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Foot Muscle Strength, Muscle Shortness, Balance, and Shoe Preferences in Different Foot Postures

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ABSTRACT

Objective: The aim of this study was to investigate the foot muscle strength, muscle shortness, tibialis posterior endurance, balance, and the shoe preference differences between the neutral and pronated foot posture.

Methods: Forty-nine participants consisting of 23 women and 26 men, and age of between 18 and 45 years were participated in the study. Foot posture, medial longitudinal arch height, height, gastrocnemius and hamstring muscle shortness, foot and ankle muscle strength, tibialis posterior muscle endurance, static balance, and shoe preferences of the participants were evaluated. Subjects were recruited into two groups according to their foot posture evaluated with Foot Posture Index: as those with neutral and pronated foot posture.

Results: Navicular drop, gastrocnemius, and hamstring muscle shortness were significantly higher in participants with pronated foot posture compared to those with neutral foot ($p<0.05$). There were no significant differences in terms of tibialis posterior, tibialis anterior, peroneal, and gastrocnemius muscle strength; tibialis posterior muscle endurance, balance, and shoe preferences between two groups ($p>0.05$).

Conclusion: Flexibility of gastrocnemius and hamstring muscles were reduced, but foot muscle strength, tibialis posterior muscle endurance, and balance remained unaffected in young individuals with excessive foot pronation. Moreover, shoe preferences may not affect the foot posture in young people. Although all age-related biomechanical effects of foot pronation are not well known yet, muscle shortness seems to arise earlier than muscle weakness and reduced balance in pronated foot posture.

Keywords: foot posture, tibialis posterior muscle, balance, shoe preference

1. INTRODUCTION

The foot provides ground contact, shock absorption, adaptation to different grounds and generates momentum for push-off in weight-bearing activities (1). Foot problems are very common in the general population. It has been reported that the rate of foot problems is ranged from 13% to 36% in adult population (2). Excessive foot pronation is characterized by flattening of the medial longitudinal arch (MLA), valgus of the rearfoot and abduction of the forefoot (3). Excessive foot pronation causes impaired load distribution in the gait, increased stresses in the foot and ankle joints, shearing forces in the knee joint, and internal rotation in the hip joint. Hallux valgus, plantar fasciitis, tibialis posterior dysfunction, tarsal tunnel syndrome, and patellofemoral pain syndrome are known to be associated with excessive foot pronation (3-6).

During standing and walking, active stabilization of MLA is provided by the extrinsic and intrinsic muscles of the foot. Excessive foot pronation is commonly associated with dysfunction of the tibialis posterior muscle, which plays a primary role in the dynamic stabilization of the rearfoot and MLA. The tibialis posterior attempts to compensate for the supportive task of the elongated plantar connective tissues in excessive foot pronation. Muscle fatigue and overuse injuries may occur as a result (4). Gastrocnemius muscle shortness is also known to be associated with foot pronation as a factor that increases rearfoot valgus (6).

Lower MLA was demonstrated to be associated with poor postural control especially in unipedal standing (7). Lower MLA with tibialis posterior muscle weakness or dysfunction leads to reduced structural stability of the foot and finally impaired postural stability (8, 9). Besides, tibialis posterior muscle fatigue alters the dynamic foot function, which may reduce postural stability (10).

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An appropriate shoe protects and supports the foot, improves the function, and controls the foot deformities and musculoskeletal injuries. Shoes with poor characteristics are associated with foot, knee and low back pain, foot deformities, falls, ulcerations and amputations in various age and disease groups or in healthy adults. It is important to reveal the risk factors caused by different shoes, to prevent or treat possible shoe related pathologies (11).

There are several studies investigating the relationship between excessive foot pronation and the biomechanical properties of the lower limb and its effect on balance (7, 8, 12, 13). Unver et al. (13) indicated that pronated foot may lead to increased pelvic inclination and low back pain. Kabak et al. (7) revealed that athletes with bilateral pes planus had reduced postural stability in one leg standing with the dominant side. Besides, there is some evidence about the effects of shoe preferences on foot-related pathologies (14, 15). Buldt and Menz (16) indicated that ill-fitted shoes were associated with foot pain and foot disorders. However, the literature is limited about the relationship between shoe preference and foot posture and the effect of tibialis posterior fatigue on balance in different foot postures. Additionally, there are limited studies investigating the relationship between shoe preference and foot posture and the effect of tibialis posterior fatigue on balance in different foot postures. The purpose of this study was to investigate the foot muscle strength, lower extremity muscle shortness, tibialis posterior endurance, balance, and the shoe preference differences between the healthy young individuals with neutral and pronated foot posture.

2. METHODS

This was a cross-sectional study conducted between April 2016 and September 2017 at İstanbul Aydın University University. Forty-nine participants consisting of 23 women and 26 men were recruited in the study. Asymptomatic sedentary individuals who do not participate in a regular sporting activity or exercise program and aged between 18 and 45 years included. The exclusion criteria were systemic, neurologic, rheumatologic, or orthopedic diseases, and history of surgery on the lower extremities. Before the study was conducted, the required permission was obtained from the Clinical Research Ethics Committee of İstanbul Aydın University (Date:17.02.2016, Number: 2016-06). All participants were informed about the study, and an informed consent form was signed by each participant.

Demographic data of the participants were recorded, and the dominant foot of each participant was determined. Foot posture, MLA height, gastrocnemius and hamstring muscle shortness, foot and ankle muscle strength, tibialis posterior muscle endurance, static balance and footwear preferences of the participants were evaluated once. According to the Foot Posture Index (FPI) results, the participants were divided into two groups: those with a neutral and pronated foot posture.

2.1. Foot Posture

FPI was used to evaluate the foot posture. This assessment was conducted while the participants were in a relaxed standing position. Talar head palpation, curves above and below the lateral malleolus, inversion/eversion of the calcaneus, talonavicular joint prominence, MLA height, and abduction/ adduction of the forefoot were evaluated. Each of these criteria got scores between – 2 and +2, and total score was obtained. A score between 0 and 5 indicated neutral, above 6 indicated pronated and negative scores indicated supinated foot (17). FPI was found to be a valid and reliable tool to evaluate static foot posture (18).

2.2. MLA Height

MLA height was evaluated by navicular drop (ND) test. The difference of the navicular height in between the weight-bearing standing and the non-weight-bearing sitting positions in mm was taken as the navicular drop (19).

2.3. Muscle Shortness

The shortness of the gastrocnemius and hamstring muscles were measured using a universal goniometer. Measurements were made while the participant was in the supine position. For the hamstring muscle shortness measurement; the assessor flexed passively one hip as much as possible keeping the knee extended, while the other lower extremity was on the table with the hip in a neutral position and the knee extended. The hip flexion angle was measured with the goniometer at the last degree of flexion that the hip joint could reach. The axis of the goniometer was aligned with the hip joint, the stationary arm was parallel to the trunk, and the moveable arm was parallel to the longitudinal axis of the femur. The angular value measured in the goniometer was subtracted from 90 degrees and recorded as the amount of shortness. This method has been shown to be a reliable method for measuring hamstring muscle shortness. For the gastrocnemius muscle shortness measurement; the assessor dorsiflexed passively one ankle as much as possible keeping the knee extended while the participant was in the supine position. The ankle dorsiflexion angle was measured with the goniometer at the last degree of dorsiflexion that the ankle joint could reach. The axis of the goniometer was aligned with the lateral malleolus, the stationary arm was parallel to the lateral midline of the fibula, and the moveable arm was parallel to the lateral aspect of the calcaneus. The angular value obtained by subtracting 90 degrees from the value measured with the goniometer was recorded as the amount of shortness (20, 21).

2.4. Muscle Strength

The isometric strength of tibialis anterior, tibialis posterior, gastrocnemius and peroneal muscles were measured using “Nicholas Manual Muscle Tester” (model 01160, The Lafayette Instrument Company, Lafayette, Indiana).

Measurements were made in a sitting position with the back support (with hips flexed and knees flexed 10 degrees with rigid roll under the popliteal fold). The feet were positioned outside the bed. Pad placement of the dynamometer was as follows: for dorsiflexors at the level of the metatarsal heads in the dorsum of the feet, for plantar flexors at the base of the metatarsal heads on the foot sole, for invertors just below the first metatarsal head in the medial line of the forefoot, and for evertors just below the fifth metatarsal head in the lateral line of the forefoot. The participants were asked to maintain the maximum contraction for 3 to 5 seconds, while the assessor fixed the dynamometer. "Make test" was used for the assessments, to avoid the participants overpowering the assessor. Measurements were performed 3 times for each muscle group, and the highest value was recorded (22, 23, 24).

2.5. Tibialis Posterior Muscle Endurance

The single-limb heel rise was used to evaluate tibialis posterior muscle endurance. The participant was in a standing position on a single leg, with a completely extended knee, while the contralateral leg was lifted maintaining the knee flexed. Each participant was asked to repeatedly lift the heel as high as possible until exhaustion. The fingertips of the participants were lightly placed on the assessor's hands for balance support during the test. The test was completed when the participant fails to reach a consistent height of each heel rise or makes compensation. Maximum number of heel rise repetitions and the spent time was recorded for each participant (25). Maximum repetitions test of singe-limb heel rise was found to have acceptable test-retest reliability (26).

2.6. Static Balance

Static balance of the participants was evaluated by Balance Error Scoring System (BESS). Evaluations were performed on a medium-hard foam pad. The subjects were evaluated in the single leg (on each left and right foot) and tandem position respectively, with the hands-on the waist, eyes closed. In the original BESS, evaluations are performed in three different positions: single-leg stance, double-leg stance, and tandem stance. However, since this study was conducted with healthy young people, there would be no balance impairment in double-leg stance position, so that position was not used in the current study. The observer monitored the subjects for 20 seconds at each position and recorded the number of standard balance errors determined in the test. The balance errors are as follows: lifting hands off of the iliac crest, eye opening, stepping, stumbling, or falling, moving the hip into more than 30 degrees of flexion or abduction, lifting the forefoot or heel, and remaining out of the testing position for more than 5 seconds. The total number of errors in each position was recorded as the balance error score (27). Participants were evaluated twice with this system; initially once, and once after tibialis posterior muscle fatigue, which was created by single-limb heel rise test (25).

2.7. Shoe Preferences

Participants were asked to choose 5 shoe models which they frequently used in the last 5 years from a catalog with 152 shoe models with different features and models. Each shoe selected was scored according to the adequacy of its sole, heel, and upper sections, and its stabilization and shock absorption features. These parameters used in scoring were established based on previous literature that developed shoe evaluation tools (11, 28). Shoes that provide the mentioned features exactly were scored 2, those with insufficiency in one or two of these features were scored 1, those with insufficiency in three or more were scored 0 points. The total score of the 5 selected shoes was recorded. This shoe catalog and scoring system were developed by the authors of the current study.

2.8. Statistical Analysis

Data were evaluated using the Statistical Package for Social Science 18 (SPSS Inc, Chicago, IL) program for Windows. The significance level was set to $p<0.05$. Normality tests (visual and analytical) were conducted. Since the continuous variables were not normally distributed, Mann–Whitney U test was used to compare age, body mass index, ND, muscle shortness, muscle strength, muscle endurance, balance, and shoe preferences data between the two groups with the neutral and pronated foot. Chi-square test was used to compare the sex ratio between two groups.

3. RESULTS

Forty-nine participants were included in the study. According to the FPI results, the participants were divided into two groups; 33 had neutral, 16 had pronated foot posture. Demographic data and FPI results of the participants were presented in Table 1. There were no significant differences between the demographic features of the two groups ($p>0.05$).

***Table 1**. Demographic data and FPI scores of the participants*

	NFPG (n=33)	PFPG (n=16)	p
Age (mean ± SD)	21.55± 2.57	21.88±3.46	0.96
BMI (mean ± SD)	22.14± 2.30	23.36±4.41	0.89
Gender (F/M)	17/16	6/10	0.35
FPI (mean ± SD)			
left	2.42±1.56	7.87±1.92	**<0.001**
right	2.06±1.76	7.31±1.99	**<0.001**

NFPG, neutral foot posture group; PFPG, pronated foot posture group; BMI, body mass index; F, female; M, male; FPI, foot posture index; SD, standard deviation.

Navicular drop, gastrocnemius, and hamstring muscle shortness were significantly higher in participants with pronated foot posture compared to those with neutral foot ($p<0.05$). There were no significant differences in terms of tibialis posterior, tibialis anterior, peroneal, and gastrocnemius muscle strength between two groups (p>0.05) (Table 2).

Table 2. *Comparison of ND, muscle shortness and muscle strength outcomes between neutral and pronated foot posture groups*

	NFPG (n=33) (mean ± SD)	PFPG (n=16) (mean ± SD)	p
ND (mm)			
left	6.33±2.21	10.50±3.09	**<0.001**
right	6.75±2.09	10.93±3.23	**<0.001**
Tibialis posterior muscle strength (N)			
left	25.54±5.11	27.02±7.62	0.67
right	26.55±5.94	31.05±8.39	0.09
Tibialis anterior muscle strength (N)			
left	27.26±6.04	30.22±8.90	0.26
right	27.98±6.12	30.28±8.96	0.63
Peroneal muscle strength (N)			
left	25.09±5.87	27.18±9.15	0.65
right	25.38±5.85	27.44±8.01	0.38
Gastrocnemius muscle strength (N)			
left	33.29±7.38	33.22±9.50	0.71
right	33.29±8.23	34.18±10.76	0.68
Gastrocnemius muscle shortness (°)			
left	3.87±14.96	7.62±12.87	**0.037**
right	4.45±14.25	8.18±13.29	**0.009**
Hamstring muscle shortness (°)			
left	4.75±29.43	15.93±17.02	**0.007**
right	5.66±26.59	11.25±15.23	**0.017**

NFPG, neutral foot posture group; PFPG, pronated foot posture group; SD, standard deviation; ND, navicular drop.

Table 3. *Comparison of single-limb heel rise and BESS scores between neutral and pronated foot posture groups*

	NFPG (n=33) (mean ± SD)	PFPG (n=16) (mean ± SD)	p
Single-limb heel rise score			
Repetition			
left	29.13±10.23	33.56±12.81	0.23
right	29.54±10.35	35.31±16.49	0.17
Time			
left (sec)	27.72±8.67	36.70±17.43	0.06
right (sec)	29.00±12.96	38.81±22.87	0.17
BESS score			
Initial			
left limb	8.42±3.82	9.75±6.07	0.54
right limb	7.72±4.27	8.00±4.01	0.75
tandem	4.00±3.89	5.06±4.94	0.53
BESS score			
After TP fatigue			
left limb	7.78±5.38	11.12±6.98	0.10
right limb	9.24±5.64	9.68±6.40	0.91
tandem	4.45±4.25	4.18±4.24	0.82

NFPG, neutral foot posture group; PFPG, pronated foot posture group, SD, standard deviation; BESS, Balance Error Scoring System; TP, tibialis posterior.

Table 3 presents the single-limb heel rise and BESS outcomes of the groups. There were no significant differences in terms of single-limb heel rise and BESS scores between the participants with neutral and pronated foot posture (p>0.05).

Comparison of five-year shoe preference scores of the groups with neutral and pronated foot posture indicated no significant difference between the groups (p>0.05) (Table 4).

Table 4. *Comparison of five-year shoe preference scores between neutral and pronated foot posture groups*

	NFPG (n=33) (mean ± SD)	PFPG (n=16) (mean ± SD)	p
Shoe preferences score	5.57±1.82	5.53±2.06	0.86

NFPG, neutral foot posture group; PFPG, pronated foot posture group, SD, standard deviation.

4. DISCUSSION

This study was conducted to reveal foot muscle strength, lower extremity muscle shortness, tibialis posterior endurance, balance, and the shoe preferences between the neutral and pronated foot posture. Current results indicated that gastrocnemius and hamstring muscle shortness was higher in pronated foot posture compared to neutral foot posture. Foot muscle strength, tibialis posterior endurance, balance, and shoe preferences were similar in neutral and pronated foot posture.

It has been reported that 25% of individuals with excessive foot pronation have gastrocnemius and soleus shortness which leads to pain and functional limitation (29). Kızılcı et al. (30) demonstrated that gastrocnemius flexibility is less in healthy young men with pes planus than those without. However, Unver et al. (13) revealed that the gastrocnemius, soleus, and hamstring muscle flexibility were similar in both pes planus and neutral foot posture. Nevertheless, the current study revealed that excessive foot pronation was associated with gastrocnemius and hamstring muscle shortness in healthy young individuals. Although it is accepted that there is a strong relationship between pes planus and plantar flexor muscle shortness, it is not clear whether the plantar flexor muscle shortness is the cause or the result of the pes planus (31). Hindfoot valgus associated with pes planus and pronated foot posture is thought to lead to functional shortening of the gastrocnemius-soleus complex (32). On the other hand, reduced dorsiflexion during the stance phase of the gait due to plantar flexor muscle shortness may compensate with hindfoot pronation leading to pronated foot posture (31).

Excessive foot pronation is known to be associated with the weakness of tibialis posterior and intrinsic foot muscles (4,12). In excessive foot pronation, plantar intrinsic muscles and tibialis posterior activation are more needed to support MLA and stabilize the foot in the weight-bearing activities, resulting in muscle fatigue and insufficiency (4). In the current study, the reason for similar foot muscle strength and tibialis posterior muscle endurance in neutral and pronated foot posture groups may be because the participants were young and did not have high activity levels (like athletes). Snook (33) found a decreased isokinetic concentric plantarflexion strength in individuals with pronated foot posture, compared to normal. In that study mean ND of the participants with pronated foot posture was 15.1 mm. On the other hand, the pronated foot posture group had ND mean of 10.9 mm in the current study. This indicates that the participants in our study had mild ND. The fact that the participants with the pronated foot posture in our study had less ND may also explain the unaffected muscle strength and endurance.

Pronated foot posture with lower MLA and tibialis posterior dysfunction lead to reduced postural stabilization due to impaired foot stability (8,10). However, according to current results, static balance scores were similar in neutral and pronated foot posture groups at baseline and after tibialis posterior fatigue was created. Considering that one of the most important stabilizers of the foot is the tibialis posterior muscle; this result may be related to the unaffected tibialis posterior muscle strength and endurance of the group with pronated foot posture. Harrison and Littlewood (34) exhibited that static postural stability decreased as the severity of the foot pronation increased. Besides, it has been reported that foot deformities, foot pain, and gait alterations caused by foot pronation can negatively affect postural stability in older individuals (35). Based on the results of our study, it can be suggested that mild pronated foot posture does not affect static balance in young individuals.

The results of the present study revealed that the features of the shoes chosen by the neutral and pronated foot posture groups in the last five years were similar. The shoe properties are known to be related to several foot pathologies (36, 37). It has been revealed that inappropriate shoes lead to forefoot deformities and foot pain in older individuals (38). Foot pain and deformities were not evaluated in the current study, but our results showed that the preference for shoes in healthy young individuals may not affect the foot posture.

This study has some limitations. Although only healthy young individuals were included in our study, studies involving different age groups are needed to investigate the relationship of foot posture with biomechanical properties, balance, and shoe preferences. The sample size was not calculated and a small sample size included in the current study. Besides, the numbers of participants with neutral and pronated feet were not similar. The foot posture of a randomly selected 49 young adults was evaluated instead of starting with two groups with neutral and pronated feet. Since the current shoe evaluation tools were developed to evaluate the present shoe of the subject, we used a method that we developed in order to evaluate the shoe preferences of the participants in the last 5 years. Therefore, the validity and reliability study of the catalog and scoring system we use for this purpose has not been conducted. Finally, more accurate results might be obtained if the balance was evaluated using a more objective method that could detect displacements in the center of mass.

5. CONCLUSION

The current results revealed that flexibility of gastrocnemius and hamstring muscles were reduced, but foot muscle strength, tibialis posterior muscle endurance, and balance remained unaffected in young individuals with excessive foot pronation. Besides, shoe preferences may not affect the foot posture in young people. Although there is a need for follow-up studies that investigate how muscle strength, shortness, and balance can be affected during the advancing ages in excessive foot pronation; it can be reported that muscle shortness might begin earlier than muscle weakness and reduced balance in pronated foot posture.

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