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Original research

The effect of working memory intervention on the gait patterns of the elderly

Elaheh Azadian [a, *], Mahdi Majlesi [b], Amir Ali Jafarnezhadgero [c]

[a] Department of Motor Behavior, Faculty of Humanities, Islamic Azad University, Hamedan Branch, Hamedan, Iran
[b] Department of Sport Biomechanics, Faculty of Humanities, Islamic Azad University, Hamedan Branch, Hamedan, Iran
[c] Department of Physical Education and Sport Sciences, Faculty of Educational Science and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran

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A B S T R A C T

Introduction: The purpose of this study was to evaluate the role of working memory (WM) training on walking patterns in elderly people.
Methods: 20 elderly adults were selected and assigned randomly to two groups: WM training group and control group. WM training group received 6 weeks of computerized training on various spatial and verbal WM tasks. The spatial-temporal parameters, the ground reaction force and the timing activity of muscles in pre-posttest and in a follow-up were taken.
Result: The results indicated that a significant change in gait speed, double support time and stride time ($p < 0.05$). Alternations in ground reaction force (GRF) components were found significant. Timing of muscle activity also showed non-significant change after WM intervention.
Conclusion: Based on the results of this study, it can be concluded that WM intervention can be applied to improve gait parameters. The improvements in vertical ground reaction force after training may result in an increase upright stability and a decreased in rate falls.

1. Introduction

People's ability to walk and perform simultaneous tasks, such as talking or bypassing obstacles requires quite complex behavior. Falling is one of the most common problems affecting the elderly when walking, and almost 50% of people over the age of 80 experiences a fall at least once a year (Walshe et al., 2015). There are several risk factors related to falling such as muscle strength, motor function, postural control, and as Salthouse (2012) suggests, a cognitive decline.

According to current reports, falling is associated with changes in the prefrontal cortex and areas of the brain related postural control (Herman et al., 2010; Huxhold et al., 2006). Executive function includes a series of cognitive processes such as planning, coordinating task and multitasking, exerting inhibitory control, decision making and working memory (WM). Each of these skills individually, or in combination, is essential in carrying out daily activity (Stuss and Alexander, 2000). Also WM was associated with postural control and mobility (Gothe et al., 2014). Impairment of working memory may impact one's ability to walk efficiently and safely (Van Iersel et al., 2006).

Several studies have shown that reduced capacity of WM, decreases gait speed and weakens performance in complex movements, reduces ability to respond to environmental changes (such as obstacles, uneven surfaces), increased walking variability (Hausdorff, 2007; Hausdorff et al., 2001; Van Iersel et al., 2006; Verghese et al., 2009b) and the compensatory responses among the elderly which can lead to repeated fall experiences (Allali et al., 2008; Ble et al., 2005; Clouston et al., 2013; Hausdorff et al., 2005; Hausdorff JM, 2006; Herman et al., 2010). The results of these studies provide evidence in support of a relationship between walking and fall with specific cognitive factors (Holtzer et al., 2006).

Several studies have reported that falling is associated with changes in some gait parameters. Slow gait speed and reduced stride length, increased step width, and prolonged phase of dual reliance are related to falling (Guralnik et al., 1995; Verghese et al., 2009a; Yogev et al., 2007), while no relationship has been found between kinetic variables and timing of muscle activity. Therefore, gait assessment is one of the main recommendations for assessing risk factors for falling and prevention of falling. Also, a few studies

* Corresponding author.
E-mail addresses: azadian1@yahoo.com (E. Azadian), majlesi11@gmail.com (M. Majlesi), amiralijafarnezhad@gmail.com (A.A. Jafarnezhadgero).

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conducted on the effect of cognitive training on gait characteristics. The results of these studies was contrary, for example, Verghese et al. (2010) and Li et al. (2010) showed that cognitive training can affect gait speed and balance, but the results of Smith-Ray et al. (2013) study don't showed any improvement in gait speed.

The ability to appropriately activate muscles is a prerequisite for generating muscle moments necessary for walking (Horstmann et al., 2013). Measurement of ground reaction forces could be used to evaluate the body's control of its center of gravity and to provide information on postural control during movement and gait stability (Wollesen et al., 2015). In addition, evaluation of the timing of muscles activation ('on-off' pattern) accounts for clinical application in walking pathology (Benedetti et al., 2012). Thus, it would appear to be of both clinical and public health importance to identify factors that might be precursors to compromised lower extremity function (Guralnik et al., 1995).

Therefore, our research question was whether intervention training of working memory can improve gait parameters in elderly with balance impairment? Reports on the impact of cognitive intervention of walking are conflicting and there is a lack of research on kinetics and timing of muscle activation, so this study aimed to investigate the effect of WM intervention on spatial-temporal parameters, ground reaction force and timing of muscle activation.

2. Materials and methods

2.1. Participants

Participants in the study were 20 male senior adults, selected through purposive sampling from among all available adults. Those who scored less than 52 (out of a total of 56 points) on the Berg Balance Score (BBS) and/or completed a 10-m walk with a self-selected gait speed of 1.1 m/s or less were considered balance impaired (Silsupadol et al., 2009). Those who scored less than 24 on the Mini-Mental State Examination (MMSE) and scored less than 45 on the BBS (Berg et al., 1991) were recruited for the study.

Participants were assigned to working memory training (WM) group and a no-treatment control group, by used simple randomization (Fig. 1). None of the participants reported any neurological or vestibular disorder or orthopedic condition, including lower limb injury in the six months prior to data collection. All participants had normal or corrected-to-normal vision. Gait and cognitive characteristic in all participants were measured three time, pre-post and two months after intervention. The study was approved by the research council of the Hamedan branch of Islamic Azad University and subjects were informed of the nature and aim of the study and signed an informed consent form.

2.2. Intervention

Participants received remediation three times weekly for six weeks. The first training session involved teaching basic computer skills, such as how to use a mouse. The sessions included 45-min training program, during which each individual started training according to their progress in the previous session, so each person practiced based on their own particular strengths and weaknesses. Each training session included a mixture of 20 tasks that had been translated and designed by Sina Institute of Psychology, Tehran, Iran, from Mindfit (Verghese et al., 2010).

Working memory training included visual, auditory and stabilized tasks each of which contained three parts related to numbers, letters, and shapes. Each task had nine levels of difficulty that increased based on the number of stimuli presented. In the working memory training, stimuli were presented for approximately one second after which they faded and then were presented on a monitor that contained nine irrelevant stimuli (numbers, letters, and shapes). As the level of difficulty increased, the number of stimuli presented would also increase. The participants had to identify the names of the stimuli presented in order and/or in reversed the order from last to first (forward and backward manner). The stabilization phase included nine circles where the stimuli were present and then faded and the participants had to identify the names and the location of the stimuli. At the end of each daily training routine, participants could compare their performance against a table that described their progress.

2.3. Outcome measures

2.3.1. Spatial-temporal examination

Three-dimensional lower-body kinematic data was collected with the Plug in Gait marker set for identifying the heel contact and push off of gait cycle (Meyns et al., 2012). A total of 16 retro-reflective markers were positioned on the skin overlying specific bony landmarks or anatomical positions on the lower body. Reflective markers were attached bilaterally to lower limbs using the plug-in gait marker set model, including: anterior-superior iliac spine, posterior-superior iliac spine, lateral epicondyle of the knee, lower lateral one-third surface to the thigh, lateral malleolus, lower one-third of the shank, over second metatarsal head and on the calcareous. All subjects were instructed to walk at a self-selected speed along the 12 m walkway and to practice until they could make consistent and natural contact with both force plates. Six walking trials were performed and a 2-min rest was allowed between conditions. A trial was accepted when subjects walked with no visible alteration in gait mechanics; whereas, it was excluded in case the foot was placed on the edge of the force plate, results were averaged to yield representative values (Jafarnezhadgero et al., 2017). The tested spatial-temporal variables were stride time, double support time (phase of dual reliance) and gait speed (Verghese et al., 2009a).

2.3.2. Ground reaction force examination

Measurements of Ground reaction force (GRF) were taken using a piezoelectric force plate embedded in the middle of the walkway. The raw force plate signal was amplified and digitized at 1 kHz. Dependent variables from the GRF data were calculated from the raw force channels and filtered with a zero-lag low-pass Butterworth Filter at a cutoff frequency of 20 Hz. All forces were normalized according to the subject's body weight (Damavandi et al., 2012).

As shown in Fig. 2 below, three peaks were identified as follows in the vertical ground reaction force: the first peak, or weight acceptance peak force (Fz_{p1}), the second peak, or push-off peak (Fz_{p2}), minimum between the peaks (Fz_{min}) and weight acceptance peak rate, calculations are shown in Fig. 2 (A). Calculations were also made for two peaks in the anterior-posterior, including braking peak (Fy_{p1}) at the first half of the stance phase and propulsive peak (Fy_{p2}) at the second half of the stance Fig. 2 (B). One peak was calculated in the Medial-lateral direction (Fx_p) during the stance Fig. 2 (C). (Castro et al., 2013).

2.3.3. Electromyography examination

The following three muscles were considered on either side of each subject: gastrocnemius medialis, vastus lateralis and tibialis anterior. Ag/AgCl electrode pairs (bipolar configuration; inter-electrode distance, center to center, was 22 mm) were positioned on the skin after careful shaving and cleaning of the area with an abrasive cleaner and alcohol swabs to reduce any skin impedance. Electrodes were placed over the muscle belly, parallel to orientation

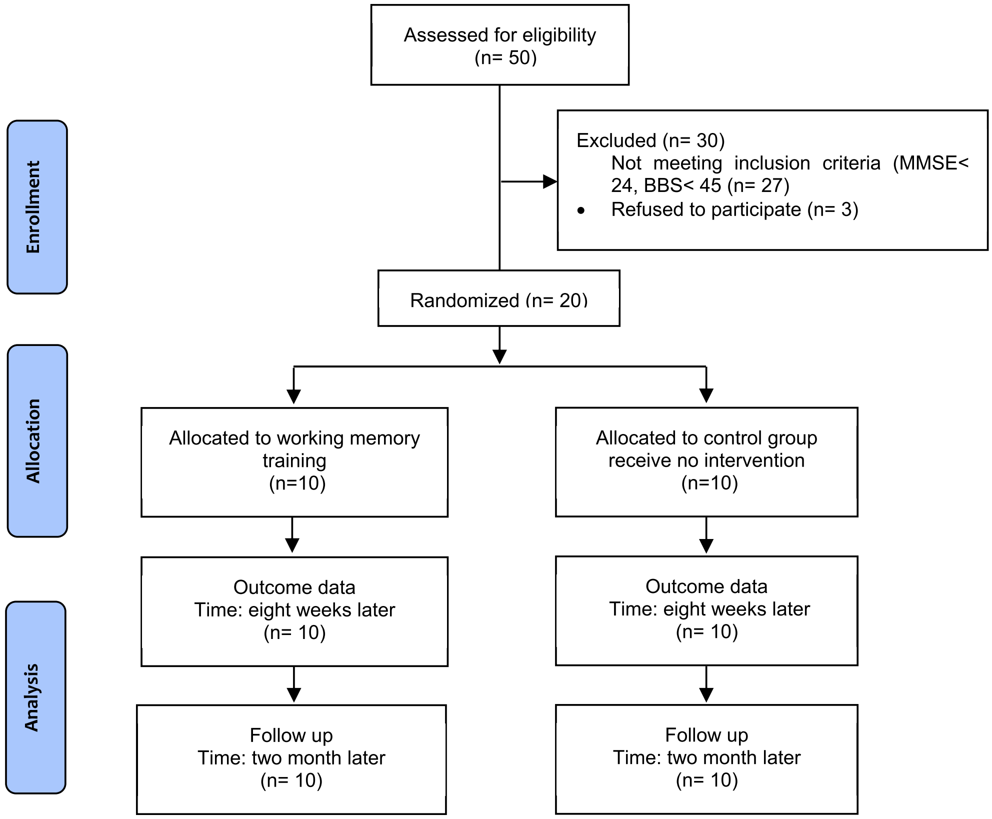

Fig. 1. Flow diagram of participant progress.

of the muscle fibers, and all procedures for EMG recording were conducted according to SENIAM criteria (Hermens et al., 2000).

The signal was amplified using a sixteen-channel system (BTS FreeEMG 300, Milan, Italy), at a sampling rate of 1200 Hz. EMG data were high-pass filtered at 20 Hz and full-wave was rectified prior to the calculation of variables. The high-pass filter was utilized to remove movement artifact and the DC bias (O'Connor et al., 2006). The mean amplitude was calculated for each stride, as well as for onset and offset of activity for each muscle. In order to determine evaluations for onset and off-set of muscle activity, the rectified signal was low-pass filtered at 24 Hz and the amplitudes were normalized to the highest peak from the three neutral condition trials for each subject. Thresholds for onset and offset were set at 10% of the peak. Linear envelopes were also created by filtering the rectified signal with a 12 Hz low-pass filter to enable illustrations. EMG data were time-normalized to 100% of a full stride (right heel-contact to right heel-contact) (Horstmann et al., 2013; Schimidt et al., 2014).

2.3.4. Additional variables

At the beginning of the study, a number of measures were taken to ensure comparability between groups (Table 1). Participants completed questionnaire balance confidence (Activities-Specific Balance Confidence scale: 15), Wechsler Adult Intelligence Scale Digit Symbol Substitution Test was run to estimate working memory status and physical fitness was measured using the 6-min walk test. There were no significant differences between group pre-training of these measures. BBS and Wechsler Adult Intelligence Scale Digit Symbol Substitution Test were readministered at the end of intervention and follow-up for evaluating the effect of training on balance and fall risk and to estimate working memory status.

2.4. Statistical analysis

Repeated measure ANOVA was used to compare groups on the research variables. In this study, two between-group factors (WM and control groups) and three within-subject factors, including trainings (pre-test, post-test, and follow-up levels), as well as the factor of foot (with the right and left legs) were considered. The parameters of spatial-temporal, GRF, and timing of muscle activity were each analyzed separately. Data were analyzed using SPSS software with a significance level of $\alpha = 0.05$.

3. Results

3.1. Spatial-temporal parameter

The results were indicative of a significant decrease in main effect of stride time ($p < 0.001$, F (2,17) = 10.47, ES = 0.4) after WM intervention. The results of a pairwise comparison demonstrated significant differences between the pre-test with the post-test, and follow-up test. The multivariate test showed that there is a significant interaction between the factors of time * group on the stride time (P = 0.007, F (2,17) = 6.8, ES = 0.45). Stride time in the post-test showed a significant decrease of about 25% and 12% compared to the values obtained in the pre-test and in the control group respectively, while this amount showed a non-significant change in the follow-up test (Fig. 3 (A)).

Also, in the variable of stride time, the results indicated that there was significant increase in main effect of gait speed ($p < 0.001$, F (2,17) = 10.81, ES = 0.37) after WM intervention. Interaction between factors of time * group on the gait speed (P = 0.002, F (2,17) = 9.75, ES = 0.53) is significant. Based on the results, after implementation of working memory training, gait

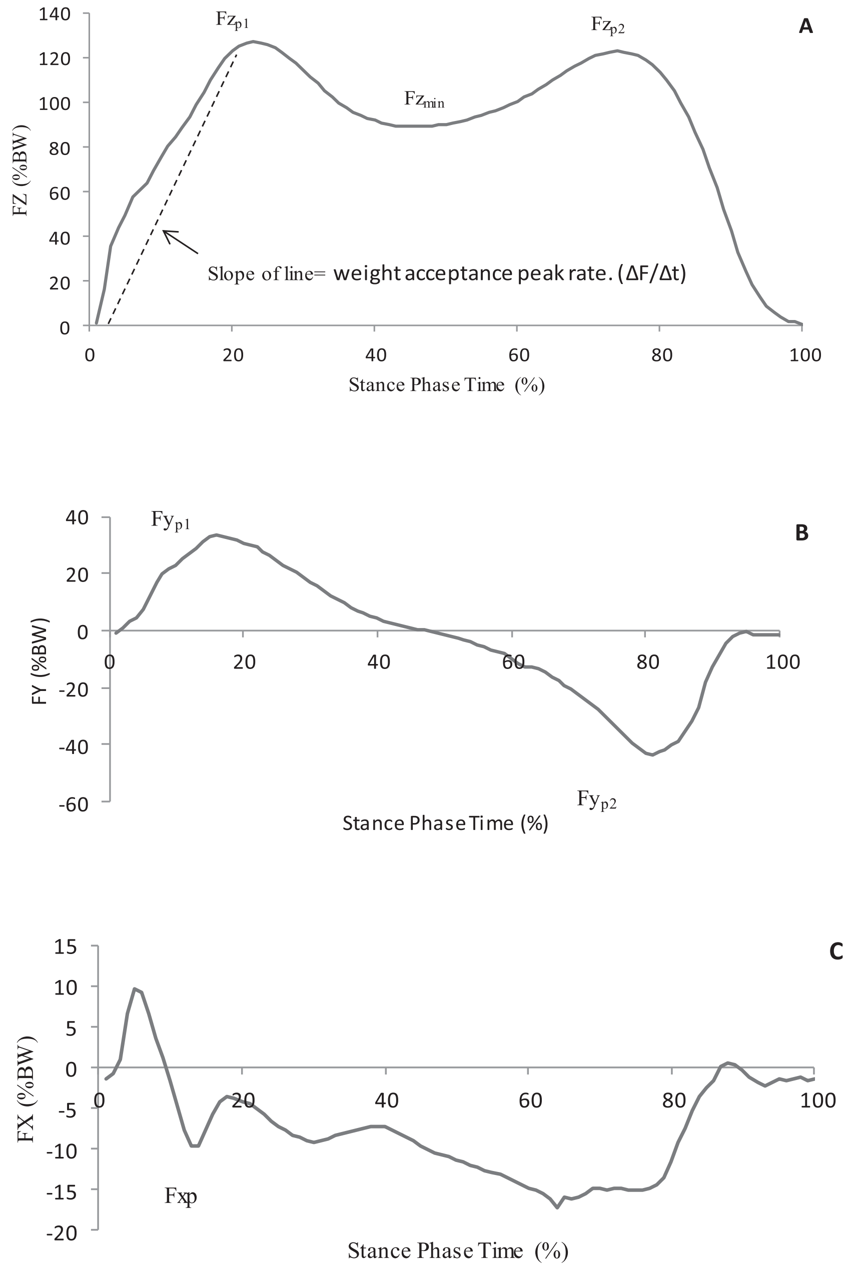

Fig. 2. This data was obtained from the experimental group. Three peaks were identified in the vertical ground reaction force (A), and weight acceptance rate is defined as the rate of change (ΔF/Δt) of the ground reaction force between initial contact and weight acceptance peak force. Two peaks were identified in the anterior-posterior ground reaction force (B), and one peak was calculated in the Medial-lateral direction. Abbreviations; Fz_{p1}: weight acceptance peak force, Fz_{p2}: push-off peak, Fzmin: minimum between the peaks, Fy_{p1}: braking peak, Fy_{p2}: propulsive peak, Fx_p: Medial-lateral direction.

speed in the WM group increased significantly about 22% as compared with the pre-test; whereas, it showed no significant changes in the follow-up test compared to that in the post-test. The result of comparison of gait speed in the WM group and the control group showed that gait speed increased about 11% in WM group as compared to that in control group which was significant in the post-test but it was not statistically significant in follow up test (Fig. 3 (B)).

The result of main effect at the time of double support showed no significant changes from the pre-test after WM group intervention ($p = 0.36$, $F = 1.08$, $ES = 0.11$). However, interaction between the factors of time * group was significant ($p = 0.04$, $F = 3.42$, $ES = 0.31$). Therefore, based on the results of the factor analysis, it could be argued that training caused a reduced double support time in WM group as compared with the obtained time the control group (Fig. 3 (C)).

3.2. Ground reaction forces

Results of the main effect of ground reaction forces indicated that the time had a significant effect on Fzp1 ($p = 0.02$, $F = 5.19$) and on Fzmin ($p = 0.008$, $F = 6.88$), however no significant changes were observed in the other GRF variables. The within-group comparison showed that in comparison with the pretest ground reaction forces in WM training group increased more significantly in Fzp1 and in Fzmin than that in the pre-test. But, interaction

Table 1
Participant characteristics per group.

	WM		Control		Sig
	M	*SD*	*M*	*SD*	
Age (y)	73.8	4.05	73.7	4.4	0.99
Height (m)	1.64	0.05	1.65	0.06	0.33
Weight (kg)	63.2	8.7	70.8	14.2	0.2
ABC	85.1	7.6	86.6	7.9	0.93
MMSE	24.1	1.9	24.9	2.1	0.7
BBS	44.8	5.4	45.0	5.3	0.47
6 min walk	454	62	465	75	0.86

Note. Abbreviations; M: mean; SD: standard deviation; 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 30-point questionnaire.

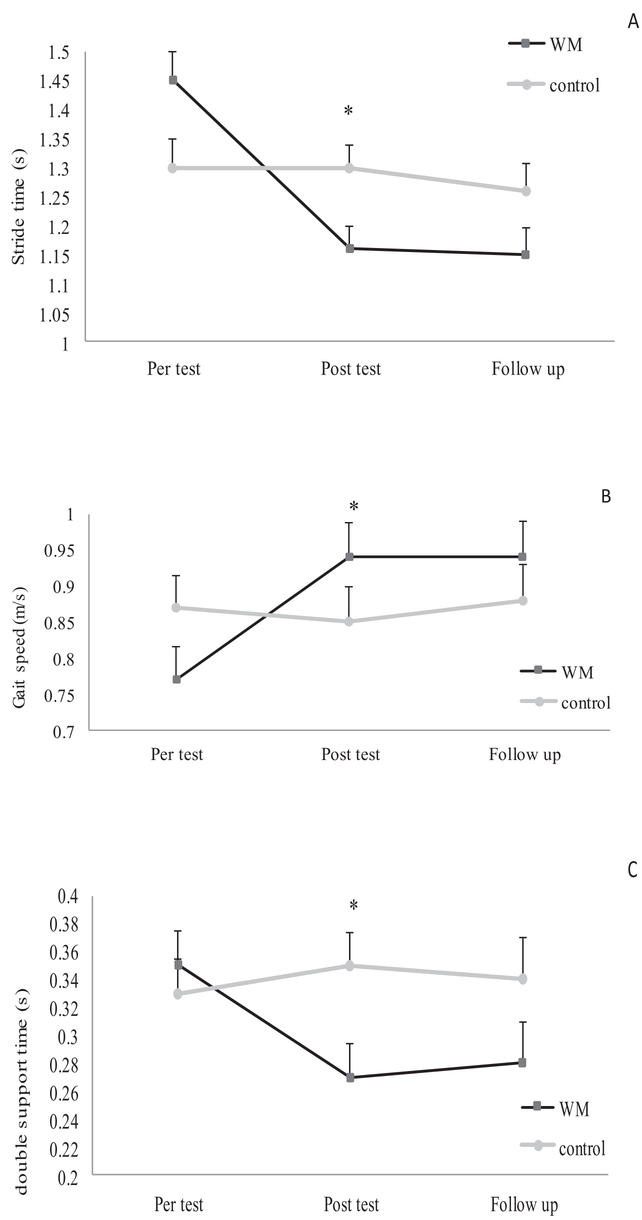

Fig. 3. Interaction between training and groups in and stride time (A), gait speed (B) and in double support time (C).

between the factors of time * group was not significant in all variables of GRF. All this indicated that the differences between the two groups were not significant (Table 2).

Results for weight acceptance rate showed that training had no significant effect on this parameter ($p > 0.05$). Results of the main effect foot factor indicated an asymmetry in the right and left foot performance and the weight acceptance rate of the right foot was significantly smaller than that of the left foot ($p = 0.024$, $F = 6.3$, $ES = 0.3$).

3.3. Electromyography

Results for timing of muscle activity for tests on gastrocnemius medialis, vastus lateralis and tibialis anterior muscles showed that for a self-selected gait speed, timing of muscle activity indicated no significant change in evaluations taken before and after the cognitive intervention.

3.4. Additional measures

The result showed that after the training sessions, the values of Digits Wechsler increased significantly in WM training group; whereas, for Backward Wechsler no significant changes were observed (Table 3). In addition, as shown in Table 3, the main effect of BBS increased significantly ($p = 0.007$, $F = 5.9$, $ES = 0.3$) in training group. Also, significant interaction between the factors of training and group ($P = 0.02$, $F = 4.01$, $ES = 0.2$) was found, indicating that the improvements on the BBS were comparable across the training groups.

4. Discussion

The purpose of this study was to investigate the effect of working memory training on gait pattern of the elderly with impaired balance. Few studies have been done to date on evaluation of kinetic parameters associated with falling in the elderly. In general, the results of our research indicated that Wechsler test, as indicator of working memory were improved after training. Also, improvements in gait parameters such as gait speed and stride time and double support time were also observed after WM training.

Assessment of the gait parameters during training and 2 months afterwards showed that WM training caused a significant increase in gait speed and a reduction in stride time and double support time. These results correspond with those obtained in a study by Verghese et al. (2009a,b). They showed that cognitive training enhanced gait speed. However, the study of Smith-Ray et al. (2013) revealed that cognitive training had a significant effect on the time of TUG test, while gait speed had not changed in the 10-m test. In this regard, no research was found to have used a follow-up test to study the long-term effect of trainings. Previous studies have emphasized increased double support and stride time, as well as reduced gait speed as the main risk factors of falling in the elderly and reflect a compensatory strategy to enhance gait stability and maintain the body's center of gravity within the range of base of support in such individuals (Verghese et al., 2009a; Yogev et al., 2007). Based on the results of the current research, it can be concluded that the WM training could be introduced as a new strategy to prevent falling by applying a positive impact on the risk factors for falling.

Also, the results showed that after WM training the amount of BBS increased by 3.66 point (from 44.78 to 48.44). Following Shumway-Cook et al. (1997) study, who suggests that in the BBS a one point change in the scores between 54 and 46, equals a 6%–8% increase in fall risk. The increased in BBS observed in the present study, implied a 22%–30% reduction in fall risk.

Table 2
Interaction between two factor group and training in ground reaction forces, mean (SE).

	WM group			Control group		
	Pre	Post	Follow up	Pre	Post	Follow up
Fz_{p1}	106.84 (1.7)	*110.81 (2.5)	*113.23 (2.7)	107.66 (1.8)	108.62 (2.7)	108.89 (2.9)
Fz_{p2}	110.5 (1.2)	111.03 (1.2)	111.17 (1.2)	108.89 (1.3)	108.75 (1.3)	109.24 (1.3)
Fz_{min}	92.37 (1.3)	*84.92 (2.4)	*82.53 (2.8)	90.42 (1.4)	87.52 (2.6)	88.77 (3.02)
Fy_{p1}	21.8 (1.9)	25.59 (2.1)	26.68 (2.3)	33.3 (1.99)	24.99 (2.3)	25.18 (2.4)
Fy_{p2}	30.7 (2.06)	35.97 (2.4)	37.22 (2.3)	30.79 (2.2)	30.65 (2.5)	30.5 (2.5)
Fx_p	9.73 (0.83)	9.75 (0.86)	8.93 (0.88)	9.57 (0.89)	9.16 (0.91)	8.78 (0.93)
Loading rate	4.26 (0.36)	5.49 (0.43)	5.58 (0.44)	4.98 (0.38)	4.91 (0.46)	4.9 (0.47)

Note. * denote statistical differences between pre-test.

Table 3
Interaction between two factor group and training in ground reaction forces, mean (SD).

	WM group			Control group		
	Pre	Post	Follow up	Pre	Post	Follow up
BBS	44.8 (5.4)	*48.4 (4.1)	*46.2 (4.3)	45.0 (5.3)	45.2 (5.5)	45.1 (5.7)
Wechsler forward	2.7 (0.9)	3.0 (1.1)	*3.44 (0.7)	2.5 (1.2)	2.6 (1.4)	2.5 (1.3)
Wechsler forward	2.2 (1.2)	2.6 (0.5)	2.5 (0.5)	2.5 (1.6)	2.4 (1.3)	1.3 (1.2)

Note. * denote statistical differences with pre-test.

The GRF represents a summation of forces from all segments of the body during locomotion and can provide a representation of center of mass control. Fzp1 component occurs shortly after the heel strike action. At this time, the body weight is transferred to the supporting leg and the body mass center is located at the highest point. The results of ground reaction forces show that after the cognitive intervention, amount of the vertical ground reaction forces significantly increased in Fzp1 and decreased in Fzmin in WM training group but there were not significant changes in compression with control group (i.e. at the mid-stance phase). Therefore, change of the ground reaction force in WM group may be associated with increased gait speed. As mentioned, the results of this study showed that gait speed increased significantly in WM group compared to control group. Andriacchi et al. (1977) showed that the vertical component of GRF and its loading rate are most important variables that related to gait speed. In line with the findings of Andriacchi study, with increasing gait speed the amount of Fzp1 increased was predictable.

Crowinshield and Brand (1978) found that adults over the age of 60 years showed a decrease in the peak hip joint moments, which was found to be related to the shorter stride length in the older adults. Therefore, it is possible that because of the decreased ability to control an upright posture of the upper trunk in the sagittal plane, older adults adopt a smaller stride length to reduce the ground reaction force. This reduction in ground reaction force, in turn, decreases the balance challenges to the upright stability of the upper body in the sagittal plane. The maintenance of the upright posture of the upper body prevents a potential fall preceded by an unsteady upper-body movement (Woollacott and Tang, 1997). Therefore, the measure in gait speed and GRF can be a sign of improving upright posture and thus reduce the falls risk in elderly people with balance impairment. Based on the results, despite the increase in GRF, loading rate did not change significant. This could be considered a positive sign that the rate of damage in the joints and muscles in elderly people had reduced.

Clinical implications, increase in weight acceptance rate and decrease in walking speed in balance impaired elderly may reduce the dynamic and passive mobility of the limbs' joint and muscle strength. Therefore, a regular rehabilitation program is suggested to enhance their functional abilities. This study suggested that WM intervention can improve cognitive function and therefore, may be increase automatic motor control (catching to tapping control) (Hausdorff et al., 2005) and so may decrease the fall risks. The limitations of the study are that the number of participants was small and that they were males. It is thus suggested that in future studies, walking with concurrent cognitive tasks be used to produce a challenging condition. Another limitation of this study which could have affected the generalizability of the findings may be due to the fact that female participants were not represented in the study as there were few of them willing to participate in the study.

5. Conclusion

This study was part of the research on the prevention of falls, aimed at presenting a comprehensive assessment of walking and the impact of working memory intervention on it due to a gap in the research related to cognitive interventions. Based on the results obtained in the study, WM training seems to effect to gait pattern and as a result, using this training method was found as helpful in reducing the risk of falling among elderly people with impaired balance. According to the research literature, older people should have a minimum level of cognitive capacity in order for physical trainings to be effective. Thus, it can be concluded that this method of cognitive intervention serves to enhance walking stability in the elderly with impaired balance by affecting their postural control.

Conflicts of interest

None of the authors have conflicts of interest to declare.

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Elaheh Azadian, PhD, is assistant professor at the Hamedan Branch of Islamic Azad University. Her research interests focus on the motor control of human movement.

Mahdi Majlesi, PhD, is assistant professor and dean of Faculty of Humanities at the Hamedan Branch of Islamic Azad University. His research interests focus on postural control and gait analysis in clinical population.

Amir Ali Jafarnezhadgero, PhD, is assistant professor and head of Department of Physical Education and Sport Sciences at the University of Mohaghegh Ardabili. His research interests focus on gait analysis in clinical population.