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Original Article

Sex Differences in Hamstring Flexibility Changes After Specific Warm-up

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Background: Although warm-ups before exercise are widely accepted, research on sex differences in improving hamstring flexibility is limited. Differences in the physical and physiological characteristics between males and females may result in different responses to warm-ups.

Objects: This study aimed to examine sex differences in the effects of specific warm-up on hamstring flexibility.

Methods: This study included 24 young adults with hamstring tightness. The participants performed five maximal knee extensions and flexions at 90° flexion of the hip, and the maximal knee extension angle was measured in real-time using a smartphone clinometer application.

Results: The groups did not significantly affect the maximal knee extension angle but showed a significant effect for repetition ($p = 0.002$) and group-repetition interaction ($p = 0.002$). Males had no significant change in hamstring flexibility; however, females showed a significant increase in flexibility in the 5th trial compared with the 1st trial ($p = 0.041$). These results demonstrated sex-specific differences in flexibility improvement over time.

Conclusion: The findings of this study suggest that specific warm-up can successfully improve hamstring flexibility in females. This may be due to various factors, such as muscle stiffness of the lower extremity, estrogen levels, and temperature sensitivity. In clinical settings, specific warm-up might be helpful for females who participate in sports or activities, such as running or jumping, which require a full range of motion in the hip and knee joints.

INTRODUCTION

Although there are some controversies due to limited scientific evidence, warm-ups are frequently performed to prevent sports injuries by increasing muscle flexibility [1]. Warm-ups are classically divided into passive and active warm-ups [2]. Passive warm-ups increase body temperature using external means, such as hot packs, leading to muscle relaxation [3]. Contrastingly, active warm-ups increase heart rate and muscle temperature through voluntary movements, such as light running and jumping [4]. A specific warm-up is a type of active warm-up that involves repeating specific movements to selectively relax a target muscle more selectively [5]. For example, if performing an exercise that requires flexibility of the hip and knee joints, apply a specific warm-up to the hamstrings.

Males and females exhibit significant differences in physical and physiological characteristics, particularly muscle properties [6-8]. Females generally have less muscle mass and a lower percentage of fast-twitch fibers than males, which are more suitable for endurance exercises and have higher resistance to muscle fatigue [9-11]. These differences are expected to result in different responses to warm-ups between males and females. Most existing research has focused on using high-intensity stretching for muscle elongation. Previous studies examining increased flexibility after stretching have shown that the increase in flexibility in females is comparable or superior to that in males [12-14]. This is likely because females have relatively lower musculotendinous stiffness than males, making them more likely to experience an increased range of motion [12]. However, little research has been conducted on the effects of specific warm-up performed at a relatively low intensity compared with stretching.

This study aimed to examine the differences in the effects of specific warm-up on hamstring flexibility between males and females. By clarifying the sex differences in the effects of specific warm-up, this study is expected to contribute to developing effective methods for applying warm-up before exercise and establishing strategies for injury prevention.

MATERIALS AND METHODS

1. Participants

Twenty-four healthy young adults participated in this experiment (Table 1). Participants with hamstring tightness as determined by the active knee extension (AKE) test were included. Participants with a history of surgery on the lower extremities or those who had experienced pain in the lower extremities within the past 6 months were excluded. The Institutional Review Board of Woosong University approved this study (IRB no. 1041549-221011-SB-149), and all participants provided informed consent before the experiment.

Table 1. Participants characteristics

Variable	Male (n = 12)	Female (n = 12)	Total (N = 24)
Age (y)	23.6 ± 2.1	20.7 ± 2.2	22.1 ± 2.6
Height (cm)	175.4 ± 5.7	163.9 ± 3.5	169.7 ± 7.5
Weight (kg)	71.6 ± 9.5	58.3 ± 10.9	64.9 ± 12.1
Body mass index (kg/m^2)	23.2 ± 2.1	21.6 ± 3.4	22.4 ± 2.9

Values are presented as mean ± standard deviation.

2. Procedures

To ensure reliability, a single examiner performed all measurements for each participant. The participants lay on the treatment table in the supine position, with the pelvis and left femur stabilized using straps to restrict unnecessary movement. The AKE test was performed to confirm participation eligibility [15]. Participants who met the inclusion criteria underwent a specific warm-up consisting of five maximal knee extensions and flexions of the right leg, with the hip flexed to 90° (Figure 1). The lower leg was allowed to flex naturally before the start of the experiment. The examiner instructed participants to slowly perform maximal knee extension until they felt tension in the active and/or passive tissues on the back of the thigh. At the endpoint, the participants gradually reduced their effort to extend the knee and then naturally returned to the knee flexion position. The examiner measured the maximal knee ex-

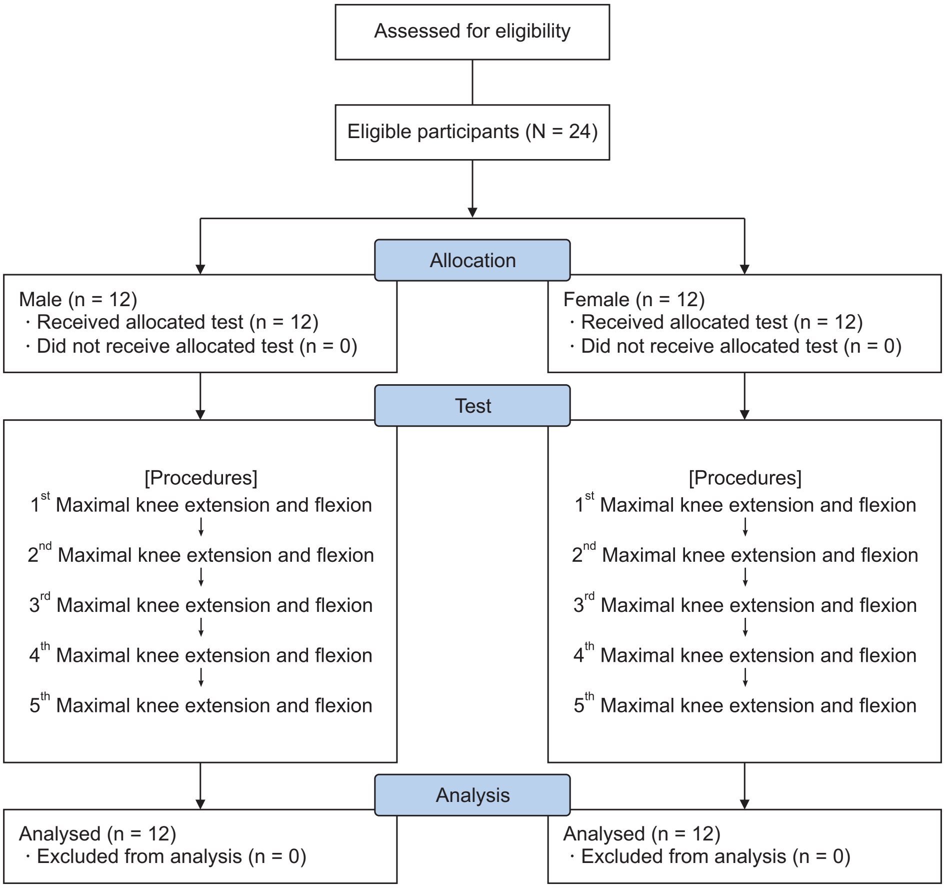

Figure 1. CONSORT flow diagram.

tension angle in real-time using a clinometer application on an iPhone 11 (Apple Inc.) and calculated the 180° extension angle for statistical analysis [16,17]. A metal rod was attached to the smartphone, with the ends pointed at the lateral epicondyle of the femur and lateral malleolus. The smartphone was placed in the middle of the two landmarks [18-20].

3. Data Analysis

The normality of the data was assessed using the Shapiro–Wilk test. Two-way repeated-measures analysis of variance (ANOVA) was performed to examine the effects of group (males and females) and repetition (five trials) on hamstring flexibility. Additionally, a repeated measures ANOVA was conducted to examine the effects of repetition in each group. AKE change was calculated as 'AKE at 1st trial – AKE at 5th trial.' The data were analyzed using IBM SPSS Statistics ver. 27.0 (IBM Co.), and the level of statistical significance was set at $p < 0.05$.

RESULTS

The sex (males and females) showed no significant main effect on hamstring flexibility ($p = 0.744$); however, repetition had a significant main effect ($p = 0.002$). There was also a significant interaction between sex and repetition ($p = 0.002$) (Figure 2). These results suggest that improvements in hamstring flexibility over time differ between males and females. In more detail, pairwise comparisons showed no significant change in hamstring flexibility over time in males (Table 2); however, a significant increase in the 5th trial compared to the 1st trial in females was observed ($p = 0.041$) (Table 3).

DISCUSSION

This study was conducted whether there are sex differences in the effects of specific warm-up on hamstring flexibility. The results showed that a specific warm-up consisting of five trials of active knee extension and flexion did not significantly

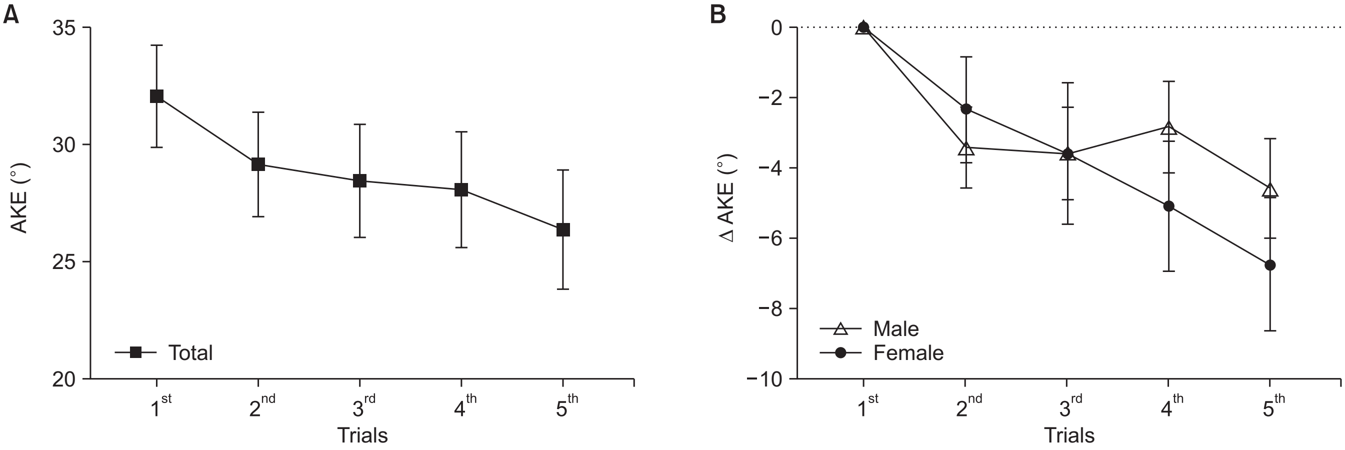

Figure 2. Changes in AKE over time. (A) Total participants with AKE, (B) males and females with Δ AKE. AKE, active knee extension; Δ AKE, AKE change.

Table 2. Pairwise comparisons of hamstrings flexibilities between trials in males

Trials (I)	Trials (J)	Mean difference (I-J)	Standard error	p-value
1	2	3.417	1.145	0.124
	3	3.583	1.323	0.203
	4	2.833	1.296	0.513
	5	4.583	1.411	0.078
2	3	0.167	0.878	> 0.99
	4	−0.583	1.258	> 0.99
	5	1.167	1.347	> 0.99
3	4	−0.750	0.808	> 0.99
	5	1.000	0.921	> 0.99
4	5	1.750	0.629	0.179

Table 3. Pairwise comparisons of hamstrings flexibilities between trials in females

Trials (I)	Trials (J)	Mean difference (I-J)	Standard error	p-value
1	2	2.333	1.494	> 0.99
	3	3.583	2.002	> 0.99
	4	5.083	1.836	0.183
	5	6.750	1.867	0.041
2	3	1.250	1.393	> 0.99
	4	2.750	1.360	0.682
	5	4.417	1.334	0.069
3	4	1.500	1.151	> 0.99
	5	3.167	1.342	0.378
4	5	1.667	0.595	0.172

increase the maximal knee extension angle in males. However, a significant increase in the maximal knee extension angle was observed in females after five trials. These findings may be explained by several factors, including the inherent characteristics of the musculoskeletal system, female hormone effects, and differences in temperature sensitivity.

Females have less muscle mass, leading to higher active extensibility of the hamstrings and lower active and passive muscle stiffness [21]. This is consistent with clinical trial results showing that hamstring and triceps surae stiffness is lower in females [13]. Even under stretching, the gastrocnemius muscle was also found to be less stiff in females [22]. Animal studies have shown that the Achilles tendon size is relatively small in females, indirectly suggesting that it has less resistance to knee joint extension [23]. In human studies, females have greater muscle-tendon complex length and tendon elongation when the ankle joint is subjected to lower torque [24]. Additionally, ligaments and other passive tissues tend to be more elastic in females, which may allow a more effective response to increased flexibility [25].

Estrogen, a female hormone, may also play a role in these findings. This hormone is closely related to muscle mass and force and protects against exercise-induced muscle damage [26]. However, estrogen negatively affects soft tissue stiffness. With hormones, joint laxity can increase, making joints more vulnerable to tensile force and increasing the risk of sports injury [27-29]. In females, increased estrogen levels increase hamstring extensibility and decrease stiffness [30,31]. Therefore, soft tissues can be easily elongated in females with high estrogen [32].

Females may be more sensitive to temperature than males [33]. In an experiment involving young and healthy adult females, greater increases in muscle temperature and longer maintenance of muscle temperature after exercise were observed in females than in males [34]. Increased muscle temperature is associated with decreased stiffness and improved muscle performance [35,36]. In a previous study, countermovement jump height increased significantly after a warm-up of the gluteal muscles [37]. Additionally, it was also reported that active warm-up effectively increased the temperature of the quadriceps muscle by approximately 3°C and increased maximal power output by inducing faster activation with greater conduction velocity [38]. However, further research is needed to confirm the types of warm-ups and their optimal application times to maximize muscle performance, as not all warm-ups are equally effective [39].

This study provides scientific evidence that specific warm-up can significantly improve hamstring flexibility in females. However, this study has some limitations. Participants were limited to young and healthy adults; therefore, the findings cannot be generalized to other populations. In addition, this study evaluated the acute effects of specific warm-up; therefore, the effects of long-term specific warm-up on hamstring flexibility remain unknown. This study measured only the change in hamstring flexibility as the dependent variable, which may have limited the interpretation of the results. Further research addressing these limitations is required to provide a more comprehensive understanding of the effects of specific warm-up on females.

CONCLUSIONS

This study confirmed that a specific warm-up program was more effective in improving hamstring flexibility in females than in males. This may be particularly beneficial for females participating in sports or activities requiring good hamstring flexibility, such as running or jumping.

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CONFLICTS OF INTEREST

No potential conflict of interest relevant to this study was reported.

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