Title: Acute Effects of Manual Massage and Self-Myofascial Release on Postural Control and Gait in Parkinson's Disease: A Comparative Intervention Study

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Abstract

Background: Parkinson's disease is a common and progressive neurodegenerative disorder primarily affecting older adults. It is characterized by motor symptoms including resting tremor, muscle rigidity, bradykinesia (slowness of movement), and postural instability, all of which contribute to reduced quality of life and diminished functional ability. Non-pharmacological approaches, such as massage therapy and foam rolling, have been suggested as potential complementary strategies to improve motor performance and reduce fall risk in this population. The present study aimed to examine the acute effects of a single session of massage versus foam rolling on balance, functional performance, and gait parameters in individuals diagnosed with Parkinson's disease.

Methods: A randomized controlled trial with a pre-test/post-test design was conducted involving 30 elderly individuals with Parkinson's disease. Participants were randomly assigned to either a massage group (n = 15) or a foam rolling group (n = 15). Both interventions were delivered in a single session, with each participant receiving only one intervention (either massage or foam rolling), and both groups were assessed concurrently before and immediately after the intervention. Outcome measures included the Berg Balance Scale (assessing static and dynamic balance), the Timed Up and Go (TUG) test (measuring functional mobility), the Single-Leg Stance test (evaluating postural control), the Sit and Reach test (assessing lower back and hamstring flexibility), and a knee proprioception test (measuring joint position sense). Data were analyzed using repeated measures analysis of variance (ANOVA), with the significance level set at $\alpha = 0.05$.

Findings: The results demonstrated that both interventions led to a statistically significant improvement in balance, motor performance, and gait parameters in the elderly participants with Parkinson's disease ($p < 0.001$ for all within-group comparisons). The between-group effect was not significant for most of the outcome measures; however, a notable exception was observed for the Berg Balance Scale, where the massage group showed significantly better performance compared to the foam rolling group ($F = 7.22$, $p = 0.012$). The time × group interaction effect was not statistically significant for any of the assessed variables ($p > 0.05$), indicating that the pattern of improvement over time did not differ between the two interventions.

Conclusion: Both massage and foam rolling effectively improve motor performance and balance in elderly with Parkinson's disease; however, massage shows superiority in some indicators such as neuromuscular control and muscle tone reduction. These findings support short-term, cost-effective rehabilitation programs to reduce fall risk and enhance quality of life.

Keywords: Foam Rolling, Parkinson's Disease, Aging, Fascia, Mobility.

Highlights

- The massage intervention demonstrated significant efficacy in improving a wide range of motor and balance functions. Following the intervention, the massage group exhibited statistically significant improvements in all assessed metrics. These enhancements included reduced time on the Timed Up and Go (TUG) test, increased single-leg stance time, improved sit-and-reach flexibility, enhanced knee joint position sense, and a substantially higher score on the Berg Balance Scale.

- Similarly, the foam rolling intervention produced significant immediate benefits across the same functional domains. Post-intervention assessments revealed a significant main effect of time for the foam rolling group, with notable improvements in gait speed (TUG), static balance (single-leg stance), flexibility, proprioception, and overall balance as measured by the Berg Balance Scale. This confirms that a single session of foam rolling is also an effective method for enhancing motor performance in elderly individuals with Parkinson's disease.

- When comparing the two methods, both interventions showed similar positive effects across most functional outcomes. However, the massage group demonstrated greater improvement in overall balance compared to the foam rolling group, suggesting a potential advantage of massage in enhancing comprehensive balance control in individuals with Parkinson’s disease.

Plain Language Summary

Parkinson's disease is a common neurological disorder in older adults that leads to symptoms like tremors, stiffness, slow movement, and impaired balance. These symptoms can significantly reduce patients' quality of life and their ability to perform daily activities. This study investigated the immediate effects of massage and foam rolling on balance, functional performance, and gait in elderly individuals with Parkinson’s disease.

The findings demonstrated that both a single session of massage and a single session of foam rolling were effective in producing significant immediate improvements in the participants' balance and motor performance. While both interventions were beneficial, the massage group showed superior improvement in overall balance compared to the foam rolling group. In conclusion, both methods are practical and cost-effective rehabilitation techniques that can be used to quickly enhance motor function and reduce the risk of falls in patients with Parkinson's disease, with massage offering a slight advantage in certain aspects of balance control.

Introduction

Parkinson's disease (PD) is one of the most common progressive neurodegenerative disorders in the elderly. It is caused by a decrease in dopamine levels in the brain and is characterized by symptoms such as tremor, muscle stiffness, bradykinesia, and postural instability(۱).These complications lead to gait abnormalities, reduced speed and step length, and an increased risk of falling(2). Consequently, they impose a significant burden on the patients' general health and quality of life(۳). According to the latest results from the Global Burden of Disease Study 2021, the global prevalence of Parkinson's disease in 2021 was approximately 11.77 million people, and the disease burden in terms of Disability-Adjusted Life Years (DALYs) has more than doubled over the past three decades. This increasing trend has been observed not only in high-income countries but also in developing countries(۴). In Iran, the consequences of Parkinson's disease have also shown an upward trend in recent years, with significant disparities in prevalence and disease burden based on social development indices reported(۵). Studies have indicated that balance disorders and motor problems can emerge from the early stages of the disease and can even predict disease progression and the degree of disability(۶). Therefore, rehabilitation interventions, particularly balance and motor training, play a crucial role in managing these complications and improving patients' quality of life(۷).

In addition to pharmacological treatments, various non-pharmacological interventions have been proposed to improve motor function and balance. Massage, as a soft tissue manual therapy, works by increasing blood circulation, reducing inflammation, and stimulating sensory receptors, leading to pain relief, reduced muscle tension, and improved neuromuscular responses(۸). Scientific research has shown that massage, through tissue release, can reduce muscle stiffness and improve the viscoelastic properties of the tissue(۹). Massage therapy is frequently integrated as a complementary intervention alongside conventional treatment for Parkinson's disease, aimed at ameliorating motor impairments and improving overall quality of life. (۱۰). Studies have demonstrated that massage therapy can improve motor symptoms in patients; a systematic meta-analysis involving 363 patients with Parkinson's disease showed that massage therapy had a significant effect on improving motor symptoms compared to the control group. Furthermore, the Unified Parkinson’s Disease Rating Scale Part III (UPDRS-III), which is the primary measure for assessing motor function, showed a significant improvement after massage therapy (SMD=-0.46, 95% CI: -0.67 to -0.24, $p<0.00001$) (10). In another study conducted at the University of Miami and Duke University, Parkinson's patients who received two 30-minute massage sessions per week for five weeks exhibited better daily functioning, higher sleep quality, and lower levels of stress hormones (norepinephrine and epinephrine) in urine samples(۱۱). Massage therapy contributes to pain relief and enhanced range of motion through several mechanisms: it promotes blood flow, alleviates muscle tension, improves flexibility, and reduces joint stiffness. (۸). Various massage techniques, including traditional Japanese massage (Anma), Thai massage, neuromuscular therapy, and classic massage techniques, have been reported to be effective in reducing tremor, muscle stiffness, and increasing gait speed(۱۰ ,۸). Additionally, massage therapy has positive effects on non-motor symptoms such as anxiety, depression, sleep disorders, and fatigue(۱۱). However, it is necessary to emphasize that massage therapy alone cannot cure Parkinson's disease

and should be used as a complementary method alongside standard pharmacological treatments and physiotherapy.

Another method for myofascial release that has recently gained significant attention is the use of a therapeutic tool called a foam roller. Foam rolling, as a form of soft tissue release and self-myofascial release, applies direct and controlled pressure to muscles and tendons, producing effects on the body similar to massage(12). Studies have shown that regular use of foam rolling can reduce muscle stiffness and improve the viscoelastic properties of tissues, which contributes to smoother movement and better muscle function(۱۳). Furthermore, foam rolling can stimulate mechanoreceptors, accelerate the recovery process after physical activity, and induce a sense of relaxation in the limbs(۱۴). Recent systematic reviews and meta-analyses indicate that foam rolling can increase the range of motion and reduce pressure pain threshold and pain(۱۵). From a physiological perspective, there is evidence that foam rolling improves pain perception and function by altering pain thresholds, reducing local muscle tension, and exerting neuromodulatory effects, likely through spinal and central tract(۱۶). Therefore, this method is considered highly beneficial as a simple, cost-effective, and accessible tool, especially for the elderly and patients with movement disorders like Parkinson's, who can use it independently without assistance. Both massage and foam rolling activate similar physiological mechanisms by applying mechanical pressure to soft tissues. These mechanisms include stimulating sensory receptors, improving local blood flow, and altering the viscoelastic properties of muscles. Studies have shown that both methods can reduce muscle stiffness and similarly influence the mechanical behavior of tissue(۱۷).

Despite the well-documented positive effects of massage and foam rolling, no research to date has directly compared the impact of both methods on elderly individuals with Parkinson's disease and investigated their effects. Therefore, the present study aims to fill this scientific gap by evaluating the immediate effects of massage and foam rolling on selected muscles of the lower limbs and their impact on balance, function, and gait in elderly patients with Parkinson's disease. It is expected that the results of this research will pave the way for designing short-term, effective, and cost-effective rehabilitation programs to reduce the risk of falls and enhance the quality of daily life in this population.

Methods

Participants

This quasi-experimental study employed a pretest-posttest design without a control group. Based on calculations using G*Power software (statistical power of 0.80, effect size of 0.60, and significance level of 0.05), a total of 30 elderly individuals with Parkinson's disease were randomly assigned into two equal groups: massage (n=15) and foam rolling (n=15). Randomization was performed using a computer-generated random number table (Microsoft Excel). Group allocation was concealed in sealed envelopes that were opened sequentially by an independent researcher. Participants(9 males and 6 females in each group) were recruited from elderly individuals with Parkinson's disease who were under the care of rehabilitation centers and specialized geriatric clinics in Tehran. They were invited to participate through public announcements and direct invitations. After assessing the inclusion criteria, they were enrolled in the study. Due to the acute nature of the interventions and the challenges associated with homogenizing older adult samples with Parkinson's disease according to inclusion criteria, a separate control group was not

considered. Additionally, to eliminate the interactive and residual effects of the first-phase intervention, a one week interval between the two interventions (massage and foam rolling) was observed.

The inclusion and exclusion criteria for this study were defined similarly to previous research on non-pharmacological interventions in patients with Parkinson's disease(۱۸ ,۸). The inclusion criteria for the present study were: age over 60 years, ability to perform stretching movements, absence of contraindications for massage and myofascial release, relative ability to walk independently, absence of acute cardiovascular diseases or hypertension, absence of acute injury or surgery in the lower limbs, and provision of informed consent. The exclusion criteria included: occurrence of severe pain, intolerance to pressure, expression of dissatisfaction with the interventions and tests, new injury or acute medical problems during the study process. All participants signed an informed consent form after the procedures were fully explained to them.

Research Instruments and Procedure

Following the selection process, training sessions, and obtaining consent from the subjects, the initial phase began. Prior to the intervention, the participants' demographic information was recorded. Subsequently, all participants underwent the aforementioned assessments, and the results of each test were accurately recorded to enable a precise examination of pre- and post-intervention changes.

The intervention was conducted in a single session. Each group received only one type of intervention (massage or foam rolling), ensuring that the acute effects of each modality were examined. Given the acute nature of the intervention, the study focused on immediate effects; however, it is acknowledged that a single session may not be sufficient to produce sustained changes in outcomes such as balance or proprioception.

Upon completion of the interventions, the participants were re-evaluated using the same initial assessments, and the test results were meticulously recorded to allow for pre- and post-intervention comparison. This phase not only enabled us to accurately examine the effects of massage and foam rolling on motor function and the scores of each test but also provided a reliable basis for analyzing the results and offering practical recommendations for designing short-term, targeted rehabilitation programs for elderly individuals with Parkinson's disease. (Figure 1)

Figure 1. Measurement of functional and motor variables from the samples.

Balance Assessment

Balance was assessed using the short-form Berg Balance Scale (BBS), which includes 9 items from the original 14-item Berg Balance Scale. This scale has been reported to have high convergent validity and internal consistency in the elderly and patients with Parkinson's disease(١٩). The short-form Berg Balance Scale assesses both static balance (single-leg stance and tandem stance) and dynamic balance (reaching forward with an outstretched arm, transferring weight, standing up from a seated position, turning 360 degrees, placing the alternate foot on a stool, and picking up an object from the floor)(٢٠) .

Gait Assessment

The Timed Up and Go (TUG) test measures the time taken to stand up from a chair, walk three meters, turn around, and return to a sitting position.(٢١). (ICC = 0.87–0.99, r = 0.90–0.97).(22)

Motor Function Assessment

The Single-Leg Stance (SLS) test was used to assess static balance control in the elderly(٢٣). The Sit-and-Reach test was employed to measure lower body flexibility and hamstring muscle flexibility. The reliability and validity of this test have been confirmed in numerous studies, showing moderate criterion-related validity for estimating hamstring extensibility (r = 0.46–0.67) and excellent test-retest reliability (ICC > 0.85)(٢٤) .

Knee Proprioception Assessment

Knee proprioception was assessed using the Joint Position Sense (JPS) test, specifically measuring the angle reproduction error, with a handheld inclinometer. This method has been reported to have excellent validity and reliability (ICC = 0.980–1.00)(۲۵) .

Intervention Protocol

The massage protocol involved superficial massage of the lower limbs (muscles of the anterior/posterior thigh and calf) for 15 to 20 minutes. The manual pressure intensity during the massage was moderate, ensuring the participant felt mild pressure without pain(۲۵). The foam rolling protocol involved rolling a soft foam roller on the lower limbs with low intensity for approximately 5 minutes per leg (muscles of the anterior/posterior thigh and calf), in 2 to 3 sets, with short rest periods between sets. The foam rolling pressure intensity was such that the participant felt moderate pressure and stretching in the muscle, without causing severe pain or discomfort (۲۶). No objective instrument was used to measure the exact applied force, which is acknowledged as a limitation of the study.

To minimize confounding factors and maintain consistent conditions, all assessments and interventions were conducted during the mid-day hours (10:00 AM to 12:00 PM). Participants had consumed breakfast or a light meal at least one hour before the session to reduce the effects of hunger or satiety on motor performance. All tests were performed in a quiet room with constant temperature and adequate lighting. Furthermore, before the intervention began, participants were given full explanations and were asked to refrain from any strenuous physical activity or receiving similar interventions (massage or stretching exercises outside the protocol) during the study period.

Statistical Methods

All data were first examined for normality using the Shapiro-Wilk test. The homogeneity of the groups before the intervention was assessed using an independent t-test for age, height, weight, and BMI, and no significant difference was observed ($p>0.05$). To investigate the effects of the interventions, a repeated measures analysis of variance (Repeated Measures ANOVA) was performed with one within-subjects factor (time: pre and post) and one between-subjects factor (group: massage and foam rolling). The sphericity assumption was checked using Mauchly's test, and if violated, the Greenhouse-Geisser correction was applied. The significance level was set at 0.05, and all analyses were conducted using SPSS version 26.

Results

The study was conducted on 30 elderly individuals with Parkinson's disease, who were randomly assigned to two groups: massage (n=15) and foam rolling (n=15). The two groups were homogeneous in terms of demographic characteristics, including age, sex (18 men and 12 women), height, weight, and body mass index, with no significant differences observed between them ($p>0.05$) (Table 1).

Table 1. Demographic characteristics of the study participants and results of the independent t-test for differences between groups.

Group	Age	Height	Weight	BMI
Total (N30)	78.10±4.97	172.96±8.20	73.20±7.47	24.47±2.04
Massage (N15)	78.53±4.86	172.06±9.28	71.66±7.13	24.19±1.46
Foam roll (N15)	77.66±5.21	173.86±7.17	74.73±7.73	24.75±2.51
t (p-value)	0.47 (0.642)	-0.59 (0.557)	-1.13 (0.269)	-0.74 (0.465)

First, the baseline status of the participants in the massage and foam rolling groups was examined. A one-way analysis of variance showed that the mean scores of the TUG test (F=2.43, p=0.13), single-leg stance test (F=2.55, p=0.12), sit-and-reach test (F=0.55, p=0.46), and knee joint position sense test (F=3.16, p=0.086) showed no significant difference between the two groups. Only the Berg Balance Scale (F=6.62, p=0.016) indicated a difference between the groups. Overall, the pretest results demonstrated relative homogeneity of the groups in most indicators, validating the subsequent comparisons.

In the second stage, which involved the results obtained after applying the intervention for each group, the findings revealed a significant main effect of time in all tests: motor function in the TUG test decreased (F=39.32, p<0.001), single-leg stance time increased (F=77.46, p<0.001), the sit-and-reach test improved (F=17.00, p<0.001), the knee joint position sense test improved (F=43.45, p<0.001), and the Berg Balance Scale score increased (F=153.12, p<0.001). These results indicate that participants showed significant improvement in all dimensions of motor and balance function in the post-test compared to the pre-test (Table 2).

The main effect of group was not significant in most tests: TUG (F=2.62, p=0.117), single-leg stance (F=3.21, p=0.084), sit-and-reach test (F=0.75, p=0.393), knee joint position sense test (F=3.37, p=0.077), with the exception of the Berg Balance Scale, where the group effect was significant (F=7.22, p=0.012), indicating an overall difference between the groups in this variable, with the massage group showing better performance than the foam rolling group. Furthermore, the time × group interaction effect was not significant in any of the tests (p>0.05), suggesting that both massage and foam rolling interventions had a similar impact on improving balance, gait, and function in the elderly.

Table 2 - Mean and standard deviation of the measurement variables in each group in the pre-test and post-test

Variables	Time	Massage	Foam roll	F	p	η^2
TUG	Pre-test	32.66±15.26	24.86±11.95	2.43	0.13	0.080
	Post-test	29.13±12.78	21.66±11.67	39.32	0.001	0.58
Leg standing	Pre-test	1.86±2.23	5.06±7.43	2.55	0.12	0.083
	Post-test	3.46±2.82	7.33±7.05	77.46	0.001	0.73
Sit and reach	Pre-test	14.00±15.33	9.06±11.27	0.55	0.46	0.019
	Post-test	16.86±16.73	12.53±15.18	17.00	0.001	0.38
Joint Position Sense	Pre-test	12.46±3.90	9.93±3.89	3.16	0.086	0.101
	Post-test	10.20±3.98	7.60±3.99	43.45	0.001	0.61
Berg Balance Scale–Short Form	Pre-test	22.13±5.51	26.60±3.85	6.62	0.016	0.191
	Post-test	25.86±4.34	29.73±3.21	153.12	0.001	0.85

Discussion

The results of the present study indicated that both massage and foam rolling interventions led to significant improvements in balance, motor function, and gait in elderly individuals with Parkinson's disease, and their effects were generally similar. However, an overall difference between the groups was observed in the Berg Balance Scale. These findings are consistent with previous studies in the field of rehabilitation interventions for Parkinson's patients(۸, ۱۰). In the pre-test phase, the two groups showed no significant differences in demographic characteristics and baseline test scores ($p>0.05$), which strengthens the validity of the comparative analyses. The exception was the Berg Balance Scale, where a difference was observed ($F=6.62$, $p=0.016$, $\eta^2=0.18$). This finding is also in line with the standard principles of clinical trial studies and similar findings in previous research(۱۹).

Following the intervention, the main effect of time was significant in all tests. The Berg Balance Scale ($\eta^2 = 0.85$ in the massage group and $\eta^2 = 0.73$ in the foam rolling group), the Single-Leg Stance test ($\eta^2 = 0.73$ in the massage group and $\eta^2 = 0.69$ in the foam rolling group), and the TUG test ($\eta^2 = 0.58$ in the massage group and $\eta^2 = 0.61$ in the foam rolling group) demonstrated this effect. The main effect of group was only significant for the Berg Balance Scale ($F=7.22$, $p=0.012$), and the time × group interaction effect was not significant in any of the tests ($p>0.05$). These results align with recent studies indicating the positive effects of massage and foam rolling on reducing muscle tension, increasing the range of motion, and improving motor function(۱۰, ۲۷). Massage, by stimulating mechanoreceptors in the skin, fascia, and muscle, modulates hemodynamic and autonomic responses. This intervention, through the activation of parasympathetic pathways, leads to a reduction in blood pressure, decreased arterial stiffness, and improved venous return. Furthermore, the increased release of nitric oxide (NO) due to massage causes vasodilation and enhances local and systemic blood flow, consequently facilitating oxygen delivery and the removal of accumulated metabolites in the muscles. From a neurophysiological perspective, the stimulation of mechanoreceptors and Golgi Tendon Organs (GTOs) during massage reduces muscle tension, improves neuromuscular coordination, and regulates muscle tone. These changes, mediated by decreased sympathetic activity and increased parasympathetic activity, result in better balance of the autonomic nervous system, improved cardiovascular function, and enhanced muscular efficiency. These hemodynamic and autonomic effects can play a significant role in improving physical performance and motor control in the elderly(۲۸, ۲۹). The use of foam rolling as a myofascial release technique induces beneficial changes in the autonomic nervous system responses, which leads to improved neuromuscular coordination and facilitates muscle regeneration and recovery processes. The uniform and rhythmic pressure of the foam roller on soft tissues reduces fascial adhesions, increases local blood flow, and enhances the transport of metabolic substances within the muscle. These changes, particularly through the stimulation of mechanoreceptors and increased sensory input to the central nervous system, result in improved motor control and proprioception. Furthermore, foam rolling reduces the stimulation of pain receptors and facilitates inhibitory responses at the spinal level, leading to a decrease in post-activity muscle pain and an improvement in the range of motion(۳۰).

The superiority of massage over foam rolling in the Berg Balance Scale can be attributed to differences in their physiological and neuromuscular mechanisms. Due to the hand contact and targeted pressure, massage more effectively activates cutaneous receptors and Golgi Tendon Organs (GTOs), leading to the inhibition of the stretch reflex and a reduction in muscle tone(۳۱).

In contrast, foam rolling applies more uniform pressure and focuses more on stimulating the fascia and increasing blood flow. However, due to its inability to induce strong neural inhibition and directly reduce muscle tone, its effect is more limited compared to massage(۳۲).

Considering the obtained effect sizes, these interventions were impactful not only statistically but also from a clinical perspective, particularly in reducing the risk of falls and improving activities of daily living, which are critical issues for elderly individuals with Parkinson's disease. This finding is consistent with previous studies(۳۳).

Considering the design and execution of the present study, several notable limitations exist that could affect the generalizability of the results.

First, this research was quasi-experimental and lacked a control group, which may impact internal validity and the ability to make definitive causal inferences about the effects of the interventions. Furthermore, the sample size was limited to 30 individuals, and participants were selected from only one center or geographical area; therefore, the results may not be generalizable to the entire population of elderly individuals with Parkinson's disease.

Another limitation to consider is the short duration of the interventions and their administration on a single day for each phase, which restricts the ability to investigate the long-term and sustained effects of the interventions. Additionally, some tests, such as single-leg stance, picking up objects from the floor, and performing the TUG test, were dependent on individual skill and the cooperation of the elderly participants. This dependency could be influenced by factors like fatigue, motivation, and the participants' daily condition, potentially leading to data variability. Regarding the measurement instruments, although the devices and tests had appropriate reliability and validity, some measurements, such as those taken with the handheld inclinometer for knee proprioception, could be subject to operator error or changes in the subject's body position. There were also limitations regarding access and the administration of massage, as some elderly participants or their companions did not permit video recording or precise documentation of the procedure, which could affect the uniformity of intervention delivery.

Finally, individual characteristics such as daily activity levels, medications, general health status, and physiological and neuromuscular differences among the elderly could influence the response to the interventions, and fully controlling for these factors in the study design was not feasible. Therefore, it is recommended that future studies employ larger samples, longer intervention durations, and include a control group, alongside the assessment of long-term effects and the investigation of personal and environmental variables, to provide more valid and generalizable results.

The findings of the present study can serve as a key guide for designing short-term, cost-effective rehabilitation programs for elderly individuals with Parkinson's disease and emphasize the

importance of incorporating a combination of massage, foam rolling, and static stretching techniques to improve physical function.

Conclusion

The findings of the present study demonstrated that both massage and foam rolling interventions had a significant positive effect on improving balance, motor performance, and gait in elderly individuals with Parkinson's disease, with the overall effect of the two methods being similar. However, in the Berg Balance Scale, the massage group exhibited better performance compared to the foam rolling group, indicating the superiority of massage in enhancing neuromuscular control, reducing muscle tone, and improving reflexive responses and proprioception.

From a clinical perspective, these findings hold significant importance, as they can contribute to reducing the risk of falls, increasing independence in daily activities, and enhancing the quality of life in elderly individuals with Parkinson's disease. The present results are consistent with recent research in the field of combined rehabilitation interventions and emphasize the importance of implementing multi-faceted approaches, including massage and foam rolling, in improving motor performance in the elderly.

Considering the study's limitations, including the limited sample size, absence of an independent control group, and short duration of interventions, it is recommended that future research be conducted with larger samples and a controlled trial design. Furthermore, investigating the long-term effects of the interventions and conducting detailed analyses of biomechanical and neuromuscular indicators could provide a better understanding of the physiological and neuromechanical mechanisms underlying improved motor performance in the elderly.

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Conflict of Interest

The authors declare that they have no known competing financial, personal, or professional interests that could have appeared to influence the work reported in this paper.

Ethical Considerations

This study was conducted in strict accordance with the ethical standards for research involving human participants. The protocol received formal approval from the Ethics Committee of the Sports Sciences Research Institute (Code: IR.SSRC.REC.1402.129). Prior to their involvement, written informed consent was obtained from all participants. The confidentiality of all personal and medical data was rigorously maintained throughout the study, and information was used exclusively for research objectives.

Author Contributions

M.S. : Conceptualization, project administration, supervision of all study phases, manuscript writing, and revision/editing.

M.F. : Investigation, data acquisition, protocol implementation, formal analysis, and practical execution of the study.

S.H.M. : Conceptualization (co-development of the idea), methodology consultation, supervision of implementation, and statistical oversight.

R.N. : Writing of the original draft, statistical analysis, result interpretation, and data analysis.

AI Use Statement

During the preparation of this manuscript, the authors used DeepSeek solely for grammatical and stylistic editing of selected portions of the text. No AI tool was used for data analysis, result interpretation, or scientific decision-making.

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