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Original Article

Effect of Eight Weeks of Sensorimotor Training on Knee Proprioception and Balance in Elderly Women: A Randomized Controlled Clinical Trial

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ABSTRACT

Background: A common issue experienced by the elderly, often due to specific diseases or the natural aging process, is a decline in balance and posture control. This study aimed to investigate the impact of an eight-week sensorimotor training program on the balance and proprioception of older women.
Methods: This study was a randomized controlled clinical trial conducted with the participation of older women aged 60-75 who frequented gyms in Urmia. From this population, thirty older women were randomly selected, meeting specific inclusion criteria, and were purposively divided into two groups: the experimental group (with an average age of 70.06±2.64 years, height of 156.13±6.14 cm, and weight of 73.11±7.81 kg) and the control group (with an average age of 67.93±2.12 years, height of 154.15±7.22 cm, and weight of 70.83±5.22 kg). The experimental group underwent an 8-week sensorimotor training program, consisting of three sessions per week, while the control group did not receive any training. Knee proprioception was assessed before and after the training by capturing photographs at a flexion angle of 40-60 degrees while standing. Additionally, static and dynamic balance was evaluated using the Sharpened Romberg Test and Time of Up and Go Test, respectively. The collected data were analyzed using ANCOVA, and the significance level was set at P≤0.05.
Results: After the training intervention, the experimental group exhibited a noteworthy decrease in the absolute error of angle reconstruction (P=0.001). Moreover, there was a substantial enhancement in both static balance, with eyes open and closed (P=0.001), and dynamic balance (P=0.001) compared to the control group.
Conclusion: the results of this study suggest that sensorimotor training can effectively enhance proprioception and improve balance in elderly individuals. This improvement is attributed to the positive impact of sensorimotor training, particularly in closed-chain movements, which strengthens the proprioceptive feedback from the muscles of the lower limbs. Consequently, this contributes to better balance and proprioception in older adults.

Background

Loss of balance is one of the common disorders in the elderly as a result of the aging process. With the advancements in healthcare and preventive measures, human life expectancy has increased, leading to a growing elderly population [1]. Aging is a natural phase in human life, marked by a decline in functional abilities and sensory perception. Among the common issues affecting the elderly, reduced balance, increased postural

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instability, and the risk of falls stand out [1]. As individuals transition into old age, various physiological systems, including musculoskeletal, vestibular, somatosensory, and visual systems, which are crucial for maintaining balance, undergo changes that make the elderly more susceptible to balance-related injuries, such as fractures and prolonged disability [1].

Balance is a complex motor skill that plays a vital role in preventing falls [2]. Researchers categorize the factors contributing to balance control issues in the elderly into two groups: external and internal factors [2]. External factors encompass elements like uneven ground and inappropriate footwear choices. Internal factors, on the other hand, are linked to physiological system dysfunctions within the body, such as diminished muscle endurance, restricted joint range of motion, and reduced visual, vestibular, and proprioceptive capabilities [2].

The proprioception provides information about the internal mechanical events of the body, i.e., the conscious and Proprioception refers to the body's ability to gather information about its internal mechanical processes. It encompasses both conscious and unconscious awareness of the body's position in space, including knowledge of joint angles (sense of position), perceiving changes in movement direction and speed (sense of movement), and understanding the exertion and weight during motion (sense of force). The accuracy of proprioception relies on the health of the sensory apparatus, including mechanoreceptors and the pathways connecting them from the periphery to the central nervous system [3]. Proprioception is essentially the amalgamation of sensory input from muscle receptors, tendons, joint capsules, ligaments, meniscus connections, and skin. These inputs collectively contribute to joint stability, posture control, and regulation of movement. Among these, muscle spindles are the primary source of proprioceptive feedback, playing a pivotal role in balance control [3, 4]. Consequently, it is essential to objectively evaluate and measure proprioception to identify the risk of falling. This, in turn, helps in employing appropriate treatment methods aimed at enhancing proprioception, balance, and posture control. Such interventions are crucial for preventing the risk of falls and preserving the elderly's functional independence in their daily activities [5].

In recent times, there has been growing emphasis on training approaches, specifically proprioceptive and neuromuscular training, as a means to enhance proprioception and balance in the elderly [6-9]. Janda introduced these training techniques under the term "sensorimotor training." Sensorimotor training represents a unique form of proprioceptive and balance training tailored for individuals dealing with chronic musculoskeletal pain syndromes. The underlying concept of this training approach shifts the focus from isolating and strengthening specific muscle groups around a joint to recognizing the central nervous system's pivotal role in regulating movement and orchestrating muscle activation in coordinated patterns to maintain joint stability [6, 10]. This form of training places challenges on the sensorimotor system, aiming to restore normal movement patterns, enhance dynamic joint stability, and alleviate stress on the joints [11].

Sensorimotor training involves the activation of various neural pathways, including the spinocerebellar, spinothalamic, vestibular spinal, and cerebellar vestibular tracts, which communicate with higher subcortical structures. These structures provide vital regulatory information to sustain balanced posture [10]. Research findings have indicated that traditional training methods such as resistance or stretching alone may not be sufficient to enhance the balance of elderly individuals with knee osteoarthritis. The incorporation of sensorimotor training into rehabilitation programs for such individuals has yielded more positive effects on balance and functional abilities [6]. In a similar vein, a study by Smith et al. examined the influence of cognitive exercises on the balance and gait of the elderly. The findings highlighted that cognitive exercise had a significant impact on enhancing balance and gait in elderly individuals [12].

Consequently, based on the limited studies available, sensorimotor training has shown promise in improving pain, mobility, and overall function by enhancing coordination, strength, muscle endurance, balance, flexibility, proprioception, and joint stability in patients and elderly individuals [6-9]. However, there remains a lack of comprehensive scientific evidence regarding the effectiveness of sensorimotor training on proprioception and balance in the elderly. Thus, the objective of this study was to investigate the impact of a sensorimotor training program on proprioception and balance in elderly women.

Methods

Design

The research design for this study is a randomized controlled clinical trial with a pre-test and post-test structure. It has obtained ethical clearance from the Research Ethics Committee of the Sports Sciences Research Institute under the reference IR.SSRI.REC.1400.1218 and has been officially registered in the Clinical Trial Registration Center of Iran under the registration number IRCT20200125046250N2.

Participants

The study's statistical population comprised elderly women aged 60-75 years who attended gyms in Urmia. Thirty elderly women were purposively selected based on specific inclusion criteria to form the sample. The inclusion criteria encompassed the following: age between 60 and 75 years, absence of medical conditions that could affect balance (e.g., Parkinson's disease, inner ear disorders, vestibular system disorders), no history of trauma, injury, or surgery, no diagnosis of osteoporosis or advanced osteoarthritis, no pain or movement limitations in lower limb joints as determined by a specialist, no history of diseases, fractures, or significant postural abnormalities that would contraindicate exercise, no medical conditions preventing participation, and the completion of an informed consent form [6].

Exclusion criteria involved a participant's unwillingness to continue in the study, absences from training sessions, and any injuries or illnesses that occurred during the study period [6].

From the pool of eligible participants meeting the inclusion criteria, 15 were randomly assigned to the experimental group, and 15 to the control group. Before the intervention, anthropometric measurements were conducted, including height and weight, and pre-test assessments of proprioception and static and dynamic balance. The experimental group then engaged in an eight-week sensorimotor training program, while the control group continued with their regular health care and daily activities. Following the completion of the training program, post-test assessments were conducted on all participants.

Sensorimotor Training Program

The sensorimotor training program was based on Janda's theory and involved three main components: static, dynamic, and functional exercises [10]. The experimental group completed this program over an 8-week period, with three sessions per week [13] (Table 1). The duration of each session started at 30 minutes and gradually increased following the principle of overload, ultimately reaching around 50 minutes in the final sessions of the program.

Each session began with a 5-minute warm-up period that included light aerobic activities, walking, and general stretching exercises. Subsequently, participants engaged in the specified exercises based on their training level, adhering to training principles. Finally, they concluded each session with a 5-minute cool-down period, which involved general stretching exercises and slow walking.

Measurement Tests

To assess knee proprioception, three markers were placed at the following locations: the upper quarter of the line connecting the trochanter major to the midpoint of the lateral knee joint line, the neck of the fibula, and the upper part of the lateral malleolus. An additional marker was attached to the iliotibial band and in the upper part of the popliteal pooch.

With the subject seated and the knee bent at 90 degrees, the test was performed in a closed-chain position with the sole of the foot in contact with the ground, and the hands resting on a support in front of them. The opposite leg was placed in a relaxed position with the knee bent. The subject was instructed to shift their body weight onto the tested leg while keeping their eyes closed. Starting from the neutral position, where the knee was at zero degrees, the subject was asked to move their leg to an angle between 40 and 60 degrees and hold this position for 5 seconds, then return the knee to the neutral position. The subject repeated this process three times, trying to maintain the same angle for 3 seconds during each repetition.

To capture the knee position for analysis, a digital camera was set up on a tripod at a distance of 2 meters and a height of 70 cm. Images of the subject's knee were then transferred to a computer, and the center of the markers in each image was connected by drawing straight lines. Using software such as Kinovea, the numerical values of the angles were calculated. The absolute error rate was determined by subtracting the tested angle's value from the value of the reconstructed angle for each repetition, and this was done without using a±sign [14].

Static balance was assessed using the Sharpened-Romberg Test, which has a reported reliability of 0.90-0.91 for trials with eyes open and 0.76-0.77 for trials with eyes closed. In this test, the subjects were asked to stand barefoot with one leg positioned in front of the other

Table 1: Sensorimotor training program

Stage	Exercise
Static (Weeks 1 to 2)	1. Jogging and stretching 2. Romberg stance / hard surface / open eyes / with & without disturbance 3. Romberg stance / soft surface / closed eyes / with & without disturbance 4. Marching stance / hard surface / open eyes / with & without disturbance 5. Marching stance / soft surface / closed eyes / with & without disturbance 6. Tandem stance / hard surface / open eyes / with & without disturbance 7. Tandem stance / soft surface / closed eyes / with & without disturbance 8. Static mini-squat / hard surface / open eyes / with & without disturbance 9. Static mini-squat / soft surface / closed eyes / with & without disturbance 10. Cool-down
Dynamics (Weeks 3 to 4)	1. Jogging and stretching 2. Half step / unstable surface 3. Shooting in front of Traband / soft surface / Internal, external, posterior, anterior directions 4. One leg stand / hard surface / throwing & catching the ball 5. One leg stand / soft surface / throwing & catching the ball 6. Forward lunge/ position: fixed / progress with the resistance band 7. Side lunge / position: fixed / progress with the resistance band 8. Single leg march in front of TheraBand / hard surface 9. Single leg march in front of TheraBand / soft surface 10. Cool-down
Functional (Weeks 5 to 8)	1. Jogging and stretching 2. Backward walk / open eyes 3. Squat against wall 4. Double leg squat / unstable surface 5. Dumbbell forward lunges 6. Climb and descent stairs 7. Climb and descent stairs from the side 8. Side to side single leg hops 9. Side to side single leg hops / throwing & catching the ball 10. Cool-down

Table 2: Demographic characteristics of subjects (n= 30; mean and standard deviation)

	Control (n=15)	Experimental (n=15)	T-test	P value
Age (year)	67.93±2.12	70.06±2.64	1.37	0.126
Height (cm)	154.15±7.22	156.13±6.14	0.84	0.411
Weight (kg)	70.83±5.22	73.11±7.81	0.78	0.463

Table 3: Results of covariance analysis regarding the absolute error of angle reconstruction, static and dynamic balance in the research groups

Dependent variable	Group	Pre-test M±SD	Post-test M±SD	F	P	η^2
Absolute angle reconstruction error (degrees)	Control Experimental	6.13±3.56 7.93±4.64	5.93±2.96 2.20±1.82	24.578	0.001	0.477
Static balance with eyes open (seconds)	Control Experimental	38.80±5.87 41.33±3.56	37.67±5.11 60.07±8.38	82.650	0.001	0.754
Static balance with eyes closed (seconds)	Control Experimental	6.73±2.76 8.80±3.26	6.00±2.14 41.73±3.33	108.91	0.001	0.976
Dynamic balance (seconds)	Control Experimental	11.13±1.84 12.80±3.05	11.33±1.95 7.67±2.33	21.856	0.001	0.447

and their arms crossed over their chest. The score was determined based on the time the subject could maintain this position with their eyes open and closed [15].

Dynamic balance was measured using the Timed Up and Go Test, which is considered to have a 99% reliability. In this test, the subject was instructed to rise from a chair without using their hands, walk along a 3-meter path, turn around, and return to sit in the chair as quickly as possible without running. The time taken to complete the test was recorded [15].

Statistical Methods

In this study, the t-test for two independent groups was used to compare the demographic information of the subjects in the two groups. To determine the effect of the independent variable, which was sensorimotor training, on the measured dependent variables (proprioception, static and dynamic balance), an analysis of covariance (ANCOVA) was employed. The pre-test data was included as a covariate to account for any pre-test effects.

Before conducting the ANCOVA, several assumptions were checked: Homogeneity of the regression slopes ($P>0.05$); homogeneity of variances (Levene's test), and normal distribution of the data (Shapiro-Wilk test) ($P>0.05$).

Effect sizes (reported as η^2) were used to quantify the magnitude of the independent variable's effect on the dependent variables. Typically, effect sizes are categorized as small (0.01), moderate (0.06), or large (0.14) [16]. Statistical significance was set at a 95% confidence level ($P<0.05$), and the data analysis was performed using SPSS version 20.

Results

Table 2 shows the subjects' demographic characteristics. The results of the independent t-test showed no significant difference between the two groups in terms of age, height, and weight ($P>0.05$).

The results of the statistical analysis indicated that sensorimotor training led to a significant reduction in the absolute error of angle reconstruction and a significant improvement in static balance with eyes open and closed and dynamic balance in the experimental group compared to the control group after the training intervention ($P\leq0.05$) (Table 3).

Discussion

The results of this study demonstrate that an 8-week sensorimotor training program, which encompasses static, dynamic, and functional proprioceptive training, significantly enhances balance in older women. These findings align with the results of previous studies by Westlake et al. [17], Sheikh et al. [18], and Papalia et al. [19]. However, there is a discrepancy with the study outcomes reported by Zemková et al. and Khajeh et al.

Zemková et al. suggested that sensorimotor training significantly improved visual feedback for postural control but did not increase static and dynamic balance [20]. On the other hand, Khajeh et al. found no significant improvement in the 60-degree knee angle error after eco-gymnastics exercises designed to enhance knee position sense in older women with osteoarthritis [21].

Several factors may contribute to this inconsistency. First, the effectiveness of the exercises and the methodology for assessing knee position sense may have varied across studies. In Khajeh et al.'s study, the knee position sense error assessment was performed in a seated position and an open chain movement. It is well-documented that proprioceptive accuracy is higher during closed-chain movements and weight-bearing activities [22]. These weight-bearing exercises are more effective in improving one's sense of joint positioning. Additionally, proprioception of foot joints is notably more accurate during weight-bearing activities than non-weight-bearing ones [22].

In the present study, most exercises involved closed-chain movements and weight-bearing activities, particularly in the functional step. Performing balance exercises in a closed chain position induces coordinated muscle contractions, leading to improved and organized function of skin, joint, and muscle mechanoreceptors. Consequently, this results in enhanced stability for individuals. Furthermore, proprioception and balance are closely intertwined [23]. The ability to maintain balance while standing heavily relies on assessing body imbalance. When standing, the body experiences minor imbalances, primarily around the ankle axis, often in the sagittal plane. Thus, the vestibular system and proprioception are more actively engaged during standing than other postures [24].

Most of the exercises in the sensorimotor approach adopted in this study were executed in a standing position. This emphasis on standing exercises is another reason contributing to the effectiveness of the training regimen in enhancing balance and proprioception.

According to Janda's theory, the human movement system relies on sensorimotor input to execute accurate movement patterns. This input assists in planning movement programs and precise movement patterns based on information the central nervous system receives, including data from sensory systems such as proprioception. When these systems function poorly for any reason, it can lead to alterations in movement patterns and the development of compensatory patterns, ultimately affecting posture and balance negatively [10].

Sensorimotor training enhances neuromuscular control, improving motor control and posture regulation [25]. The exercises implemented in this study, emphasizing correct movement patterns, appear to have positively impacted sensorimotor input in older people, consequently improving proprioception and balance. Sensorimotor training integrates bodily movements with automatic stability, progressing from static activities to dynamic and functional ones.

This training approach encompasses strengthening the neuromuscular and skeletal systems, primarily enhancing and developing central nervous system function through sensory awareness, coordination, motor control quality, and reprogramming [10].

Balance training can potentially decrease proprioceptive error by enhancing neuromuscular training [26]. Ahmed conducted a study comparing sensorimotor and traditional training effects on the balance of elderly patients with knee osteoarthritis. The results indicated that sensorimotor training was significantly more effective than traditional training in improving proprioception and balance among patients with knee osteoarthritis [6].

Maintaining balance while standing during activity necessitates muscle contractions and a complex interplay between the neuromuscular and skeletal systems [27]. Muscle mechanoreceptors play a crucial role in the active reconstruction of joint angles, while joint capsule mechanoreceptors contribute to the passive reconstruction of joint angles [25]. Research has demonstrated that as individuals age, arthritis symptoms may manifest, leading to compromised proprioception in affected joints. Maintaining balance relies on sensory input, decreasing sensory input can elevate the body's instability, resulting in heightened muscle engagement to sustain balance [28]. Hence, sensorimotor training with active movements can enhance muscle endurance and, in turn, improve proprioception during the standing test.

Limiting or eliminating visual input is another approach to enhance proprioception and balance [29]. In the sensorimotor training employed in this study, exercises like one-legged standing and balance board exercises with closed eyes were included. These activities enhance postural adaptability and pose challenges to the sensorimotor system. In general, alterations in the sensorimotor systems play a significant role in enhancing balance [30]. Different activities demand varying levels of sensorimotor processing. Motor skills like walking, sitting, and standing, which involve the lower limbs, necessitate substantial neuromuscular coordination and balance, all of which were addressed in the training.

Conclusion

One of the limitations of the present study was the use of a relatively small sample size. In experimental human studies, having a sample size of n=30 for both the experimental and control groups is typically required to approach a distribution similar to 'z' rather than 't'. Another limitation was the lack of blinding of the participants to the study. To ensure transparency and gain the participants' informed consent, the study's objectives, intervention type, and testing procedures were thoroughly explained to each participant at the outset. Additionally, the absence of a follow-up test was another limitation. Therefore, we could not determine whether the improvements observed in the experimental group would be sustained over time. Despite these limitations, the study's findings suggest that eight weeks of sensorimotor training can enhance proprioception static and dynamic balance in older women. Consequently, it is recommended to consider such training as a safe and readily accessible intervention for older people.

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