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ORIGINAL ARTICLE

Comparison of ROM, perceived tightness, and kinetic variables during balance, walking, and running tasks in athletes with and without hamstring tightness using sensor insoles

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Abstract

Objective The length of the hamstring muscles plays an important role in human movements. The aim of the present study was to compare ROM, perceived tightness, and kinetic variables during balance, walking, and running tasks in athletes with and without hamstring tightness.

Methods Thirty healthy female athletes (15 with hamstring tightness and 15 controls) were assessed for ROM, perceived tightness, and kinetic parameters which were obtained by Moticon SCIENCE insoles and Moticon software during single-leg balance, slow/fast walking, and running. Independent *t* test was used to compare the outcome measures between two groups.

Results The results showed that the control group and the athletes with hamstring tightness are significantly different in regards to ROM, perceived tightness ($P = 0.001$), the mean center of pressure in the mediolateral direction (MCOPML) ($P = 0.01$) in single- leg balance, maximum total force of stance phase (MaxTFSP) ($P < 0.02$) in slow walking, and mean Y end point of gait line (MYEPGL) ($P = 0.04$) in fast walking. In the running task, none of the study variables were significantly different between the two groups of athletes with and without hamstring tightness.

Conclusion It is recommended to pay more attention to the hamstring flexibility, especially during balance and walking tasks and regaining its normal length should be included in the rehabilitation plans.

Keywords ROM · Perceived tightness · Balance · Gait · Running · Hamstring tightness

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Abbreviations

SLR	Straight leg raise
AKE	Active knee extension
MCOPAP	Mean of center of pressure displacement in anteroposterior direction
MCOPML	Mean of center of pressure displacement in mediolateral direction
SDCOPAP	Standard deviation of pressure displacement in anteroposterior direction
SDCOPML	Standard deviation of pressure displacement in mediolateral direction
BBCOPAP	Bounding box of center of pressure displacement in anteroposterior direction
BBCOPML	Bounding box of center of pressure displacement in mediolateral direction
MCOPV	Mean of center of pressure velocity
COPTL	COP trace length

Introduction

Sufficient hamstring extensibility is an important factor of fitness and spinal health. The multi-joint nature, variety of functions, the tonic-postural feature, and the large amount of tensile forces applied to the hamstring muscle make it prone to be tightened [1]. Also, prolonged sitting postures, especially at work and when working with a computer, can lead to serious imbalances in different muscle groups including hamstrings [2]. Hamstring injuries are among the most common non-contact muscle injuries in male footballers [3] and tightening of these muscles can affect the position of the proximal and distal joints. Minoonejad et al. reported significant difference in Q-Angle and thoracic torsion, in people with and without hamstrings tightness, suggesting a special attention to be paid to hamstring length [4]. Hamstring tightness increases pelvic tilt as well as lumbar kyphosis during trunk flexion. Therefore, it is associated with low back pain, kyphosis, spondylolisthesis, and disc herniation. In addition, short hamstrings can lead to acute injuries (sprains or strains) and chronic conditions such as groin injuries [5]. It is suggested that more flexion in low back pain patients could be a mechanism for compensating the decrease in lumbar muscle strength [6]. Hamstring tightness can further compensate for the quadriceps muscle, resulting in excessive muscle activity, tendonitis, or patellofemoral pain syndrome [7].

Furthermore, the length of the hamstring muscles plays an important role in human movements, including walking and running. Hamstring tightness increases the compressive force in patellofemoral joint due to the increased passive resistance in the swing phase of walking and running [8].

Gait analysis is widely used in diagnosis and decision-making in treatment planning [9]. Hamstring tightness reduces the ability to absorb shocks to the lower limbs and knee extension during walking, thus reducing the step length [7]. It does not seem that people with hamstring tightness have a normal gait pattern, especially in the middle- and late-swing phase [7].

Running is a recreational or competitive sport and is an essential form of mobility in many sports. The flexibility of the muscle groups involved in running should be considered. Restrictions in lower limb flexibility can cause changes in the dynamic range of motion, biomechanics, injury risk, and performance. Hamstring tightness may affect the kinematics, function, and risk of injury during running [7]. Most efforts to increase running performance emphasize on improving muscle performance. Running puts a lot of demand on musculoskeletal structures, especially the hamstring muscle, which is more active during running than other lower limb muscles [10].

The lower limb is a chain of columns and joints that support the weight of the body, making it possible to absorb shocks during walking. This chain includes the thigh, knee, ankle, toes, and related joints to correct mechanics of the individual in static and dynamic conditions during sports activity and ensures the health of the individual. Therefore, biomechanical and pathomechanical knowledge is always important in understanding injury and preventing its occurrence. It is important to know the effects of reduced flexibility on the kinematics of running in runners, as the altered patterns of gait and running can make them prone to overuse injuries and degenerative pathologies in long time [11].

Moticon SCIENCE insoles consists of fully wireless foot sensors (13 capacitive sensors) integrated with an internal memory, and can be used inside any shoe to three-dimensional measurements of foot pressure and acceleration in three dimensions in space. The system can be used experimentally and may provide a new approach to motion research, as it frees participants from wires and it is not limited to use in laboratory settings [12].

To our knowledge, there is a little evidence about the kinetics parameters of balance, walking, and running in athletes with and without hamstring tightness. We hypothesized that these individuals have different patterns in functional activities and tried to evaluate this hypothesis by Moticon SCIENCE sensor insoles which are highly repeatable, valid, and functional.

Materials and methods

The present study was a basic-applied and descriptive-analytical study which was approved by Ethics Committee of Tehran University of Medical Sciences and Iranian Registry of Clinical Trials (IRCT20130121012210N7).

Participants

Sample size was calculated based on the previous studies [12, 13], the formula of sample size and the placement of M-L COP SD and A-P COP SD parameters. 10.49 to 14.10 were obtained, and finally, 15 individuals in each group were considered as the final sample size

$$n = \frac{(Z_{1-\alpha/2} + Z_{1-\beta})^2(\mathrm{SD}_1{}^2 + \mathrm{SD}_2{}^2)}{(d_1 - d_2)^2}$$

$$\text{M - L COP SD}: \ n = 10 \times \left(1^2 + 1.03^2\right)/(3.6–2.39)^2 = 14.10$$

$$\text{A - P COP SD}: \ n = 10 \times \left(6.9^2 + 3.31^2\right)/(13.8–6.36)^2 = 10.49.$$

Participants included 30 non-professional female athletes (15 female athletes with hamstring tightness and 15 female athletes without hamstring tightness) in an age range of 18–32 years, who exercised three times a week for at least 2 h. Inclusion criteria were the absence of previous injury to the hamstring muscles on both sides and bilateral hamstring tightness according to the results of the ROM tests (the popliteal angle of − 30° and higher in the active knee extension (AKE) test, and straight leg raise (SLR) was less than 90° in the hamstring tightness group). Exclusion criteria were a history of low back pain, musculoskeletal and neurological disorders in the lower extremities over the past year, and any disease and underlying condition that affected the flexibility of the hamstring muscle.

Instrumentation

The Moticon SCIENCE insoles (Moticon SCIENCE, Munich, Germany) (two insoles, size number 38, with 13 capacitive sensors for each insole and sampling rate of 50 Hz), which were connected to Moticon software, were used. No new calibration was performed for this study.

Procedures

Athletes were recruited from sports clubs in Tehran. Inclusion and exclusion criteria were checked in both groups. The objectives and the procedure of the study were explained to them, and the informed consent form was signed by them. They had the right to refuse to participate at any stage of the evaluation at their own discretion.

Age, height, weight, and the background information were obtained by the registration form. The athletes then warmed up for 15 min to prevent any possible injuries, including cycling and lower limb stretching exercises. The assessments were then performed including the examination of hip and knee ROM, perceived hamstring tightness, single-leg standing task, walking at two different speeds, and running.

ROM assessment

SLR and AKE tests were used to evaluate the inclusion criteria, as well as the evaluation of the two study groups.

SLR

At first, the participant was examined in the supine position and the tester stood on the side of the tested leg. The center of the goniometer was located on the greater trochanter and its fixed arm along the trunk. The participant was asked to flex her hip joint as far as possible with a straight knee, while the other arm of the goniometer was moved along the femur and the angle was recorded at the end range.

AKE

As in the previous test, the participant was in a supine position. The anterior of the pelvis and leg were fixed by a belt. The hip and knee joints were tested in the 90–90 position, and the center of the goniometer was placed on the lateral condyle of the femur and its fixed arm along the femur. At the same time, the moving arm, which ran along the fibula to the lateral malleolus, was moved and the final angle was recorded for analysis.

Each of the above measurements was recorded three times, with 1 min interval.

Perceived tightness

VAS was shown to participants and they were asked how hard they felt in their hamstring muscles during the SLR test (zero: no tightness and 10: maximum tightness). The average of the three reported values was considered for the final analysis.

Balance, walking, and running evaluation

Moticon SCIENCE insoles were put inside Skecher running shoe (Skech-knit Model) and they were connected to the Moticon software for recording data. The trial consisted of three times of slow walking, fast walking, and running in a 15-m pathway, and 20-s single-leg balance on the right and left legs (Fig. 1).

Data processing

The recorded trials were tested for each participant using Moticon software, and the studied variables were extracted for each individual, and finally, the mean values were used for final analysis.

Statistical analysis

Data collected from dependent and independent variables were analyzed by SPSS software version 19. The Kolmogorov–Smirnov test was used to assess the normality of the variables. The independent *t* test was used to assess the homogeneity of the two groups of athletes with and without hamstring tightness in terms of demographic variables. Then, the independent *t* test was used to compare study variables in two groups.

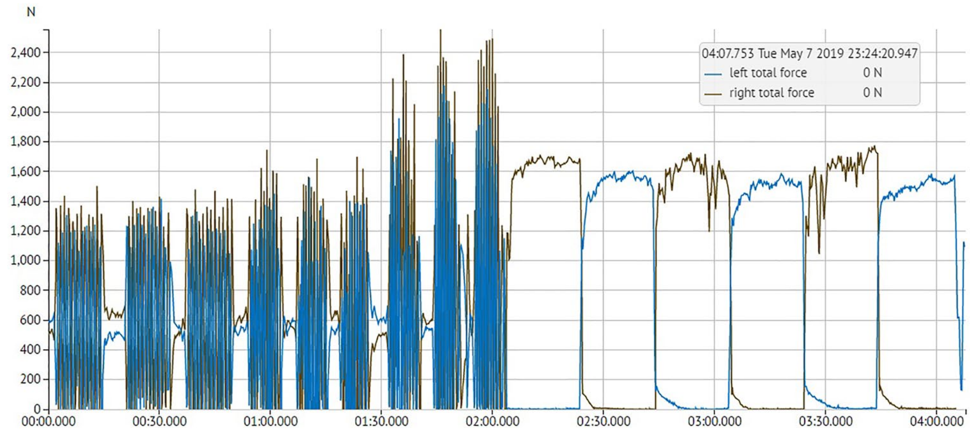

Figure. 1 The above record is for three slow walking, three fast walking, three running, and three single-leg balance tasks (first on the right leg and then on the left one, respectively). The blue color indicates the left foot sensors and the black color indicates the right foot sensors

Results

The Kolmogorov–Smirnov test indicated normal distribution of all variables in two groups. There was no significant difference in age, weight, height, and BMI between groups (Table 1).

In general, the results of the present study showed that the control group (without hamstring tightness) and the athlete with hamstring tightness are significantly different in regards to range of motion (SLR, AKE) and perceived tightness ($P = 0.0001$) (Table 1).

In the single-leg balance task, among all the parameters compared between the two groups, only the mean center of pressure in the mediolateral direction (MCOPML) was significantly different between groups ($P = 0.01$) (Table 1).

During slow walking task, there was no significant difference between groups except for Max total force of stance phase (MaxTFSP) ($P < 0.02$). In the fast walking task, the only variable that showed a significant difference between groups was Mean Y end point of gait line (MYEPGL) ($P = 0.04$), and the other parameters were not significantly different (Table 2).

Table 1 The results of independent t- test for demographic, ROM, and COP-related variables in single-leg balance test (15 hamstring tightness, and 15 controls)

Variables	Mean ± SD		*t*	Sig
	Control	Hamstring tightness		
Age (year)	27.27 ± 4.04	29.53 ± 3.40	− 0.93	0.10
Weight (Kg)	58.93 ± 8.05	60.87 ± 8.14	− 0.92	0.36
Height (cm)	163.33 ± 4.26	165.20 ± 4.41	− 1.67	0.10
BMI (Kg/cm^2)	22.12 ± 3.13	22.28 ± 2.66	− 0.22	0.83
SLR (°)	92.80 ± 1.53	82.38 ± 2.44	19.81	0.0001*
AKE (°)	-13.80 ± 4.60	-33.74 ± 2.43	20.97	0.0001*
VAS	1.77 ± 0.71	5.86 ± 1.31	− 15.02	0.0001*
Single-leg balance				
MCOPAP (mm)	-35.59 ± 12.57	-39.58 ± 8.62	1.44	0.16
MCOPML (mm)	-5.53 ± 1.74	-6.48 ± 1.05	2.57	0.01*
SDCOPAP (mm)	8.51 ± 2.48	8.45 ± 2.03	0.10	0.92
SDCOPML (mm)	2.51 ± 0.49	2.66 ± 0.58	− 1.13	0.26
BBCOPAP (mm)	45.65 ± 16.48	44.43 ± 11.54	0.33	0.74
BBCOPML (mm)	13.05 ± 3.25	12.96 ± 2.40	0.11	0.91
MCOPV (mm/s)	36.33 ± 26.96	30.96 ± 10.26	1.02	0.31
COPTL (mm)	1.29 ± 1.82	0.65 ± 0.26	1.89	0.06

SLR straight leg raise, *AKE* active knee extension, *MCOPAP* mean of center of pressure displacement in anteroposterior direction, *MCOPML* mean of center of pressure displacement in mediolateral direction, *SDCOPAP* standard deviation of pressure displacement in anteroposterior direction, *SDCOPML* standard deviation of pressure displacement in mediolateral direction, *BBCOPAP* bounding box of center of pressure displacement in anteroposterior direction, *BBCOPML* bounding box of center of pressure displacement in mediolateral direction, *MCOPV* mean of center of pressure velocity, *COPTL* COP trace length

Table 2 The results of independent t test for the studied variables during slow and fast walking and running tasks (15 hamstring tightness and 15 controls)

Variables	Mean ± SD		*t*	Sig
	Control	Hamstring tightness		
Slow walking				
MLGL (mm)	117.84 ± 18.82	110.12 ± 22.62	1.44	0.16
MWGL (mm)	6.15 ± 1.83	6.09 ± 1.94	0.12	0.90
MXSPGL (mm)	− 4.76 ± 3.02	− 4.28 ± 1.31	− 0.81	0.42
MYSPGL (mm)	− 77.33 ± 13.99	− 74.30 ± 14.64	− 0.82	0.42
MXEPGL (mm)	− 2.59 ± 2.92	− 2.94 ± 2.28	0.52	0.60
MYEPGL (mm)	38.81 ± 11.71	33.69 ± 12.44	1.64	0.11
MTFSP (N)	923.60 ± 169.26	895.58 ± 129.92	0.72	0.47
MaxTFSP (N)	1439.50 ± 211.33	1324.18 ± 175.20	2.30	0.02*
MDSD (s)	0.19 ± 0.07	0.21 ± 0.12	− 0.93	0.36
MSTD (s)	0.69 ± 0.09	0.71 ± 0.09	− 0.76	0.45
MSWD (s)	0.71 ± 0.09	0.39 ± 0.06	0.51	0.61
Fast walking				
MLGL (mm)	78.65 ± 35.96	81.06 ± 56.53	− 0.20	0.84
MWGL (mm)	5.07 ± 1.80	4.99 ± 2.22	0.16	0.87
MXSPGL (mm)	− 3.21 ± 1.63	− 3.73 ± 1.29	1.37	0.17
MYSPGL (mm)	− 82.02 ± 7.05	− 78.62 ± 8.75	− 1.65	0.10
MXEPGL (mm)	− 4.28 ± 2.63	− 3.90 ± 2.78	− 0.54	0.59
MYEPGL (mm)	− 6.38 ± 39.17	11.69 ± 29.31	− 2.02	0.04*
MTFSP (N)	998.31 ± 127.52	975.16 ± 143.38	0.66	0.51
MaxTFSP (N)	1383.50 ± 194.84	1307.91 ± 156.02	1.66	0.10
MDSD (s)	0.14 ± 0.08	0.13 ± 0.07	0.44	0.78
MSTD (s)	0.39 ± 0.12	0.41 ± 0.06	− 0.90	0.37
MSWD (s)	0.45 ± 0.08	0.43 ± 0.07	0.88	0.38
Running				
Mean TF (N)	116.31 ± 158.84	1219.82 ± 153.87	− 1.39	0.17
Max TF (N)	1895.55 ± 763.18	1800.50 ± 198.58	0.66	0.51
MSWD (s)	0.45 ± 0.05	0.46 ± 0.11	− 0.09	0.92

MLGL mean length of gait line, *MWGL* mean width of gait line, *MXSPGL* mean *x* start point of gait line, *MYSPGL* mean *y* start point of gait line, *MXEPGL* mean *x* end point of gait line, *MYEPGL* mean *x* end point of gait line, *MTFSP* mean total force of stance phase, *MaxTFSP* max total force of stance phase, *MDSD* mean double support duration, *MSTD* mean stance duration, *MSWD* mean swing duration, *Mean TF* mean total force, *Max TF* max total force

In the running task, none of the study variables were significantly different between groups of athletes with and without hamstring tightness (Table 2).

Discussion

The results of the present study indicated significant difference in range of motion (SLR, AKE), perceived tightness, mean center of pressure in mediolateral direction (MCOPML), maximum total force stance phase (MTFSP) in slow walking, and mean Y endpoint of gait line (MYEPGL) in fast walking.

One study found that younger men had shorter left hamstrings and women had shorter right hamstrings. Hamstring tightness is more common in females [14]. Due to the effect of sex and side of the tested leg, female sex and bilateral tightness were among the inclusion criteria, having a more homogeneous sample.

The results of Welch and Williams' study showed that hamstring flexibility causes different mechanical profiles in men and women. Hamstring flexibility may reduce torque through active or passive tension. These differences may be evident in the performance and injury of female runners [15]. On the other hand, hamstring tightness is associated with increased gait effort [physiological cost index (PCI)], pelvic posterior tilt, and knee flexion during the stance phase of the gait cycle. It is also associated with reduced walking speed, stride and step length, hip flexion, and pelvic rotation, and also causes premature dorsi- and plantar flexion of the ankle joint [15]. Since during the swing phase of the gait cycle, the hamstring muscle is stretched over both the knee and hip joints, hamstring performance is very important at this phase [16]. Improper hamstring length can lead to insufficient braking force to overcome overflexion of the hip and overextension of the knee during the swing phase [16]. The hamstring muscles are activated from foot strike to terminal stance or early swing, and are re-activated from mid-swing to foot strike. Therefore, late stance and early stance of running are very dangerous for hamstring injury [17].

The results of a study by Gaudreault et al., who compared knee kinematics during walking in runners with hamstring and iliotibial band (ITB) tightness, found a relation between muscle flexibility and three-dimensional kinematics of the knee joint. They suggested that there is a link between muscle flexibility and knee kinematics on the transverse plane [17]. According to their findings, the knee is close to its maximum extension torque and the hamstring is significantly lengthened at initial contact of running, leading to higher loading on this muscle during the end of the swing and the beginning of stance phases [15].

As the walking speed increases, there are significant differences in the activation patterns between the biceps femoris and semitendinosus, indicating that complex neuromuscular coordination patterns are activated during running, especially at maximum speeds [18]. In summary, in higher speeds of running, hamstrings have a higher risk of injury during the late-swing phase than the standing phase. These findings suggest that rehabilitation programs should focus more on eccentric exercises, because they are more beneficial than concentric loading of hamstrings and also are an effective way to shift the length of the hamstring to the optimum and longer length [19, 20]. The running mechanism may explain why flexibility exercises alone or in combination with warm-up cannot prevent hamstring injury. This is because the hamstring muscles are not stretched maximally during running and does eccentric work. Therefore, it should be considered that hamstring injuries are multifactorial and flexibility, strength, warming, and fatigue should be considered [20].

Based on the studies mentioned above, it can be said that the present study is consistent with the previous studies in terms of the effect of hamstring tightness on range of motion (SLR and AKE tests), as well as perceived tightness. Although no comprehensive study has been done to investigate the kinetic differences during walking at slow and fast speeds, as well as running in individuals with and without hamstring tightness, as noted above, kinematic differences such as the changes in the angles of the hip, knee, and ankle joints, and the length of the step and the speed of walking can be occurred after the tightening of hamstring. Here, the question is, given the kinetic and kinematic requirements of the three tasks of slow and fast walking and running, why no significant change was observed between the two groups of athletes with and without hamstring tightness? One possible answer can be loss of enough accuracy and sensitivity of the sensor insoles due to the high-speed movements during running. Moreover, the musculoskeletal changes and adaptations related to hamstring tightness may not be enough to make a difference in these tasks.

It is clear that one of the most effective muscles in hip and ankle strategy is the hamstring muscle, which maintains balance with other posterior muscles by correcting the displacement of the center of gravity [14]. In one study, the relationship between hamstring muscle and static and dynamic balance in healthy young individuals was examined. The displacement of the center of pressure was used as a measure of static and dynamic balance during single-leg stance on force plate to examine the quality of balance control when inducing external perturbation. Their results showed no relationship between hamstring muscle tightness and center of pressure sways as a static and dynamic balance index [17]. In 2004, Garfinkel et al. showed that changes in muscle length can cause postural disorders that can affect the balance performance. Ragiba et al. (2012) showed that shortening of the hip flexor and hamstring muscles causes a change in the type of posture that affecting individual's balance [21]. Apparently, our results were not consistent with the first study, but confirmed the results of the next two studies, because, as it was mentioned, individuals with hamstring tightness can increase the mean displacement of the center of pressure in the mediolateral direction.

Universal goniometer is easily usable, so it is preferable for clinical use, but electrogoniometer is more accurate and repeatable, so it is better for laboratory setting [22]. It can be suggested to use electrogoniometer for assessing ROM in further studies.

Conclusion

The results of the present study showed that the two groups of athletes with and without hamstring tightness have significant difference in terms of knee and hip range of motion, perceived hamstring tightness, mean center of pressure in mediolateral direction (MCOPML) in single-leg balance test, maximum total force stance phase (MTFSP) in slow walking, and mean Y endpoint of gait line (MYEPGL) in fast walking. Therefore, clinicians should pay a special attention to this muscle, because its tightness can have significant effects on balance and walking, and can cause underlying injury. Also, this study provided the basis for using sensor insoles to examine individuals with musculoskeletal injuries of the lower extremities and to assess the effects of the various rehabilitation interventions on kinetic parameters.

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Author contributions SF supervised all stages of the study, analyzed and interpreted the data, and wrote the manuscript. ASH participated in the planning and supervised all stages of the study. PS contributed to the study design and data collection. SHA contributed to the planning and editing the manuscript. All the authors have read and approved the final manuscript.

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Availability of data and materials The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no competing interests.

Ethics approval and consent to participate The present study was approved by the Ethical Committee of the Tehran University of Medical Sciences, Iran. From all participants who were willing to participate, a written informed consent was obtained.

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

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