Research Paper: The Immediate Effect of Static Hamstring Stretching on Dynamic Balance and Gait Biomechanical Variables in Athletes With Hamstring Tightness: A Preliminary Study

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ABSTRACT

Introduction: Flexibility is an essential component of muscle function, and insufficient muscle flexibility may lead to muscle injuries. Decreased hamstring flexibility is one of the frequently reported risk factors for a hamstring strain and diminished athletic performance. Stretching is a commonly used intervention for increasing muscle length. There is a lack of evidence concerning the possible effects of hamstring stretching in balance and gait biomechanics. So, this study was designed to investigate the potential effects of static hamstring stretching on the range of motion (ROM), dynamic balance, and biomechanical variables of gait in athletes with hamstring tightness.

Materials and Methods: This study is a single-group, pretest-posttest clinical trial performed on semi-professional female athletes. Twelve female athletes aged 20 to 35 years with bilateral hamstring tightness received a single session of unilateral static hamstring stretching on their randomly selected side. All subjects were assessed for straight leg raise, popliteal angle (using standard goniometry), perceived hamstring tightness (using a visual analog scale). They completed single-leg standing and 15-m walking and running tasks before and immediately after the intervention. The biomechanical parameters, including gait-line length, swing duration, and stance duration in walking tasks, maximum total force and mean total force in running task, and center of pressure (COP) displacement and standard deviation during balance task were measured using OpenGo sensor insole system. The pre-post values were compared using the paired sample t-test, and the level of significance was 0.05.

Results: The values for straight leg raise and popliteal angle significantly increased ($P<0.05$) compared with the baseline, while perceived tightness significantly decreased following stretching ($P<0.001$). The amplitude ($P=0.006$) and standard deviation ($P=0.016$) of COP displacement in the mediolateral direction during the single leg stance balance task were significantly decreased after the intervention. Stance duration in slow walking ($P=0.004$), as well as stance duration ($P=0.012$) and swing duration ($P<0.001$) in fast walking, were significantly decreased ($P<0.05$) after stretching. No change was observed in gait biomechanical variables during the running test ($P>0.05$).

Conclusion: The results of this study indicate that static hamstring stretching can be a promising intervention not just for increasing hamstring flexibility but also for improving balance ability.

Keywords: Static stretching, Hamstring flexibility, Dynamic balance, Gait biomechanical variables

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1. Introduction

Flexibility is one of the most important features of muscle function. Decreased muscle flexibility is more common in fast-twitch muscles, especially those crossing more than a single joint. It makes them susceptible to both strain and overuse injuries. The hamstring muscle is known as a muscle commonly involved with tightness and consequent injuries, especially in athletes [1]. Hamstring tightness can increase the risk of a hamstring strain and low back pain (LBP), and patellofemoral pain syndrome [1]. Moreover, a decrease in hamstring flexibility may cause compensatory adaptations in pelvic motions, posture, and vertebral curves during daily activities. Hamstring tightness is also related to strain, eccentric exercise-related injuries, and impaired performance in athletes [1]. To solve these problems, therapists have used various methods to increase muscle flexibility, including stretching, heat, and massage [2]. Different stretching methods such as static stretching, dynamic stretching, and proprioceptive neuromuscular facilitation (PNF) techniques may help increase muscle flexibility [2]. Several studies have shown a significant increase in knee extension range of motion (ROM) and hamstring length following static hamstring stretch [2-8], while some others found no significant change in knee joint ROM [9]. The beneficial effects of stretching on knee ROM and stiffness have been represented in patients with knee osteoarthritis and healthy subjects [10, 11]. Stretching is a widely-used method for increasing joint ROM and muscle flexibility which may be helpful in injury prevention and rehabilitation after injuries. Current evidence about its effectiveness for improving muscle flexibility is controversial [6, 12].

In addition to the potential effects of stretching on muscle flexibility, the balance ability may also be influenced by this method through some possible mechanisms. It has been suggested that hamstring stretching may normalize the lumbopelvic rhythm in individuals with hamstring shortening [13]. Moreover, the normal length of the hamstring can affect hip strategy through its proximal attachment to the ischial tuberosity. Several authors have investigated the possible effects of stretching on balance ability, but they have reported inconclusive results: some indicating positive effects [14], some adverse effects [15, 16], and the others without meaningful effects [17].

To study the effectiveness of different interventions to lower limbs, providing quantitative data about kinematics, kinetics, and feet dynamics can be greatly valuable. Evaluation of the physiological cost index (PCI) and gait analysis have shown undesirable changes in gait following induced hamstring tightness [18]. A single hamstring stretching session has been shown not to affect the knee, hip, and pelvis kinematics [19]. A relationship between available knee extension and dynamic restriction of knee extension during the terminal swing phase has already been proven [20].

Two groups of devices are often used to provide quantitative data about foot kinetics and dynamics: fixed force platforms and wearable sensors, such as insoles and socks. Although force platform is considered a standard gold method to determine the gait events, its use is limited to laboratory settings, and the number of steps is limited by the number of force platforms [21].

On the other hand, sensor insoles have been commonly used in different fields, such as footwear designing, athletic performance analysis, posture monitoring, injury prevention, and diagnosis of foot pathologies [21]. Recently a new wireless wearable insole has been introduced by OpenGo to measure plantar pressure and foot acceleration equipped with integrated internal memory [21].

There has been no study investigating the effect of hamstring stretching on gait biomechanical variables in athletes with hamstring tightness during single leg stance, walking, and running. According to the results of a recent literature review in 2019, high-quality evidence for a possible beneficial effect of static hamstring stretching for injury prevention and improving functional status was lacking [22]. So, this study was performed to find whether static hamstring stretching can improve dynamic balance and gait biomechanical variables during walking and running in athletes with bilateral hamstring tightness. We hypothesized that static hamstring stretching could improve hamstring flexibility, as well as dynamic balance performance and gait biomechanics.

2. Materials and Methods

Study design

This study was a single-group, pretest-posttest clinical trial, designed and performed in the research center of Tehran University of Medical Sciences, 2019. Twelve female athletes aged 20-35 years with bilateral hamstring tightness (straight leg raise [SLR]<90°, popliteal angle [PA]>30°) who had equal or more than one year regular sport activity for at least three sessions per week each lasting for two hours, were included. This sample size was calculated according to the data of our pilot study,

Figure 1. The 90-90 Active Knee Extension test

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regarding α=0.05 and β=0.20. All volunteers with a history of a hamstring injury, low back pain (LBP), neurologic symptoms, and musculoskeletal disorders during last year were excluded. Before starting the procedure, the subjects were informed about the process, goals, and method of the study, and they signed informed consent. All subjects were allowed to discontinue the study, even with no definite reason. The time of the tests for each subject was established before regular daily exercise and at least a week before participating in a sports competition.

Study procedures

All subjects were evaluated for SLR and PA both as inclusion criteria and outcome measures. These assessments were performed using standard goniometric measurements. To perform the SLR test, we asked the subjects to lie supine and raise one leg gently with a full extended knee while the contralateral leg remained on the bed straightly. The examiner stands beside the bed while locating the goniometer axis on the greater trochanter, holding the moving arm of the goniometer and the subjects' trunk and the fixed arm and the lateral side of the thigh. PA (or active knee extension) was measured while hip and knee were held in a 90-90 position using a strap up to the popliteal crease to fix the hip joint in 90° of flexion (Figure 1). Two 5-cm straps were also used, one at the anterior superior iliac spine and another one, 2-cm superior to non-tested tibia tuberosity [23]. The subjects were then asked to extend the knee joint maximally. The examiner holds the moving arm along with the lateral aspect of the fibula, and the angle between the moving arm and femoral axis was recorded.

After that, the perceived hamstring tightness was measured using a visual analog scale (VAS) regarding 0 for no tightness and 10 for maximum tightness. The scale was shown to the subjects, and they were asked how much tightness they felt in their hamstring muscle [2]. Finally, they were asked to wear their athletic shoes while insoles were replaced by a pair of OpenGo sensor insoles (Moticon GmbH, Germany). OpenGo system was used with a pair of sensor insoles (size 37, with 13 capacitor sensors, and 50-Hz sampling rate) for data gathering during the following tests (Figure 2):

Single leg stance balance task

Each subject was asked to maintain her balance while standing for 20 s on the right and then on the left foot. This task was repeated three times with an interval of 10 s.

Slow walking, fast walking, and running task

Then, the subjects were asked to walk along a 15-m pathway at two different walking speeds (slow and fast) and then run at the preferred speed, each repeated three times. The average values of the three trials were considered for comparative analysis.

The sensor insoles were used to record some biomechanical parameters during balance, walking, and running tasks, including gait-line length, total force, swing,

Figure 2. The Moticon's sensor insoles

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Table 1. Comparison of straight leg raise (SLR), popliteal angle (PA), and perceived tightness (measured by visual analog scale [VAS]) before and after stretch (n=12)

Variables	Mean±SD		Effect Size (Cohen's d)	P
	Before Intervention	After Intervention		
SLR (°)	82.16±2.85	84.11±3.49	1.38	0.00**
Popliteal Angle (°)	-33.83±2.31	-31.47±2.08	2.38	0.00**
Perceived tightness (VAS)	6.08±1.30	5.08±1.49	2.70	0.00**

** P<0.01.

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and stance duration, and displacement of the center of pressure (COP).

Study intervention

Once baseline data gathering was completed, each subject lay down on the bed in a supine position, and the examiner moved the randomly selected leg toward hip flexion while gripping the ankle and holds the knee joint in full extension as far as the subject sensed hamstring stretch. The examiner held this position for 30 s, and then the leg was returned to starting position [24]. This stretching process was repeated three times for each subject with a 10-s break between trials.

Statistical analysis

The sensor insoles' data were extracted by Moticon software and were analyzed in SPSS v. 19.

The Shapiro-Wilks test was used to test the distribution of each dependent variable. Pre-post comparisons for all dependent variables were made using paired t-test, and the level of significance was P<0.05.

3. Results

The Mean±SD age, height, weight, and BMI of the subjects were 29.50±3.50) years, 165.00±4.99) cm, 59.58±6.88) kg, and 21.80±2.20) kg/m^2, respectively. The results of the Shapiro-Wilk test showed normal distribution of these demographic characteristics (P>0.05).

As shown in Table 1, SLR and PA increased significantly (P<0.001), while perceived tightness decreased significantly (P<0.001) after stretching. Results of the single leg stance balance test showed that the mean and standard deviation of COP mediolateral displacement were significantly decreased (P<0.05) while mean and standard deviation of COP anteroposterior displacement did not change following the intervention (P>0.05).

The mean duration of the swing phase (MSWD) decreased significantly during both slow walking and fast walking tasks (P<0.05), while the mean duration of the stance phase (MSTD) and mean length of the gait line (MLGL) decreased significantly just during the fast walking task (P<0.05). There was no significant change in any variable during the running task (P>0.05). Results of the single leg stance balance test and 15-m walking and running tasks are summarized in Table 2.

4. Discussion

This study was performed to find the immediate effect of static hamstring stretching on hamstring flexibility,

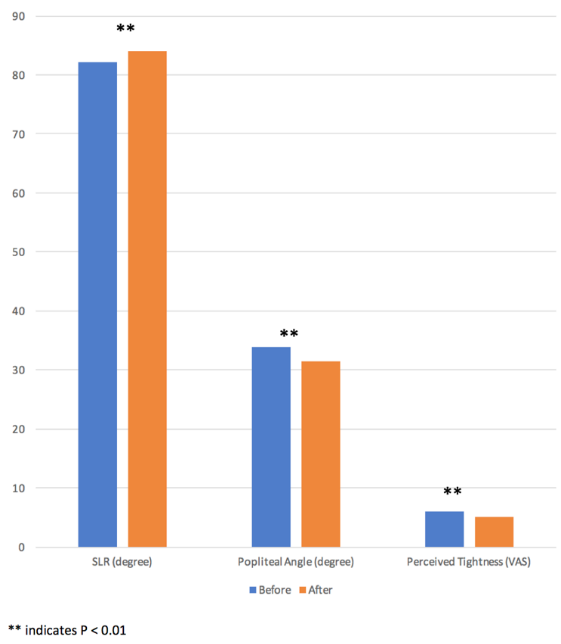

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Figure 3. Comparison of SLR, PA and perceived tightness before and after stretching

COP: center of pressure; SD: standard deviation; M-L: mediolateral; A-P: anteroposterior; TF: total force.

Table 2. Comparison of the biomechanical variables during balance, walking, and running tests (n=12)

Biomechanical Variables		Mean±SD		Effect size (Cohen's d)	P
		Before Intervention	After Intervention		
Single leg balance task					
Mean COP displacement A-P (mm)		-40.32±9.90	-44.20±6.42	0.62	0.05
SD COP displacement A-P (mm)		7.91±1.52	8.11±3.08	0.06	0.82
Mean COP displacement M-L (mm)		-6.60±1.15	-5.45±1.44	0.98	0.00**
SD COP displacement M-L (mm)		2.63±0.65	1.80±0.92	0.81	0.01*
Walking Task	Walking speed				
Gait line length (mm)	Slow	114.00±24.62	122.83±23.69	0.50	0.10
	Fast	96.23±37.34	71.72±35.55	0.73	0.02*
Swing time (s)	Slow	0.66±0.06	0.61±0.06	0.24	0.00**
	Fast	0.40±0.05	0.33±0.06	1.64	0.01*
Stance time (s)	Slow	0.39±0.07	0.37±0.06	1.04	0.40
	Fast	0.44±0.07	0.37±0.06	0.86	0.01*
Running Task					
Mean TF (N)		1237±160.51	1167±117.47	0.45	0.14
Max TF (N)		1804±206.17	2128±290.72	0.24	0.41
Swing time (s)		0.47±0.04	0.45±0.02	0.30	0.28

* P<0.05; ** P<0.01.

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dynamic balance, and biomechanical variables of gait in female athletes with bilateral hamstring tightness.

Our results demonstrated a significant increase in SLR and PA values, as well as a significant decrease in perceived tightness following static stretching. During the single-leg stance task, the mean and standard deviation of COP mediolateral displacement was significantly dropped, while the mean and standard deviation of COP anteroposterior displacement remained unchanged. The results showed a significant decrease in MSWD either in slow or fast walking and a significant decrease in MSTD and MLGL in fast walking. None of the measured biomechanical variables during running significantly changed.

Already, different ways have been used to evaluate muscle flexibility, including subjective (perceived tightness) and objective (SLR and PA) outcome measures. In addition, several methods, including static and dynamic stretching, PNF, thermal modalities, and so on, have commonly been used to improve the flexibility of different muscle groups, especially those with a higher risk of strain injuries [19].

The significant increase in SLR values, indicating a positive effect of the static stretching method on hamstring flexibility, supports previous reports [3, 5, 7, 25]. Reid et al. observed an immediate increase in hamstring flexibility following a stretching protocol in 55 elderly subjects with and without knee osteoarthritis. Their participants received three 60-s stretches with 60-s intervals [11]. Nelson found acute improvement of hamstring flexibility in both static stretching and eccentric exercise groups compared to controls. He performed his study on 75 young athletes with hamstring stiffness [10]. Other researchers found similar results [26-29].

A physiologic mechanism can explain increased knee ROM and hamstring length. Once a muscle is stretched, lengthening of the muscle (and underlying spindles) is sensed by the central nervous system, and its impulses lead to reflexive muscle contraction, acting as resistance against excessive lengthening. If the muscle is held in an elongated position for some seconds, Golgi tendon organs are activated, causing inhibition of muscle spindles and eventually muscle relaxation [2]. On the contrary, Bazett-Jones et al. [9] found no significant change in knee ROM following static hamstring stretch. They evaluated the effect of a stretching protocol, including 6 weeks of static stretching on knee ROM, in healthy athletes. The different results could be attributed to their healthy subjects. Moreover, in their study, knee ROM was measured six weeks after the beginning of the intervention, while in the current study, the measurements were performed immediately after the intervention.

A relationship between muscle flexibility and knee kinematics in the transverse plane during walking has been previously observed by some authors [30]. Gaudreault et al. demonstrated a relationship between the flexibility of hamstring and iliotibial band and knee kinematics in the transverse plane [31]. They showed that the runners had a significantly less flexible iliotibial band than the non-runners. The runners demonstrated a greater mean tibial external-rotation angle at initial contact and a smaller mean peak tibial internal-rotation angle than the non-runners.

The significant decrease in perceived muscle tightness following stretching observed in the current study indicates that in addition to the beneficial effects of stretching on ROM and muscle flexibility, it may be an effective intervention to help the subjects feel more comfortable with their hamstring muscle. Mhatre et al. [24] also reported improved perceived tightness following static hamstring stretch, using active knee extension and slump tests.

The hamstring muscle group may have an essential role in balance strategies due to its simultaneous activity across both hip and knee joints [32]. So, the impaired hamstring flexibility may have some adverse effects on balance performance among populations with different activity levels.

Gurfinkel et al. reported that changes in muscle length could cause postural disorders that can lead to impaired balance ability [33]. Zagyapan et al. also stated that shortening of the hip flexor and hamstring muscles causes postural changes that affect the individual's balance [34]. Moreover, Palmer et al. measured hamstring stiffness and the overall stability index following a passive stretching intervention in 11 elderly subjects. They reported improved stiffness and stability following such intervention [35]. On the other hand, some potential adverse effects of stretching intervention on dynamic balance have been suggested. Ahmadabadi et al. assessed the effect of stretching of some muscle groups, including hamstrings, gluteals, quadriceps, and hip flexors, on static and dynamic balance [36]. Their results showed that stretching could improve static balance, while dynamic balance might be adversely affected by such general stretching program.

The results of the single leg stance balance test showed that static stretch could improve dynamic balance performance in mediolateral direction by decreasing mean and standard deviation of COP-mediolateral, while no significant change was observed in the mean and standard deviation of COP-anteroposterior, indicating no change in balance ability in the anteroposterior direction. Our findings were consistent with the previous reports by Hyong and Kang [15] and Reddy and Alahmari [16]. However, Behm et al. [17] observed some conflicting results as they reported adverse effects of stretching exercise on subjects' balance. The contradictory results found by Behm et al. could be partly due to methodological differences. Their subjects underwent stretching of three muscle groups (hamstrings, quadriceps, and plantar flexors), not only hamstrings. Besides, they used a computerized wobble board test and balance ratio as outcome measures for balance evaluation. Lim et al. [14] observed no significant effect of hamstring stretching on balance performance.

It should be noted that they assessed double leg balance. Moreover, their study was performed on healthy non-athlete subjects. So, the contradiction between our results and previously reported results can be explained by considering differences in samples, interventions, and outcome measures. Additionally, in our study, the balance performance was evaluated in different movement planes (ML & AP) separately, while some of the previous studies have reported uniplanar results. It should be noted that according to a nonlinear point of view, some researchers believe that decrease in amplitude and standard deviation of COP displacement can be interpreted as increased rigidity of the system and decreased balance performance [37].

The observed decrease in MSWD in slow walking can be regarded as a potential improvement of performance which may lead to an increase in average walking speed. It can partly be attributed to increased hamstring length (which, according to the force-velocity relationship, can increase contraction velocity) [38].

A concurrent decrease in MSWD and MSTD during fast walking, indicating increased walking speed, seems reasonable regarding the previously explained positive effect of stretching on contraction velocity [39]. It was previously suggested that hamstring tightness might lead to a decrease in walking speed [40].

In addition to ground reaction force and plantar pressure distribution, gait-line length is a commonly reported parameter in sensor insole systems. Gait-line is the progression of the ground reaction force point of application along the sole of the foot during each step [41]. Some authors believe that gait-line is a helpful parameter to find gait pathologies [42]. We found a significant decrease in MLGL in the fast walking test following hamstring stretching. This decrease can partly be associated with increased intrinsic foot muscles' tonicity to produce and keep the longitudinal plantar arch [43]. A similar decrease in gait line length was previously observed by Yoo et al., who compared normal walking with arch-building walking [43]. They used this type of walking as an exercise in which the subject is asked to walk while pulling the first metatarsal head toward the heel without toe flexion. Those authors proposed the decreased gait line length as a positive change in gait biomechanics. Similarly, Ray and Snyder suggested that a shorter gait-line is related to more normal gait biomechanics and less energy expenditure during walking [44]. Also, the relationship between hamstring tightness and increased energy consumption during walking has been previously reported by Williams and Welch [40]. Although some previous studies suggested static stretching as an intervention with potential negative effects on running performance [45], our results indicated no adverse effect of this intervention on biomechanical variables of running. Total force (TF) is the summation of three components of the ground reaction force during gait cycles, so a decrease in maximum TF or mean TF can be considered as a positive change following any intervention. According to Table 2, the mean total force and mean swing duration in running task decreased following hamstring stretching, but these changes were not statistically significant. So, by increasing the number of stretching sessions, it may be possible to observe more significant positive changes in running.

The results of this study support our study hypothesis regarding the possible positive effects of hamstring stretching on dynamic balance and gait biomechanics. It should be mentioned that the number of available sensor insoles in the current study was very low, so the process of data gathering was relatively slow, and we couldn't include on-field evaluations due to these limitations. Moreover, these results should be cautiously generalized to the general population because we included only female athletes due to limited available sizes of insoles. More studies in different settings seem to be needed, especially during real sports competitions or training sessions, to understand better the possible effects of stretching on athletic performance and gait biomechanics.

5. Conclusion

According to our results, static stretching seems to be an appropriate intervention to increase hamstring flexibility and eliminate extension ROM restriction in female athletes with hamstring tightness. Moreover, stretching may help to have more normal gait biomechanics and better mediolateral dynamic balance.

The number of available sensor insoles in the current study was very low, so the process of data gathering was relatively slow, and it was not possible to include on-field evaluations. Moreover, these results should be cautiously generalized to the general population because we included only female athletes due to limited available sizes of insoles. Besides, the examiner was not blinded to the time of the examination (pre- or post-intervention). Both examinations were done on the same day for each participant, so that it might be a source of bias in our study. More studies in different settings are needed, especially during real sports competitions or training sessions, to understand better the possible effects of stretching on athletic performance and gait biomechanics.

Ethical Considerations

Compliance with ethical guidelines

The participants were informed of the purpose of the research and its implementation stages. A written consent has been obtained from the subjects. This study was approved by the Ethics Committee of Tehran University of Medical Sciences.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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