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The Effect Of Lower Limb Muscle Fatigue On Strength And Balance In Healthy Adults

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Abstract

Background: Following lower limb strength training exercises, patients with stroke often experience muscle fatigue, which can frequently lead to falls. Therefore, this study aims to explore how lower limb muscle fatigue caused by squats affects the strength and balance of healthy individuals before extrapolating it to patients with stroke.

Design: Cross-sectional study

Methods: The study followed a cross-sectional design. The study was conducted on 30 healthy adults. Strength and balance were measured before and after performing wall squat exercises. Muscle strength was measured using a dynamometer, while balance was assessed with the S3 check system. A paired t-test was used for the analysis.

Results: The knee extensor and hip extensor showed a significant decrease after wall squat ($p < 0.05$). However, there was no significant difference observed in knee flexor and hip abductor between before and after wall squat. Balance did not show a significant difference between before and after wall squat.

Conclusion: Muscle fatigue caused by wall squats was found to reduce the strength of the knee and hip extensors, while having no impact on balance. The results of this study may serve as foundational data for future research targeting patients with stroke.

Key words: fatigue; lower extremity; muscle strength; postural balance

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Ⅰ. Introduction

Fatigue, commonly encountered in daily life, refers to a state characterized by muscle weakness, reduced strength, and diminished physical performance. At the neuromuscular system level, muscle fatigue is described as a reduction in the highest amount of force that muscles can produce (Enoka & Duchateau, 2008). The decrease in this force or power is typically expressed relative to a baseline value. Before the body perceives the effects of fatigue, numerous neurophysiological mechanisms are disrupted, and these changes can sometimes serve as early warning signs of fatigue. Furthermore, upon the onset of exercise, the initial state of the neuromuscular system, including factors such as energy stores, ion concentrations, and arrangement of contractile proteins, undergoes alterations. Subsequently, fatigue progressively develops until the muscles can no longer perform the necessary tasks (Boyas & Guével, 2011). Fatigue is a complex and multifactorial phenomenon influenced by the nature of the task (i.e., type and duration of exercise, speed and duration of muscle contractions).

Squats are one of the commonly used exercises in clinical settings for lower limb muscle strengthening in patients with stroke (Gray et al., 2012). Squats are dynamic and closed-chain exercises, which means they are influenced by various factors. The depth of movement, position of the feet, strength of core muscles, and position of the head can all alter muscle activation (Lorenzetti et al., 2018). Men and women employ distinct motor strategies throughout the kinematic chain (Zawadka et al., 2020). Fatigue is another critical factor in squat exercises. Many studies have shown changes in the kinematics and kinetics of movement due to fatigue (Sanford et al., 2016). These changes include increased forward leaning, forward shifting of ground reaction forces, and reduction in range of motion (Erman et al., 2023).

Squats are compound exercises involving not only the muscles of the thighs but also those of the entire trunk and lower limb. Various studies have been conducted on different types of squats (Mackey & Riemann, 2021), muscle activation (Slater & Hart, 2017), and muscle fatigue (Erman et al., 2023). However, research on how squat-induced muscle fatigue affects strength or balance has not been conducted.

Therefore, So, this study aims to explore how lower limb muscle fatigue caused by squats affects the strength and balance of healthy individuals before extrapolating it to patients with stroke. The purpose of this study is to examine the effects of lower limb muscle fatigue on strength and balance in healthy adults.

Ⅱ. Methods

1. Participants

This study recruited 30 participants who met the selection criteria among healthy adults for experimentation. The sample size for the experimental subjects was determined using the G-Power software (version 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany) based on data from prior research. Based on previous research data, the t-test was conducted with an effect size of 0.5, an alpha level of 0.05, a statistical power of 0.8, and a 1:1 allocation ratio. Consequently, the total sample size was determined to be 27 participants. However, consideringa dropout rate of 10%, the sample size was augmented to 30 participants. Participant recruitment involved voluntary participation from the staff of Soonchunhyang University Bucheon Hospital. The inclusion criteria for the subjects are as follows: individuals who are healthy adults capable of performing squats. The exclusion criteria for the subjects are as follows: Individuals who have had neurological disorders or lower extremity musculoskeletal injuries within 6 months leading up to the start of the study (Mackey & Riemann, 2021). Before the experiment, the research participants received sufficient explanation about the experimental procedures and signed a consent form to participate in the study. This study received Institutional Review Board (IRB) approval from Sahmyook University (approval no. 2024-03-011-001).

2. Study procedure

All participants performed the wall squat exercise. Participants positioned themselves with their backs against the wall and their feet shoulder-width apart, maintaining a parallel stance. Both hands were positioned at the Anterior Superior Iliac Spine (ASIS). Participants lowered their backs along the wall until the knee joint reached a 100° flexion angle. Then, they carefully eased back up, ensuring that the knee joint did not fully extend. They repeated this process until muscle fatigue was induced (Vaegter et al., 2019). The criteria for muscle fatigue were as follows: firstly, when a participant was unable to continue the exercise and opted to stop, and secondly, when a participant's squatting speed did not match the pace set by a metronome. The metronome was set to a pace of 0.5 seconds (Baffa et al., 2012).

3. Outcome measures

Participants completed evaluations of muscle strength and balance before and after the squats. Muscle strength was measured using a handheld dynamometer (microFET3, Hoggan Health Industries, USA, 2011). An assessment of the interrater reliability of the Handheld dynamometer has shown a very high (from 0.97 to 0.98) intraclass correlation coefficient (ICC) of the same-day intrarater. Additionally, the test-retest reliability for the various measures has been demonstrated to be very high (ICC from 0.83 to 0.95) (Grootswagers et al., 2022). Balance was assessed with the balance board (S3 check system, MFT, Germany, 2008). An assessment of the interrater reliability of the S3-Check system has shown a very high ICC ranging from 0.90 to 0.98 for the stability indices "right/left" and "front/back." The sensorimotor index for "right/left" demonstrated a high correlation (ICC: 0.82 to 0.84), while the correlation for "front/back" was moderate (ICC: 0.67 to 0.69). Additionally, the test-retest reliability for various metrics was exceptionally high, with ICCs ranging from 0.90 to 0.98 (Baierle et al., 2013).

The muscles assessed for muscle strength evaluation were as follows: knee extensor (quadriceps femoris), knee flexor (hamstring), hip extensor (gluteus maximus), and hip abductor (gluteus medius). Muscle strength was measured through Maximum Voluntary Contraction (MVC) of the dominant side for all participants. The testing positions and angles for each muscle were based on the Manual Muscle Test (MMT) guidelines (Kendall, 2005).

The S3-Check system not only assesses balance ability but also measures postural stability and sensory motor control function. The measuring surface tilts from +20° to -20°, with an accuracy of 0.5°. The sampling rate is 100 Hz. Testing directions can be set as "forward/backward" and "right/left." The system measures the magnitude and frequency of movement. As a result, it provides quantitative measurements of the participant's comprehensive sensory-motor ability, balance, and postural stability. The experiment took place in a quiet setting. Participants were asked to take off their shoes and position their feet on the balance board while standing on both feet. During the measurement, participants crossed their arms in front of their bodies to eliminate compensatory arm movements and minimize the influence of shoulder function during the test. After going through a warm-up phase, participants became accustomed to the equipment. The test itself consisted of randomly consecutive two measurement series for each test direction (Baierle et al., 2013). The initial 5 seconds were disregarded, followed by the calculation of the sensorimotor index from the amplitude over the subsequent 30 seconds. Additionally, the stability index was computed from the degree of deviation of the platform from horizontal. For each index, the average of the second best trial was used for statistical analysis, where a high score (up to a maximum of 9) indicated weak control, while a low score (starting from 1) indicated a high level of posture control (Jäger et al., 2017).

4. Statistics analysis

The data are shown as mean ± standard deviation. Descriptive statistics were used to analyze the participants' general characteristics. To verify the normal distribution of the measured variables, the Shapiro-Wilk test was employed, with all values meeting the normality assumption. Paired t-tests were used to compare within-group differences before and after muscle fatigue. Results were deemed statistically significant if the p-value was below 0.05. The data obtained in this study underwent statistical analysis using SPSS Statistics, version 22.0 for Windows (IBM Corp., Armonk, NY, USA).

Ⅲ. Results

The study included 30 participants (12 males and 18 females). The mean age was 36.1 years, the mean height was 168.5 cm, and the mean weight was 63.2 kg (Table 1).

Table 1. General characteristics of subjects (*n*=30)

		Subjects
Gender	Male	12
	Female	18
Age (years)		36.1 ± 9.4
Height (cm)		168.5 ± 7.8
Weight (kg)		63.2 ± 12.6

Values are mean ± standard deviation.

The measurement results for muscle strength are presented in Table 2. Both knee extensor and hip extensor showed a significant decrease in strength after the experiment (p<0.05). However, there was no significant difference in muscle strength for knee flexor and hip abductor between before and after the experiment.

Table 2. Comparison of muscle strength measured by the dynamometer. (n=30)

	Pretest	Posttest	t	p
Knee extensor (kg)	21.1 ± 8.0	18.0 ± 8.8†	2.710	.011*
Knee flexor (kg)	10.7 ± 4.0	10.2 ± 5.0	.258	.798
Hip extensor (kg)	15.4 ± 8.1	13.1 ± 7.9†	1.829	.048*
Hip abductor (kg)	21.6±9.5	21.1±9.2	.351	.728

Values are mean ± standard deviation. †: Significant difference compared pretest. *p < 0.05.

The measurement results for balance are presented in Table 3. There were no statistically significant differences observed for both body stability based on the degree of platform deviation and sensorimotor based on amplitude between before and after the experiment.

Table 3. Comparison of balance ability measured by the S3-Check. (n=30)

	Pretest	Posttest	t	p
Body Stability (score)	3.39±1.24	3.23±1.08	1.129	.233
Body Stability (%)	127.87±27.17	122.90±25.98	.976	.337
Sensorimotor (score)	2.80±1.18	2.80±1.17	.014	.989
Sensorimotor (%)	136.93±26.96	136.97±26.71	-.006	.995
Symmetry (%)	49.77±10.31	49.97±11.96	-.072	.943

Values are mean ± standard deviation.

Ⅳ. Discussion

This study aimed to compare the effects of muscle fatigue induced by wall squats on lower limb strength and balance in healthy adults. After wall squats, significant decreases in knee extensor and hip extensor strength were observed. This is believed to be due to muscle fatigue, resulting in a reduction in the recruitment rate of motor units and sub-sequent decrease in strength (Gandevia, 2001). In contrast, no significant differences were observed in the strength of the knee flexors and hip abductors before and after performing wall squats. This is thought to be because these muscles are activated less during wall squat exercises. Previous research found that the activation of the hip abductors during wall squats was lower relative to other muscles (O'Sullivan et al., 2010). Another study reported that the activation rate of the knee flexors during wall squats was lower compared to other exercises (Lee et al., 2022). This result suggests that wall squats activate the knee extensors and gluteus maximus more than the knee flexors and gluteus medius, leading to muscle fatigue.

According to the literature, there is approximately a 34% decrease in maximal strength during muscle fatigue (Merle, 2001). However, in this study, both the knee extensor and gluteus maximus strength showed a reduction of approximately 15%. This suggests that there was a recovery of muscle fatigue between the time immediately following the exercise and the time of strength evaluation. According to previous research, it has been suggested that up to 67% of muscle fatigue can be recovered within 25 seconds immediately after exercise (Padulo et al., 2015). In this study, due to the lack of electromyography and metabolite analysis, it was not possible to accurately confirm the correlation between muscle fatigue and strength.

There were no significant differences in balance between before and after wall squat exercises in this study. Muscle fatigue adversely affects neuromuscular control, leading to a weakening of both strength and motor control. However, in healthy adults, two selective strategies, ankle strategy and hip strategy, exist to maintain balance (Morasso, 2022). The ankle strategy restores the center of pressure to a stable position through rotation around the ankle joint. This strategy is especially employed to restore balance when there is slight interference. On the other hand, the hip strategy is employed when ankle movement is restricted or when there is excessive interference with balance (Kanamiya et al., 2010). In this study, as the participants were healthy adults with high balance abilities, it is presumed that they predominantly used the ankle strategy to restore balance. While muscle fatigue resulted in a decrease in strength of the knee extensors and gluteus maximus, these are primarily muscles activated when employing the hip strategy. Therefore, it is presumed that the muscular fatigue induced by squats would have less impact on the muscles primarily activated in ankle strategies, consequently exerting a lesser effect on balance ability.

Since the participants in this study were healthy adults, it is likely that using the ankle strategy posed minimal difficulty. However, in stroke survivors, reliance on the hip strategy is common due to ankle deficits (de Oliveira et al., 2008). In other words, for patients with stroke, the impact on balance may differ from the findings of this study, as they often rely more on the hip strategy due to ankle impairments. Additional research targeting stroke survivors with impaired ankle function will be necessary in the future.

This study has several limitations. Although the study included 30 participants, the small sample size might constrain the generalizability of the findings. Secondly, the absence of measurements using electromyography or metabolite analysis precluded an objective quantification of muscle fatigue. Thirdly, due to the measurement of muscle strength based on MVC, if participants had stronger muscles than the evaluator, their strength might have been underestimated. For future research, it is essential to confirm the objective muscle fatigue in patients with stroke and investigate its correlation with balance.

V. Conclusion

This study aimed to examine how lower limb fatigue impacts muscle strength and balance in healthy adults. In this study, Muscle fatigue caused by wall squats was found to reduce the strength of the knee and hip extensors, while having no impact on balance. The results of this study may serve as foundational data for future research targeting patients with stroke.

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