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The Effect of Different Dual-Task Balance Training Methods on Balance and Cognitive Function of Older Adults

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Abstract

Background: This research aims to investigate the effectiveness of different dual-task training methods on balance and cognitive function in the elderly.

Methods: The participants in this study were 36 elderly individuals aged 65 years and older who met the research entry criteria. The selected individuals were divided into three groups, 12 people each, based on the pre-test Berg balance scores. The research groups included two dual-task balance training groups, one with fixed and one with variable priority, and a control group. The Berg balance test was used to assess functional balance in the elderly, and the serial reaction time test was used to assess cognitive function. Data analysis was conducted using covariance analysis and the Bonferroni post hoc test.

Results: The data analysis showed no significant difference between the control group and the dual task groups with fixed and variable priority in the balance test. The serial reaction time test results indicated a significant difference between the control group and the dual-task practice groups with fixed and variable priority. Moreover, there was a significant difference between the two dual-task practice groups post-intervention.

Conclusion: This research demonstrated that dual-task training, particularly with variable priority, resulted in faster information processing in the elderly. Therefore, it appears that, in addition to the theory of limited attention capacity, other mechanisms, such as the allocated attentional ability, can effectively impact cognitive performance.

Keywords: Elderly, Fixed priority, Variable priority, Attention, Information processing

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Introduction

The aging process in the elderly often leads to disruptions in both motor and cognitive functions, consequently affecting their balance performance. Older adults' ability to maintain balance involves coordination and motor control processes to sustain the body's postural control during static and dynamic activities. Research findings have indicated that attention-demanding and consciousness activities can enhance coordination, balance, information processing speed, and postural control (1,2). Balance relies on cognitive and motor components, and deficiencies in maintaining balance can result in falls among the elderly. Falls are a significant cause of mortality in this demographic, particularly in dual-task conditions where individuals are required to perform multiple activities simultaneously (3). While balance indicators may be adequate for single activities, such as standing straight, they can become disrupted when engaging in multiple simultaneous activities, a common occurrence in daily life, such as simultaneously walking and conversing or crossing the street while being attentive to passing cars (4). When performed together, the interference between the cognitive and the motor activities can lead to a decline in performance in one or both tasks (5). Numerous studies have been conducted to reduce balance disorders and the incidence of falls, resulting in various intervention programs to mitigate their risk (6,7). However, the difference in findings in this area may be attributed to the diversity of training methods utilized. Traditionally, interventions targeting these two aspects have addressed them separately, with balance exercises and cognitive training being distinct components (single tasks) of older adult wellness programs. Nevertheless, emerging research suggests that integrating these two elements through dual-task balance training may hold significant promise for enhancing both balance and cognitive function in older adults (8).

The concept of dual-task balance training entails simultaneously performing a balance-related task while engaging in a cognitive task, such as solving a puzzle or reciting a sequence of numbers. This approach is founded on the interconnectedness of the brain and body and aims to yield more comprehensive and impactful results by training them in tandem. By concurrently challenging both physical and cognitive systems, dual-task balance training aims to improve balance, stability, cognitive processing, and attentional control (3).

The existing research in this field demonstrates the superiority of dual-task exercises over single-task exercises in enhancing the balance performance of the elderly. For instance, Trombini-Souza et al have highlighted that dual-task balance exercises reduce the risk of falling in the elderly (9). Additionally, Muir-Hunter and Wittwer have identified dual-task balance exercises as a critical factor in increasing the walking speed of elderly individuals with balance disorders (10). Moreover, several researchers have emphasized the role of dual-task training in enhancing the memory and cognitive performance of the elderly by challenging cognitive processing and attentional control compared to single-task training (11). Li et al have also reported that dual-task training leads to more significant improvements in the cognitive and motor functions of elderly individuals with Parkinson's disease than single-task training (11).

Furthermore, Pichierri et al underscored the significance of dual-task exercises in improving cognitive functions in the elderly with mild cognitive impairment (12). While it is evident that simultaneous engagement in cognitive and motor tasks can lead to a decline in performance in one or both of these activities, many researchers have also indicated that dual-task training can more effectively impact the cognitive and balance performance of the elderly. However, one aspect yet to receive more attention in this field is the different methods of divided attention during dual-task training based on various theories (9,13). Drawing from the theory of limited attention capacity, the interference in performing tasks simultaneously may be attributed to central information processing capacity constraints. When the processing demands exceed the capacity of the central system, performance is compromised. Therefore, dual-task exercises with fixed priority, in which individuals are required to equally attend to both cognitive and motor activities simultaneously, can enhance task performance by increasing task automaticity and reducing processing demands. This, in turn, improves cognitive and motor skills, leading to enhanced performance (14,15).

On the other hand, some researchers argue that the interference in executing tasks simultaneously is not solely due to limited information processing capacity, but rather the individual's inability to allocate attention to both motor and cognitive tasks, a crucial factor in creating interference (16). According to this perspective, dual-task exercises with variable priority are deemed suitable as individuals are required to shift their attention between motor and cognitive tasks during the exercise to enhance cognitive flexibility and improve attention allocation between motor and cognitive tasks (13-17). Building on this viewpoint and the task integration model, which emphasizes the importance of attention and focus shift in performing simultaneous cognitive and motor tasks, dual task training with variable priority significantly reduces interference in task execution (9). Trombini-Souza et al found two dual-task training methods, one with variable and one with fixed priority, to be effective in improving the balance performance of elderly individuals with mild cognitive disabilities (9). Bayot et al also suggested that practicing with variable priority results led to faster learning and better retention of training benefits than fixed priority training, while fixed priority was suitable for performing complex cognitive and motor control (17). Additionally, Wollesen et al highlighted that dual-task training enhances the ability to divide attention between motor and cognitive tasks (14). Furthermore, Bayatlu et al emphasized that focusing on and equally attending to cognitive and motor tasks simultaneously in the dual-task training protocol reduces the risk of falling in the elderly by enhancing task automaticity (15). Silsupadol et al also noted that dual-task training with variable priority is a suitable approach to improving the balance of healthy elderly individuals and underscored the need for further research to determine the exact effects of this type of training (16).

Given the conflicting results regarding the effectiveness of dual-task exercises with fixed and variable priority and the various existing theories and considering that most research on the effectiveness of these exercises has primarily focused on measuring motor factors such as gait while overlooking the cognitive factor, the objective of this study was to compare the effectiveness of dual-task exercises with fixed and variable priority on balance and cognitive performance in the elderly.

Methods

This was a semi-experimental research with practical objectives, utilizing a pre-test and post-test design with a control group. The statistical population consisted of older men aged 65 to 80 who had retired from the armed forces of Kerman city. From the volunteers, a sample of 36 individuals was selected and randomly divided into three groups: a control group, a dual-task group with fixed priority, and a dual-task group with variable priority. The inclusion criteria for this study were normal vision, the ability to stand for at least one minute, walk unaided or with a regular cane for a distance of 10 meters, follow simple instructions, and a score higher than 24 on the Berg test. In addition, participants were required to briefly examine their psychological state using the MMSE (18,19) and not have any diseases or take medications affecting balance (16). Participants with a history of neurological disease, cardiovascular disease, rheumatic and metabolic diseases, and severe disorders and deformations in the joints of the lower limbs were excluded from the study (16,20).

Sample size

The sample size was determined using Cohen's formula, and considering the first type error ($\alpha = 0.05$), the power of the test β (β-1 = 0.80), and effect size (0.65), a total sample of 36 participants (12 individuals per group) was calculated using G*Power software (21-23).

Instrument

Berg balance scale

Berg's balance scale consists of 14 subtests, each scored on a 5-point scale, designed to assess balance in elderly individuals. Higher scores indicate a greater level of functional independence in performing tasks and, consequently, a higher level of balance. The maximum total score on this scale is 56. Recommendations for performing each test, either collectively or individually, were provided to the subjects, and these instructions were presented verbally or demonstrated practically. It was crucial for the subjects to fully comprehend the expected performance, as their first attempts were used as a scoring criterion. The test required simple devices such as a timer, a chair, and a step 18 to 20 cm high. On average, the time needed to complete the tests ranged from 10 to 20 minutes, depending on the subjects' abilities (24). This research used the Persian version of the test by Salavati et al, which has been shown to have equivalence and standardization. The test had high internal consistency (Cronbach's alpha = 0.92–0.98), interrater reliability (intraclass correlation coefficient ICCs = 0.95–0.98), and test-retest reliability (ICC = 0.97) (25).

Serial Reaction Time Task

The software designed for the Serial Reaction Time Task (SRTT) is an excellent tool for examining and evaluating memory and cognitive performance. Initially proposed by Nissen and Bulmer in 1987 and later translated by Lam et al, this tool presents multiple target stimuli in various spatial locations, requiring participants to respond quickly by pressing the key associated with the location of the presented stimulus. This motor task has both motor and cognitive components, demanding attention to provide a motor response to a cognitive stimulus. The software utilized in this research offers the capability to set goals, stimuli, time intervals for presenting stimuli, sequence types, stimulus presentation order within a block, rest intervals between blocks, and the size and spacing of stimuli on the page. These features distinguish this software from other versions available in the market. The method for developing this software involved using Visual Studio 2015 with SQL version 2016 to implement C# and store task information (26). Iranmanesh et al reported a reliability score of 0.91 for this tool. They confirmed its formal validity, emphasizing that the tool measures the desired task with a computer timer accurate to one-thousandth of a millisecond (27).

Procedure

After selecting the participants and obtaining the necessary permissions, individuals were provided with information about the research process, objectives, and the importance of consent forms. The individuals' information was collected, and participants were randomly divided into three groups based on their Berg balance pre-test scores (16). Pre-test and post-test assessments for the serial reaction time task and Berg balance scale were conducted the day before and after the exercise protocol. The serial reaction time test involved a predetermined sequence of 1, 4, 3, 2, 2, 4, 1, 3, 4, 1, 2, 3, which was repeated six times in the block test (28). Participants were required to respond to stimuli appearing in four positions on a computer monitor by pressing the corresponding key on the keyboard. Reaction times and errors in recognizing the correct response were recorded during the test (29).

The participants engaged in dual-task and control exercises throughout the training period for four consecutive weeks, with three 45-minute sessions each week (8,30). The duration and frequency of the training sessions were determined based on previous research, which indicated that 10 to 12 hours of balance training (13,16,17) and 1–5 hours of dual-task practice (8,15) could improve balance performance and dual-task abilities in the elderly (31). The balance training program for the four weeks was designed based on task difficulty and personal safety principles, following the division of Gentiles' movement tasks. The exercises included standing, transitioning, and walking (13,30). To ensure participant safety, a 3 to 5-minute warm-up and cool-down period was implemented at the beginning and end of each training session. The exercise protocol encompassed a variety of activities, such as standing on a narrow support surface with eyes open or closed, walking on a narrow support surface, standing in a tandem pose, walking around obstacles, sitting and standing up, balancing a book on their head while walking, and engaging in activities with a ball (8,13). For the dual-task groups, cognitive tasks like counting backward, spelling backward, and reciting days of the week or months of the year were incorporated (16,30). Participants in the control group performed the balance exercises without any simultaneous cognitive activities (15,31).

In the dual-task groups, participants with fixed priorities simultaneously performed cognitive tasks while practicing balance exercises, maintaining equal attention on both tasks at all times (8,14). In contrast, in the dual-task group with variable priorities, the training sessions were equally divided between balance and cognitive tasks. The key distinction was that the examiner guided participants to allocate equal attention to both tasks in the group with fixed priorities. In contrast, in the group with variable priorities, participants were guided to focus on the balance task for 50% of the time or repetitions and the cognitive task for the remaining 50% (9,13,17,32). To ensure accurate implementation of assignments in the dual-task group with variable priority, participants received detailed explanations before each practice session to ensure proper execution of the movements. Furthermore, during the practice session, the examiner meticulously supervised the activities of this group (13).

Statistical Analysis

In the data analysis, first, the pre-test and post-test scores of balance and serial reaction time in the three groups were presented using their mean and standard deviation. Then, to determine the effect of the single-task and dual-task balance exercise courses (with fixed and variable priorities) on balance and serial reaction time, analysis of covariance (ANCOVA) and Scheffe's post hoc test were used ($P < 0.05$). Before making any statistical inferences about the effects, the validity of the statistical model, the normality of the error distribution (Shapiro-Wilk test), and the equality of error variances between groups (Levene's test) were investigated. Also, all calculations were done with SPSS 26 software.

Results

Table 1 presents the mean and standard deviation of the pre-test and post-test balance scores and serial reaction time in the three groups before conducting covariance analysis.

In Table 2, the Shapiro-Wilk test indicates that the assumption of normality of distribution for the balance score and serial reaction time error is not rejected. Similarly, Levene's test shows that the assumption of equal error variances between the groups for the balance score and serial reaction time is not rejected, confirming that the statistical distribution has been met.

The results of the analysis of covariance in Table 3 reveal significant differences in the mean balance scores among the three methods of practice: single task, a dual task with fixed priority, and dual task with variable priority. In other words, the exercise method significantly impacted the balance of the elderly ($F = 2.32$, $P = 0.307$). Furthermore, the covariance analysis demonstrated that the mean serial reaction time scores under single-task conditions significantly differed across the three practice methods. The training method significantly influenced the serial reaction time in the single task conditions of the elderly ($F = 2.32$, $P = 0.000$), with an effect size of 64.1% according to the Eta coefficient. The post hoc test by Sheffe (Table 4) further confirms that the average serial reaction time of the elderly was significantly lower in the dual-task with fixed priority and dual-task with variable priority exercises compared to the single-task method (fixed priority, $P = 0.020$; variable priority, $P = 0.000$). Additionally, the serial reaction time of the dual-task exercise with variable priority was significantly lower compared to that of the dual-task exercise with fixed priority ($P = 0.013$).

In conclusion, the dual-task training methods with fixed priority and variable priority resulted in lower serial reaction times than the single-task treatment, indicating improved performance in dual-task conditions.

Discussion

The primary objective of this study was to examine the impact of dual-task training with fixed and variable priority on the balance and cognitive performance of elderly individuals as measured by the Berg balance scale. The research results indicated that balance performance in the experimental and control groups improved following a practice period. Although the dual-task balance training

Table 2. Levene's test and Shapiro-Wilk test results for model validity of covariance analysis

Variable	Levene's test		Shapiro-Wilk test	
	F	*P*	Test statistics	*P*
Balance	0.434	0.652	0.966	0.322
Serial reaction time	0.545	0.585	0.982	0.803

Table 1. Mean and standard deviation of the score pre-test and post-test of balance and serial reaction time in single-task and double-task conditions in the three training methods

Variable	Practice method	Pre-test		Post-test		Difference between post- and pre-test	
		Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Balance	Single Task (Control)	46.33	1.07	48.00	1.35	2.67	1.56
	Dual-task with fixed priority	46.58	1.00	48.67	1.30	2.80	1.08
	Dual-task with variable priority	46.50	0.67	49.2	1.51	2.42	1.24
Serial reaction time	Single Task (Control)	1099.25	163.17	1033.83	137.76	-65.42	39.37
	Dual-task with fixed priority	1120.17	164.34	957.33	109.95	-152.83	93.28
	Dual-task with variable priority	1115.58	154.87	903.42	76.07	-247.17	96.56

Table 3. Covariance analysis of the effect of training methods on balance and serial reaction time in single-task and dual-task conditions

Variable	Source	Sum of squares	Degrees of freedom	Mean square	*F*	*P*	Eta squared
Balance	Pre-test	11.126	1	11.126	6.787	0.014	0.175
	Practice method	4.019	2	2.009	1.226	0.307	0.071
	Error	52.457	32	1.639	-	-	-
Serial reaction time	Pre-test	318888.84	1	318888.84	318.315	0.000	0.787
	Practice method	154212.85	2	77106.43	28.608	0.000	0.641
	Error	86248.41	32	2695.26	-	-	-

Table 4. Bonferroni's follow-up test for a two-by-two comparison of balance and serial reaction time in single and dual-task conditions among the three training methods

Variable	Pairwise comparison		Mean difference	*P*
Balance	Dual-task with fixed priority	Single Task (Control)	-0.42	0.740
	Dual-task with variable priority	Single Task (Control)	-0.75	0.384
	Dual-task with fixed priority	Dual-task with variable priority	-0.33	0.824
Serial reaction time	Dual-task with fixed priority	Single Task (Control)	-87.42*	0.020
	Dual-task with variable priority	Single Task (Control)	-181.75*	0.000
	Dual-task with fixed priority	Dual-task with variable priority	94.33*	0.013

groups with variable and fixed priority performed better than the control group, the difference was not statistically significant. It is important to note that individuals in the control group engaged in balance exercises without any cognitive tasks, such as single-task balance training, which naturally contributed to improved balance performance. This finding is consistent with previous research by Silsupadol et al and Wollesen et al, demonstrating that single and dual-task balance exercises enhance balance in elderly individuals (8,14,33). Wollesen et al suggested that single-task balance exercises improved static balance, while dual-task balance exercises improved dynamic balance, indicating that both types of exercises are beneficial for improving the essential components of the balance function (14). Additionally, Silsupadol et al highlighted the importance of training volume and intensity in the effectiveness of different training methods on balance in older adults (8). Furthermore, it is important to note that the training protocol in this study consisted of 12 sessions and included activities related to standing, walking, and transitioning designed based on the principles of movement tasks and personal safety, by Gentile's classification of movement tasks. As the training sessions progressed from the first session to the last, the exercises became progressively more challenging, requiring more significant effort on the part of the participants (12). Thus, this training protocol improves functional balance in both control (single-task) and dual-task conditions. However, our findings are inconsistent with those of Li et al, who reported that a 12-week exercise program did not improve balance performance in elderly individuals, citing the high baseline balance capacity of the participants before the program as the reason for the results (11).

Furthermore, our study found no significant difference between the two dual-task training methods with fixed and variable priority in the Berg balance scale, aligning with the findings of Silsupadol et al (3,16). This lack of significance may be attributed to the differences in the training methods and test conditions used in this research. While the dual-task training groups practiced with two different dual-task settings, the balance test was conducted in single-task conditions without any dual-task component. Gobbo et al also highlighted that elderly individuals exhibit comparable and acceptable balance performance in single-task conditions, but adding a secondary task can disrupt their performance (34). Therefore, due to the test's single-task modality and the similar performance of the elderly in these conditions, no significant differences were observed between the different types of dual-task training. The current research revealed that dual-task balance exercises with fixed and variable priority significantly enhanced cognitive performance in the elderly compared to the control group. This finding is supported by Mirelman et al, Smith et al, and Trombini-Souza et al (9, 33, 35). Smith et al emphasized that dual-task exercises involving simultaneous cognitive and motor activities increase cognitive load and necessitate coordination between attention, working memory, and executive functions in older adults. Over time, as cognitive control processes improve, attention and multitasking abilities, crucial components of cognitive functions, also improve, leading to increased information processing speed and reaction time in the elderly (35). Mirelman et al emphasized that dual-task training improves the transfer process of new cognitive tasks and multitasking skills, thereby enhancing information processing speed, which is not achieved through single-task exercises (33). Trombini-Souza et al found that dual-task exercises involving multiple cognitive and motor tasks lead to more pronounced neuroplastic and cognitive improvements than exercises focusing solely on individual tasks (9). However, these findings contradict previous research results (10,36,37). Muir-Hunter and Wittwer argued that based on the principle of exercise specificity, for improving cognitive and motor factors, the exercise and test conditions should be similar. They suggested that training in the dual-task method, followed by a test in single-task conditions may not be suitable for enhancing performance in cognitive and motor tests. They recommended that balance or cognitive tests be performed separately without simultaneous tasks to yield better results (10).

Finally, the current research findings revealed that the dual-task group with variable priority exhibited significantly lower reaction times than the dual-task group with fixed priority. This finding aligns with the results of Trombini-Souza et al and Buragadda et al (9, 32).

Buragadda et al emphasized that based on the hypothesis of task integration, dual-task training with variable priority, which involves changing and transferring attention between cognitive and motor tasks during exercise, induces higher integration between motor and cognitive tasks. This integration has been linked to enhancing the ability to allocate attention in the elderly, a crucial factor in reducing cognitive load during simultaneous tasks and increasing cognitive flexibility (32). In contrast, the dual-task practice with fixed priority primarily leads to automaticity and does not significantly impact cognitive flexibility or attention allocation in older adults. Therefore, dual-task exercises with variable priority, involving the transfer of attention between cognitive and motor tasks, have been shown to improve cognitive flexibility in the elderly and lead to faster information processing compared to the fixed-priority dual-task method. Trombini-Souza et al also highlighted the beneficial effects of variable-priority dual-task training, attributing the superior performance of the variable-priority group to the improved ability to allocate attention between tasks, which is particularly crucial for proper performance in cognitive tests among the elderly (9).

However, these findings contradict the results of Silsupadol et al, who found no significant difference between the two dual-task practice methods. Their study focused on elderly individuals with impaired balance, prioritizing maintaining balance over cognitive activity, leading to an absence of practice for shifting attention between tasks (16).

Conclusion

The current research demonstrates that the dual-task balance training program, incorporating fixed and variable priority methods, enhances balance and cognitive performance among elderly individuals. Therefore, it is recommended to design balance exercises based on dual-task methods, particularly those emphasizing attention allocation, to enhance cognitive abilities and reduce the risk of falls in these individuals. Furthermore, future research should explore the impact of dual-task exercises on walking characteristics, which are crucial for maintaining balance and preventing falls among the elderly. Psychological factors such as fear of falling and motor self-confidence should be examined, as they significantly limit movement activities among the elderly. A study on the effectiveness of dual-task exercises on these psychological factors is warranted. The current research findings contradict those of Silsupadol et al (13). In their study, elderly individuals with impaired balance tended to prioritize their balance over cognitive activity due to limitations, resulting in the absence of practice for shifting attention between tasks.

Consequently, their research revealed no significant difference between the two dual-task practice methods.

In contrast, the current study's findings indicate that the dual-task balance training program, incorporating fixed and variable priority methods, improved balance and cognitive performance among elderly individuals. The variable priority method resulted in faster information processing and enhanced cognitive performance compared to the fixed-priority dual-task approach. It is recommended to design balance exercises based on dual-task methods, particularly those emphasizing attention allocation, to improve cognitive abilities and the appropriate division of attention between tasks and to enhance cognitive and movement factors involved in balance production, reducing the risk of falls in these individuals. Moreover, the current research investigated the effectiveness of dual-task exercises on balance among elderly individuals. However, it did not address the walking characteristics of these individuals, which are crucial for maintaining balance and preventing falls in this demographic. Future research should explore the impact of dual-task exercises on walking characteristics among the elderly. Additionally, psychological factors such as fear of falling and motor self-confidence, which contribute to falls and limit movement activities among the elderly, were not examined in this study. Therefore, it is recommended that a similar study be conducted to assess the effectiveness of this type of exercise on psychological factors such as fear of falling and movement confidence among elderly individuals.

Authors' Contribution
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Writing–original draft: Hesam Iranmanesh.
Writing–review & editing: Hesam Iranmanesh,Hossein Shirvani.

Competing Interests
The authors declare that they have no competing interests.

Ethical Approval
All ethical principles such as obtaining informed consent from participants, confidentiality of their information, and allowing them to leave the study at any time were considered in this study. Ethical approval was obtained from the research Ethics Committee of Baqiyatallah University of Medical Sciences of Tehran(code:IR. BMSU.BAQ.1401.126).

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