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Differences in the effects of square stepping exercise and Otago exercise on dynamic balance based on body mass index in the elderly

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ABSTRACT

Background: The increasing elderly population in Indonesia face higher risks of balance disorders and falls, threatening independence. Exercise interventions, such as strength and balance training, can improve dynamic balance. This study aimed to analyze the differences in dynamic balance improvement between square stepping exercise and Otago exercise in older adults based on body mass index (BMI).

Methods: The sample was randomly divided into two groups: square stepping exercise (SSE group) and Otago exercise (OT group). Dynamic balance was assessed using the timed up and go (TUG) test, conducted before and after the intervention. This study used a 2×3 factorial experimental design with purposive sampling. Older adults aged 60–75 years with good cognitive and walking ability were included, while those with sensory impairments, mobility limitations, or lower extremity disorders were excluded. Sixty eligible participants were randomly assigned to either the SSE group (n = 30) and the OT Group (n = 30). Data were analyzed using a 2×3 factorial ANOVA, with statistical significance set at $p < 0.05$.

Results: This study found that both SSE and OT interventions significantly improved dynamic balance in older adults, as measured by pre- and post-intervention TUG test. Both groups showed reduced TUG test times: the OT group from 13.76 to 11.84 seconds, and the SSE group from 14.48 to 11.13 seconds. ANOVA analysis indicated that the type of exercise significantly affected dynamic balance ($F(1.54) = 4.515$; $p=0.038$), while BMI and its interaction showed no significant effect ($p> 0.05$).

Conclusion: Both exercises improved dynamic balance in older adults. However, the SSE group showed greater effectiveness than the OT group. Exercise type significantly influenced balance outcomes, while BMI had no significant effect.

Keywords: balance, dynamic balance, elderly, land-based exercise, Otago exercise, square stepping exercise.
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INTRODUCTION

The aging process is a condition in which the body's ability to repair itself and maintain physiological homeostasis gradually declines, making it unable to regenerate damage suffered, such as infections. This condition can impact the growing elderly population, with complex health issues such as chronic diseases, osteoporosis, disabilities, cognitive decline, and psychosocial changes leading to reduced functional status and even premature death.[1,2] Aging causes structural and functional decline across multiple organ systems including gastrointestinal, cardiovascular, respiratory, sensory, neurological, and musculoskeletal systems while also increasing risks of isolation and mental health issues, all of which can significantly reduce the quality of life in older adults. The musculoskeletal system, particularly the lower extremities, undergoes significant changes during the aging process.[3,4] Impaired postural control involving sensory, cognitive, and musculoskeletal systems highlights the importance of maintaining stability.[6] Balance disorders in older adults, caused by declines in sensory, cognitive, and musculoskeletal systems, increase fall risk and threaten mobility, independence, and safety.

The increase in fat mass proportion in the elderly is caused by many factors, including reduced daily physical activity, metabolic changes, and hormonal changes. There are common differences in body composition between older women and men, such as an increase in body fat percentage, reduced insulin sensitivity, decreased physical activity, metabolic changes, and hormonal changes that occur after menopause. These changes are largely influenced by hormonal changes (particularly a decrease in estrogen) and the associated metabolic consequences.[7,8] A sedentary lifestyle in older adults reduces calorie expenditure and accelerates muscle loss, increasing the risk of sarcopenia. Even with a normal or slightly elevated body mass index (BMI), fat accumulation can occur, leading to mobility decline and other health problems associated with excess body fat.[9] Such a lifestyle can lead to a decline in mobility, productivity, and the ability to interact with the environment among older adults.

Properly dosed and regular exercise is highly beneficial for maintaining for maintaining physical and mental health in the elderly. There are several exercises that can be done to improve postural balance, one of which is the square stepping exercise (SSE). This exercise can improve dynamic balance in the elderly because it involves the sensory system, namely the proprioceptive system in the joints, and the visual sensory system.[9] SSE helps improve balance in the elderly, supporting better mobility and independence. Research also shows it can enhance physical performance, including walking speed and postural stability. A randomized controlled pilot study found that the SSE, when performed in an early geriatric rehabilitation setting, helped improve various balance parameters and other physical functions in elderly patients.[10] The SSE includes various step patterns forward, lateral, and backward that enhance multisensory input essential for dynamic balance. This exercise enhances motor adaptation and cortical activation, which improves vestibular function, movement control speed, and information-processing efficiency. It also trains visual components by encouraging forward gaze and a wider visual field, enabling older adults to walk more steadily and confidently.

Another exercise that is necessary in maintaining balance and even reducing the risk of falls in the elderly is the Otago exercise (OT).[11] The balance exercises in the OT program aim to teach the body how to maintain balance, which makes it easier for the elderly to perform functional movements and prevent falls while moving.[12] OT are designed to improve strength, balance, and mobility in older adults and can be easily performed at home or in community settings with professional guidance. These exercises have been proven to enhance balance, increase confidence in daily activities, and reduce fall risk.[13] OT positively support physical changes in older adults through warm-ups that prevent injury and maintain flexibility, and strengthening programs that preserve leg muscle and bone health for independent mobility. Regular walking sessions done individually or in groups further enhance endurance by improving body temperature regulation and breathing.[14]

This study investigated differences between SSE and OT on dynamic balance in older adults based on BMI. Participants generally showed moderate fall risk at pre-test, and those with higher risk exercised under professional supervision. The research fills a gap by systematically comparing both programs effects on dynamic balance across BMI groups, including individuals with elevated fall risk.

METHODS

This study used a 2×3 factorial experimental design with purposive sampling. Conducted at Ngudi Waras and Sehat Sentosa Elderly Health Centers, Center of Java, Indonesia, from November to December 2024, it included elderly participants aged 60–75 years with good cognitive and walking abilities, while excluding those with sensory impairments, mobility limitations, or lower extremity disorders. Of the 120 older adults screened, 60 met the eligibility criteria and were included in the study. A total of 53 individuals were excluded due to sensory impairments, mobility limitations, lower extremity musculoskeletal disorders, or inadequate cognitive function, while seven eligible participants declined to provide informed consent.

Eligible participants were randomly assigned to the intervention groups using simple randomization. Written informed consent was obtained from all participants after they received a clear explanation of the study objectives, procedures, potential benefits, and risks, and participation was entirely voluntary. Participant characteristics included age, gender, and BMI, and all individuals completed the timed up and go for testing before and after the intervention. The final sample was randomly assigned to either the SSE Group (n=30) or the OT group (n=30). The OT Group consisted of warm-up, strengthening, balance, and walking exercises performed three times per week for two weeks, each with 10 repetitions.

The TUG test is a practical and widely used clinical tool for assessing dynamic balance. It provides a simple method to evaluate lower limb function, mobility, balance, and the risk of falls in various populations.[15,16] TUG test with a cutoff score of 13.5, yields a sensitivity of 86% and a specificity of 87% in identifying balance deficits among community-dwelling adults.[17] The measurement procedure for the TUG test involves instructing the participant to rise from a seated position in a standard chair, walk a distance of three meters, turn around, return to the chair, and sit down again, with the total duration of the task recorded in seconds.[18] The test uses a ratio scale based on completion time, interpreted as follows: <10 seconds indicates normal mobility and independent outdoor activity, <20 seconds suggests mobility limitations affecting independent outdoor activity, and <30 seconds indicates a need for assistance when walking or using assistive devices. The analysis demonstrated excellent reliability, with test–retest and inter-rater ICC values of 0.982 and 0.995, respectively. The test–retest assessment showed $\alpha = 0.991$ (excellent), $p < 0.001$, and $r = 0.962$ (very strong correlation), while the inter-rater assessment yielded $\alpha = 0.997$ (excellent), $p < 0.001$, and $r = 0.990$ (very strong correlation). These results indicate that the TUG test possesses excellent test–retest and inter-rater reliability as a measure of dynamic balance and is therefore recommended for use in older adults.[19]

A microtoise stadiometer is a height measuring device typically used in medical or clinical settings. It consists of a measuring tape that can be pulled up or down, with a clear measurement scale for accurately checking a person's height.[20] A weighing scale was used to measure body mass with a certain degree of precision. These scales display measurement results in units of weight such as kilograms (kg) or pounds (lb). The BMI is a simple measure of weight status calculated as weight (kg) divided by height squared (m^2), with categories: <18.5 underweight, 18.5–22.9 normal, 23–24.9 overweight, 25–29.9 obesity class I, and >30 obesity class II.

The SSE involves movements of the lower limbs, following a square (box) walking pattern (**Table 1**). Participants

Table 1. Square stepping exercise routine

No	Movement
1	Walking Forward
2	Walking Backward
3	Walking to the Right Side
4	Walking to the Left Side

followed progressively complex stepping sequences in forward, lateral, diagonal, and backward directions, emphasizing accuracy, coordination, and visual guidance to enhance multisensory input. The SSE was conducted three times per week for six weeks, consisting of a 5-minute warm-up, patterned stepping exercises with 10 repetitions per sequence, and a 5-minute cool-down, as adapted from the protocol described by Shigematsu et al., which has been shown to improve dynamic balance and gait performance in older adults.[21]

The OT Program consisted of warm-up, strengthening, balance, and walking exercises (Table 2). Lower-limb strengthening focused on major muscle groups, including the hip abductors, knee extensors, and ankle plantar flexors, using body weight and ankle cuff resistance. Balance training included activities such as single-leg stance, backward walking, heel-to-toe walking, and controlled turning movements. The Otago exercise program was performed three times per week for six weeks, with each exercise repeated 10 times, followed by a cool-down session, based on the standardized protocol developed by Campbell and Robertson for fall prevention in older adults.[14]

All statistical analyses were conducted using the Statistical package for the social sciences (SPSS) software. Descriptive statistics, including means, standard deviations, and frequency distributions, were used to summarize participant characteristics. Paired t-tests were applied to evaluate within-group differences between pre- and post-intervention measurements, while independent t-tests were used to compare outcomes between the intervention groups. The primary analysis was performed using a 2×3 factorial analysis of variance (ANOVA) to examine the main effects of exercise type and body mass index (BMI) category, as well as their interaction, on dynamic balance outcomes. Post-hoc analyses were conducted using the Tukey test. A significance level of $p < 0.05$ was adopted for all statistical tests. This research has been declared ethically appropriate by the Health Research Ethics Commission of the Faculty of Health Sciences, Universitas Muhammadiyah Surakarta, Indonesia, with number No. 677/KEPK-FIK/XII/2024.

Table 2. Otago exercise routine

No	Movements	No	Movements
1.	Head Movements	19.	Heel Toe Standing – Hold Support
2.	Neck Movements	20.	Heel Toe Standing – No Support
3.	Back Extension	21.	Heel Toe Walking – Hold Support
4.	Trunk Movements	22.	Heel Toe Walking – No Support
5.	Ankle Movements	23.	One Leg Stand – Hold Support
6.	Front Knee Strengthening Exercise	24.	One Leg Stand – No Support
7.	Back Knee Strengthening Exercise	25.	Heel Walking – Hold Support
8.	Side Hip Strengthening Exercise	26.	Heel Walking – No Support
9.	Calf Raised – Hold Support	27.	Toe Walking – Hold Support
10.	Calf Raised – No Support	28.	Toe Walking – No Support
11.	Toe Raise – Hold Support	29.	Heel Toe Walking Backward
12.	Toe Raise – No Support	30.	Sit To Stand – Two Hands
13.	Knee Bands – Hold Support	31.	Sit To Stand – One Hand
14.	Knee Bands – No Support	32.	Sit To Stand – No Hand
15.	Backwards Walking–Hold Support	33.	Stair Walking
16.	Backwards Walking–No Support	34.	Calf Stretch
17.	Walking and Turning Around	35.	Back Of Thigh Stretch
18.	Sideways Walking		

Hold support, indicates exercises performed with external support; No support, indicates exercises performed independently.

Table 3. Subject characteristics

Characteristics	N	Mean ± SD	
		SSE	OT
Sex			
Male	7		
Female	53		
Age		65.9 ± 4.4	67.9 ± 4.8
Pre-Elderly (60-69)	37		
Elderly (70-79)	23		
Body Mass Index (kg/m^2)			
Underweight	12		
Normal	28		
Overweight	20		

N, number of participants; SD, standard deviation; SSE, square stepping exercise group; OT, Otago exercise group; BMI, body mass index (kg/m^2)

RESULTS

Subject characteristics

A total of 60 older adults participated in this study, the majority of participants were female (n = 53). The mean age was 65.93 ± 4.40 years in the SSE group and 67.93 ± 4.83 years in the OT group. Most participants were 60–69 years old (n = 37), while 23 participants were aged 70–79 years. Based on BMI, participants were categorized as underweight (n = 12), normal weight (n = 28), and overweight (n = 20) (Table 3).

Effect of Otago exercise on dynamic balance

The elderly group that received the OT intervention showed an improvement in dynamic balance (Table 4). The average time on the pre-test changed from 13.76 seconds to 11.84 seconds on the post-test, with a time difference of 1.92 seconds. The results indicate an improvement in dynamic balance performance during the TUG. Figure 1 shows changes in the standard deviation (SD) of TUG scores before and after the intervention. In the SSE group, SD decreased from 2.15 to 2.04, indicating more consistent post-intervention performance. In contrast, the OT group showed an increase in SD from 2.12 to 2.25, suggesting greater variability after the intervention. Overall, SSE demonstrated more uniform outcomes compared to OT.

Effect of square stepping exercise on dynamic balance

The elderly group that received the SSE intervention showed improvements in dynamic balance (Table 4). The change can be seen from the pre-test time of 14.48 to 11.13 at the post-test, with a time difference of 3.35. However, the standard deviation variation in the SSE group was more stable, indicating that individual improvements were more consistent (pre-test SD: 2.15, post-test SD: 2.04).

Comparison between Otago exercise and square stepping exercise on dynamic balance

A comparative analysis between the OT and SSE groups shows that the SSE group had more significant results than the OT group. The difference in dynamic balance improvement in the SSE group (3.35 seconds) was greater than that in the OT group (1.92 seconds). Based on the results of the 2x3 factorial ANOVA test analyzed using SPSS as presented in Table 5, it was found that the type of exercise factor (SSE and OT) had a significant effect on the dynamic balance of the elderly with an F value (1.54) = 4.515, $p = 0.038 < 0.05$. This indicates that the type of exercise provided significantly contributes to the measurement results. However, the body mass index factor (underweight, normal, overweight) did not significantly affect the dynamic balance of the elderly, with an F value of (2,54) = 0.288, $p = 0.751 > 0.05$. This means that differences in body mass

Table 4. Pre- and post- intervention changes in dynamic balance

Method	Statistic	Pre-Test	Post-Test	Changes
SSE	Amount	434.6	319.6	115.0
	Average	14.5	11.1	3.4
	S3D	2.2	2.0	0.1
OT	Amount	412.91	355.2	57.7
	Average	13.76	11.8	1.9
	SD	2.12	2.3	0.1

OT, Otago exercise; SD, standard deviation; SSE, square stepping exercise.

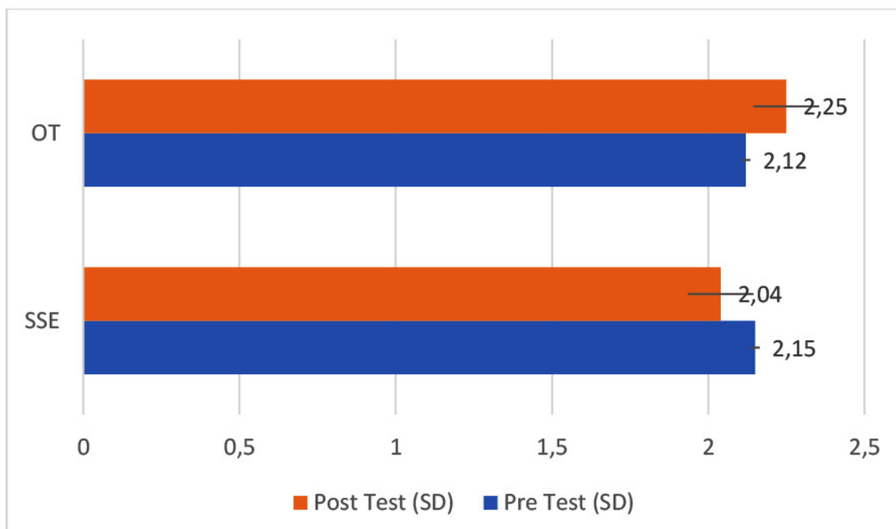

Figure 1. Standard deviation (SD) of the pretest and posttest of the Otago exercise (OT) and square stepping exercise (SSE) groups

Table 5. Statistical analysis using a 2x3 analysis of variance (ANOVA) factorial

Variable	Sum of square	df	Mean Square	F value	F_{table}	Decision
SSE vs OT (A)	29.916	1	29.916	4.515	4.02	Ha Accepted
BMI (B)	3.814	2	1.907	0.288	3.18	Ho Accepted
Interaction (A*B)	14.089	2	7.045	1.063	3.18	Ho Accepted

BMI, body mass index; df, degrees of freedom; Ha, alternative hypothesis; Ho, null hypothesis; OT, Otago exercise; SSE, square stepping exercise.

Table 6. Tukey HSD post-hoc test between BMI categories after group interventions

Group comparison	Mean difference	P-value	95% confidence interval	
			Lower bound	Upper bound
Underweight vs Normal	-0.6938	0.716	-2.8342	1.4466
Underweight vs Overweight	-4.937	0.859	-1.7716	2.7589
Normal vs Overweight	2.001	0.962	-1.6161	2.0164

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index categories (underweight, normal, overweight) do not have a significant effect on dynamic balance measurement results. Additionally, the interaction between exercise type and body mass index (underweight, normal, overweight) also did not show a significant effect on postural balance in the elderly, with an F value of (2,54) = 1.063, p = 0.352 > 0.05. This means that the effect of exercise type on dynamic balance measurement results does not depend on the body mass index of the elderly (underweight, normal, overweight).

The results of post-hoc analysis using the Tukey HSD method in **Table 6** showed that there were no significant differences between body mass index (BMI) groups in terms of POST SSE and OT values (p > 0.05). Comparisons between groups, namely underweight vs. normal weight, underweight vs. overweight, and normal weight vs. overweight, all showed significance values (p > 0.05). These comparisons revealed that the underweight vs. normal BMI group (p=0.716), underweight vs. overweight BMI group (p=0.859), and normal vs. overweight BMI group (p=0.962) all showed similar responses. These findings are supported by the analysis of homogeneous subsets, where all BMI categories are grouped into the same subset, indicating homogeneity between groups. Thus, BMI status does not significantly influence changes in POST SSE and OT values in this study.

DISCUSSION

This study demonstrated that both SSE and OT effectively improved dynamic balance in older adults, with SSE producing greater improvements than OT. The superior effect of SSE may be attributed to its use of progressively complex, multidirectional stepping patterns that enhance coordination, proprioception, and postural control. In older adults, impaired balance can reduce mobility and daily function, making targeted exercises necessary. SSE and OT are effective interventions, with SSE showing greater improvement in dynamic balance due to its superior impact on coordination and postural control. SSE uses progressively complex stepping patterns to train proprioception and motor responses. It also stimulates the visual system, both of which are essential for maintaining balance in older adults.[21] SSE stimulates brain motor function, enhancing vestibular control and directional stability, which improves balance and mobility in older adults. Stepping in multiple directions strengthens leg muscles, further supporting postural control.[22] This finding is consistent with several previous studies which reported that the SSE demonstrated greater improvements in fall risk reduction and functional performance compared to the OT program. Their study concluded that while the OT program is more effective for improving balance in older adults with knee osteoarthritis, SSE is superior in reducing fall risk and enhancing functional activity.[23]

SSE is more effective at enhancing balance-related outcomes in older adults. SSE was found to be effective in improving short-term balance and reducing fall risk. Although improvements in TUG performance were observed among participants performing Square Stepping Exercise, the difference between groups was not statistically significant, and considerable variability in outcomes was reported across studies.[24] A previous research showed that exercises involving multidirectional movements are more effective for improving balance than static strength-based exercises.[22] OT aim to improve strength and balance, particularly in the lower limbs, to reduce fall risk. However, their mostly static nature and limited multi-system stimulation may result in less optimal strength gains and balance improvement in older adults. This aligns with another previous study which indicates that the OT program focuses primarily on muscle strength and static balance.[25]

Obesity in older adults is often associated with reduced lower-limb strength, including the quadriceps, which is essential for knee stability and postural control, contributing to decreased balance and an increased risk of falls.[26] Additionally, obesity is linked to slower walking speed due to greater mechanical load and weakened neuromuscular responses, impairing daily mobility.[27] Body composition, such as BMI or obesity, can affect exercise responses in older adults. Both Otago's strength and balance training and square stepping exercise's multidirectional patterns help improve balance and walking mechanics, even in individuals with higher body weight.

This study has several limitations. First, the absence of a non-exercise control group limits the ability to attribute improvements in dynamic balance exclusively to the SSE and OT interventions. Second, the relatively small sample size may reduce statistical power and limit the generalizability of the findings. Third, the short duration of the intervention and lack of long-term follow-up prevent conclusions regarding the sustainability of balance improvements. Future studies should include a control group, larger and more diverse samples, longer intervention periods, and follow-up assessments to confirm the long-term effectiveness of these exercise programs in older adults.

CONCLUSION

Both interventions improved dynamic balance in older adults. The SSE group demonstrated a greater mean difference (MD = 3.35 seconds) in TUG performance compared with the OT group (MD = 1.92 seconds). Factorial ANOVA revealed a significant main effect of exercise type on dynamic balance (F = 4.515, p = 0.038), indicating that SSE was more effective than OT. No significant effects were found for BMI (p = 0.751) or for the interaction between exercise type and BMI (p = 0.352).

ETHICAL CLEARANCE

This research has been declared ethically appropriate by the Health Research Ethics Commission of the Faculty of Health Sciences, Universitas Muhammadiyah Surakarta, Indonesia, with number No. 677/KEPK-FIK/XII/2024.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest, whether financial, personal, academic, or institutional, that could affect the integrity and objectivity of this research.

AUTHOR CONTRIBUTIONS

W contributed to the study concepts and design, definition of intellectual content, literature search, clinical and experimental studies, data acquisition, data analysis, statistical analysis, manuscript preparation, editing, review, and served as the guarantor of the study. MD contributed to the definition of intellectual content, literature search, clinical studies, data acquisition, data analysis, and manuscript editing. MFH contributed to the definition of intellectual content, experimental studies, data analysis, statistical analysis, manuscript preparation, and manuscript review. FFE contributed to the study design, definition of intellectual content, experimental studies, data acquisition, data analysis, statistical analysis, manuscript editing, and manuscript review.

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