

# Research Paper: Effect of Cognitive Training on Lower Limb Muscular Activity in Older Adults With Balance Impairment During Walking



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## ABSTRACT

**Purpose:** The purpose of this study was to compare the effects of two different approaches of dual-task training and executive training on lower limb muscular activity in older adults with balance impairment.

**Methods:** This was a quasi-experimental study performed with a pre-test and post-test method. Thirty old adults (Mean±SD age=73.8±4.6 y, height=1.65±0.06 m, weight=69.17±12.67 kg) were randomly assigned to one of the three groups: two experimental groups included Cognitive Dual-Task training (CDT; participants did exercises under the dual-task condition with cognitive tasks, such as forward counting, simple visual search task, etc.) and Executive Function training (EF; included a mixture of 20 tasks involving working memory tasks, inhibitory and speed of processing tasks), and a control group. The training session lasted 45 min and was held three times a week for eight weeks. Gait muscle activity under single-task and Dual-Task (DT) conditions was recorded before and after training.

**Results:** during the stance phase of normal walking, the amplitude of Electromyography (EMG) activity of right Tibialis Anterior (TA) muscle in the post-test was about 32% lower than that in the pre-test in the CDT group (P=0.011), and no statistically significant change was between pre- and post-training in the EF and control groups (P>0.05). During the swing phase of DT walking, the amplitude of EMG activity of the right Vastus Lateralis (VL) muscle in the post-test was about 15.5% higher than that in the pre-test in the CDT group (P=0.013), and in the right VL muscle during the post-test was lower than that in the pre-test in the EF group (P=0.01). In the CDT group, right ankle co-contraction during the stance phase in the post-test was statistically different from that in the pre-test. In all three groups, muscular EMG asymmetry demonstrated no statistically significant change between pre- and post-training measures (P>0.05).

**Conclusion:** Overall, both training groups showed similar muscular activity in the post-test than pre-test; however, in the EF training group, walking velocity improved more than that in the CDT group. Therefore, because of improvements in both walking velocity and muscle activities after EF training, this training mode is suggested for older adults.

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## Highlights

- Gait muscle activity was affected by two dual-task and executive training.
- Co-contraction and muscular EMG asymmetry showed no statistically significant changes.

## Plain Language Summary

Age-related changes individuals' cognitive level, such as attention, executive function, and speed of processing that can affect gait and balance performance. During walking, this high levels of cognitive information and attention are required to evaluate, plan, and perform this task. Maintenance and improvement of muscle function in old age is an important parameter to sustain normal daily activity and functional independence. In this study, 30 old adults were randomly assigned to three groups (cognitive dual-task, executive function, and a control group) that participated in eight weeks of training for three sessions per week. Gait muscle activity under single-task and dual-task conditions were recorded before and after training. Increased co-contraction in older adults might be related to the increased cost of walking. Also, higher walking velocity and unchanged or lower muscular EMG activation in the training groups may be associated with high gait efficiency and lower proximal joint load in older adults.

## 1. Introduction

It is postulated that aging is accompanied by alterations in the structural and functional integrity of the brain [1]. These alterations occur, at the individuals' behavioral level, because of progressive disorders of motor and cognitive functions [2] and muscular activation [3]. Muscles and alpha motor neurons contact each other at the neuromuscular junction. One of the major causes of muscle weakness in older adults is the loss and deterioration of alpha motor neuron innervation to muscle with age [4]. Age-related changes in the muscular activation of walking are clearly present in older adults [5]. Compared to young adults, older adults demonstrate higher amplitudes in Vastus Lateralis (VL), Biceps Femoris (BF), and Gastrocnemius (GS) [6], and higher co-contraction across the ankle [7] and knee joints [8], which probably contributes to reduced joint power during the propulsion phase of the walking. These results may be due to lower muscle effectiveness that occurs with aging, as indicated by the reduced peak forces exerted by the extensor muscles and the diminished momentum-generating capacity [9]. Also, older adults exhibit greater positional variability with the ankle joint compared to the young adults likely due to their inability to activate the tibialis anterior muscle from 30–60 Hz [10]. Previous studies have demonstrated that Electromyography (EMG) oscillations from 13–60 Hz reflect the modulation of the motor neuron pool by higher centers [11]. Degeneration of the motor unit is associated with decreased peak muscle power in the lower extremity of older adults [12].

Efficient and safe walking is important to sustain independence and to decrease the risk of falls in older adults [13]. However, during walking, high levels of cognitive information and attention are required to evaluate, plan, and perform this task. Maintenance and improvement of muscle function into old age is an important parameter to sustain normal daily activity and functional independence [14]. This issue highlights the need for exercise methods that are effective and can be performed regularly.

The previous studies on motor Dual-Task (DT) effects have inspired a few recent investigations of DT training as a means to improve walking [15, 16]. The findings of these studies have indicated the positive effects of cognitive, motor, or motor-cognitive DT performance [15, 16]. Executive Function (EF) indicated higher-order cognitive processes that control, integrate, and maintain other cognitive abilities. A recent study has evaluated the effect of two kinds of training (DT versus EF) on spatial-temporal and symmetry of gait in older adults [15]. The results of this study demonstrated that both training groups showed improvements in gait parameters in the post-test compared to that of the control group; however, in the EF training group, symmetry of limbs and inter-coordination improved more than that the Cognitive Dual-Task (CDT) training group [15]. However, there is no study evaluating muscle activities in older adults after these training protocols. Thus, the aim of this study was to evaluate the effect of two cognitive training methods (DT versus EF) on muscle activation under normal and DT walking conditions and also on ankle joint co-contraction and muscular EMG asymmetry during normal walking in older adults. In the present study, muscles ex-

amined were the Tibialis Anterior (TA), Medial Gastrocnemius (MGas), and the Vastus Lateralis (VL) because of their specific roles in mobility and large powerful movements and because weakness in these muscles has been associated with postural instability and increased risk of falls in older adults [17].

## 2. Materials and Methods

### Subjects

This study was a clinical trial. This study was done at Islamic Azad University, Hamadan branch, in 2019. We used the G\*Power software to calculate a priori power analysis with the F-test family. The power analysis was done with an assumed alpha level of 0.05, a type 2 error rate of 0.20, and an effect size value of 0.80. The analysis demonstrated that 10 subjects per group would be enough to observe significant group-by-time interaction effects. The subjects of this study included 30 male old adults with balance impairments. Subjects were selected through purposive sampling from all available older adults. Old adults were regarded as impaired balance who scored less than 52 (total score equal to 56 points) on the Berg Balance Score (BBS) [18], and/or completed a 10-m walk with a self-selected walking speed of 1.1 m/s or lower [18]. Also, they had scored higher than 24 on the Mini-Mental State Examination (MMSE) [18]. Participants were excluded if they reflected any neurological or vestibular disorder or orthopedic condition, including lower limb injury six months prior to data collection. All subjects had a normal range of vision.

The research was approved by the Ethics Committee of Ardabil University of Medical Sciences (IR.ARUMS.REC.1395.77) and was registered at the Iranian Clinical Trial (IRCT2016110230657N1) site. Participants were assigned to one of three groups randomly: (1) Cognitive Dual-Task (CDT) training group; (2) Executive Function training (EF) group; and (3) control group. During the randomization, a complex of sealed, opaque envelopes was utilized to ensure the concealment of allocation. Each of them contained a card showing which group the participant was allocated. The control group did not receive any intervention during the intervention period.

### Intervention

#### Cognitive dual-task training

Each training session lasted 45 min and was held three times a week for eight weeks. The training protocol was in accordance with that described by Uemura et al. [16].

In DT training, the cognitive load was progressively increased during the 24-session program. In sessions 1-6, the subjects were asked to execute only the motor task without a cognitive task. In sessions 7-12, participants did exercises under the dual-task condition with simple cognitive tasks (such as forward counting, simple visual search task, etc.). In sessions 13-24, cognitive tasks became more difficult (asking the subjects to name the different categories of animals, plants, and/or to search visually, repeat numbers or letters, etc.). Backward counting as a cognitive task was not used in any of the groups, because it would be used as a dual-task in the measurements. Standing exercises included standing and shifting the center of gravity in different directions, and walking exercises involved walking forward, backward, and to the sides.

#### EF training

In the EF training group, the first training session was devoted to teaching basic computer skills. The EF training sessions also included a 45-min training program (three times a week for a period of eight weeks), during which each individual started training based on their progress in the previous session. Therefore, when a subject did successfully complete a certain stage, they would be allowed to move to the next stage. Each training session was conducted in accordance with the guideline of Verghese et al. [19], and included a mixture of 20 tasks involving working memory tasks, inhibitory control, and speed of processing tasks that had been designed by Sina Institute of Psychology, Tehran, Iran [19]. Working memory training included visual, auditory, and stabilized tasks, each of which contained three parts related to the number, letters, and shapes. Every task had nine difficult levels increasing in difficulty proportionate to the strength of the stimuli presented [19].

In the working memory training, stimuli were presented approximately one second and then faded. Then, participants had to identify the location and the name of the stimuli among irrelevant stimuli. Each task was performed in both forward and backward manners. Inhibitory training included ignoring the distracter stimuli. The speed of processing training contained simple to difficult tasks based on the number of stimuli distracters and their movement. The participant was instructed to keep his/her eyes on the main stimulus, which was displayed along with a distracter stimulus. Then, all stimuli were masked and started moving around the screen. The participant had to keep the track of the main stimulus and once moving stopped, they had to click on the shape that they believed contained the main stimulus. As the

participant's performance improved, the number and speed of moving of distracter stimuli on the screen increased. For inhibitory training, the participants learned to ignore the distracter stimuli. At the end of each daily training routine, participants were required to compare their performance against a table that described their progress. The participants received a financial reward, once they had attended all the training sessions.

## Outcome measures

### Kinematic recording and analysis

A four-camera Vicon system (Oxford Metrics, Oxford, UK) was used to record three-dimensional lower-body kinematic data (100 samples/s) with the Plug-In Gait marker set. A total of 16 retro-reflective markers were positioned on the skin overlying specific bony landmarks or anatomical positions of the lower body. Reflective markers were attached at bilaterally lower limbs with plug-in gait marker set model, including the anterior superior iliac spine, posterior superior iliac spine, lateral epicondyle of the knee, lower lateral 1/3 surface to the thigh, lateral malleolus, lower 1/3 of the shank, over the second metatarsal head, and on the calcaneus [20]. Successful trials included four consecutive foot strikes with full marker visibility. Trials were not retained when the participant made excessive movements of the head, arms, or trunk unrelated to walking. Participants were granted some practice trials before each condition. Despite careful measurements, some trials had to be omitted due to irregularities in the kinematics. Each participant was asked to walk 10 m under two different conditions, one under single-task condition (normal walking) and the other, under the dual-task condition of walking and counting backward.

### EMG recording and analysis

A portable EMG system (BTS FREE EMG 300, BTS Bioengineering, Italy) with six pairs of bipolar pre-gelled Ag/AgCl surface electrodes (circular with 11 mm in diameter; 25 mm center-to-center distance; input impedance of 100 M $\Omega$ ; and common-mode rejection ratio of >110 dB at 50-60 Hz) was used to record the activity of the Tibialis Anterior (TA), Medial Gastrocnemius (MGas), and Vastus Lateralis (VL) muscles of both the right and left lower limbs at a sampling frequency of 2000 HZ.

Before the placement of the electrodes, the skin surface over the selected muscles was shaved, cleaned with alcohol (70% Ethanol - C<sub>2</sub>H<sub>5</sub>OH), and abraded gently, according to the SENIAM recommendations [21]. Then, the electrodes were placed on the skin over the selected muscles using double-sided tape.

The TA muscle electrodes were placed vertically at 1/3 on the line between the tip of the fibula and the tip of the medial malleolus and were oriented in the direction of the same line. For MGas, the electrodes were placed vertically on the most prominent bulge of the muscle. For VL muscle, the electrodes were placed at 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella and were oriented in the direction of muscle fibers [22, 23]. EMG signals were processed using a bandpass filter (10-500 Hz) along with a notch filter for the interference of the electronic device (50 Hz). For EMG analysis, the Root Mean Square (RMS) was calculated and the peak RMS value of the four trials was averaged and then normalized based on the Maximum isometric Voluntary Contraction (MVIC) (for TA, Gast-M, and VL muscles) [3].

The rate of ankle co-contraction between TA and MGas muscles of the ankle joint was calculated through the following equation [24]:

$$\text{Directed co-contraction} = 1 - (\text{TA muscle activity} / \text{MGas muscle activity})$$

In the above equation, when the number is closer to zero, the rate of co-contraction increases, and when the number is closer to 1 or -1, the amount of co-contraction is reduced. Finally, to evaluate the level of gait asymmetry, the authors employed the Robinson Asymmetry index (AS) for inter-parameter comparisons [25].

$$\text{Asymmetry} = [X_R - X_L / (0.5 \times (X_R + X_L))] \times 100$$

Where, X is the amount of muscular activity and R and L are values of the right and left lower limb.

### Statistic

Normal distribution was confirmed using the Shapiro-Wilk test. To analyze the data obtained from pre and post-tests, different statistical measures were taken. First, ANOVA was run to compare the difference between the subjects in two experimental and control groups before the treatment in terms of demographic features, like age, weight, height, and other cognition abilities. The data obtained were analyzed using paired samples t-test and MANOVA at a P-value of 0.05. Additionally, the effect sizes (d) were calculated as a ratio of mean difference divided by the mean standard deviation of both conditions. The effect size of 0.2 is considered as "small", 0.5 as "moderate", and 0.8 as "large" effect [26]. Statistical analyses were performed using the SPSS v. 22.

### 3. Results

There were not any statistically significant differences in terms of cognitive status and demographic characteristics between the three groups (Table 1). The age, height, Body Mass Index (BMI), Activities-specific Balance Confidence (ABC), MMSE, BBS, and a 6-min walking (m) are summarized in Table 1. There were no clinically relevant differences between the groups.

The average normal walking speed in three groups were as follows: CDT group: pre-test:  $0.83 \pm 0.04$ ; post-test:  $0.90 \pm 0.04$ ;  $P > 0.05$ , EF group: pre-test:  $0.76 \pm 0.04$ ; post-test:  $0.92 \pm 0.04$ ;  $P = 0.002$ , and control group: pre-test:  $0.81 \pm 0.04$ ; post-test:  $0.80 \pm 0.04$ ;  $P > 0.05$ . Furthermore, the average DT walking speed in three groups were as follows: CDT group: pre-test:  $0.81 \pm 0.13$ ; post-test:  $0.90 \pm 0.12$ ;  $P > 0.05$ , EF group: pre-test:  $0.75 \pm 0.11$ ; post-test:  $0.91 \pm 0.13$ ;  $P = 0.005$ , and control group: pre-test:  $0.75 \pm 0.15$ ; post-test:  $0.76 \pm 0.13$ ;  $P > 0.05$ .

Table 2 provides the results from the interaction of group/training on muscular EMG activations during the stance phase of walking. As shown in Table 2, in the CDT group but not the control group, the amplitude right TA muscle during the stance phase of normal walking in the post-test was about 32% lower than that in the pre-test ( $P = 0.011$ ;  $ES = 1.16$ ). In the EF and control groups, the EMG activation of TA, M-Gas, and VL muscles in both right and left sides during the stance phase of normal walking demonstrated no statistically significant change between pre- and post-training measures ( $P > 0.05$ ). However, in the EF group but not the control group, the amplitude of EMG activity in the right VL muscle during the post-test was lower than that in the pre-test during the stance phase of DT walking ( $P = 0.031$ ;  $ES = 0.79$ ) (Table 2).

Table 3 provides the results from the interaction of group/training on muscular EMG activations during the swing phase of walking. In the CDT group but not the control group, the amplitude of right VL muscle during the swing phase of normal walking in the post-test was about 15.5% higher than that in the pre-test ( $P = 0.042$ ;  $ES = 0.78$ ) (Table 3). In both CDT and EF groups, the amplitude of EMG activity of right VL muscle during the swing phase of DT walking in the post-test was about 33% ( $P = 0.013$ ;  $ES = 1.61$ ) and 24% ( $P = 0.01$ ;  $ES = 0.90$ ) higher than that in the pre-test, respectively (Table 3). Furthermore, in the EF group, the amplitude of EMG activity of left Gas muscle during the swing phase of normal walking in the post-test was about 36% higher than that in the pre-test ( $P = 0.011$ ;  $ES = 1.21$ ) (Table 3).

In the CDT group, right ankle co-contraction during the stance phase in the post-test was statistically different than that in the pre-test ( $P = 0.009$ ) (Figure 1). In the EF and control groups, right and left ankle co-contraction demonstrated no statistically significant change between pre- and post-training measures ( $P > 0.05$ ) (Figure 1). In all three groups, the asymmetry index of EMG activity demonstrated no statistically significant change between pre- and post-training measures ( $P > 0.05$ ) (Figure 2).

### 4. Discussion

The purpose of this study was to evaluate the effect of two cognitive training methods (DT versus EF) on muscle activation (TA, MGas, and VL muscles of both sides), ankle joint co-contraction, and muscular EMG asymmetry during walking in older adults.

In the CDT group, the amplitudes of EMG activity of right TA muscle during the stance phase of normal walking and EMG activity of right VL muscle during the stance phase of DT walking in post-test were lower than those in the pre-test. Normal and DT walking speeds did not change between the post-test and the pre-test in the CDT group. Therefore, the lower amplitude of TA muscle may be related to increases in the motor unit synchronism, as a consequence of motor learning, which could reduce the EMG activity [27]. In the EF group, the EMG activation of TA, MGas, and VL muscles during the stance phase of normal walking in both right and left sides demonstrated no statistically significant change between the pre- and post-training measures. Also, in the EF group, the amplitude of EMG activity in the right VL muscle during the post-test was lower than that in the pre-test during the stance phase of DT walking. Furthermore, walking velocity increased significantly in the EF training group (21%) than it did in CDT (8%) and control groups. Previous studies have demonstrated that increased walking speed may cause a significant increase in the amplitude of lower limb muscular activation during the stance phase of walking [28, 29]. Also, it has been reported that older adults will have higher amplitudes in vastus lateralis, biceps femoris, and gastrocnemius [6], which may be due to reduced muscle effectiveness with aging, as indicated by the lower peak forces exerted by the extensor muscles [30] and the diminished momentum-generating capacity. Therefore, higher walking velocity and unchanged or lower muscular EMG activation in the EF group after the training program may be associated with high gait efficiency and lower proximal joints load in older adults [31, 32].

Furthermore, in experimental groups, the EMG activation of selected muscles (except for right VL in the CDT group) during the swing phase of normal walking in both right and

**Table 1.** Participants' characteristics per group

Characteristics	Mean±SD			Sig.
	CDT Group	EF Group	Control Group	
Age (y)	73.9±5.5	73.8±3.9	73.7±4.4	0.99
Height (m)	1.68±0.06	1.64±0.05	1.65±0.06	0.33
Weight (kg)	73.5±15.1	63.2±8.7	70.8±14.2	0.2
ABC	85.6±7.2	85.1±7.6	86.6±7.9	0.93
MMSE	25.1±2.7	24.1±1.9	24.9±2.1	0.70
BBS	46.7±3.9	44.0±5.6	44.9±5.2	0.47
6 min walk (m)	473±59	454±62	465±75	0.86

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Y: year; m: Meter. Activities-specific Balance Confidence (ABC) Scale is a 16-item questionnaire/survey. Each item is rated from 0% (no confidence) to 100% (complete confidence). Berg Balance Score (BBS) is a 14-simple balance-related tasks. Mini-Mental State Examination (MMSE) is a brief quantitative measure of cognitive status in adults and included a 30-point questionnaire. CDT: Cognitive Dual-Task training; EF: Executive Function training.

left sides demonstrated no statistically significant change between pre- and post-training measures. This study is in line with the previous studies [15, 19] indicating that walking and postural performance are affected by the cognitive

**Table 2.** Interaction of group/training on muscular EMG activations (%MVIC) during the stance phase of normal walking and Dual-Task walking

Condition	Muscle	Mean±SD					
		CDT Group		EF Group		Control Group	
		Pre	Post	Pre	Post	Pre	Post
Normal walking	TA-Right	50.5±15.5	34.2±12.6 <sup>ab</sup>	42.1±7.9	41.0±5.8	46.6±9.8	44.1±12.7
	Gas-Right	41.5±9.2	45.9±5.4	39.3±8.1	45.5±9.3	39.4±10.7	42.07±16.1
	VL-Right	40.1±9.7	37.3±8.5	39.1±14.2	43.2±14.6	36.8±7.1	43.4±11.9
	TA-Left	43.2±6.8	44.1±6.9	41.9±9.7	50.2±9.8	44.7±7.6	43.9±10.0
	Gas-Left	40.4±6.8	45.8±13.6	60.5±64.3	46.0±13.2	41.2±10.0	38.9±15.7
	VL-Left	41.2±12.4	43.8±15.0	47.3±30.8	42.3±9.9	40.0±8.9	39.0±11.5
DT walking	TA-Right	47.1±11.9	38.1±13.3	47.1±9.7	46.7±11.3	47.2±6.6	42.6±11.2
	Gas-Right	39.8±7.5	43.2±9.9	43.1±9.2	42.8±12.5	43.1±9.5	37.6±13.9
	VL-Right	48.7±13.2	38.1±13.3 <sup>a</sup>	48.5±10.5	39.1±13.2 <sup>a</sup>	47.8±13.2	42.2±13.4
	TA-Left	51.2±9.9	44.8±9.8	50.0±8.8	49.7±7.3	44.3±7.5	42.7±7.2
	Gas-Left	46.7±10.5	46.8±9.7	45.1±12.3	46.7±14.6	50.9±12.0	37.9±12.1
	VL-Left	41.3±10.1	40.9±17.9	46.6±12.9	41.8±13.1	42.3±7.9	41.9±7.5

PHYSICAL TREATMENTS

<sup>a</sup>Statistical differences between pre-post training; <sup>b</sup>Statistical differences between training groups and the control group. CDT: Cognitive Dual-Task training; EF: Executive Function training; VL: Vastus Lateralis; TA: Tibialis Anterior.

**Table 3.** Interaction of group/training on muscular EMG activations (%MVIC) during the swing phase of normal walking and DT walking

Condition	Muscle	Mean±SD					
		CDT Group		EF Group		Control Group	
		Pre	Post	Pre	Post	Pre	Post
Normal walking	TA-Right	49.2±10.7	48.0±11.9	50.3±12.4	54.6±12.8	53.0±11.1	60.3±10.3
	Gas-Right	41.4±13.5	47.5±17.6	44.7±14.3	41.7±16.0	42.7±11.9	41.9±8.3
	VL-Right	41.3±10.2	47.7±6.2 <sup>a</sup>	44.2±14.1	54.4±14.4	49.6±9.9	46.0±7.8
	TA-Left	51.7±11.2	52.1±4.5	50.9±12.2	54.9±7.1	54.9±10.4	53.4±10.8
	Gas-Left	44.4±10.3	49.4±10.5	40.7±16.4	42.3±11.4	40.6±19.3	38.3±12.2
	VL-Left	48.7±9.1	49.4±10.9	45.4±17.1	55.4±14.6	48.0±9.6	51.3±8.9
DT walking	TA-Right	47.7±10.6	49.3±10.9	51.6±5.9	57.5±10.6	53.9±8.5	50.5±12.0
	Gas-Right	44.4±8.8	40.8±19.0	48.9±17.9	48.7±21.7	45.1±12.2	43.0±13.2
	VL-Right	39.1±5.2	52.0±10.8 <sup>a</sup>	45.8±11.5	56.3±11.8 <sup>a</sup>	52.1±5.6	49.5±7.8
	TA-Left	47.9±11.4	54.9±10.1	48.3±10.3	56.3±9.9	52.5±12.8	53.6±12.1
	Gas-Left	42.9±11.3	40.3±11.7	39.7±13.7	54.0±9.8 <sup>ab</sup>	43.5±10.9	40.3±9.8
	VL-Left	44.7±10.4	41.5±16.8	46.8±16.4	55.4±11.9	46.4±11.4	46.9±11.3

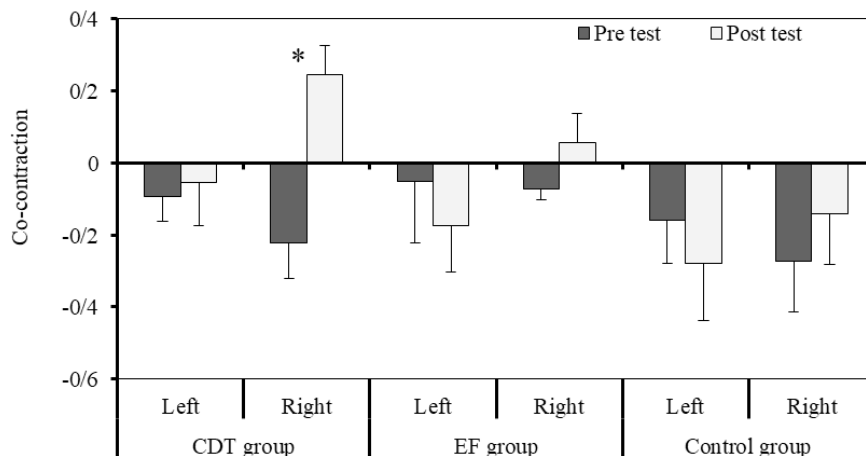
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<sup>a</sup>Statistical differences between pre-post training; <sup>b</sup>Statistical differences between training groups and the control group; CDT: Cognitive Dual-Task training; EF: Executive Function training; VL: Vastus Lateralis; TA: Tibialis Anterior.

intervention (CDT and EF training programs) in older adults with balance impairment. In both CDT and EF groups, the amplitude of EMG activity of the right VL muscle during the swing phase of DT walking in the post-test was higher than that in the pre-test. Also, in the EF group, the amplitudes of EMG activity of left Gas muscle during the swing

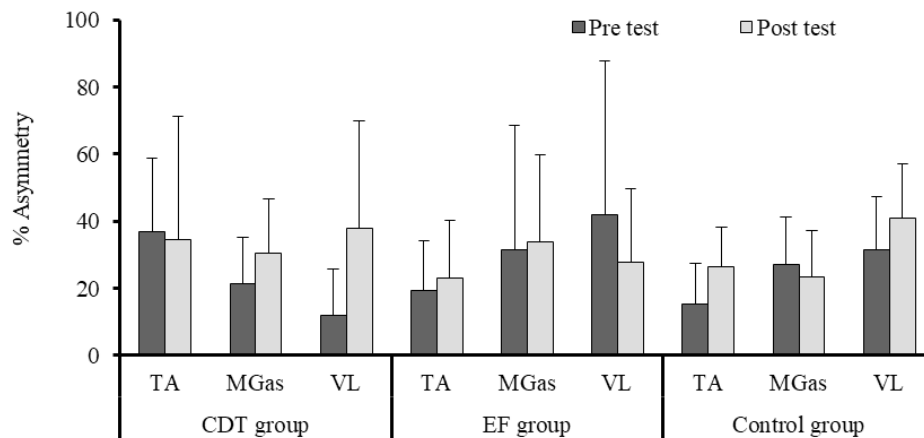
phase of normal walking in the post-test were higher than that in the pre-test.

In the CDT group, right ankle co-contraction during the stance phase in the post-test was statistically different than that in the pre-test. However, as agonist/antagonist co-activity typically decreases with motor learning



PHYSICAL TREATMENTS

**Figure 1.** Ankle joint co-contraction during pre- and post-tests of the stance phase of normal walking in three groups CDT: Cognitive Dual-Task training; EF: Executive Function training; Values are expressed as Mean±SD.



## PHYSICAL TREATMENTS

**Figure 2.** Muscular Electromyography asymmetry during pre- and post-tests of the stance phase of normal walking in three groups CDT: Cognitive Dual-task Training; EF: Executive Function training; Values are expressed as Mean $\pm$ SD.

and training [33], a change in muscular pattern, due to an improvement in inter-muscular coordination, was expected in the CDT group after the training period [34]. These changes suggest that motor strategy would be re-organized to optimize the muscular effort, by maximally directing agonist activity to generate movements against the external load in the direction of the trajectory requested. Therefore, decreased antagonist activity (TA activity) allowed an improvement in the walking efficiency level during the push of phase in the ankle joint. Compared to young adults, older adults demonstrated lower joint power during the push-off phase of walking [3, 7, 8]. In the present study, this rearranged motor strategy adopted by the CDT group after training protocol increased the effectiveness of the push movement in older adults during walking. In spite of higher walking velocity in the EF group, the right and left ankle co-contraction demonstrated no statistically significant change between pre- and post-training measures. A possible justification for this observation is that in order to avoid postural instability and falls, the aging body is likely to develop compensatory strategies; for instance, when exposed to changes in their base of support, older adults 'co-contract' or co-activated the muscles around the ankle joint [35]. Muscle co-contraction refers to the simultaneous contraction of the agonist and antagonist muscle about a joint, which is often associated with stiffening of the joint [36]. In addition, increased co-contraction in older adults might be related to the increased cost of walking [32]. Due to the increase in walking velocity in EF groups, unchanged ankle co-contraction after training protocol indicated an improvement in gait efficiency.

In all three groups, muscular EMG asymmetry demonstrated no statistically significant change between pre- and post-training measures. These findings are inconsistent with other reports demonstrating that gait asymmetry (in Spatio-temporal walking parameters) is decreased by the cognitive intervention [15]. Azadian et al. showed that EF training compared to CDT training appears to have a more significant impact on the symmetry and coordination of gait [15]. These may be due to different methodologies that were used in these studies compared to our study.

A major limitation of the present study was the sample size. Another limitation was that only male adults were represented in the study; thus, generalizations cannot be made over female adults, these can be open questions for future investigations.

## 5. Conclusions

Overall, all experimental groups showed improvement in gait efficiency especially on muscular activation that was associated with momentum-generating capacity [9]. However, in the EF group, walking velocity improved more than those in the CDT training group. This intervention can offer a feasible public health approach for reducing falls in older adults.

## Ethical Considerations

### Compliance with ethical guidelines

The research was approved by the Ethics Committee of Ardabil University of Medical Sciences (Code:



IR.ARUMS.REC.1395.77) and was registered at the Iranian Clinical Trial site (Code: IRCT2016110230657N1)

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### Authors' contributions

Conceptualization, methodology, formal analysis, investigation, data curation, writing: Elaheh Azadian; Visualization, editing of manuscript: Amir Ali Jafarnejadgero.

### Conflict of interest

The authors declared no conflict of interests.

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