT) and dual-task (BBT-SST, BBT-SST-N, BBT-FD-N) conditions were observed only in the IDT group. No significant changes were found in either group for TUG, dual-task cost (DTC), IADL, or community integration (CIQ), suggesting limited transfer to functional mobility or real-life participation following the intervention. These findings highlight the distinction between "moving while thinking" (IDT) and "thinking while moving" (ADT), showing that integrating cognitive demands within motor tasks can better facilitate cognitive-motor coordination.

The most prominent finding of this study was that IDT training led to significantly greater improvements in dual-task cognitive performance, as reflected by the BBT-SST-N score, compared to ADT training. The serial sevens subtask embedded within the BBT-SST-N requires sustained attention and working memory under motoric load. The serial subtraction component of the BBT-SST-N task requires sustained attention and working memory while simultaneously performing a motor task. Participants in the IDT group demonstrated the ability to manipulate numerical information while executing coordinated motor sequences, indicating enhanced dual-task integration. This effect was not observed in the ADT group. The superior performance observed in the IDT group may be attributed to the structural embedding of the cognitive task within the motor activity, which reduces the need to divide attention across unrelated tasks and promotes more efficient resource allocation, possibly facilitating learning dual task manipulation capacities during training practice. This aligns with previous research on incorporated training modalities such as Tai Chi and dance-based exergaming, which have been shown to improve cognitive flexibility and attention shifting in older adults through integrated task demands.[15,23] Both IDT and ADT paradigms align with the principles of the guided plasticity facilitation model, which posits that physical activity induces neurotrophic signaling (eg., BDNF), while cognitively demanding tasks direct synaptic strengthening through targeted neural activation.[4,22] However, the degree of task integration may influence the efficiency of neural co-activation and plasticity. In the ADT paradigm, the lack of relevance between motor and cognitive components may result in greater attentional demands and increased task interference, particularly for older adults with reduced cognitive reserve.[21,46–48] In contrast, IDT may better support functional neural connectivity across prefrontal, parietal, and sensorimotor regions by requiring simultaneous coordination of goal-directed cognition and movement within a unified task structure.[49] This enhanced integration could underlie the superior cognitive outcomes observed in the IDT group.

Within-group analyses further revealed that both training modalities significantly improved global cognitive outcomes, including MoCA, DSST, and WL scores, suggesting that simultaneous motor-cognitive training can benefit cognitive functioning regardless of the task integration approach. These findings align with previous research demonstrating that concurrent physical and cognitive stimulation promotes neuroplastic adaptations through exercise-induced neurotrophic effects (eg., BDNF release) and cognitively driven synaptic refinement.[4,8,22] However, the observed effect sizes, particularly for DSST in the IDT group (d = 0.159), were small, indicating that the magnitude of improvement may be modest in practical terms. Prior studies suggest that higher-frequency or more intensive dual-task protocols—typically 2–3 sessions per week over 12 weeks—can produce larger and more clinically meaningful gains in executive function, processing speed and working memory.[8] These findings highlight that while both ADT and IDT are beneficial for cognitive enhancement, optimizing training dosage, intensity, and progression may be crucial to maximizing their real-world impact. Significant improvements in motor (BBT) and motor-cognitive dual-task measures (BBT-SST, BBT-SST -N, BBT-FD-N) were observed only in the IDT group. This advantage may be attributed to the functional relevance and integrated structure of IDT tasks, which allowed participants to form stable cognitive-motor associations and strengthen task-specific neural pathways. Such embedded training promotes more automatic motor execution while maintaining cognitive engagement, facilitating better retention and adaptation.[4] In contrast, ADT tasks, lacking meaningful linkage between motor and cognitive components, may have provided fewer opportunities for consolidation and skill generalization, resulting in limited training gains. Importantly, the ecologically valid nature of IDT tasks more closely mirrors everyday dual-task challenges—such as walking while planning actions or recalling items—thereby fostering transferable improvements that may support real-life cognitive-motor functioning in older adults.

No significant changes in dual-task cost (DTC) were observed in either training group. DTC, defined as the decrement in motor or cognitive performance under dual-task compared to single-task conditions, is considered an indicator of attentional resource allocation efficiency.[50] Older adults, particularly those with mild cognitive impairment, typically exhibit higher DTC, reflecting vulnerability in managing concurrent cognitive-motor demands. Although the present interventions did not produce statistically significant reductions, it is noteworthy that DTC values did not worsen over time. In aging populations, where dual-tasking abilities often decline with age, maintaining or preventing further deterioration of DTC may itself be clinically meaningful, as higher DTC is associated with greater fall risk and cognitive decline. Several factors may explain the absence of significant improvement. The training frequency (once per week) and relatively short intervention dose may have limited the development of refined task prioritization strategies. Evidence from VR-based and adaptive dual-task programs shows that higher frequency, progressive difficulty, and individualized task adaptation are key to reducing DTC and improving attentional control during dual-tasking.[18] Future studies should consider more intensive or adaptive training protocols to better target reductions in DTC and enhance resilience to attentional interference in older adults.

Similarly, no significant improvements were observed for the Timed Up and Go (TUG) test following either training program. This finding is in line with previous research where once- or twice-weekly dual-task interventions produced limited effects on functional mobility.[51] By contrast, studies employing higher training frequencies (three sessions per week over six weeks) and structured, game-based or resistance-combined dual-task approaches have reported measurable improvements in TUG performance and other functional fitness indicators in older adults.[52] The differences observed across studies may be partly explained by the training "dose," with higher frequency and greater cumulative practice fostering better motor learning and mobility adaptation. Additionally, many of the more effective interventions were delivered in controlled, individualized laboratory settings, allowing real-time feedback and task difficulty adjustments, which are challenging to replicate in large, community-based group formats. These factors may have contributed to the absence of significant TUG improvements in the present study, despite maintaining baseline mobility levels.

No significant improvements were observed in IADL and CIQ scores in this study. This finding may be partly explained by a ceiling effect, as participants demonstrated relatively high functional independence at baseline (mean IADL scores were close to the maximum of 32), leaving limited room for measurable gains. Although no significant changes were detected in the present study, this result is not inconsistent with previous systematic reviews.[6,9] Prior evidence indicates that the overall effects of dual-task training on IADL and quality of life are generally small to moderate, with more pronounced improvements typically reported in populations with lower baseline functioning or neurocognitive impairments.[9,53] Accordingly, the lack of significant changes observed in this study, which involved relatively high-functioning community-dwelling older adults, is both reasonable and expected. Based on these findings, the results suggest that traditional group-based dual-task training may have limited effectiveness in enhancing daily functional performance and quality of life. Recently, technology-assisted interventions, such as VR-based exergaming, have been proposed as promising strategies to overcome these limitations. VR platforms can simulate realistic IADL scenarios, adapt task complexity in real time, and provide immersive and highly engaging training environments.[19,54] Future research should further investigate whether such immersive technologies can more effectively translate the cognitive-motor benefits of dual-task training into meaningful improvements in daily functioning and quality of life, particularly for populations with greater functional needs or lower baseline independence.

Several limitations of this study should be acknowledged. First, the design was not a randomized controlled trial, and the majority of participants were women, which may limit the generalizability of the findings to broader older adult populations. In addition, unequal group sizes resulting from cluster-based allocation may have introduced potential bias. Although this gender distribution reflects the typical composition of community exercise groups, future studies should aim to recruit more gender-balanced samples and consider individual-level randomization where feasible to enhance external validity. Second, the dual-task interventions were delivered in a community group setting with limited opportunities for individualized task adaptation. The lack of personalization in training intensity, task difficulty, and feedback may have attenuated potential gains, particularly for participants with differing baseline abilities. Third, the relatively low training frequency (once per week) may have been insufficient to elicit larger or longer-lasting improvements. Future research should explore the dose-response relationship by examining the effects of higher-frequency, progressively challenging dual-task programs on cognitive and functional outcomes. Finally, the assessment tools used for daily function (eg., IADL, quality of life measures) may have been subject to ceiling effects in this high-functioning sample. Employing more sensitive and ecologically valid measures could help detect subtle improvements in real-world functional performance.

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Conclusion

This study demonstrated that "moving while thinking" (IDT) was more effective than "thinking while moving" (ADT) in enhancing cognitive performance under dual-task conditions, as measured by the BBT-SST-N. While both training modalities led to significant gains in global cognitive function, processing speed, and working memory among community-dwelling older adults, only IDT produced additional improvements in single motor task performance and motor-cognitive coordination during dual-tasking. These findings suggest that training programs embedding cognitive demands within motor tasks may offer superior benefits and more closely mirror the cognitive-motor integration required in everyday life. Despite these promising results, the neural mechanisms underlying the advantages of IDT remain unclear. Future studies should incorporate neurophysiological measures—such as electroencephalography (EEG)—to better understand the brain processes supporting dual-task learning and integration. Moreover, research involving individuals with mild cognitive impairment or dementia, as well as interventions delivered through immersive virtual reality environments simulating real-life dual-task scenarios, may further enhance our understanding of training efficacy. Such approaches could inform the development of personalized, ecologically valid interventions aimed at optimizing dual-task performance and promoting functional independence in aging populations.

Data Sharing Statement

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

This study was conducted with the approval of The National Cheng Kung University Hospital Institutional Review Board [Approval number 109-036]. Before participation, all participants were informed of the study purpose, procedures, and their rights as participants, and each provided written informed consent. All methods were conducted in accordance with relevant guidelines and regulations. Research involving human participants, human material, or human data was performed in accordance with the Declaration of Helsinki.

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Disclosure

The authors report no conflicts of interest in this work.

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