

Original Article

Acute Effects of Static Stretching and Mulligan Bent Leg Raise on Hamstring Flexibility and Jumping Performance in Asymptomatic Young Adults: A Single-Session Study

Tahir Keskin¹, Mesut Ergan¹, Zeliha Başkurt¹, Ferdi Başkurt¹¹Süleyman Demirel University Faculty of Health Sciences Physical Therapy and Rehabilitation Department, Isparta, Turkey

Abstract

Objectives: This study compared the acute effects of static stretching (SS) and the Mulligan bent leg raise (BLR) technique on hamstring flexibility and jumping performance in asymptomatic young adults. **Methods:** Forty-two participants with bilateral hamstring tightness were randomly assigned to the SS or BLR group (n = 21 each). Active knee extension (AKE), vertical jump (VJ), and single-leg hop (SLH) performance were assessed before and immediately after a single intervention session. **Results:** A significant main effect of time was found for all outcomes (p < 0.05). Significant time × method interactions were observed for AKE and SLH, but not for VJ. The BLR group showed greater improvements in hamstring flexibility (AKE: +6.38°) compared with the SS group (+2.10°). SLH performance improved more in the BLR group, whereas VJ improvements were similar between groups. After adjusting for baseline AKE differences, post-intervention AKE remained significantly higher in the BLR group. **Conclusion:** Both SS and BLR produced beneficial acute effects on hamstring flexibility and jumping performance. BLR demonstrated larger acute improvements in hamstring flexibility and single-leg hop performance in this sample; however, these findings should be interpreted cautiously and may not be directly generalizable to athletic populations. **ClinicalTrials.gov ID:** NCT07138950.

Keywords: Flexibility, Hamstring Muscles, Jump Performance, Mulligan BLR, Static Stretching

Introduction

Flexibility training is a fundamental component of exercise programs aimed at optimizing both health and performance. The ability of muscles to adapt to mechanical stress varies according to their structural and functional characteristics, and reduced flexibility is particularly common in fast-twitch muscles that span two joints. The hamstring muscle group, which functions as a bi-articular structure and is heavily involved in daily activities and athletic movements,

is especially prone to flexibility deficits and injury. Optimal hamstring length and flexibility influence not only joint range of motion but also lower extremity motor skills such as force production, sprinting, and jumping^{1,2}. Accordingly, it is essential to evaluate different stretching and mobilization strategies with respect to both flexibility outcomes and their functional performance implications.

Conventional static stretching techniques aim to increase the passive length of muscle by modifying the viscoelastic properties of the muscle-tendon unit. These adaptations have been associated with reduced muscle-tendon stiffness and increased tolerance to stretch³. Despite its widespread inclusion in warm-up routines, static stretching (SS) has been reported to induce transient reductions in muscle strength, sprint performance, and jumping ability in the acute phase^{4,5}. However, the existing literature remains inconclusive⁶⁻⁹. Opplert et al. highlighted that heterogeneity in stretching protocols represents a major barrier to consensus and emphasized the importance of studies employing clearly defined and standardized stretching procedures¹⁰. In contrast, regularly applied SS protocols

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Corresponding author: Tahir Keskin, Assist. Prof. Süleyman Demirel University Faculty of Health Sciences Physical Therapy and Rehabilitation Department, Isparta, Turkey
E-mail: tahirkeskin2323@gmail.com
ORCID iD: 0000-0002-9237-3300

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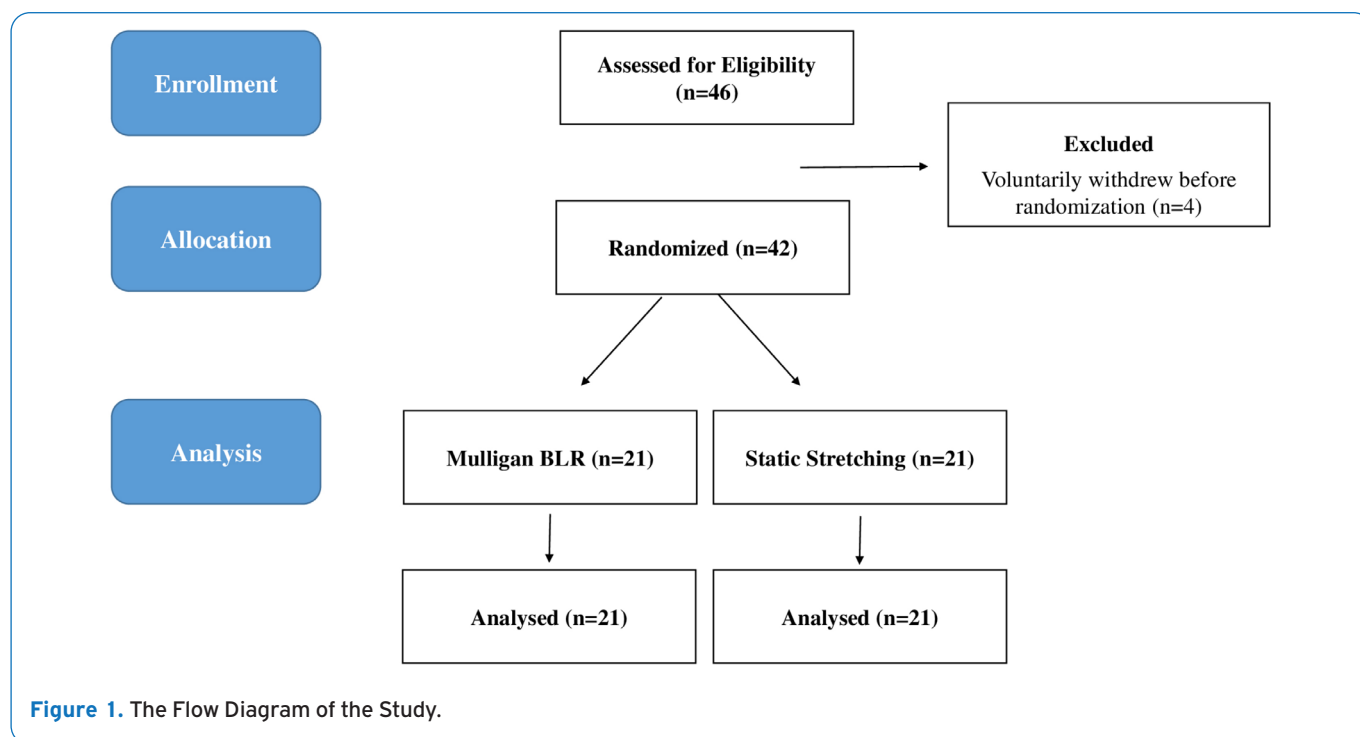


Figure 1. The Flow Diagram of the Study.

have been shown to enhance flexibility and may positively influence functional performance over the long term by improving muscle–tendon unit coordination⁶.

Mobilization-based approaches have been proposed as alternative strategies that target not only passive tissue extensibility but also neuromuscular control and proprioceptive mechanisms. Among these approaches, the Mulligan Bent Leg Raise (BLR) technique has been proposed as an effective method for improving hamstring flexibility. The BLR is a mobilization-with-movement technique that emphasizes active patient participation and is applied in a dynamic and functional manner¹¹. It is hypothesized that this approach facilitates neuromuscular integration and enhances proprioceptive input. Several studies have reported that mobilization-based techniques, including BLR, may result in faster and more pronounced flexibility gains than SS, potentially translating into superior motor performance outcomes¹²⁻¹³.

Jump performance is closely related to the force-generating capacity and elastic properties of the lower extremity musculature. Adequate hamstring flexibility may facilitate efficient force transmission—particularly during eccentric contractions—and contribute to improved jumping performance¹⁴. Therefore, examining the relationship between flexibility interventions and jumping performance may provide clinically and practically relevant insights for both athletic and rehabilitative settings.

This study aimed to compare the acute effects of static

stretching and the Mulligan Bent Leg Raise technique on hamstring flexibility and jumping performance. It was hypothesized that both interventions would produce acute improvements, with findings that may offer insights relevant to warm-up and rehabilitation practices.

Materials and Methods

Study Design

The present study, conducted between January and March 2025, employed a parallel-group randomized controlled design to examine the acute effects of SS and the BLR technique on hamstring flexibility and jumping performance. The study was designed as a single-blind trial, and each intervention was administered by researchers with expertise in the respective techniques.

Participants

A total of 46 undergraduate students (23 males and 23 females) aged between 21 and 26 years, enrolled in the Department of Physiotherapy and Rehabilitation at Süleyman Demirel University, were assessed for eligibility. All participants were asymptomatic and screened for hamstring tightness using the active knee extension (AKE) test. Participants were classified as having hamstring tightness based on the AKE test when full knee extension could not be achieved with the hip positioned at 90° of flexion and a clear sensation of hamstring stretch was reported

before reaching full extension. This qualitative criterion was used for screening purposes rather than a strict numerical cut-off. The study objectives and procedures were explained in detail, and written informed consent was obtained from all volunteers prior to participation.

Participants were included if they were asymptomatic, demonstrated hamstring tightness as assessed by the AKE test, volunteered to participate, and had no functional or medical conditions that could affect test performance. Given the absence of a universally accepted AKE cut-off value to define severe hamstring tightness¹⁵, no strict AKE-based exclusion threshold was applied. This approach allowed the inclusion of participants with varying degrees of hamstring tightness, thereby providing a more representative sample for the investigation of acute intervention effects. Exclusion criteria included a history of lower extremity injury within the previous two years, the presence of a neurological disorder, corticosteroid use, or participation in organized sports other than recreational activities.

Sample calculation

Sample size estimation was performed using G*Power software (version 3.1.9.4). Based on a previously reported effect size of 0.50 for changes in AKE¹², a type I error rate of 0.05, and a statistical power of 90%, a minimum of 19 participants per group was required. To account for potential dropouts, the study was designed to include a total of 46 participants.

Randomisation and Blinding

Four participants voluntarily withdrew from the study before randomization due to personal reasons. Therefore, a total of 42 participants were randomly allocated to either the BLR group (n = 21) or the SS group (n = 21). Subjects who met the inclusion criteria were randomly allocated to two groups using a computer-assisted randomization program. Each participant was assigned a sequential identification number, and group allocation was performed by a researcher independent of the intervention providers. No additional allocation concealment procedures (such as sealed opaque envelopes or centralized allocation) were implemented beyond the use of an independent allocator. This study was designed as a single-blind randomized controlled trial. The outcome assessor was blinded to group allocation throughout data collection and outcome assessment. Due to the nature of the interventions, participant blinding was not feasible.

Interventions

Both SS and BLR interventions were administered by experienced researchers in the field. One researcher (ME) applied the SS protocol, while another researcher (TK) administered the BLR technique. Outcome measures, including AKE, vertical jump (VJ), and single-leg hop (SLH) performance, were assessed immediately before and after

the interventions.

All interventions were applied to the dominant limb only, despite the presence of bilateral hamstring tightness. To ensure consistency, all outcome measurements were also performed on the same dominant limb. Participants were explicitly instructed not to perform any additional warm-up activities prior to the interventions or outcome assessments in order to isolate the acute effects of the applied techniques.

Mulligan Bent Leg Raise Technique

The BLR technique is a mobilization-with-movement approach that combines passive stretching with active participant involvement to enhance hamstring flexibility and increase AKE range of motion.

Participants were positioned supine on an elevated treatment table. The therapist sat lateral to the limb being treated and placed the participant's popliteal fossa on their shoulder, with the hip and knee flexed to 90°. Gentle distraction was applied to the distal femur, followed by an isometric contraction in which the participant was instructed to press the leg against the therapist's shoulder. Upon relaxation, the therapist applied pressure to the flexed knee, extending it in the direction of hip flexion within a pain-free range. The end position was maintained for 5 seconds before returning to the neutral position. This sequence was repeated three times, in accordance with previously described protocols^{12,16}.

Static Stretching

For the SS protocol, participants lay supine on a treatment table with the knee fully extended. The therapist supported the ankle and placed the participant's leg on their shoulder, passively flexing the hip until a stretch sensation was perceived in the posterior thigh. This position was maintained for 30 seconds and repeated five times¹⁷.

The dosage and application parameters for both interventions were selected based on commonly used clinical protocols and previous studies investigating the acute effects of SS and BLR techniques. For SS, a duration of 30 seconds was chosen in line with existing evidence suggesting that short-duration stretching is less likely to induce acute reductions in muscle strength or explosive performance. The BLR technique was applied according to established descriptions in the literature, using controlled repetitions and movement-assisted mobilization consistent with clinical practice^{8,12,17,18}.

Outcome Measures

Vertical Jump

VJ performance was measured using a vertical jump meter (TKK 5406, Takei, Japan). Participants stood upright with feet shoulder-width apart and hands placed on the hips to eliminate upper extremity assistance. From this position, participants performed a maximal vertical jump

Table 1. Demographic Variables of Participants.

Variable	BLR (n=21) Mean± SD	SS (n=21) Mean± SD	p*
Age (years)	22.85±1.06	22.71±0.71	0.61
Weight (kg)	60.04±9.05	64.33±12.64	0.21
Height (cm)	168.95±7.74	167.33±10.20	0.55
BMI (kg/m ²)	21.04±2.94	22.78±2.94	0.36
Sex (Female/male), n (%)	10/11, (48/52%)	11/10, (52/48%)	0.50

BLR = Bent Leg Raise; SS = Static Stretching; SD = Standard Deviation; BMI = Body Mass Index; cm = centimeter; kg = kilogram; n = sample size. Independent samples t-test was used for continuous variables and chi-square test for categorical variables.

Table 2. Baseline and Post Values Per Group for all Outcome Variables.

	Baseline (mean±SD)		p	Post (mean±SD)		p
	BLR(n=21)	SS (n=21)		BLR(n=21)	SS (n=21)	
Active Knee Extension Test (°)	58.86±10.66	66.76±8.87	0.013	65.24±10.75	68.86±8.47	0.23
Vertical Jump (cm)	31.12±7.40	29.60±6.63	0.48	33.21±7.70	30.79±7.09	0.29
Single Leg Hop Test (cm)	128.19±22.83	124.52±29.93	0.65	142.76±23.42	130.81±29.16	0.15

BLR = Bent Leg Raise; SS = Static Stretching; SD = Standard Deviation; °=degree.

following approximately 90° of knee flexion. Three trials were performed, and the best performance was recorded for analysis^{18,19}.

Single Leg Hop Test

For the SLH test, participants were instructed to hop forward on the dominant leg and land on the same leg while maintaining balance. The hopping distance was measured from the starting line to the heel of the landing foot. Three trials were performed, and the best performance was recorded for analysis, consistent with the vertical jump protocol^{18,20,21}.

Active Knee Extension Test

The AKE test was used to assess hamstring flexibility and has demonstrated good validity and reliability in healthy adult populations²². Measurements were obtained using a digital goniometer (Halo Medical Devices, Australia). Participants were positioned supine, with the hip and knee flexed to 90°. The therapist stabilized the thigh to maintain the hip angle and instructed the participant to actively extend the knee. The angle of knee extension was recorded using the goniometer¹².

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics (Version 22, IBM Corp., Armonk, NY, USA).

Descriptive statistics were calculated for all variables. To examine the effects of time (pre-test vs. post-test), group (BLR vs. SS), and their interaction on the outcome measures, a 2 × 2 repeated measures analysis of variance (RM-ANOVA) was conducted for each dependent variable. Additionally, analysis of covariance (ANCOVA) was performed for active knee extension (AKE) to adjust for baseline differences between groups. Prior to RM-ANOVA, assumptions of normality, homogeneity of variances, and sphericity were assessed. When the sphericity assumption was violated, the Greenhouse–Geisser correction was applied. Effect sizes were quantified using partial eta-squared (η_p^2), with values of 0.01, 0.06, and ≥ 0.14 interpreted as small, moderate, and large effects, respectively²³. The level of statistical significance was set at $p < 0.05$. To enhance clinical interpretation, mean change scores (Δ) with 95% confidence intervals were calculated for each outcome in both groups. In addition, between-group effect sizes for change scores were computed using Cohen's d , along with their corresponding 95% confidence intervals.

Results

The study was conducted with 42 participants with hamstring tightness, with a mean age of 22.78 ± 0.89 years. No statistically significant differences were observed between groups in terms of demographic variables. The demographic characteristics of the participants are

Table 3. Repeated Measures ANOVA Results.

	Effect	Sum of Squares Type III	df	MS	F	p	η^2_p
Active Knee Extension Test	Time	377.19	1	377.19	241.86	< 0.001	0.858
	Time × Method	96.43	1	96.43	61.83	< 0.001	0.607
	Error (Time)	62.38	40	1.56			
Vertical Jump	Time	56.19	1	56.19	22.68	< 0.001	0.362
	Time × Method	4.34	1	4.34	1.75	0.193	0.042
	Error (Time)	99.12	40	2.48			
Single Leg Hop Test	Time	2283.86	1	2283.86	32.06	< 0.001	0.445
	Time × Method	360.43	1	360.43	5.06	0.030	0.112
	Error (Time)	2849.71	40	71.24			

presented in Table 1.

A repeated measures analysis of variance (RM-ANOVA) was performed to examine the effects of time (pre-test vs. post-test), method (BLR vs. SS), and their interaction on active knee extension (AKE), vertical jump (VJ), and single-leg hop (SLH) performance. Baseline and post-intervention values for all outcome measures are presented in Table 2, and RM-ANOVA results are summarized in Table 3.

AKE Test Results: RM-ANOVA revealed a significant main effect of time and a significant time × method interaction for AKE, indicating differential improvements between groups over time (Table 3). Both groups demonstrated increased AKE following the intervention, with greater pre-post improvements observed in the BLR group (Table 2).

Given the presence of baseline imbalance in AKE values, an additional ANCOVA was conducted to adjust for baseline AKE. After adjustment, a significant group effect was observed for post-intervention AKE ($F_{1,39} = 47.34$, $p < 0.001$). The adjusted mean post-test AKE was higher in the BLR group ($69.08^\circ \pm 0.40$) compared with the SS group ($65.02^\circ \pm 0.40$), yielding an adjusted mean difference of 4.06° (Table 4).

Vertical Jump Test Results: For vertical jump performance, RM-ANOVA demonstrated a significant main effect of time, indicating improvements following the intervention in both groups (Table 3). However, the time × method interaction was not significant, suggesting that the magnitude of improvement did not differ between groups. Baseline and post-intervention values are shown in Table 2. As baseline VJ values were comparable between groups, no covariate adjustment was performed.

Single-Leg Hop Test: RM-ANOVA for single-leg hop performance revealed a significant main effect of time as well as a significant time × method interaction (Table 3). Both groups showed post-intervention improvements; however, the magnitude of improvement was greater in the BLR group compared with the SS group (Table 2). Baseline SLH values did not differ significantly between groups;

therefore, no additional covariate adjustment was deemed necessary.

Clinical Interpretation of Change Scores: To facilitate clinical interpretation, mean change scores (Δ) with 95% confidence intervals were calculated for each outcome in both groups, and between-group effect sizes were computed (Table 5). The BLR group demonstrated greater improvements in AKE compared with the SS group, with a very large between-group effect size ($\Delta_{BLR} - \Delta_{SS} = 4.29^\circ$, Cohen's $d = 2.40$, 95% CI: 1.55–3.25). For SLH performance, a moderate between-group effect size favoring the BLR group was observed ($\Delta_{BLR} - \Delta_{SS} = 8.28$ cm, $d = 0.69$, 95% CI: 0.07–1.31). In contrast, the between-group effect size for VJ performance was small to moderate, and the confidence interval crossed zero ($d = 0.41$, 95% CI: -0.20–1.02). Overall, large within-group effect sizes were observed for AKE, whereas moderate to large within-group effects were observed for vertical jump and single-leg hop performance (Table 3).

Discussion

The present study investigated the acute effects of SS and the BLR technique on hamstring flexibility and jumping performance. The findings indicate that both interventions were associated with improvements in AKE, VJ height, and SLH performance. Within this sample, larger improvements in hamstring flexibility and single-leg hop performance were observed in the BLR group; however, these findings should be interpreted with caution due to baseline differences in active knee extension between groups. After adjustment for baseline AKE values using ANCOVA, the BLR technique demonstrated a greater effect on post-intervention AKE compared with SS. Improvements in jumping performance were generally comparable between groups, particularly for vertical jump performance.

SS has traditionally been a fundamental component

Table 4. Adjusted post-intervention AKE values (ANCOVA).

Outcome	Group	Adjusted Mean \pm SE	95% CI	F (1,39)	p
AKE ($^{\circ}$)	BLR	69.08 \pm 0.40	68.26 – 69.89	47.34	<0.001
	SS	65.02 \pm 0.40	64.21 – 65.83		

*BLR=Bent Leg Raise; SS=Static Stretching; AKE=Active Knee Extension Test. *Baseline AKE was included as a covariate in the ANCOVA model. *Adjusted means were evaluated at a baseline AKE value of 62.81 $^{\circ}$.*

Table 5. Between and within Group Differences for Clinical Meaning.

Outcome	BLR Δ mean (95% CI)	SS Δ mean (95% CI)	Δ BLR - Δ SS	Cohen's d
AKE ($^{\circ}$)	6.38 (5.36–7.40)	2.10 (1.60–2.59)	+4.29	2.40
VJ (cm)	2.09 (1.22–2.96)	1.18 (0.05–2.31)	+0.91	0.41
SLH (cm)	14.57 (9.29–19.85)	6.29 (0.63–11.94)	+8.28	0.69

BLR=Bent Leg Raise, SS=Static Stretching, AKE=Active Knee Extension Test.

of warm-up routines aimed at enhancing flexibility. Nevertheless, previous studies have reported that SS may acutely impair performance in activities requiring explosive strength, such as sprinting and jumping^{2,5}. These effects have been attributed to reductions in muscle–tendon unit stiffness and alterations in neuromuscular activation, including decreased muscle spindle sensitivity, altered Golgi tendon organ responses, delayed motor unit recruitment, and impaired intramuscular coordination². Consequently, dynamic stretching is frequently recommended during warm-up routines. Despite this, SS has consistently been shown to be effective in improving flexibility, and flexibility-oriented exercises remain essential in certain sports contexts for both performance optimization and injury prevention²⁴. Importantly, the negative performance effects associated with SS appear to be strongly influenced by stretching duration²⁵, muscle length², and the overall warm-up protocol. Short-duration SS (≤ 30 –45 seconds), particularly when integrated with dynamic movements, has been reported to attenuate or even reverse performance decrements²⁵. In line with these findings, the present study demonstrated improvements in jumping performance following SS, suggesting that the relatively short duration and controlled application of the SS protocol may have minimized potential adverse effects while preserving gains in flexibility.

Both BLR and SS were found to acutely enhance hamstring flexibility and hop performance. However, the more pronounced improvements observed in AKE and SLH following BLR suggest that this mobilization-based approach may confer additional benefits beyond those

achieved through SS alone. While SS has a well-established role in increasing muscle extensibility, its acute effects on muscle strength and explosive performance remain inconsistent^{26,27}. In contrast, mobilization techniques such as BLR may simultaneously address flexibility and neuromuscular function, potentially resulting in more favorable performance-related outcomes. In the present study, BLR demonstrated greater acute improvements in flexibility and single-leg hop performance, although these findings should be interpreted within the context of the study design and sample characteristics.

The BLR technique, grounded in the principles of mobilization with movement, is proposed to enhance hamstring flexibility through combined mechanical and neurophysiological mechanisms^{28,29}. The application of traction and movement during BLR may facilitate posterior pelvic tilt, contribute to reduced neural mechanosensitivity, and promote the release of myofascial structures, including the thoracolumbar fascia³⁰. Additionally, BLR has been suggested to stimulate proprioceptive input, potentially enhancing neuromuscular coordination and motor unit recruitment³¹. These mechanisms may help explain the greater improvements observed in single-leg hop performance, a task that requires not only force production but also balance, proprioception, and postural control.

In contrast, vertical jump performance improved similarly in both groups. Single-leg jumping requires not only explosive strength but also the integrated training of multiple motor skills, including balance, proprioceptive feedback, postural control, and neuromuscular coordination²⁹. Mulligan mobilization has been demonstrated to exert

beneficial effects on joint mechanics and the neuromuscular system, extending beyond the scope of passive flexibility¹¹. Consequently, this approach has the potential to yield substantial performance enhancements in unilateral tasks that demand balance. Unlike single-leg hopping, the vertical jump is a bilateral task that primarily reflects lower extremity power and explosive strength, which may be less sensitive to short-term changes in flexibility or proprioceptive input. Therefore, while both interventions enhanced flexibility, the neuromotor contributions of BLR may be more relevant to unilateral functional tasks such as the single-leg hop.

Several limitations of this study should be acknowledged. First, only acute effects were examined, and the findings cannot be extrapolated to long-term adaptations. Second, the sample consisted of asymptomatic physiotherapy students rather than trained athletes, which limits the generalizability of the results to athletic populations. Additionally, the narrow age range of participants further restricts external validity. Future studies incorporating longitudinal designs, sport-specific populations, and complementary neuromuscular or electrophysiological assessments are warranted to further elucidate the mechanisms and practical relevance of these interventions.

In conclusion, the present study demonstrates that both SS and the BLR technique can induce positive acute effects on hamstring flexibility and selected aspects of jumping performance in asymptomatic individuals. Within this sample, the BLR technique demonstrated larger acute improvements in active knee extension and single-leg hop performance compared with SS; however, baseline differences in AKE limit firm causal attribution. Vertical jump performance improved similarly in both groups. As the study population consisted of asymptomatic physiotherapy students, the applicability of these findings to athletic populations should be considered exploratory and warrants further investigation. Future studies involving trained athletes and longer-term intervention protocols are needed to confirm whether BLR provides superior benefits in sport-specific performance contexts.

Ethics Approval

Ethical approval of the study obtained from Bingöl University Health Sciences Scientific Research and Publication Ethics Board (26.12.2024- 16/24-16). The study was conducted in accordance with the principles of the Declaration of Helsinki 1964 and its later amendments.

Consent to Participate

Informed written consent was obtained prior to randomization from all participants.

Authors' Contributions

Conceptualization: TK, FB; Methodology: TK, ZB, FB; Formal analysis and investigation: ME; Writing - original draft preparation: TK, ME; Writing - review and editing: TK, ZB, FB; Resources: ME, ZB; Supervision: ZB, FB. All authors read and approved the final version of the manuscript.

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We used Chat GPT solely for English-language editing to improve grammar, wording, and clarity. The tool did not generate scientific content, analyses, interpretations, or references. All authors verified the content and accept full responsibility for the integrity and accuracy of the article.

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