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EVALUATING DYNAMIC BALANCE AND ISOMETRIC HIP MUSCLE STRENGTHS OF HEALTHY ADOLESCENTS WITH DIFFERENT FOOT POSTURE ALTERATION

VREDNOTENJE DINAMIČNEGA RAVNOTEŽJA IN IZOMETRIČNE MOČI MIŠIC KOLKA PRI ZDRAVIH MLADOSTNIKIH Z RAZLIČNIMI SPREMEMBAMI DRŽE STOPAL

ABSTRACT

Hip abductor (ABD) and adductor (ADD) muscle imbalances lead to injuries in lumbo-pelvic hip complex, and these imbalances and other factors such as foot posture might affect dynamic balance. The present study aims to examine body mass index (BMI), dynamic balance and hip muscle strength values of adolescents with different foot posture alteration. Fifty-nine healthy adolescents (mean age 12±3 years, height 156±11.46 cm, weight 50.57±11.60 kg) voluntarily participated in the study. The participants were divided into two groups according to Foot Posture Index (FPI): (Neutral Foot Group (NFG), n=48 / Prone Foot Group (PFG), n=11). The participants' single leg – both legs dynamic balance values were measured by using balance measurement device (TOGU$^{tm)}$, and their hip ABD and ADD isometric muscle strengths were measured through the load cell. The dynamic balance, BMI and muscle strength values of the groups were compared by using Independent Sample t-Test. A statistically significant difference was found between the groups according to right and left single leg dynamic balance values ($p<0.05$). The study revealed that one of the most significant factors affecting dynamic balance in adolescents is foot posture. It is believed that using insoles suitable for the foot posture might be helpful in increasing the efficiency of dynamic movements carried out on a single leg and it is essential to suggest some exercises to correct foot postures when necessary.

Keywords: hip abductor-adductor, pronated foot, load cell, dynamic balance

IZVLEČEK

Neravnovesje abduktorjev (ABD) in adduktorjev (ADD) kolka lahko vodi do poškodb ledvenega, medeničnega in kolčnega dela. Hkrati z nekaterimi drugimi dejavniki, kot je drža stopala, pa lahko vpliva tudi na dinamično ravnotežje. Namen te študije je preučiti vrednosti indeksa telesne mase (ITM), dinamičnega ravnotežja in moči mišic kolka pri mladostnikih z različnimi spremembami drže stopala. V raziskavi je prostovoljno sodelovalo 59 zdravih mladostnikov (povprečna starost 12±3 leta, višina 156±11,46 cm, teža 50,57±11,60 kg). Udeleženci so bili razdeljeni v dve skupini glede na indeks drže stopal (FPI): (skupina z nevtralnim stopalom (NFG), n=48 / skupina z nagnjenim stopalom (PFG), n=11). Vrednosti dinamičnega ravnotežja udeležencev na eni nogi ter obeh nogah so bile izmerjene z napravo za merjenje ravnotežja (TOGU $^{tm)}$, izometrična moč mišic pa z merilnikom obremenitve. Vrednosti dinamičnega ravnotežja, ITM-ja in mišične moči ABD in ADD so bile primerjane z uporabo t-testa za neodvisne vzorce. Med skupinama je bila ugotovljena statistično pomembna razlika glede na vrednosti dinamičnega ravnotežja med desno in levo nogo pri enonožni stoji ($p<0.05$). Študija je pokazala, da je eden najpomembnejših dejavnikov, ki vplivajo na dinamično ravnotežje pri mladostnikih, drža stopal. Menimo, da bi lahko uporaba primernih vložkov pripomogla k večji učinkovitosti dinamičnih gibov, ki se izvajajo na eni nogi skupaj s korekcijskimi vajami za pravilno držo stopal.

Ključne besede: abduktor in abduktor kolka, pronacija stopala, dinamično ravnotežje, dinamometer

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INTRODUCTION

Foot, which supports the body and carries body weight, fulfills other significant functions as well such as undergoing shock absorption by forming a support surface to enable the body to touch the ground, adapting to different surfaces and generating momentum for push off while moving forward during physical activities (Saltzman & Nawoczenski, 1995). The foot skeleton alignment, known as foot posture, varies for each individual (Angin et al., 2018). Deformations in foot structure and problems faced regarding its functions might negatively affect individual's daily life and sport performances by causing problems in almost all parts of the body in addition to feet (Lopezosa-Reca et al., 2020). Thus, foot posture, through altered lower limb motion patterns, can induce injuries (Buldt et al., 2015) and has been associated with abnormal foot motion during gait and posture (Alonso-Montero et al., 2020). In addition, foot posture variations can induce plantar pressure pattern alterations, which consequently alter the proximal lower limb joints' range of motion (Alonso-Montero et al., 2020). Foot posture is usually classified into three categories, neutral foot, supinated foot (pes cavus), and pronated foot (pes planus) depending on the length of medial longitudinal arch (MLA) (Redmond, 2005). Pronated foot is on the most common reasons of people's referring to orthopedics and clinics as seen in a wide range of deformities such as reduction of MLA height, heel external rotation and anterior foot abduction. Pronated foot is a foot posture with a low height of the medial longitudinal arch (Gwani et al., 2017). The decrease in the height of the medial longitudinal arch occurs due to the failure of the arch structure which can reduce the ability of the foot as a shock absorber in various weight bearing activities. This can increase the forces acting on the legs and proximal body parts and increase the risk of musculoskeletal injuries (Kirby, 2017). Particularly, among the musculoskeletal problems, the pes planus deformity is common in children, adolescents, and adults. Chougala et al. (2015) reported that, according to Dennison's evaluation method, 44% of young adults are predisposed to the risk of pes planus (Chougala et al., 2015). Also, highly pronated foot causes tibia to maintain longer internal rotation than normal, which leads to valgus stress and increased internal rotation in hips. As a result, iliopsoas muscle stretches and lumbar lordosis increase since pelvis tilts forward (Tang et al., 2015). Angular deviations in lower extremity affect foot biomechanics and cause problems in upper joints as well. Such changes might result in defects in walking in addition to pains in foot, knee, hip and lower back, which in turn negatively affects standing position, balance, walking, running and other similar activities (Al Abdulwahab & Kachanathu, 2015). The previous studies found that pronated foot structure is related to back pain, degenerative joint disease (halluks abducto-valgus), general lower-extremity pain (patellar tendinitis) and foot ache (Uden, Scharfbillig & Causby, 2017) while supinated foot is the reason of ankle sprains and iliotibial band syndrome (Williams, 3rd McClay & Hamill, 2001). Thus, identifying the factors affecting foot posture is likely to play a significant role in clinical evaluations and determining injury-related risk factors for adolescent athletes and increasing their sports performances accordingly.

A lot of factors affect foot posture structure and its function. The studies concluded that foot posture structure is affected during physical development of individuals by some external factors such as location (urban or rural), physical activity levels, types of shoes and shoe wearing age as well as some internal factors such as biology (gender, age, loose connective tissue and family story) or obesity (Fritz & Mauch, 2013). There are a number of mechanisms by which obesity may affect the foot. These include biomechanical changes to foot structure, such as pes planus, and changes to the plantar fat pad, including increased plantar pressures, inadequate muscular strength and/or power, particularly in activities requiring movement against gravity, and changes in gait (Shree et al., 2018). There are also some studies claiming that an increase in BMI values of adolescents correlates with deformations in foot posture (Gonçalves et al., 2020) and dynamic balance is negatively affected (Bukowska et al., 2021), whereas Cilli et al. (2009) found no correlation between flatfoot and weight and height.

However, no studies have focused on the relationship between hip muscle strength, BMI, dynamic balance and foot posture in adolescents. Gluteal muscles (maximus, medius and minimus) stabilize the hip by neutralizing hip ADD and internal rotation torque of gravity and maintain appropriate leg alignment by eccentrically controlling adduction and internal rotation torque of thighbone. Hip adductors and abductors muscles imbalances can lead to the occurrence of injuries in the lumbo-pelvic-hip complex (Tyler et al., 2001). Also, weakening of the gluteus maximus is a cause of foot deformities like pronated foot posture (Rathnamala, Senthil & Kulkarni, 2020). Pronated foot posture disturbs dynamic balance, and muscles and bones become prone to higher loads, which also negatively affects balance. Since foot, ankle, knee and hip joints together constitute the lower-extremity kinematics chain, the foot supports the body as the lowest link of this kinematics chain which provides somatosensory input. In this respect, even the smallest dynamic change in foot is thought to affect all body controls associated with dynamic balance (Pollock, Durward, Rowe & Paul, 2000) and postural sway, which is a sensorimotor process aiming to maintain stability and restore the balance during an activity (Cote, Brunet, Gansneder & Shultz, 2005). The study conducted by Telfer, Abbott, Steultjens & Woodburn, (2013) reported that while wider foot support surface in pronated foot structure is expected to affect balance positively, balance, in fact, is negatively affected due to the changes in medio-longitudinal arch structure. A study conducted with old adults showed that hip ABD muscle strength correlates with balance (Porto et al., 2019) and ABD –ADD muscle training improves balance (Inacio, Creath & Rogers, 2018). On the other hand, a study carried out with healthy young individuals found a low correlation between hip ABD-ADD muscle group and single leg balance (Tao et al., 2020). Another study conducted with young people reported a negative correlation between dynamic balance and foot posture (Irez, 2014). The critical review of the related literature did not reveal any studies dealing with how adolescents' foot posture, dynamic balance and hip ABD-ADD muscle strength affect each other. The aim of this study is to determine the effects of foot posture alteration of healthy adolescents, which is an indicator of deformation in foot mechanics, on BMI, single leg and double legs dynamic balance and hip muscle strength.

METHODS

Participants

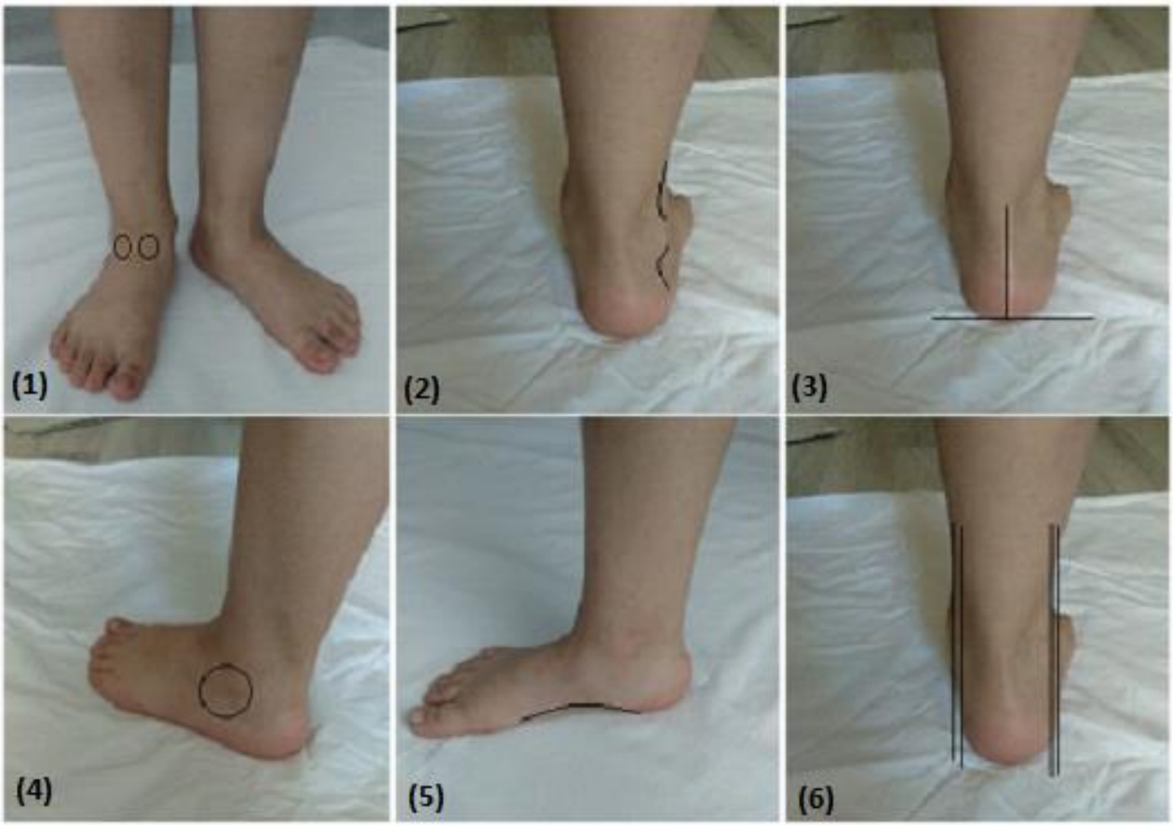
Sixty-two adolescents voluntarily participated in the study. The participants were divided into three groups according to their foot posture index scores: (NFG; n=48, mean age 12.31±2.1 years, height 156.96±11.82 cm, weight 50.90±12.03 kg, BMI 20.47±3.10 kg/m^2), (PFG; n=11, mean age 12.27±2.2 years, height 153.09±9.7 cm, weight=49.21 ±9.95 kg, BMI 20.54 ±2.77 kg/m^2), (Supinated Foot Group n=3). Since the number of individuals with supinated foot (n=3) was not sufficient, this group was excluded from the study and the analysis. Left and right legs of the participants had similar FPI values. The adolescent participants were excluded from the study if they have experienced lower-extremity injuries in the last six months, have a neurological defect and other problems related to hearing and sight. Ethical committee approval of the study was obtained from Eskişehir Technical University Science and Engineering Sciences Scientific Research and Publication Ethics Committee (E-87914409-050.03.04-18775). In addition, all the participants signed the informed consent form, and necessary written permissions were obtained from the parents of the participants.

Measurements

Foot Posture Index

The foot posture during full weight carrying was measured by using FPI-6 (Redmond, 2005), which was found to have a good intra-rater reliability and an acceptable validity. FPI-6 provides a composite score obtained by collecting six sub-measurement values; namely 1) talar head palpation, 2) supra and infra lateral malleolar curvature, 3) calcaneal frontal plane position, 4) prominence in the region of the talonavicular joint, 5) congruence of the medial longitudinal arch, and 6) abduction/adduction of the forefoot on the rearfoot (Redmond, 2005). According to the overall score and reference values suggested by Redmond (2005), the feet were classified as pronated (+6 to +12), neutral (0 to +5) and supinated (–1 to –12).

Figure 1. Six items of the Foot Posture Index (FPI).



(1) Talar head palpation, (2) supra and infra lateral malleolar curvature, (3) calcaneal frontal plane position, (4) prominence in the region of the talonavicular joint, (5) congruence of the medial longitudinal arch, (6) abduction/adduction of the forefoot on the rearfoot

Figure 2. Foot Posture Index Evaluation (Redmond, 2005).

Foot Standing Alignment Models

Foot in Neutral position
Calcaneus becomes vertical, and/or the medial longitudinal arch length is normal.

Foot in Pronation Position
Calcaneus eversion that is 3 degrees higher than normal, the prominence of medial in the talonavicular joint, and low medial longitudinal arch length.

Dynamic Balance

Dynamic balance measurements were carried out by using “Sigma Portable Balance Measurement System” (Cosmagamma, Italy)”. Developed for balance and proprioceptive exercises, Sigma Portable Balance Measurement System evaluates sensitivity of skeleton, muscular system and nervous system. Measurements in this system are performed through a multi-axial accelerometric sensor moving on a maximum 1 cm horizontal plane. This special sensor detects any changes in the platform and its position, and the scanned area in the projection of centroid is calculated in cm^2. Prior to the dynamic balance measurements, the participant athletes were asked to place their feet comfortably in the predetermined positions so that their feet were parallel to each other and had equal distances to the center. “Stability Test” option was chosen in the system to obtain dynamic balance measurement. First, double feet dynamic balance measurements were done for 30 seconds and, later, the measurements of each foot were performed separately in turn. Each measurement was repeated three times, and the best balance score was selected for the analysis.

Hip Muscle Strength

Hip ABD-ADD muscle strength was measured isometrically by using Load Cells Systems (Power link Sensor-S/N: PS000146B Made in GERMANY). The participants were asked to warm up for 5 minutes before the muscle strength measurements. The sensor was mounted on the wall by using a skyhook. While the participant was standing side at a place 37 cm far from the wall, the load cell was placed on 5 cm proximal of the leg to be measured by using a strap. Later, he was asked to pull his body back as strongly as he can without changing his standing side position. The measurements were done three times for 5 seconds for ABD and ADD muscles of each leg. The interval between the measurements was 60 seconds, and the highest score was taken for the analysis (Kollock, Cortes, Greska & Oñate, 2016). The values calculated in kilograms were converted into Newton values and multiplied by leg length (m) to find torque values. Finally, ABD/ADD ratio was calculated for each leg by dividing ABD value with ADD value.

Statistical Analysis

The descriptive information of groups and balance, BMI and muscle strength values were analyzed by using IBM SPSS Statistics 23 software (IBM, NY, USA). Data analysis was done at 95% degree of confidence, and Shapiro-Wilk test was used to determine whether the data display normal distribution or not. Since the data were found to have normal distribution, Independent Sample t-Test was applied to the data. The level of significance was taken as $p<0.05$ for all statistical calculations.

RESULTS

Table 1 below displays the data regarding the participants' FPI, age, height, body weight, body mass index and full leg length values (lateral malleolus trochanter distance). No significant differences were found between the groups in the study in terms of mean age, height, body weight, BMI and leg length.

Table 1. Characteristics of participants.

Anthropometrics	NFG n=48 Mean ± SD	PFG n=11 Mean ± SD	t	p
Years	12.31±2.10	12.27±2.20	-0.06	0.96
Heigh (cm)	156.96±11.82	153.09±9.70	0.94	0.35
Weight (kg)	50.90±12.03	49.21±9.95	0.43	0.67
BMI (kg/m²)	20.47±3.10	20.54±2.77	-0.07	0.95
Leg Length (cm)	77.36±6.65	74.45±4.70	1.37	0.17

NFG: Neutral Foot Group; **PFG:** Pronated Foot Group; **BMI:** Body Mass İndex; Significant difference: $p < 0.05$ level.

ABD-ADD torque values and ABD/ADD ratios as well as single and double legs balance scores of both PFG and NFG groups are shown below.

Table 2. The comparison of hip strength values of groups.

	NFG n=48 Mean ± SD	PFG n=11 Mean ± SD	**t**	**p**
Right Abductor Torque	79.05±24.22	76.98±23.57	0.26	0.80
Right Adductor Torque	86.52±27.69	80.53±25.02	0.66	0.51
Left Abductor Torque	76.96±22.50	74.00±19.78	0.40	0.69
Left Adductor Torque	85.90±27.15	76.46±25.15	1.05	0.30
Right ABD/ADD Ratio	0.93±0.16	0.97±0.18	-0.73	0.47
Left ABD/ADD Ratio	0.92±0.17	0.99±0.13	-1.34	0.19

NFG: Neutral Foot Group; **PFG**: Pronated Foot Group; **ABD/ADD**: Abductor /Adductor; **FPI**: Foot Posture Index; Significant difference: p < 0.05 level.

Table 2 below displays right and left hip ABD-ADD strength values, ABD/ADD ratios and standard deviation values respectively. No statistically significant difference was found between left and right hip ABD-ADD strength values and ABD/ADD ratios (p>0.05).

Table 3. The comparison of balance scores of groups.

	NFG n=48 Mean ± SD	PFG n=11 Mean ± SD	t	p
Two Leg Balance Score	3.59±0.78	3.8±0.74	-0.81	0.42
Rıght Leg Balance Score	3.36±0.74	3.95±0.64	-2.43	**0.02***
Left Leg Balance Score	3.37±0.69	3.94±0.72	-2.47	**0.02***

NFG: Neutral Foot Group; **PFG**: Pronated Foot Group; **FPI**: Foot Posture Index; Significant difference: p < 0.05 level

According to Table 3, there is a significant difference in dynamic balance values of PFG and NFG groups. The single leg dynamic balance scores of PFG group are higher than those of NFG group (p<0.05).

DISCUSSION

The aim of this study is to determine the effects of foot posture alteration of healthy adolescents, which is an indicator of deformation in foot mechanics, on BMI, single leg and double legs dynamic balance and hip muscle strength.

Pes planus, which is a form of pronated foot, is often accompanied with calcaneal eversion and abduction forefoot as well as flattening or lowering of medial longitudinal arch (MLA). The reported prevalence of pes planus changes between 0.6% and 77.9%. Pes planus prevalence for 2-6 age group was found to be between 37% and 59.7% and for 8-13 age group between 4%

and 19.1% (Halabchi, Mazaheri, Mirshahi & Abbasian, 2013). While there are studies reporting that pes planus foot structure changes according to BMI values (Woźniacka et al., 2013; Gonçalves et al., 2020), the study conducted by Evans & Karimi (2015) did not reveal a correlation between these two variables. Martínez-Nova et al., (2018) reported a minimal correlation between weight, height and prone foot structure. The findings of our study did not show a statistically significant difference between BMI of the participants both in NFG and PFG groups. It is known that when BMI increases, the load on foot sole will increase, which might result in deformations in foot structure (Woźniacka et al., 2013; Gonçalves et al., 2020). The BMI values of the adolescent groups in our study are similar to each other, and they are within the normal range according to the classification suggested by World Health Organization. Therefore, it might be concluded that the differences in foot posture in our study do not result from BMI values.

Another factor affecting foot posture and its function is muscle strength. Hip ABD, especially gluteus medius muscle, plays a crucial role in stabilizing lower-extremity and pelvis as well as in many activities including walking and jumping etc. Hip adductors and abductors muscles imbalances can lead to the occurrence of injuries in the lumbo-pelvic-hip complex (Tyler et al., 2001). Also, weakening of the gluteus maximus is a cause of foot deformities like pronated foot posture (Rathnamala, Senthil & Kulkarni, 2020). Hollman et al. (2006), in their study, found that pronated foot structure correlates with a decrease in isometric muscle strength of ABD when compared to hip ADD. Our findings are consistent with those of the study conducted by Hollman et al., (2006). Hip ABD and ADD muscle strengths of PFG group are relatively lower than the values of NFG group even though the difference is not statistically significant.

Weak body and hip muscle strengths are considered a risk factor for lower-extremity injuries such as anterior cruciate ligament rupture, patellofemoral pain syndrome and stress fractures in lower-extremity (Leetun et al., 2004). Indeed, stress fractures, knee pain and anterior cruciate ligament rupture are the most common types of injury experienced by individuals with pronated foot. In addition to these injuries, pronated foot posture disturbs balance, and muscles and bones are exposed to more weight accordingly, which negatively affects balance (Hertel et al., 2001). The study carried out by Tao et al., (2020) revealed a minimal correlation between static balance and isometric ankle and hip strength. Han et al., (2011), in their study conducted with individuals with neutral foot and those with pes planus, examined plantar pressure values during a walk. They found lower plantar pressure values and different COP (Center of Pressure) path for individuals with low arch than individuals with neutral foot. While the COP path of normal individuals generally starts from lateral heel and ends in hallux and tends to glide to medial at front foot area, the COP path of individuals having low arch moves directly from heels to hallux without a glide to the medial at front foot area (Han et al., 2011). The present study found a significant difference between the groups in terms of dynamic balance scores, and the balance scores of individuals with pronated foot were higher. This difference supports the findings of the study by Han et al., (2011). Birinci & Demirbaş (2017) found that pes planus deformity in foot negatively affects balance by leading to small perturbations and different balance strategies. In another study focusing on the effect of pes planus on athletes' balance performance, the findings revealed better balance performances on single leg by athletes who did not have pes planus problem (Kabak et al., 2019). Al Abdulwahab & Kachanathu (2015) were to investigate the role of various degrees of foot posture on static and dynamic standing balance components in a healthy adult population. This study concluded that higher degrees of FPI might have an effect on standing dynamic balance in healthy subjects. Our research findings are consistent with those of the studies reporting that pronated foot posture negatively affects balance (Al Abdulwahab & Kachanathu, 2015; Khalid et al., 2021). In addition, there are studies suggesting that hip ABD fatigue or weak hip ABD increases body sway and causes a loss of balance during the tasks carried out by single leg (Paillard, 2012; Lee & Powers, 2014). The study carried out with old adults showed that hip ABD muscle strength correlates with balance (Porto et al., 2019) and even low-level ABD-ADD muscles strength training improves balance (Inacio et al., 2018), and there is a correlation – despite being a low one – between balance on single leg and ABD muscle group (Tao et al., 2020). According to the finding of our study, dynamic balance scores increase as hip muscle strength values decrease. Similarly, Martin et al. (2014) study also showed that weak hip or its dysfunction not only cause knee injuries but also might lead to ankle and foot injuries such as patellofemoral pain syndrome, non-contact anterior cruciate ligament injury, chronic ankle sprain and plantar fasciitis. It is necessary to strengthen hip muscles and improve hip joint stability so that above mentioned injuries can be avoided. Strong hip muscles are likely to have a significant effect on knee and back foot mechanics (Snyder, Earl, Connor & Ebersole, 2009). The literature also includes some studies reporting the effect of strong intrinsic and gluteal muscles on posterior tibial dysfunction treatment in pes planus and hip joint instability in functional pes planus (Rathnamala, Senthil & Kulkarni, 2020). Also, many studies have investigated the efectiveness of exercise interventions, especially the intrinsic foot muscles strengthening exercises, on increasing the medial longitudinal arch in people with fat feet (Heo et al., 2011). Gheitasi et al., (2022) aimed to compare the efectiveness of extrinsic and intrinsic foot muscle exercises in improving the medial longitudinal arch in adolescents with fat feet. This study showed that the intrinsic exercises were more efective than the extrinsic exercises, and it is suggested to target this group of muscles to design exercises to correct the fat foot deformity of adolescents. In addition to strength exercises, exercises through proprioceptive senses might improve motor functions of individuals having pronated foot structure by allowing coordination and integration of motor units and contraction of the related muscles and finally by developing neuromuscular reactions (Nikkhouamiri, Akochakian & Shirzad Araghi, 2019).

CONCLUSION

Changes in the foot arch can cause weakness and inefficiency of the muscular system and ankle strategy and maintain balance. The current study demonstrated that one of the most significant factors affecting dynamic balance in adolescents is prone foot posture. As for adolescents, it will be useful to examine foot posture structure and design corrective exercises and use appropriate insoles, when necessary. Finally, future studies might examine foot and knee muscle strengths in addition to foot posture, balance and hip muscle strength.

Declaration of Competing Interest

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