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Hip muscle fatigue, proprioception, and dynamic balance in flexible flatfoot and healthy volunteers: A comparative study

Wafaa Adel Mohamed[1*], Nadia Fayaz[2], Karima Abdelaty Hassan[2], Mona Mohamed Ibrahim[2]

[1]Out-patient clinic, Faculty of physical therapy, Cairo University, Cairo, Egypt.
[2]Departement of Physical Therapy for musculoskeletal disorders and its surgery, Faculty of Physical Therapy, Cairo University, Cairo, Egypt.

***Correspondence to:**
Wafaa Adel Mohamed, outpatient clinic, Faculty of Physical Therapy, Cairo University.

Email:
wafaa3adel093@gmail.com

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Abstract:

Purpose: The purpose of this study was to compare hip performance (hip muscle fatigue time, proprioception, dynamic balance, and muscle strength) and the effect of hip muscle fatigue on hip extensors and abductors strength between adults with flexible flatfoot and matched healthy volunteers.

Methods: twenty four healthy and twenty tow adults with bilateral flexible flatfoot volunteers from both genders were recruited. Hip joint position sense was evaluated by digital inclinometer, hip extensors and abductors strength were assessed before and after fatigue protocol by the handheld dynamometer, and dynamic balance was assessed using the Y balance test. All tests were carried out for the dominant leg in both groups for comparison.

Results: The fatigue time and strength of hip extensors and abductors were significantly lower in the flatfoot group compared to healthy individuals ($p < 0.05$). Furthermore, a significant difference was observed in hip joint position sense (JPS) and dynamic balance. ($p < 0.05$).

Conclusion: The current study suggested that the fatigability of the hip extensor and abductor was higher and negatively affected the strength more in flatfoot subjects. The accuracy of hip joint position and dynamic balance appears to be lower among those populations. which must be considered in clinical evaluation and treatment.

Keywords: flatfoot, hip, proprioception, balance, Fatigue, Muscle performance

1. Introduction:

One of the most prevalent foot deformities is flatfoot with a prevalence of 13.6%-26.6% among adults (1).

Fatfoot is defined as a collapse of the medial longitudinal arch associated with eversion of the rear foot (2). Flatfoot causes an obligatory or compensatory change in the whole limb. Therefore, flatfoot is associated with tibial and femoral internal rotation (3) and anterior pelvic tilt (4).

As a result of these kinematic changes, the hip joint is kept in flexion, adduction and internal rotation which cause alteration in the length of hip muscles and further cause anatomical, biomechanical and physiological changes over time (5).

EMG activity of the hip extensor and abductor was reported to be higher in flatfoot to compensate for the faulty posture and to control the pelvic

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alignment (6,7). Additionally, hip muscle's eccentric and concentric torque were lower compared to normal individuals (8,9). These observations predispose hip muscles to overuse and fatigue.

In their investigation, Gribble and Hertel assessed the effect of ankle and hip muscle fatigue on balance in single-limb standing. The result revealed that fatigue of the proximal muscles impairs postural control more than distal muscle fatigue (10). The muscles surrounding the hip serve as the primary source of the afferents that signal hip joint position sense (11). Furthermore, Proske and Gandevia, demonstrated that muscle spindle has a major role in kinesthesia (12). Therefore, the observed muscle fatigue is considered a risk factor for impaired proprioception and it is associated with a defect of balance and a higher injury rate (13).

The stabilization of the trunk and pelvis, as well as the transfer of forces from the lower extremities to the spine during upright activities, are all functions of the hip muscles, which may have an impact on the onset of low back pain (14). Lower limb injuries such as anterior cruciate ligament rupture, patellofemoral discomfort, and stress fractures have been linked to weaker trunk and hip muscles as risk factors (15). It's interesting to note that the same injuries have also been linked to pronated feet.

There are theoretical facts about the relation between flatfoot and hip muscle overloading and subsequence disturbance of hip proprioception (6,7,13). Additionally, the importance of the hip joint as the biomechanical link between the trunk and lower extremities and its role in maintenance of the dynamic balance (14) raised the need for studying these associations in flatfoot compared to healthy individuals. In addition, although previous studies investigated the torque of hip muscles in flatfoot subjects (8,9), no study measured the difference in hip muscle strength before and after fatigue and compared this with normal subjects. Therefore, the purpose of this study is to compare hip performance (hip muscle fatigue time, proprioception, dynamic balance, and muscle strength) and the effect of hip muscle fatigue on muscle strength between adults with flexible flatfoot and matched healthy volunteers.

2. Materials and Methods:

The current study design was a cross-sectional observational design. The study was performed at the outpatient clinic of the Faculty of Physical Therapy, Cairo University at the period between November 2022 till February 2023. Forty-six volunteers from both genders were included in this study. groupe (A) is a control groupe (n=24) with normal medial longitudinal arch (MLA) height, and groupe (B) is a flatfoot (FF) groupe (n=22). Both groups are matched in age (18-30), height, weight and BMI. All tests were applied to the dominant leg. The informed consent form was requested to be signed after a demonstration of the study's aim and procedures This study was conducted under the ethical standards established in the Declaration of Helsinki of 1946 and was approved by the Ethical Committee of the Faculty of Physical Therapy; Cairo University (no P.T.REC/012/004279).

Sample size calculation is performed using G*POWER statistical software (version 3.1.9.2; Universitat Kiel, Germany) for one tailed test. It is based on F tests (MANOVA: repeated measures, within-between interaction), The Calculations were made using α=0.05, power 80% and effect size = 0.65 with 2 independent groups comparison for 7 variable outcomes. For this investigation, a minimum sample size of 40 was appropriate (20 per group).

The subjects were included if they have bilateral flexible flatfoot (ND)> =10 for the FF groupe and <10 for the control groupe (16), aged between 18 and 30 years and both genders (25).

Subjects were excluded if they had any lower limb orthopedic or neurological condition that may affect the results (17), deformity or previous surgery of the hip. Also, any history of sensory defect or vestibular disorders or reported general fatigue excluded the subject.

A) Hip joint position sense (JPS):

Using a digital inclinometer, the reposition accuracy of actively moving the hip to the target position was measured to quantify hip JPS. To test hip JPS in flexion, subject was supine and the digital inclinometer was positioned at the lateral and distal thigh just proximal to lateral epicondyle. To test hip abduction JPS, the participant was in side- lying position, the untested leg was flexed and tested leg rested on a step to ensure the neutral position. The inclinometer was positioned at the posterior distal thigh. Firstly, the examiner passively located the target angle (60° for flexion and 15° for abduction) to teach the participant the target angle and hold this position for 5 seconds, then the participant was blindfolded and was asked to actively move their leg to that angle (**figure 1,2**). The error was calculated for three trials and then average was calculated (18).

Figure 1: Flexion JPS (end position)

Figure (2): Abduction JPS (end position).

B) Dynamic balance:

The intersection of three pieces of tape laid out on the ground served as the starting point for the Y balance test. The subject stood with her hands on her hips and her legs flat on the floor. With a verbal cue, the subject elevated the non-dominant leg and stretched it as far over the tape as feasible. The subject then maintained a single-leg stance on the dominant leg and gently touched the tape with the distal part of the first toe. The three directions used for this test were anterior, posteromedial, and posterolateral. The distance was measured in centimeters, and the test was performed three times. The data were excluded and the test was repeated if the participant moved the standing leg from its initial position, increased weight to the first toe of the extending foot or dropped a hand from the hip (19). The three trials' average length was obtained and normalized to the subject's leg length (20).

C) Hip muscle strength and fatigue:

A. Hip extensor:

The participant was in a prone position, and hip strength was assessed by hand handheld dynamometer positioned at the posterior thigh 5 cm above femoral epicondyles. The participant was asked to do maximum isometric contraction against the dynamometer and hold for 5 seconds (21). Following the test, the subject used a modified Biering-Sorenson, The examiner supported the participant lower limb while his/her trunk not supported, his/her upper limb supported on a stool. The participant released his upper limb when he ready and held the isometric position until voluntarily exhausted. technique to exhaust the hip extensors. Hip extensor strength testing was performed just after the fatigue intervention (22).

B. Hip abductor:

The participant was resting on his or her side with the non-dominant leg flexed. Muscle strength was measured while the participant pushed isometrically as strong as he/she could against a dynamometer that was placed 5 cm above the lateral femoral epicondyle and hold for 5 seconds (23). Then immediately the participant performed the fatigue protocol. He requested that the dominant leg be abducted 30 degrees in order to contact the target angle marked on a bar. The participant immediately was assessed by HHD for post-fatigue muscle strength when he was no longer able to maintain the rhythm or accomplish 30° abduction (24). The average of 3 repetitions of maximum voluntary isometric contraction before and after fatigue for extensor and abductor's muscles was normalized for body weight (25). The length of time from the starting fatigue protocol to the fatigue point represents the fatigue time of the muscle (26,27).

Statistical analysis:

All data were analyzed by IBM SPSS Statistics 28 (IBM Corp, Armonk, Ny, USA) program. The descriptive statistics were expressed in mean and standard deviation for quantitative variables and absolute frequencies and percentages for the qualitative variables. Data were checked for the existence of extreme scores, homogeneity of variance, and the assumption of normality. This analysis was completed as a prerequisite for the analysis of difference's parametric testing. All dependent variables, except one, were found to be normally distributed as assessed by the Shapiro-Wilk test and did not violate the parametric assumption. In addition, homogeneity of variance was tested via Levene's test that revealed all data showed no violations of the assumptions of equality of variance with p-value > 0.05. ANOVA of all dependent variables of all subjects in the two groups was used to find the significant difference between patients with flexible flatfoot and matched normal subjects in hip muscle fatigue (flexors and abductors), hip proprioception and dynamic balance. The statistical significance was set at $p < 0.05$.

3. Results:

The sample of the current research was 46 participants with 24 healthy subjects in group A (control) and 22 patients with flatfoot in group B (Flatfoot). The sex distribution of group A showed that there were 9 men and 15 women, with a reported ratio of 62.5% for the former and 37.5% for the latter. The sex distribution of group B revealed that there were 16 females with a reported percentage of 72.7% while the number of males was 6 with a reported percentage of 27.3%. There was a significant difference between groups in sex distribution (p = 0.018). There was no significant difference in height (p = 0.900), weight (p = 0.125) and BMI (p = 0.090) between groups (**Table 1**).

The descriptive statistics for all dependent variables as expressed in mean ± SD and ANOVA testing were illustrated in **Table 2**. Analysis of variance (ANOVA) was conducted to investigate the significant difference between all dependent variables in both groups; Group A and Group B. The test revealed a significant difference between groups in extensor and abductor MVC pre and post-fatigue, Fatigue time and proprioception for both muscle groups, and the Y balance test in the measure three directions (Anterior, posteromedial, posterolateral).

Table 1: Descriptive statistics and the independent sample t-test for demographic data

Variable	Mean ± SD		t-value	P-value	Sig.
	Control group N = 24	Flat foot group N = 22			
Height (cm)	165.13 ± 9.79	165.45 ± 7.757	-0.126	0.900	**NS**
Weight (kg)	63.792 ± 9.212	68.432 ± 10.885	-0.565	0.125	**NS**
BMI (kg/m2)	23.410 ± 2.944	24.923 ± 2. 971	-1.733	0.090	**NS**
Age (years)	24.38 ±1.789	25.23 ±2.599	-1.305	0.199	**NS**

SD= Standard deviation, *t-value=t-statistic, *P-value=probability, *Sig. =Significance, *NS=non-significant.

4. Discussion:

The results revealed that the fatigue time and strength of hip extensors and abductors were lower in the flatfoot group compared to healthy volunteers. In addition, a significant difference was observed in hip joint position sense (JPS) and dynamic balance between FF and control groups**.** The significant difference in hip extensors and abductors was consistent with the results of previous studies. The isokinetic eccentric and concentric torque of hip extensors was observed to be lower in flat foot subjects compared to normal arch (8,9). In addition, other studies investigated the effect of adding hip extensors and abductors strengthening exercises to the treatment programs of flexible flatfoot. They demonstrated that adding these exercises is effective in MLA correction (28,29,30).

The result was not agreed with the results of the previous work (31) in which they discovered no significant difference between normal medial longitudinal arched feet and flat feet in isokinetic hip muscle strength. This contradiction may be Attributed to the differences in the sex of our samples in which in their sample the majority were males while in ours the majority were females.

In agreement with our results**,** the previous results had found the fatigability of hip muscles was higher in flatfoot individuals and the strength of hip muscles was more negatively affected by fatigue in the flatfoot group compared to the control group.

According to other research (31), subjects with flat feet produced less muscular work in the hip abductors and adductors than those with normal medial longitudinal arches, which may be the result of muscle overuse which in turn predispose them to higher fatigability. In another study, the author demonstrated that the plantar flexor of patients with plantar fasciitis with flatfoot posture is overused in propulsion and consequently weakness may be developed (32).

In a 3-D study of lower limb kinetic after inducing tibialis posterior fatigue, the results revealed a significant decrease in ipsilateral ankle moment and contralateral hip muscle strength. These modifications are seen in individuals whose tibialis posterior muscles are dysfunctional, proving that the patients' coping mechanisms are responsible for these changes (33).

On the other hand, the findings were in contrast with the results of other studies. In an isokinetic study of hip muscle in flatfoot individuals, the author concluded that there was no significant difference in hip extensor and abductor endurance between the flatfoot participants and the control normal group (27) this contradiction may be attributed to the difference in the method that was used in the evaluation between this study and the current study. Furthermore, the result is contradicted by a study of women with posterior tibial tendon dysfunction (PTTD) demonstrated impaired bilateral hip extensor and abductor performance, including strength and endurance and not only on the side of PTTD. This contradiction could be explained as the bilateral decrease in hip muscle performance may be due to the disuse as the age of this sample was 43-66. In addition, only women were included in the study so the result could be generalized only to middle-aged women (34).

According to the current study, there was a significant difference between the flatfoot and control groups in terms of hip proprioception (JPS). Turgut's findings, which looked at the immediate effects of hip-focused neuromuscular exercise on foot pronation and single-leg neuromuscular control, support this conclusion. They concluded that hip-focused neuromuscular exercise improved dynamic balance and immediately reduced navicular drop (35).

Plantarflexion, dorsiflexion, eversion (EV), and inversion (INV) movement directions are all subject to isokinetic examination of muscle strength and proprioception that showed a significant decrease in EV and INV strength but no significant difference in plantar and dorsi flexion strength between flexible flatfoot and normal groups, with disturbed the proprioception in all four directions in flatfoot subjects (36).

Table 2. Mean values of all dependent variables and ANOVA testing in groups A and B.

Variables	Groups		F	Df		*P*-value
	Flat feet (n=22) mean(SD)	healthy (n=24) mean (SD)		Between groups	Within groups	
Extensor MVC pre-fatigue (%)	0.23 ±1.43	1.84 ± 0.39	1515.9	1	444	.000*
Fatigue time (extensors) (sec)	34.71 ± 21.92	64.04 ±35.45	12.8	1	44	.001*
Extensor MVC post fatigue (%)	1.22 ± 0.16	1.58 ± 0.36	16.604	1	44	.000*
Abductor MVC pre-fatigue (%)	1.58 ± 0.30	2.00 ± 0.32	18.10	1	44	.000*
Fatigue time (abductors) (sec)	29.23 ±11.33	53.62 ±17.34	29.26	1	40	.000*
Abductor MVC post fatigue (%)	1.19 ±0.23	1.51 ±0.27	17.94	1	43	.000*
Flexor proprioception (°)	4.44 ±2.86	2.36 ±1.28	9.906	1	41	.003*
Abductor proprioception (°)	3.02 ±1.99	0.83 ±0.54	28.822	1	44	.000*
Y Balance test Anterior (%)	67.13 ±7.01	70.91 ±5.61	4.659	1	44	.036*
Y Balance test postromedial (%)	72.04 ± 11.01	79.17 ±8.92	6.488	1	44	.014*
Y Balance test postrolateral (%)	77.85 ±9.09	85.26 ±9.42	11.11	1	44	.002*

The result of the current study concerning the dynamic balance came into agreement with previous research (37). The ability to absorb shocks will decline and the sense of balance will be lost as the MLA collapses, resulting in structural or functional deformation, making it harder to walk and reducing endurance. The findings of some studies imply a functional relationship between flatfoot and dynamic balance impairment. In a systematic review, the authors suggested that intrinsic foot muscle training can enhance the dynamic postural balance of the lower limbs and have beneficial biomechanical effects on the medial longitudinal arch (38).

The results can be explained by the fact that pronated feet have reduced flexibility and strength, which may have an impact on the dynamic balance and muscular activity in the lower extremities.

In contrast, other studies' findings did not agree with that relationship. In a comparison between flatfoot and normal individuals in static and dynamic balance, the author demonstrated that FF subjects have poorer static postural support this might be because the distal joints, such as the transverse tarsal joint, regulate the stability of the position of the rear foot indirectly and the subtalar joint directly.

Pronation may rise when the subtalar joint is overly flexible during weight bearing, which could result in an unstable base of support and ultimately diminished foot stability. On the other hand, there was no difference in dynamic balance (19). The sample size of this study was small (14 for each group) which may explain the difference in the results.

The current study may help scientists and physical therapists better understand how the foot pronation may impact the function and mobility of proximal joints. As a result, the assessment would be enhanced, conservative therapy would be applied. But there was several limitations that should be considered in future studies. First, there was a significant difference in sex distribution between the two groups which may affect the results of muscle performance. Second, the Modified Biering-Sorenson that was used in hip extensor fatiue protocol also stresses the core muscles and is not specific for the extensors.

It is recommended to use an isokinetic dynamometer in the assessment of the effect of fatigue on muscle strength. Furthermore, it is recommended to use a fatigue protocol that is more specific to hip extensors. Finally larger sample size with matched sex distribution is recommended in future studies.

5. Conclusion:

The current study suggested that the fatigability of the hip extensor and abductor was higher and negatively affected the strength more in flatfoot subjects. The accuracy of hip joint position and dynamic balance appears to be lower among those populations. which must be considered in clinical evaluation and treatment.

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