

Effects of bilateral flexible flatfoot on trunk and hip muscles' torque

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Abstract

Background: Flexible flatfoot has been considered as a risk factor for a number of lower limb injuries and mechanical low back pain. This, theoretically, was attributed to dysfunction of the lumbopelvic-hip complex musculature. Despite this theoretical basis, no study has evaluated the effect of flexible flatfoot on the strength of the lumbar and hip muscles.

Objective: To investigate the influence of flexible flatfoot on concentric hip and trunk torque generation.

Methods: A case-control comparison was held between a flexible flatfoot group (20 subjects) and a normal foot group (20 subjects). An isokinetic dynamometer was used to assess the concentric torque of hip flexors, extensors, internal rotators, and external rotators; and trunk flexors, and extensors. Group differences were assessed by using a one-way multivariate analysis of variance.

Results: There was a significant decrease in hip flexors', extensors', internal rotators', and external rotators' peak torque of both sides in the flexible flatfoot group compared to the normal group, while there was no significant difference in lumbar flexors' and extensors' peak torque between the two groups.

Conclusion: Impairment in hip muscles' concentric strength was observed in subjects with flexible flatfoot when compared to normal controls. Our results may support the interrelationship between foot misalignment and proximal joints pathology.

Key words: ■ Flatfoot ■ Hip ■ Low back pain ■ Lumbosacral region ■ Torque

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Flexible flatfoot is the most common type of flatfoot and it is highly present in children and adults (Mosca, 2010). The term abnormal or excessive pronation has been used to describe a flexible pes planus as it results in a state of extensive or sustained subtalar joint complex hypermobility or pronation upon weight bearing (Donatelli, 1996).

In a closed kinetic chain, foot pronation is associated with internal rotation of the tibia, and internal rotation of the femur (Resende et al, 2015). Consequently, this results in increased pelvic anteversion, and lumbar hyperlordosis (Abdel-Raouf et al, 2013). Maintained excessive foot pronation during weight bearing activities generates internal rotational stresses at the lower extremity that may change patterns of movement and muscle balance at proximal joints (Powers, 2003).

Subtalar joint pronation occurs from heel strike to foot flat, which allows the foot to act as a shock absorber

and a torque convertor of the transverse plane rotations of the lower leg. Then, at 35% of the gait cycle, it moves toward supination, reaching its maximum just prior to toe-off, permitting the foot to be converted to a rigid lever for more efficient propelling of body weight (Rodgers, 1995; Donatelli, 1996). On the other hand, flexible flatfoot begins its stance in an unlocked, everted position and does not completely change into a rigid lever during the latter phases of stance (Mosca, 2010). The inability of the foot to attenuate the forces of weight bearing—as excessive subtalar pronation directly after heel strike significantly reduces the torque conversion and shock absorption—and to establish an effective lever for push off during gait causes changes in the lower extremity muscle function, and may also cause soft tissue breakdown (Donatelli, 1996).

In a recent review, Kendall et al (2014) found that there is a body of evidence supporting that foot hyperpronation is associated with mechanical low back pain. They showed

that the mechanisms that have been proposed for this relationship are based on either mechanical postural changes or alteration in muscular activity in the lumbar and pelvic muscles.

Hip muscles play a key role in stabilising the trunk and pelvis and in transferring forces from the lower extremities up toward the spine during upright activities, thus may influence the development of LBP (Nadler et al, 2002). By regulating rigidity within the trunk and between the trunk and lower extremities, trunk muscles—including abdominals and erector spinae—and hip muscles provide core stability to the trunk, which forms the basis for force production by the limbs (Shin et al, 2015).

Impairment in the trunk and hip muscles strength has been considered as a risk factor for lower limb injuries: anterior cruciate ligament rupture, patellofemoral pain, and stress fracture in the lower extremity (Leetun et al, 2004). Interestingly, pronated foot also has been associated with the same injuries: stress fractures (Barnes et al, 2008), knee pain (Kosashvili et al, 2008), and anterior cruciate ligament rupture (Loudon et al, 1996). The involvement of trunk and hip muscle weakness in the same injuries that have been associated with pronated foot led Barwick et al (2012) to propose that pathologies that are associated with excessive foot pronation are attributed to a dysfunction of the musculature of the lumbopelvic-hip complex.

Despite the theoretical basis linking flexible flatfoot and its associated hyperpronation to lumbopelvic-hip musculature weakness and imbalance, no study investigated the influence of flexible flatfoot on torque generation of proximal joints such as hip or trunk muscles. Therefore, the purpose of the present study was to compare the concentric peak torque of:

- Hip flexors, extensors, internal rotators, and external rotators
- Trunk flexors and extensors, of subjects with flexible flatfoot to that of normal controls.

We hypothesised that there would be a significant difference in concentric peak torque of hip and trunk muscles between subjects with flexible flatfoot and normal controls.

METHODS

Participants

Subjects were recruited from the Faculty of Physical Therapy, Cairo University, which has nearly 2000 physical therapy students. Participants were recruited through advertisement posters fixed in different places of the main physical therapy school campus, and were kept in place for 5 months of the study duration. As the physical therapy school is located in a separate building outside the university campus, only physical therapy students were available. One hundred and seventy-five students volunteered to participate in the study. Students were not enrolled during the class time.

A flowchart is presented in *Figure 1*. Forty subjects (20–27 years of age) participated in this study and were enrolled in 2 groups: a group of subjects with bilateral flexible flatfoot ($n=20$; 17 female, 3 male), and a group of subjects with normal foot alignment ($n=20$; 16 female, 4 male). Subjects were considered to have flexible flatfoot if, on visual assessment, they had a normal medial longitudinal arch in sitting and in toe raising, while on normal bilateral standing, their medial longitudinal arch disappeared and their hind foot was in valgus (Mosca, 2010), and they had more than 10 mm difference on the Navicular Drop Test. Subjects were included in the control group if they had less than 10 mm difference on the Navicular Drop Test with normal foot alignment. The following exclusion criteria were established for this study:

- History of congenital deformity (other than flexible flatfoot) or surgery in the lower extremities or the trunk
- Injury to either lower extremity or trunk in the previous year
- Regular practice of physical activity, at a frequency of three times a week or greater
- The presence of neurological disorders or cardiovascular disease that could impair their ability to perform the proposed evaluations.

Sample size calculation was performed at the beginning of the study using G*POWER statistical software (version 3.1.9.2; Franz Faul, Universitat Kiel, Germany) (Faul et al, 2009) and revealed that the appropriate sample size for this study was $n=40$, which gave observed power equal to 0.87. Calculations were made using $\alpha=0.05$, $\beta=0.2$ and an effect size of 0.6.

All subjects read and signed a consent form before the beginning of testing. Written informed consent was obtained from the individual presented in the figures

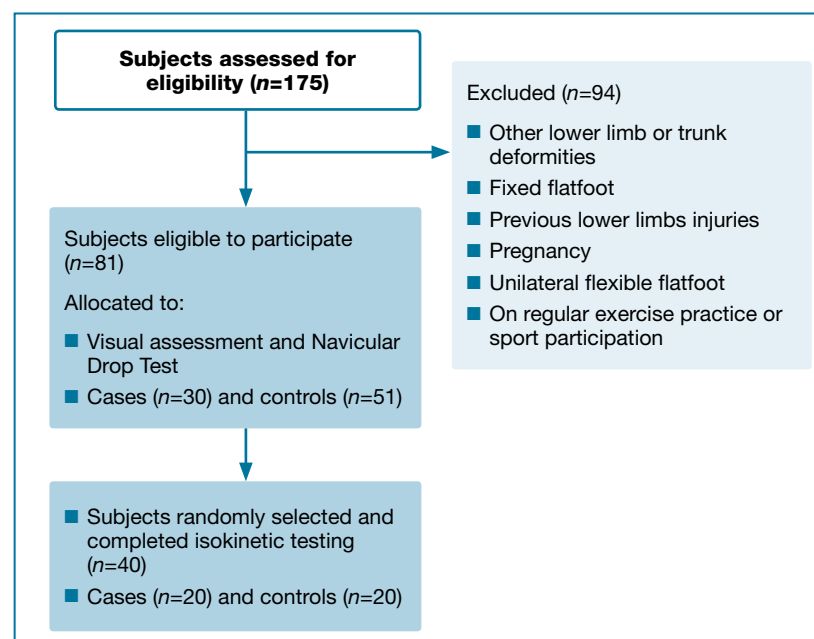


Figure 1: Flowchart

to the publication of his photographs. The study was approved by the Institutional Ethics Committee of the Faculty of Physical Therapy, Cairo University, Egypt (No: P.T. REC/102/00735). This study was conducted during the period of February to August 2015 at the Isokinetic Laboratory of the Faculty of Physical Therapy, Cairo University.

Assessment of flexible flatfoot

Visual assessment

An experienced examiner observed the medial longitudinal arch and the hind foot of subjects from three positions: normal bilateral standing position, toe raising position, and sitting position. Subjects were considered to have flexible flatfoot if they had a normal medial longitudinal arch in sitting and in toe raising, while on normal bilateral standing, their medial longitudinal arch disappeared and their hind foot was in valgus (Mosca, 2010).

Navicular Drop Test

The Navicular Drop Test, as described by Brody (1982), is used to evaluate the medial longitudinal arch and excessive pronation. The Navicular Drop Test has good inter-rater and intrarater reliability (Mueller et al, 1993), and it was well correlated with X-ray (Hannigan-Downs et al, 2000). It was suggested that 10 mm is the upper limit for normal Navicular Drop Test results (Mueller et al, 1993; Loudon et al, 1996).

The participants were placed in a sitting position with his/her bare feet flat on a firm surface, with the knee flexed to 90° and ankle joints in a neutral position. The most prominent point of the navicular tubercle was identified and marked with a pen. An index card was placed on the inner aspect of the hindfoot, with the card placed on the floor in a vertical position passing the navicular bone. The level of the navicular tubercle was marked on the card. The subject was then asked to assume a normal, bilateral, weight-bearing stance; the navicular tubercle was again palpated and its position marked on the card. The difference between the two points on the card was measured with a ruler rendering the Navicular Drop amount in millimetres. One experienced examiner performed all assessments. The measurements were taken three times and an average was calculated.

Assessment of peak muscle torque

Isokinetic evaluations were performed using Biodex multi-joint system 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, New York, USA). An isokinetic dynamometer provides an objective, reliable, and safe method, with intraclass correlation coefficients (ICC) of 0.99 and provides valid measurement regarding the angular position, torque, and velocities for testing of different groups of muscles in the upper and lower limb and trunk (Drouin et al, 2004). The device was calibrated before each assessment, and all procedures, including gravity correction of the torque measures,

were conducted according to the specifications outlined in the manufacturer's service manual. All torque testing was performed in a concentric mode at a speed of 60°/s. The speed of 60°/s was chosen to challenge muscle force production because muscle produces greater concentric force at slower isokinetic testing velocities (Perrin, 1993). Isokinetic evaluations were performed by an experienced examiner who was blinded to the results of the Navicular Drop Test, and the purpose of the study.

Hip flexion/extension concentric test

The subject was positioned in a supine with the hip moving in the sagittal plane. The supine position limits the compensation and so yields more reliable measurement (Julia et al, 2010). The knee of the tested limb was held in flexion 90° during the test, as Magee (2008) stated that knee flexion prevents the restriction of flexion movement caused by hamstring tightness and makes the gluteus maximus contribute more to the action of hip extension. The contralateral limb was rested on a support under the thigh that keeps hip flexion during the test to flatten out the lumbar spine and to stabilise the pelvis (Magee, 2008). The dynamometer axis was aligned with the greater trochanter (corresponding to the axis of hip flexion/extension). The subject's body was held by a strap around the pelvis (over Anterior Superior Iliac Spines) and one chest belt, the tested limb was attached to the dynamometer with a thigh strap (*Figure 2*). The evaluation was performed from 80° of hip flexion to 10° of hip extension in concentric mode (Julia et al, 2010).

Hip internal rotation/external rotation concentric test

The subject was placed in a supine position with the hip in a neutral position. The test was performed with the hip in 0° of flexion as with hip flexion, the potential for hip external rotation torque generation markedly diminishes, in light of the fact that with hip flexion the internal rotation moment arms of some muscles increase; the external rotation moment arms of other muscles decrease; and some muscles switch from external rotation to internal rotation (Delp et al, 1999). The knee of the tested limb was in 90° flexion, as a supine position with the knee flexed produced stronger torques than a supine position with the knee extended. The axis of the dynamometer was aligned with the centre of the patella (long axis of the femur). Three stabilisation straps were used: one around the distal thigh of the tested limb, one across the pelvic crest and one across the chest. The padded dynamometer arm was attached 5 cm above the lateral malleolus using straps (Lindsay et al, 1992) (*Figure 3*). The range of motion of this test was from 20° of hip external rotation to 10° of hip internal rotation (Silva et al, 2013).

Trunk flexion/extension concentric test

Subjects were tested while sitting on the adjustable seat of the system because sitting allows a greater range of motion of the trunk and it is more tolerated than standing.

A pelvic strap was applied against the superior aspect of the proximal thighs to minimise any contribution from the hip muscles (Diver, 1995). Two curved anterior leg pads were fastened to maintain the knee block position. In addition, a lumbar support pad was located against the lower lumbar spine. Two anterior straps were placed vertically and then connected to another horizontal strap opposite to the second intercostal cartilage on the anterior chest wall (Abdallah and Beltagi, 2014). Subjects were asked to cross their upper limb in front of the chest to prevent any uncontrolled movements and to keep the head erect to avoid any contribution from the neck muscles (Shirado et al, 1995). The axis of rotation was aligned at the intersection point of the mid axillary line and L5/S1 disc space (Diver, 1995) (Figure 4). The range of motion was 50° trunk flexion to 20° trunk extension (Abdallah and Beltagi, 2014).

Data analysis

Subject characteristics and the Navicular Drop Test were compared between both groups using unpaired t tests. Multivariate analysis of variance (MANOVA) assumptions were checked initially: the normality of data was tested by the Shapiro-Wilk test, homogeneity of variance was tested by Levene's test and correlation among the dependent variables was tested by a correlation matrix. A one-way MANOVA was conducted to determine the effect of group (flexible flatfoot and control) on concentric hip flexors', extensors', internal rotators', and external rotators' peak torques, and on trunk flexors' and extensors' peak torques. Follow-up analysis was conducted to find the dependent variables that best separates the groups and this was done through discriminant analysis. The level of significance for all statistical tests was set at $\alpha=0.05$. All statistical analysis was conducted through SPSS statistical package for social sciences (version 19; IBM SPSS, Chicago, IL, USA).

RESULTS

Participant characteristics

Table 1 shows the descriptive statistics of age and body mass index (BMI) of both groups. There was no significant difference between both groups in the mean age and BMI ($P>0.05$).

Comparison of foot posture (Navicular Drop Test) between flatfoot and normal groups

There was a significant increase in the right and left Navicular Drop Test measurements in the flatfoot group compared with normal group ($P=0.0001$) (Table 2).

Testing the normal distribution of data

The Shapiro-Wilk test was conducted to test the normal distribution of data for each dependent variable. The results revealed no significant deviation from a normal distribution for all variables in both groups ($P>0.05$).

Table 1. Participant characteristics

	Flatfoot group (mean \pm SD)	Normal group (mean \pm SD)	MD	t-value	P-value
Age (years)	21.6 \pm 1.53	22.5 \pm 1.93	-0.90	-1.63	0.11*
BMI (kg/m ²)	26.95 \pm 2.69	26.5 \pm 2.86	0.45	0.50	0.61*

SD: standard deviation; MD: mean difference; BMI: body mass index; *non significant



Figure 2: Participant position for hip flexion and extension torque measurement



Figure 3: Participant position for hip external and internal rotation torque measurement



Figure 4: Participant position for trunk flexion and extension torque measurement

Testing of homogeneity

Levene's test revealed that there was equality of variances for all dependent variables ($P < 0.05$).

Correlation between dependent variables

The correlation matrix revealed that there was a moderate correlation between the dependent variables and the correlations were significant at 0.01 and 0.05 levels of significance.

Comparison of peak torque between flatfoot and normal group

MANOVA was conducted to investigate the effect of group (flexible flatfoot, and control) on hip flexors', extensors', internal rotators', external rotators', lumbar flexors', and lumbar extensors' peak torque. Table 3 shows descriptive statistics of dependent variables as well as the significant level of comparison between groups. The MANOVA identified a significant group effect (Wilks' Lambda=0.098; $F(10, 29)=26.546$; $P=0.0001$). There was a significant decrease in torque in hip flexors, extensors, internal rotators, and external rotators of both right and left sides in the flexible flatfoot group compared with the control group ($P < 0.05$), while there was no significant difference in lumbar flexors' and extensors' peak torque between flexible flatfoot and control groups ($P > 0.05$).

Discriminant analysis

Discriminant analysis based on Wilks' Lambda statistic revealed that there was one variate (Wilks' Lambda=0.098; $\chi^2=76.48$; $P=0.0001$) and this variate significantly discriminated groups. The right hip internal rotation torque is most related to the variate function, which suggests that right hip internal rotation torque contributes most to group separation.

DISCUSSION

The purpose of this study was to evaluate the influence of bilateral flexible flatfoot on peak torque of hip flexors, extensors, internal rotators, and external rotators; and on that of trunk flexors and extensors. The results showed a significant decrease in concentric strength of the hip flexors, extensors, internal rotators, and external rotators in subjects with bilateral flexible flatfoot when compared to subjects with normal foot alignment. However, no significant difference was observed between groups regarding concentric strength of trunk flexors and extensors.

The significant change in hip muscle strength observed in subjects with flatfoot may be attributed to the maintained changes in hip muscle length. On weight bearing activities, flatfooted subjects have an excessively pronated foot, which is associated with internal rotation of both tibia and femur (Resende et al, 2015), increased pelvic anteversion, and lumbar hyperlordosis (Abdel-Raouf et al, 2013). As the hip joint is maintained in flexion, the hip flexors and internal rotators are maintained in a shortened position, because the pelvis moves anteriorly on a fixed femur and internal rotation, while the hip extensors and external rotators are maintained in a lengthened position. Gossman et al (1982) demonstrated that when the muscle is subjected to impose and sustained changes in length, it undergoes anatomical, biochemical, and physiological changes that are not immediately noticeable or easily evaluated, and those length-associated changes can be induced by postural malalignment.

Muscles kept up in an extended position develop more sarcomeres, yet have a shorter length and test stronger at its new extreme length, but are weaker in a standard muscle test position. While muscles kept up in a shortened position lose sarcomeres, they increase in sarcomere length, and become weak and infiltrated with connective tissue (Gossman et al, 1982). It was reported that standing with an increased anterior pelvic tilt with an associated increase in lumbar lordosis leads to pelvic crossed syndrome, in which there is tightness and weakness of the iliopsoas and rectus femoris (hip flexors) and weakness with inhibition of the gluteus maximus and medius (hip extensors) (Page, 2006).

The decrease in hip muscle strength reported in flat-footed subjects may also be due to overloading the hip muscles while they are working to overcome the abnormal

Table 2. Mean navicular drop of flatfoot and normal groups

Navicular Drop (mm)	Flatfoot group (Mean ± SD)	Normal group (Mean ± SD)	MD	t-value	P-value
Right side	13.15 ± 1.78	5.25 ± 0.85	7.90	17.86	0.0001**
Left side	13.7 ± 2.22	5.55 ± 1.93	8.15	12.36	0.0001**

SD: standard deviation; MD: mean difference; **significant

Table 3. Mean hip and trunk peak torque of flatfoot and normal groups

Peak torque (Nm)	Flatfoot group (mean±SD)	Normal group (mean±SD)	MD	p-value
Right hip flexors	42.83 ± 8.19	55.06 ± 9.41	-12.23	0.0001**
Left hip flexors	44.86 ± 9.76	51.1 ± 7.74	-6.24	0.03**
Right hip extensors	53.54 ± 7.70	77.92 ± 10.01	-24.38	0.0001**
Left hip extensors	55.12 ± 8.05	70.63 ± 9.49	-15.51	0.0001**
Right hip internal rotators	20.54 ± 4.14	35.62 ± 5.67	-15.08	0.0001**
Left hip internal rotators	22.67 ± 3.86	35.81 ± 6.61	-13.14	0.0001**
Right hip external rotators	26.12 ± 4.99	33.22 ± 7.77	-7.10	0.001**
Left hip external rotators	26.36 ± 5.13	34.85 ± 7.27	-8.49	0.0001**
Lumbar flexors	84.15 ± 8.42	86.83 ± 7.67	-2.68	0.30*
Lumbar extensors	123.74 ± 22.38	133.53 ± 21.99	-9.79	0.17*

SD: standard deviation; MD: mean difference; Nm: Newton metre; *non significant; ** significant

foot mechanics during gait. Ankle plantar flexor moment is the primary source of swing phase initiation momentum (Lewis and Ferris, 2008). In subjects with flatfoot, push off is greatly diminished (Hösl et al, 2014; Saraswat et al, 2014) and motion may be generated mainly at the hip for the swing phase, using 'hip flexor strategy pattern' (Lewis and Ferris, 2008). The emphasis on hip flexor muscular activity can be a contributing element to hip flexor weakness. When the muscles become overloaded, especially in a prolonged fashion, part of the muscle fibre may be destroyed (microtrauma) through rupture of the muscle cell membrane (Bennett, 1990).

Microtrauma can be the result of repetitive movements and postural asymmetries over prolonged periods of time, in which there is rupture of the sarcolemma and sarcoplasmic reticulum, with subsequent formation of trigger points that result in muscle weakness (Kostopoulos and Rizopoulos, 2001).

Despite shortage in the literature concerning the effect of flexible flatfoot on the hip muscles strength, there is a growing evidence that dysfunction of proximal musculature has significant effects on foot functioning (Barwick et al, 2012), and that strengthening the hip muscles resulted in improving foot mechanics (Snyder et al, 2009), which reflects the mechanical interdependence between hip muscles and foot function that was supported by the results of this study.

Silva et al (2013) found that subjects with forefoot varus deformity have less eccentric hip extension torque when compared to subjects with neutral forefoot alignment. However, no difference was observed between the two groups regarding eccentric hip external rotation torque. This partially agrees with the results of the current study, taking into consideration that forefoot varus deformity leads to an increase in the pronation of the subtalar joint during stance to allow the medial metatarsals to contact the floor (Alonso-Vázquez et al, 2009). The difference in the results regarding the torque of external rotators can be related to the difference of the testing position, as they measured external rotation torque in sitting with hip flexion at 90°. The potential for hip external rotation torque generation markedly decreased in this position (Delp et al, 1999); this may underestimate the external rotation torque generation in both groups, thus limiting the identification of differences that could exist.

The reduction in hip muscle strength found in flexible flatfoot can be a contributing factor in the development of low back pain. Nourbakhsh and Arab (2002) demonstrated a significant association between the strength of hip flexor muscles and low back pain; the laxity and mechanical instability in the lumbosacral area caused by iliopsoas muscle weakness can stimulate nociceptors in the surrounding soft tissue and eventually result in pain. Dysfunction of gluteus maximus and gluteus medius, which have been noted in individuals with low back pain, may cause pain by increasing the load

acting on the spine, as these muscles play a significant role in stabilising the trunk and in controlling the transfer of forces from the lower extremities up to the spine during upright activities (Nadler, 2002). Menz et al (2013) showed that excessive foot pronation during walking results in increasing the magnitude of compensatory movements at proximal joints and placing greater stresses on the lumbopelvic region, thereby contributing to the development of low back pain. Proper muscle function can control excessive joint movements and hinder the progress of pain.

The decrease in hip joint torque without a significant decrease in that of the trunk may be explained by Jull and Janda's observation—that in the pelvic crossed syndrome, if the lordosis is deep and short, then the imbalance is predominantly in the hip and pelvis muscles. On the other hand, if the lordosis is shallow and extends into the thoracic area, then imbalance predominates in the trunk muscles (Jull and Janda, 1987). As a matter of fact, this is only speculative since we did not evaluate the pelvis and spinal postural changes in this study. The non-reduced trunk torque may also be explained by the lower placement of the axis of isokinetic dynamometer at the lumbosacral junction. In a computer simulation study, Stokes (1987) found that during dynamic testing of trunk flexion and extension, the machine axis should be aligned with the L3 vertebra. The lower position of the machine axis may permit the contribution of hip muscles to the produced torque (Thorstensson and Nilsson, 1982).

Limitations

This study was limited by the decreased ability to determine a cause and effect relationship within a case-control design. However, the flexible flatfoot group in this study is believed to have developed flatfoot deformity early in their lives (identified from subjects' history); therefore, it seems more likely that the impairments in hip muscle torque are a consequence of foot misalignment. Lack of postural evaluation of the spine and pelvis should be considered and correlated with changes in muscle strength in future studies. We did not control movement dysfunctions and postural misalignments that may represent a possible aetiology for hip muscle weakness, and this should be done in future studies.

CONCLUSION

Impairment in hip muscles' concentric strength was observed in subjects with bilateral flexible flatfoot when compared to normal controls. Considering the significant role that hip musculature plays in the normal functioning of the trunk and lower extremity, our results seem to support the interrelationship between foot misalignment and proximal pathology. **IJTR**

Conflicts of interest: None declared.

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