Review Article

# Investigating the Effects of High-Arch and Flat Foot Deformities on Postural Control: A Systematic Review and Meta-Analysis

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## ABSTRACT

**Introduction:** High-arch and flat foot deformities can negatively impact an individual's performance in different situations. They may also balance as well as disturb postural control, which is essential for performing optimal routine and port activities, in addition to preventing injuries. This is a comparative meta-analysis of postural control in people with high-arch and flat foot deformities with normal feet.

**Materials and Methods:** This is a systematic review of articles published from 2004 to 2021 in Medline/PubMed, Embase/Scopus, LILACS, CINAHL, CENTRAL (cochrane central register of controlled trials), Web of Science, PEDro, and Google Scholar databases.

**Results:** The results revealed that the total balance score in people with high-arch and flat foot deformities was lower (P=0.001), compared to normal people. However, no significant difference was observed in the total balance of people with high-arch and flat foot deformities (P>0.05). Additionally, flat-foot people showed a weaker balance in the postural control test on a force plate, when compared to individuals with high-arch feet (P=0.001). Nevertheless, the results of dynamic balance were the same for all groups (P>0.05).

**Conclusion:** Our findings indicate that people with high-arch and flat foot deformities suffer from weaker postural control when compared to their normal peers. Moreover, flat-foot people showed lower scores on postural control tests on force plates, compared to subjects with high-arch feet, even though they had no significant differences for static and dynamic tests. There was no difference in the results of dynamic balance among the 3 groups.

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## 1. Introduction

The lower extremity is responsible for bearing the body weight and handling forces that are generated as a result of frequent foot and ground reactions. Given its anatomic structure and position in the lower extremity, the foot has a pivotal role in transforming propulsive forces and walking. Powered by subtalar joints, the structure of the foot is highly flexible to adapt to uneven terrain and contributes to maintaining balance [1]. Several internal and external factors make body tissues vulnerable to injuries. Some internal factors include age, gender, weak muscular balance, and most importantly the natural posture of joints and organs [2]. The foot arch is necessary for the stability of the lower limb. One of the most important internal risk factors for lower extremity injury is the position of the arch of the foot. The foot arch is an architectural construct that combines all foot elements, including joints, ligaments, and muscles into an integrated system [3]. Because of the flexibility and curvature changes, the arch adapts to uneven surfaces and transfers body weight forces to the ground. This occurs in different situations and results from optimal mechanical advantages. The foot arch is essential for flexible walking [4]. Thus, paying attention to the foot arch as the sole interactive surface between the lower extremity and the ground is imperative.

Any deformities in the sole can lead to dysfunctionality in different situations. For instance, flat foot and high-arch deformities are likely to disturb peripheral data from proprioception [2]. Flat foot may be associated with extreme pronation of subtalar joints, which can lead to imbalance and hypermobility of foot joints. On the other hand, high-arch foot deformity is linked to extreme supination of subtalar joints. It may have negative impacts on postural control because of the low support surface of the foot in the weight-bearing mode [5]. The body comprises a set of flexible parts that maintain a vertical position in which the center of mass lies at a higher latitude than the foot. Thus, the body has a naturally low balance resistance [6]. Maintaining balance in a standing position is the measure for examining the lower extremity functionality [7]; however, the flat foot plays a significant role in postural control and foot arch functions to absorb ground forces [8]. Accordingly, high-arch and flat foot may experience unsuitability under weighed pressure and disturb postural control [9].

Postural stability is the ability to maintain the center of gravity of the body, correct orientation of the posture, and maintain an accurate connection between different organs while keeping the body in touch with the environment to do a certain task [10, 11]. As noted by Janda on body chain activity, people with lower-than-normal foot arch may develop pathomechanics or physiologic disorders [12]. They may initially suffer from inner rotation, such as pain in the knee, hip, or back. Side-effects of walking on tiptoes to compensate for a flat foot and stretching lead to various secondary ailments, such as foot deformity, pain in walking, pain in the heel, injuries, backache, and finger mallet that are rooted in flat foot [13].

Postural control is essential for daily routines, optimal sports activities, and prevention of injuries [14]. Thus, the present meta-analysis compares postural control in people with flat and high-arch foot deformities with their normal counterparts to see if they have any effects on postural control. This study also aims to find which deformity disturbs postural control the most.

## 2. Materials and Methods

The following databases were used to extract qualified papers from 2004 to February 25th, 2021: Medline/PubMed, Embase/Scopus, LILACS, CINAHL, CENTRAL (cochrane central register of controlled trials), Web of Science, PEDro, and Google Scholar. The keywords were adopted from the MeSH framework, complemented by a manual search, along with a thorough paper analysis. The following keywords were searched: Balance control, center of pressure, or balance, or postural stability, or posture, or postural balance, or postural sway, or stability, or static balance, or static stance, or dynamic balance, pronation foot, or flexible flat foot, or rigid flat foot, or flat foot, or pes planus, supination foot, or cavus foot, or pes cavus, or arch height foot. The Persian equivalent of the keywords were also used to search in the following Persian databases: MAGIRAN, IranDoc, IranMedex, MedLib, and SID. The candidate papers that met the inclusion criteria were then summarized and used. A total of 25 papers were extracted.

The inclusion criteria were as follows: 1) Studies published in the Persian and English language and peer-reviewed; 2) All subjects were free from any orthopedic conditions that may affect balance; 3) Analyzing the effect of any type of flat feet or high-arched foot on postural control and dynamic balance; 4) Original studies with a cross-sectional design.

At first, papers were screened in terms of title and abstract to pick the articles concerned with balance in people with flat and high-arch foot. All English and Persian papers were closely studied. An assistant analyzed all the study abstracts. In the second phase, the papers were thoroughly studied by the researcher to compare balance in normal people with flat foot and high-arch foot subjects. Another researcher checked the final list to ensure all the papers were homogeneous. The descriptive summary of the papers was finally collected by an assistant and checked by the researcher. Disagreements were resolved by discussion. A sample table was used to extract the target population and compare the balance in 3 groups under analysis (Figure 1).

The exclusion criteria were as follows: Working with a population with no flat or high-arch foot; conference proceedings or reports, editorials, letters, case studies or series, abstract only, (systematic reviews and meta-analyses; studies performed on the elderly; studies with no concrete methodology; studies working with different foot deformities other than the ones in our systematic review; not studying balance; studies working with different functional tests.

## Outcome measures

The desired variables were examined in the form of postural control and dynamic balance, namely limits of stability, sensory orientation, postural adjustments, anticipatory postural adjustments, transitions postural adjustments, stability, and verticality.

## Quality of evidence

The risk of bias was evaluated by both reviewers using the Newcastle-Ottawa quality assessment scale (NOS). The checklist developed by Herzog, Álvarez-Pasquin [15] for cross-sectional studies was also employed. The NOS is an instrument that assesses the risk of bias by awarding a star for each answer that meets the criteria. A maximum of 10 stars can be obtained: 5 stars for selection, 3 stars for comparability, and 2 stars for outcome. Each given star projects a low risk of bias for this criterion [16]. The quality was assessed based on the Herzog, Álvarez-Pasquin [15] checklist as follows: Very good studies=9-10 stars, good studies=7-8 stars, satisfactory studies=5-6 stars, unsatisfactory studies=0 to 4 stars. NOS designers have established face and criterion validity, in addition to inter-rater reliability [17, 18].

## Statistical analyses

The Hedge g for effect size was used for the meta-analysis (difference of the means in units of the pooled standard deviation). The heterogeneity was measured using $I^2$. In this case, the random effects model was used for $I^2>50$ while the fixed effects model was used for $I^2<50$. The Egger regression test of the intercept was used to examine the publication bias. Data analysis was performed using the Comprehensive Meta-Analysis software, version 2.

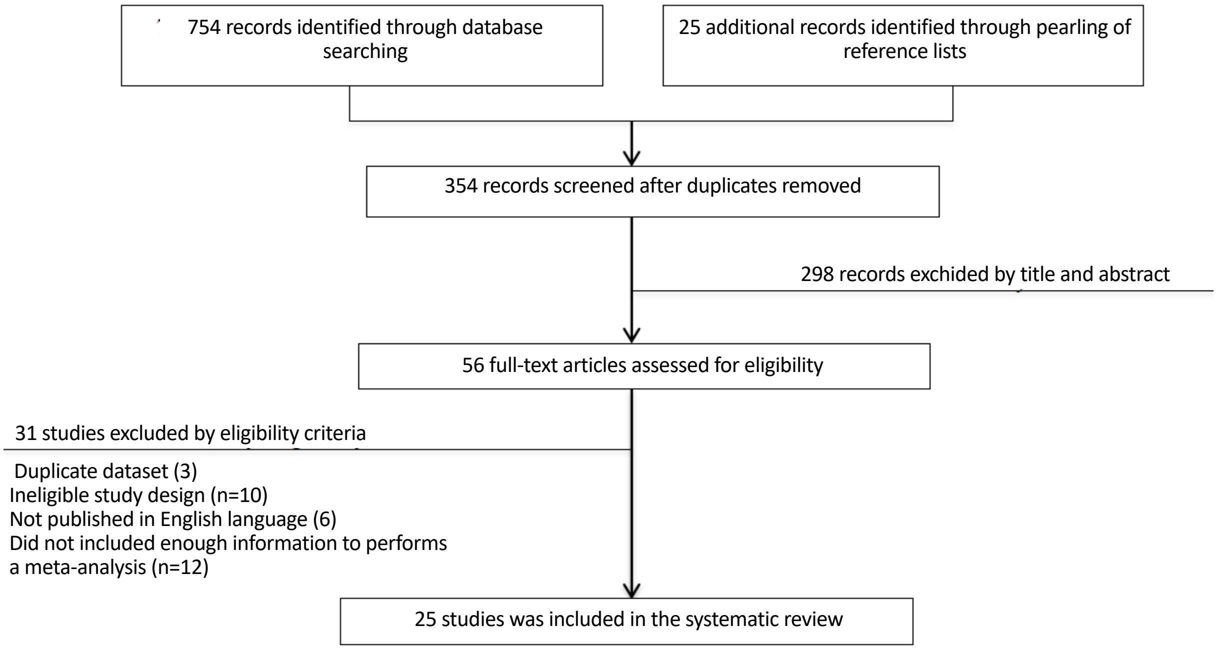


**Figure 1.** Flowchart for screening of articles

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## 3. Results

A total of 754 papers were extracted from the online databases and 25 papers were found by manual search, from which 354 articles were selected for the present analysis after removing redundant titles. Furthermore, 298 titles were removed after screening the abstracts, and 56 papers were selected for the final analysis (Figure 1). Finally, 25 papers that compared postural control and balance of flat and high-arch foot people with their normal peers were selected to be studied (Table 1).

### Quality of evidence

Based on the results of the NOS, studies that were systematically reviewed and meta-analyzed had desirable qualities as follows: 3 studies (12%)=very good (9 stars); 12 studies (48%)=good (8 stars); 6 studies (24%)=good (7 stars); and 4 study (16%)=satisfactory (5-6 stars). Accordingly, studies that were systematically reviewed and meta-analyzed are of good quality. The results are summarized in Table 1.

Figure 2 reveals the meta-analysis of flat-foot people compared to normal people. The $I^2$ index showed 76% heterogeneity; therefore, the random effect meta-analysis was applied. The effect size Hedge g was -0.25 at the 95% confidence interval (-0.43 and -0.07). The results of the meta-analysis showed that people with flat foot had a weaker balance compared to normal people (P=0.01); however, no difference was observed in the results of the dynamic test (P=0.16). The result of the Egger test was 0.051, showing no skewed distribution.

Figure 3 shows the meta-analysis of high-arch foot people compared to normal people. The $I^2$ index showed 73% heterogeneity; therefore, the random effect meta-analysis was applied. The effect size Hedge g was -0.47 at the 95% confidence interval (-0.72 and -0.23). The results of the meta-analysis showed that people with flat foot had a weaker balance compared to normal people (P=0.01); however, no difference was observed in the results of the dynamic test (P=0.30). The result of the Egger test was 0.84, showing no skewed distribution.

Figure 4 compares the meta-analysis of high-arch and flat-foot people. The $I^2$ index showed 76% heterogeneity; therefore, the random effect meta-analysis was applied. The effect size Hedge g was -0.9 at the 95% confidence interval (-0.33 and 0.14). The results of the meta-analysis showed no difference in the overall balance between the 2 groups (P=0.01). However, flat-foot people showed weaker postural control on force plates (P=0.01). The result of the Egger test was 0.41, showing no skewed distribution.

## 4. Discussion

The present study compared postural control and dynamic balance in people with flat and high-arch foot deformities with normal people. The results indicated that flat-foot people have a weaker balance compared to normal people. Similarly, high-arch people showed weaker balance compared to their normal peers. There was no difference in the postural control and dynamic balance between high-arch and flat-foot people. A detailed description of the results is given below.

### Postural control and dynamic balance in flat foot and normal people

A range of different methods are usually applied to measure dynamic balance and postural control. Accordingly, a separate meta-analysis was applied in this research. The results revealed that flat-foot people had a weaker balance compared to normal people, even though there was no difference between them in terms of dynamic balance. Studies show that flat foot people's center of pressure in postural control test on force plates was on the inner side of the foot [31]. They concluded that these people experience a higher level of pressure on the inner side of the foot. However, no significant difference was reported between normal people and flat-foot people in the dynamic balance.

Studies showed that the displacement of the center of pressure was significantly correlated to the medial arch of the foot [19, 43]. The reason for the discrepancy in this research is likely attributed to the application of changes in the pressure center rather than the pressure-mass center. Also, studies on people with the flat foot during single-leg balance motion showed that the extent of variations in both directions of anterior-posterior and medial-lateral in people with the flat foot was greater than in normal people [28, 29]. However, this increase in postural sway during the dynamic balance tests can help increase access balance in flat-foot people.

On the other hand, they showed a significant difference in static balance, reporting no significant correlation between static and dynamic tests [32]. Accordingly, the measure for evaluating dynamic balance was inappropriate. There is a significant difference between the two groups in a fixed standing position, but no significant difference exists between the 2 groups in dynamic balance The results of the meta-analysis show that flat-foot people have a weaker balance that may lead to athletic injuries and dysfunctionality in routine activities. Thus, there should be some corrective exercises to address this abnormality to prevent future possible injuries.

**Table 1.** Review of results of balance in high-arch and flat-foot people

| Author | Title | Structure and Sample Size | Age (y) | Dependent Variables | Measurement Tool | Results | NOS Scale |
|---|---|---|---|---|---|---|---|
| Hertel et al. (2002) [19] | Difference in postural control in one-leg standing position in normal people with different foot structures | Normal foot=23, flat foot=18, high-arch foot=19 | 19-23 | High-arch foot balance | Force plate, one-leg standing position | People with high-arch foot experience a greater pressure distribution compared to normal people. However, there was no significant difference in the momentum of pressure distribution. | 9 |
| Cobb et al. (2004) [20] | Effects of anterior foot arch on posture | High-arch foot=20, low-arch foot=12 | 20-37 | Postural control high-arch | Single-limb stance force plate, no-tolerance test, navicular drop test | No significant difference was observed between the study groups. The scores of postural control were higher with closed eyes. | 8 |
| Tsai et al. (2006) [21] | Comparing the effects of different foot structures on standing postural position | Normal, supinated, and pronated foot=15, female=7, male=8 | 18-31 | Foot structure Postural control | Force plate, pressure distribution center device | Postural control was weaker in the supinated and pronated foot compared to the normal foot. | 9 |
| Khodavisi et al. (2009) [22] | Effects of flat and high-arch foot deformities on dynamic balance in female teenagers | Normal foot=20, flat foot=21 high-arch foot=19 | 12-14 | High-arch foot dynamic balance | Navicular drop test, biodex balance test | High-arch people have a weaker dynamic balance than normal and flat-foot people. | 8 |
| Ghasemi et al. (2011) [23] | Comparing dynamic balance in men with different foot styles | Normal foot=30, flat foot=30, high-arch foot=30 | 23-27 | Dynamic balance | Star excursion balance test, navicular drop test | High-arch foot people exert greater pressure on the outer side of the foot and experience greater resistance in that region, while flat-foot people exert more pressure on the inner side of the foot. | 7 |
| Ali et al. (2011) [24] | Dynamic postural control in people with and without foot deformities | Normal foot=10, flat foot=10 | 19-21 | High-arch foot static and dynamic balance | Biodex, one-foot test on a force plate | Compared to normal people, subjects with flexible flat foot have weaker dynamic balance. | 8 |
| Dabholkar et al. (2012) [25] | Using stark test to compare static and dynamic balance in flat foot and normal people | Normal foot=60, flat foot=60 | 18-24 | High-arch foot rotation balance | Star excursion balance test, navicular drop test, goniometer | Balance in people with flat foot is different from normal people. | 9 |
| Takata et al. (2013) [26] | Static balance on ground, effects of flat foot and insoles | Normal foot=20 flat foot=20 | 19-23 | High-arch foot pressure distribution center | Navicular drop test, force plate | A significance level of super fit insoles on the ground was lower than BMZ insoles. | 8 |
| Bazvand et al. (2014) [27] | Postural control in people with high-arch and flat foot deformities in walking | Normal foot=10, flat foot: 10, high-arch foot=10 | 20-28 | High-arch foot, balance | Navicular drop test, force plate | There was a significant difference in the secondary double-limb support in flat-foot people compared to normal and high-arch-foot people in interior-exterior and anterior-posterior directions. However, there was no difference in displacement mean and speed in double-limb and single-limb support. | 7 |
| Tahmasebi et al (2014) [28] | Static balance in people with flat foot | Normal foot=15, flat foot=15 high-arch foot=30 | 18-24 | The pressure distribution center of the arch | Force plate, footprint | There was a significant difference in the mean center of pressure distribution in static positions. | 7 |

| Author | Title | Structure and Sample Size | Age (y) | Dependent Variables | Measurement Tool | Results | NOS Scale |
|---|---|---|---|---|---|---|---|
| Kim et al. (2014) [29] | The difference in static and dynamic balance in people with normal and flat | Normal foot=14, flat foot=14 | 20-27 | High-arch foot static and dynamic balance | Navicular drop test, stark balance test, Y-balance test | People with flat foot showed differences in static but not dynamic balance. This may show no relationship between static and dynamic balance. | 8 |
| Ghaderiyan et al. (2015) [30] | Displacement of the center of pressure in the sole of students aged 10-13 years with normal, flat and high-arch foot | Normal foot=30, flat foot=30, high-arch foot=30 | 10-13 | Center of the pressure of the foot, high-arch foot | Pedoscope, foot scanner, Staheli index | There was a significant difference in the overall postural control. Anatomic structure affects the displacement of the center of pressure. | 7 |
| Faghihi et al. (2016) [31] | Effect of different degrees of flat foot on static and dynamic balance in male teenagers | Control=10, low navicular drop=14, high navicular drop=10 | 14-18 | High-arch foot, static balance, dynamic balance | Star excursion balance test, navicular drop test, Stark balance test | Flat foot significantly reduces balance, but higher degrees of flatness had no effects on reducing balance. | 6 |
| Khodavisi et al. (2009) [22] | Comparing Q angle and dynamic balance in female athletes with flat and normal foot | Normal foot=30, flat foot=30 | 19-21 | High-arch foot static and dynamic balance, Q angle | Force plate, star excursion balance test, navicular drop test, goniometer | There was a signific difference in the Q angle between the two groups, no difference was observed in the dynamic and static balance. | 8 |
| Panahi et al. (2016) [32] | Comparing dynamic and static balance in active female college students with different high-arch foot | Normal foot=30, flat foot=30, high-arch foot=30 | 18-25 | Static balance, dynamic balance, high-arch foot | Stabilometer, navicular drop test | Static balance was weaker in people with flat and high-arch foot compared to normal people, but no difference was observed in the dynamic balance between them. | 5 |
| Kazemi et al. (2017) [33] | The relationship between Y test and pressure distribution device in evaluating dynamic balance in people with different high-arch foot | Normal foot=28, flat foot=25, high-arch foot=25 | 18-25 | High-arch foot balance pressure distribution center | Navicular drop test, Y-balance test, balance distribution device | There was a significant relationship between the Y test and the pressure distribution device in evaluating dynamic balance in people with different high-arch foot | 7 |
| Ashkezari et al. (2014) [34] | Effects of high-arch foot on static and dynamic balance in male university athletes | Normal foot=30, flat foot=30, high-arch foot=30 | 18-25 | High-arch foot dynamic balance pressure distribution center | Navicular drop test, Y-balance test, pressure distribution device | There was a significant difference in mean postural fluctuation in the standing position and dynamic balance in the three groups, though they showed no difference for the Y-balance test. | 8 |
| Hajirezaei et al. (2018) [35] | Comparing postural control, static balance, and dynamic balance in children with high-arch foot | Normal foot=15, flexible flat foot=15, structural flat foot=15, high-arch foot=15 | 10-13 | High-arch foot, static balance dynamic balance | Foot scan, stark balance test, star excursion balance test | Foot deformities, particularly structural flat foot, disturb postural control and balance and may increase the risk of injuries. | 8 |

| Author | Title | Structure and Sample Size | Age (y) | Dependent Variables | Measurement Tool | Results | NOS Scale |
|---|---|---|---|---|---|---|---|
| Ghasemi et al. (2018) [36] | Effects of functional fatigue protocol on postural control and balance of people with different high-arch foot | Normal foot=15, flexible flat foot=30, structural flat foot=15, high-arch foot=15 | 10-13 | Footprint, high-arch foot balance | Foot scanner, Staheli index | Fatigue significantly reduces all the factors in the 4 study groups but there was a significant difference between them. Before and after the fatigue protocol, there was a significant difference between the study groups. | 6 |
| Kolasangiani et al. (2019) [37] | Evaluating the effects of body posture and electric activity on foot muscles during single-foot landing in people with foot pronation and healthy people | Normal foot=27, high-arch foot=27 | 1-25 | Muscle activity, center of mass, pressure, distribution center | Electromyography, force plate, foot index structure | There was a significant difference between the pressure distribution center, center of mass, and internal gastrocnemius, soleus, anterior tibialis, and pronus longus muscles. | 7 |
| Huang et al. (2019) [38] | H reflex in hallucis abductor and postural function in normal and flat foot people | Normal foot=12, flat foot=12 | 21-31 | High-arch foot, muscle activity, pressure distribution | Navicular drop test, electromyography, force plate | In all situations, the hallucis reflex in flat foot was significantly lower. Displacement in a pressure distribution center in anterior-posterior and interior-exterior directions, and electromyography in single-limb stance were higher in flat-foot people. | 8 |
| Woźniacka et al. (2019) [39] | The relationship between high-arch foot, foot pressure distribution and posture in young females | Normal foot=38, high-arch (one foot)=23, high-arch (both feet)=20 | 20-40 | High-arch foot, pressure distribution center, postural control | Force plate, insoles | There was no difference in overall burden between the left and right legs (women with symmetric arch) in groups 1 and 3, but in group 2, the right leg underwent a heavier burden (women with asymmetric arch) | 8 |
| Fattahi et al. (2020) [40] | Immediate effects of insoles on balance in teens with high-arch and flat foot deformities | Flat foot=22, high-arch foot=12 | 11-14 | Foot examination of static and dynamic balance | Observation, foot scanner, sharpened Romberg, ENC | Body weight is transferred by talus to the heel and then to the ground. Any arch deformity leads to disrupted routine activities and impairs balance. | 8 |
| Mária et al. (2020) [41] | Effects of high-arch foot on static balance of primary school children | Normal foot=105, high-arch foot=72 | 6-14 | The pressure distribution center, high-arch foot | Force plate, navicular drop test | There was no significant difference in 17 intervals and the frequency of initial parameters. | 5 |
| Koshino et al. (2020) [42] | Postural stability and muscle activation in double-limb to single-limb movement in people with flat foot | Normal foot=10, flat foot=8, high-arch foot=9 | 19-23 | High-arch foot pressure distribution center | Foot posture index, pressure distribution device | There was no difference between the 3 groups in muscle activation time. However, postural stability and displacement of the pressure center in the initial 3 s differed significantly in the 3 study groups. | 8 |

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| Model | Group by Outcome | Study name | Outcome | Hedges's g | Standard error | Variance | Lower limit | Upper limit | Z-Value | p-Value |
|---|---|---|---|---|---|---|---|---|---|---|
| | dynamic balance | Panahi et al | dynamic balance | 0.36- | 0.26 | 0.07 | 0.86- | 0.15 | 1.40- | 0.16 |
| | dynamic balance | Khodaveici et al | dynamic balance | 0.05- | 0.31 | 0.09 | 0.65- | 0.55 | 0.16- | 0.87 |
| | dynamic balance | Kazemi et al | dynamic balance | 0.10 | 0.27 | 0.07 | 0.43- | 0.62 | 0.36 | 0.72 |
| | dynamic balance | Faghihi et al | dynamic balance | 0.92 | 0.45 | 0.20 | 0.03 | 1.81 | 2.03 | 0.04 |
| | dynamic balance | Dabholkar et al | dynamic balance | 0.76 | 0.26 | 0.07 | 0.24 | 1.27 | 2.86 | 0.00 |
| | dynamic balance | Kim et al | dynamic balance | 0.07 | 0.37 | 0.13 | 0.65- | 0.79 | 0.20 | 0.84 |
| | dynamic balance | Ashkezari et al | dynamic balance | 0.47 | 0.26 | 0.07 | -0.04 | 0.98 | 1.82 | 0.07 |
| Fixed | dynamic balance | | | 0.22 | 0.11 | 0.01 | 0.01 | 0.44 | 2.03 | 0.04 |
| Random | dynamic balance | | | 0.24 | 0.17 | 0.03 | -0.09 | 0.58 | 1.41 | 0.16 |
| | Postural control | Takata et al | Postural control | 0.66- | 0.32 | 0.10 | 1.28- | -0.03 | 2.07- | 0.04 |
| | Postural control | Hertel et al | Postural control | 0.26- | 0.31 | 0.10 | 0.87- | 0.34 | 0.85- | 0.40 |
| | Postural control | Bahmani et al | Postural control | 0.16- | 0.36 | 0.13 | 0.86- | 0.54 | 0.44- | 0.66 |
| Fixed | Postural control | | | 0.37- | 0.19 | 0.04 | 0.74- | -0.00 | 1.97- | 0.05 |
| Random | Postural control | | | 0.37- | 0.19 | 0.04 | 0.74- | -0.00 | 1.97- | 0.05 |
| | Postural control- AP | Ghaderian et al. | Postural control- AP | 1.01- | 0.27 | 0.07 | 1.54- | 0.48- | 3.74- | 0.00 |
| | Postural control- AP | Koshino et al | Postural control- AP | 1.43- | 0.51 | 0.26 | 2.43- | 0.43- | 2.80- | 0.01 |
| | Postural control- AP | Kolasangiani et al | Postural control- AP | 0.30- | 0.27 | 0.07 | 0.83- | 0.23 | 1.11- | 0.27 |
| | Postural control- AP | Tahmasebi et al | Postural control- AP | 0.64- | 0.36 | 0.13 | 1.36- | 0.07 | 1.76- | 0.08 |
| | Postural control- AP | Tsai et al | Postural control- AP | 1.31- | 0.39 | 0.15 | 2.08- | 0.54- | 3.32- | 0.00 |
| | Postural control- AP | Takács et al | Postural control- AP | 0.21- | 0.15 | 0.02 | 0.51- | 0.09 | 1.38- | 0.17 |
| | Postural control- AP | Ibrahim Ali et al | Postural control- AP | 1.27- | 0.47 | 0.22 | 2.19- | 0.34- | 2.68- | 0.01 |
| | Postural control- AP | Bazvand et al | Postural control- AP | 4.61- | 0.85 | 0.72 | 6.27- | 2.95- | 5.45- | 0.00 |
| | Postural control- AP | Ghasemi et al | Postural control- AP | 0.72- | 0.37 | 0.13 | 1.44- | 0.00 | 1.95- | 0.05 |
| Fixed | Postural control- AP | | | 0.62- | 0.10 | 0.01 | 0.82- | 0.43- | 6.27- | 0.00 |
| Random | Postural control- AP | | | 1.03- | 0.25 | 0.06 | 1.52- | 0.53- | 4.06- | 0.00 |
| | Postural control-DLS-mm-AP | Huang et al-5 | Postural control-DLS-mm-AP | 0.23- | 0.40 | 0.16 | 1.01- | 0.54 | 0.59- | 0.55 |
| | Postural control-DLS-mm-AP | Huang et al-6 | Postural control-DLS-mm-AP | 0.21- | 0.40 | 0.16 | 0.98- | 0.57 | 0.52- | 0.60 |
| Fixed | Postural control-DLS-mm-AP | | | 0.22- | 0.28 | 0.08 | 0.77- | 0.33 | 0.79- | 0.43 |
| Random | Postural control-DLS-mm-AP | | | 0.22- | 0.28 | 0.08 | 0.77- | 0.33 | 0.79- | 0.43 |
| | Postural control-DLS-S | Huang et al-2 | Postural control-DLS-S | 0.50 | 0.40 | 0.16 | 0.28- | 1.29 | 1.25 | 0.21 |
| Fixed | Postural control-DLS-S | | | 0.50 | 0.40 | 0.16 | 0.28- | 1.29 | 1.25 | 0.21 |
| Random | Postural control-DLS-S | | | 0.50 | 0.40 | 0.16 | 0.28- | 1.29 | 1.25 | 0.21 |
| | Postural control-SLS-mm-AP | Huang et al-4 | Postural control-SLS-mm-AP | 0.92- | 0.42 | 0.17 | 1.74- | 0.11- | 2.22- | 0.03 |
| Fixed | Postural control-SLS-mm-AP | | | 0.92- | 0.42 | 0.17 | 1.74- | 0.11- | 2.22- | 0.03 |
| Random | Postural control-SLS-mm-AP | | | 0.92- | 0.42 | 0.17 | 1.74- | 0.11- | 2.22- | 0.03 |
| | Postural control-SLS-mm-ML | Huang et al-3 | Postural control-SLS-mm-ML | 1.33- | 0.44 | 0.19 | 2.19- | 0.47- | 3.03- | 0.00 |
| Fixed | Postural control-SLS-mm-ML | | | 1.33- | 0.44 | 0.19 | 2.19- | 0.47- | 3.03- | 0.00 |
| Random | Postural control-SLS-mm-ML | | | 1.33- | 0.44 | 0.19 | 2.19- | 0.47- | 3.03- | 0.00 |
| | Postural control-SLS-S | Huang et al-1 | Postural control-SLS-S | 0.21 | 0.40 | 0.16 | 0.56- | 0.99 | 0.54 | 0.59 |
| Fixed | Postural control-SLS-S | | | 0.21 | 0.40 | 0.16 | 0.56- | 0.99 | 0.54 | 0.59 |
| Random | Postural control-SLS-S | | | 0.21 | 0.40 | 0.16 | 0.56- | 0.99 | 0.54 | 0.59 |
| Fixed | Overall | | | 0.27- | 0.06 | 0.00 | 0.39- | 0.14- | 4.18- | 0.00 |
| Random | Overall | | | 0.25- | 0.09 | 0.01 | 0.43- | -0.07 | 2.69- | 0.01 |

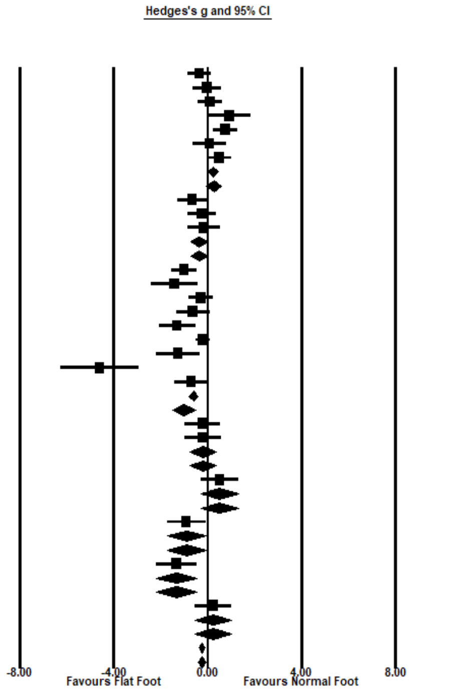


**Figure 2.** Results of meta-analysis of flat foot people compared to normal people

Abbreviations: AP: Anterior-posterior; ML: Medial-lateral; SLS-S: Single-leg standing (seconds); 95% CI: 95% confidence interval.

| Model | Group by Outcome | Study name | Outcome | Hedges's g | Standard error | Variance | Lower limit | Upper limit | Z-Value | p-Value |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dynamic balance | Panahi et al-1 | Dynamic balance | 1.21- | 0.28 | 0.08 | 1.75- | 0.66- | 4.34- | 0.00 |
| | Dynamic balance | Khodaveici et al | Dynamic balance | 0.57- | 0.32 | 0.10 | 1.20- | 0.06 | 1.78- | 0.07 |
| | Dynamic balance | Kazemi et al | Dynamic balance | 0.50 | 0.28 | 0.08 | 0.04- | 1.04 | 1.82 | 0.07 |
| | Dynamic balance | Ashkezari et al-1 | Dynamic balance | 0.48 | 0.26 | 0.07 | -0.02 | 0.99 | 1.87 | 0.06 |
| Fixed | Dynamic balance | | | 0.15- | 0.14 | 0.02 | 0.42- | 0.13 | 1.04- | 0.30 |
| Random | Dynamic balance | | | 0.19- | 0.43 | 0.18 | 1.03- | 0.65 | 0.45- | 0.65 |
| | Postural control | Panahi et al-2 | Postural control | 1.76- | 0.30 | 0.09 | 2.35- | 1.17- | 5.84- | 0.00 |
| | Postural control | Oleksy et al | Postural control | 0.28- | 0.27 | 0.07 | 0.82- | 0.26 | 1.02- | 0.31 |
| | Postural control | Ashkezari et al-2 | Postural control | 0.73- | 0.26 | 0.07 | 1.25- | 0.21- | 2.78- | 0.01 |
| | Postural control | Hertel et al | Postural control | 0.74- | 0.31 | 0.10 | 1.36- | 0.12- | 2.35- | 0.02 |
| Fixed | Postural control | | | 0.84- | 0.14 | 0.02 | 1.12- | 0.56- | 5.88- | 0.00 |
| Random | Postural control | | | 0.87- | 0.31 | 0.10 | 1.47- | 0.27- | 2.82- | 0.00 |
| | Postural control-AP | Ghaderian et al-1 | Postural control-AP | 1.01- | 0.27 | 0.07 | 1.55- | 0.48- | 3.74- | 0.00 |
| | Postural control-AP | Cobb et al-1 | Postural control-AP | 0.79- | 0.37 | 0.14 | 1.52- | -0.07 | 2.14- | 0.03 |
| | Postural control-AP | Koshino et al-1 | Postural control-AP | 0.00 | 0.44 | 0.19 | 0.86- | 0.86 | 0.00 | 1.00 |
| | Postural control-AP | Ghasemi et al-1 | Postural control-AP | 0.11- | 0.36 | 0.13 | 0.81- | 0.59 | 0.31- | 0.76 |
| | Postural control-AP | Bazvand et al-1 | Postural control-AP | -0.02 | 0.43 | 0.18 | 0.86- | 0.82 | 0.04- | 0.97 |
| | Postural control-AP | Tsai et al-1 | Postural control-AP | 0.82- | 0.37 | 0.14 | 1.55- | -0.10 | 2.22- | 0.03 |
| Fixed | Postural control-AP | | | 0.57- | 0.15 | 0.02 | 0.85- | 0.28- | 3.88- | 0.00 |
| Random | Postural control-AP | | | 0.52- | 0.20 | 0.04 | 0.90- | 0.14- | 2.66- | 0.01 |
| | Postural control-ML | Ghaderian et al-2 | Postural control-ML | 0.26- | 0.26 | 0.07 | 0.76- | 0.24 | 1.02- | 0.31 |
| | Postural control-ML | Cobb et al-2 | Postural control-ML | 0.97- | 0.38 | 0.14 | 1.71- | 0.24- | 2.59- | 0.01 |
| | Postural control-ML | Koshino et al-2 | Postural control-ML | 0.00 | 0.44 | 0.19 | 0.86- | 0.86 | 0.00 | 1.00 |
| | Postural control-ML | Ghasemi et al-2 | Postural control-ML | 0.54- | 0.36 | 0.13 | 1.25- | 0.17 | 1.48- | 0.14 |
| | Postural control-ML | Bazvand et al-2 | Postural control-ML | -0.06 | 0.43 | 0.18 | 0.90- | 0.78 | 0.13- | 0.89 |
| | Postural control-ML | Tsai et al-2 | Postural control-ML | 1.93- | 0.43 | 0.19 | 2.78- | 1.08- | 4.45- | 0.00 |
| Fixed | Postural control-ML | | | 0.56- | 0.15 | 0.02 | 0.85- | 0.27- | 3.77- | 0.00 |
| Random | Postural control-ML | | | 0.61- | 0.27 | 0.07 | 1.14- | -0.08 | 2.28- | 0.02 |
| | Postural control-SLS-S | Tsai et al-3 | Postural control-SLS-S | 0.24 | 0.36 | 0.13 | 0.46- | 0.94 | 0.68 | 0.49 |
| Fixed | Postural control-SLS-S | | | 0.24 | 0.36 | 0.13 | 0.46- | 0.94 | 0.68 | 0.49 |
| Random | Postural control-SLS-S | | | 0.24 | 0.36 | 0.13 | 0.46- | 0.94 | 0.68 | 0.49 |
| Fixed | Overall | | | 0.49- | 0.07 | 0.00 | 0.63- | 0.35- | 6.97- | 0.00 |
| Random | Overall | | | 0.47- | 0.13 | 0.02 | 0.72- | 0.23- | 3.80- | 0.00 |

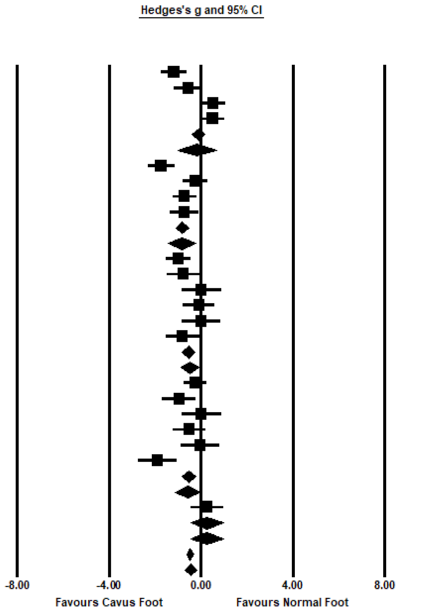


**Figure 3.** Results of meta-analysis of high-arch foot people compared to normal people

Abbreviations: AP: Anterior-posterior; ML: Medial-lateral; SLS-S: Single-leg standing (seconds); 95% CI: 95% confidence interval.

| Model | Group by Outcome | Study name | Outcome | Hedges's g | Standard error | Variance | Lower limit | Upper limit | Z-Value | p-Value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Statistics for each study | | | | | | |
| | Danamic balance | Fattahi et al-1 | Danamic balance | 0.00 | 0.33 | 0.11 | 0.65- | 0.66 | 0.01 | 0.99 |
| | Danamic balance | Panahi et al-3 | Danamic balance | 0.36 | 0.26 | 0.07 | 0.15- | 0.86 | 1.40 | 0.16 |
| | Danamic balance | Khodaveici et al | Danamic balance | 0.48- | 0.31 | 0.10 | 1.09- | 0.14 | 1.52- | 0.13 |
| | Danamic balance | Kazemi et al | Danamic balance | 0.44 | 0.28 | 0.08 | 0.10- | 0.98 | 1.60 | 0.11 |
| | Danamic balance | Ashkezari et al-1 | Danamic balance | 0.09 | 0.25 | 0.07 | 0.41- | 0.59 | 0.36 | 0.72 |
| Fixed | Danamic balance | | | 0.12 | 0.13 | 0.02 | 0.12- | 0.37 | 0.99 | 0.32 |
| Random | Danamic balance | | | 0.11 | 0.16 | 0.02 | 0.19- | 0.42 | 0.72 | 0.47 |
| | Postural control | Fattahi et al-2 | Postural control | 0.22- | 0.34 | 0.11 | 0.88- | 0.43 | 0.67- | 0.50 |
| | Postural control | Panahi et al-4 | Postural control | 2.26- | 0.33 | 0.11 | 2.90- | 1.62- | 6.89- | 0.00 |
| | Postural control | Ashkezari et al-2 | Postural control | -0.09 | 0.25 | 0.07 | 0.59- | 0.41 | 0.37- | 0.71 |
| | Postural control | Hertel et al | Postural control | 0.52- | 0.33 | 0.11 | 1.17- | 0.12 | 1.60- | 0.11 |
| Fixed | Postural control | | | 0.69- | 0.15 | 0.02 | 0.98- | 0.39- | 4.48- | 0.00 |
| Random | Postural control | | | 0.77- | 0.49 | 0.24 | 1.74- | 0.20 | 1.56- | 0.12 |
| | Postural control-AP | Ghaderian et al-1 | Postural control-AP | 0.45- | 0.26 | 0.07 | 0.96- | 0.05 | 1.75- | 0.08 |
| | Postural control-AP | Koshino et al-1 | Postural control-AP | 1.14- | 0.50 | 0.25 | 2.12- | 0.16- | 2.27- | 0.02 |
| | Postural control-AP | Ghasemi et al-1 | Postural control-AP | 0.70- | 0.37 | 0.13 | 1.42- | 0.02 | 1.91- | 0.06 |
| | Postural control-AP | Bazvand et al-1 | Postural control-AP | 3.46- | 0.69 | 0.48 | 4.82- | 2.09- | 4.98- | 0.00 |
| | Postural control-AP | Tsai et al-1 | Postural control-AP | 0.16- | 0.36 | 0.13 | 0.86- | 0.53 | 0.46- | 0.65 |
| Fixed | Postural control-AP | | | 0.69- | 0.17 | 0.03 | 1.01- | 0.36- | 4.14- | 0.00 |
| Random | Postural control-AP | | | 1.01- | 0.40 | 0.16 | 1.78- | 0.23- | 2.54- | 0.01 |
| | Postural control-ML | Ghaderian et al-2 | Postural control-ML | 0.43- | 0.26 | 0.07 | 0.93- | 0.08 | 1.66- | 0.10 |
| | Postural control-ML | Koshino et al-2 | Postural control-ML | 1.13- | 0.50 | 0.25 | 2.11- | 0.15- | 2.26- | 0.02 |
| | Postural control-ML | Ghasemi et al-2 | Postural control-ML | 0.27- | 0.36 | 0.13 | 0.97- | 0.43 | 0.74- | 0.46 |
| | Postural control-ML | Bazvand et al-2 | Postural control-ML | 2.25- | 0.56 | 0.31 | 3.34- | 1.16- | 4.04- | 0.00 |
| | Postural control-ML | Tsai et al-2 | Postural control-ML | 0.67- | 0.37 | 0.13 | 1.38- | 0.05 | 1.82- | 0.07 |
| Fixed | Postural control-ML | | | 0.67- | 0.16 | 0.03 | 0.99- | 0.35- | 4.12- | 0.00 |
| Random | Postural control-ML | | | 0.83- | 0.29 | 0.08 | 1.39- | 0.26- | 2.87- | 0.00 |
| | Postural control-SLS-S | Tsai et al-3 | Postural control-SLS-S | 1.21 | 0.39 | 0.15 | 0.45 | 1.97 | 3.12 | 0.00 |
| Fixed | Postural control-SLS-S | | | 1.21 | 0.39 | 0.15 | 0.45 | 1.97 | 3.12 | 0.00 |
| Random | Postural control-SLS-S | | | 1.21 | 0.39 | 0.15 | 0.45 | 1.97 | 3.12 | 0.00 |
| Fixed | Overall | | | 0.34- | 0.07 | 0.01 | 0.49- | 0.20- | 4.67- | 0.00 |
| Random | Overall | | | 0.10- | 0.12 | 0.01 | 0.33- | 0.14 | 0.82- | 0.41 |

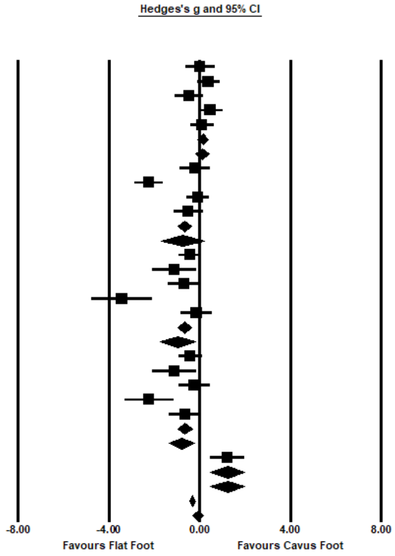


**Figure 4.** Comparison of meta-analysis of high-arch and flat-foot people

JMR

Abbreviations: AP: Anterior-posterior; ML: Medial-lateral; SLS-S: Single-leg standing (seconds); 95% CI: 95% confidence interval.

## Postural control and dynamic balance in high-arch foot and normal people

The results of the dynamic and static tests revealed that high-arch foot people had a weaker static balance compared to normal people, even though no difference was observed between them in terms of dynamic balance. Studies on postural control reported that the center of pressure in postural control tests on force plates in high-arch foot people was on the outer side of the foot, indicating that these people experience a higher level of pressure on the outer inner side of the foot. This may lead to athletic injuries and dysfunctionality in routine activities, and cause postural abnormalities as well as orthopedic disorders in the long term. The indifference to the results of the dynamic balance test in these people is likely because most of the studies used the Y test as a measure for this purpose; however, this needs further research. It is highly suggested that this deformity be treated to avoid further postural control disorders and other future complexities.

The high-arch foot is limited by physiological restrictions in the range of motion of the subtalar and mid-tarsal joint, and there is no support mechanism between the inside of the foot sole and the postural control measuring device [19]. The feedback of sensory information during joint movements depends on the sensory information of the joint receptors (including ligaments and joint capsules) and various information received from the dermal receptors and the mechanical receptors of the muscles [27]. Therefore, a high-arch foot reduces the skin sensory information received from the structure of the sole, compared to normal people [44]. This is because there is a lesser area of the support surface in the high-arch foot concerning the ground or the postural control measuring device [40]. This leads to a weaker postural control mechanism in people with a high-arch foot structure.

## Postural control and dynamic balance in high-arch and flat-foot people

The results of the dynamic and static tests revealed no significant difference between the two groups. Similarly, there was no significant difference between them in terms of the total balance index. However, the results of the postural control of force plates showed that flat-foot people had a weaker balance compared to high-arch people. This is a reliable measure and the results are accurate. Studies also report that high-arch people slightly touch the force plate and maintain a more balanced state in a standing position. Thus, they experience a lesser displacement in the center of pressure, enabling them to have better postural control. Nevertheless, further studies are required to reach more accurate and certain results. Flat and high-arch foot deformities lead to postural control disorders and need to be catered for to be treated.

Since postural control is maintained within a closed movement chain and depends on the integrated feedback of the movements of the hip, knee, and ankle joints, any impairment in each of these segments or disruption in the mechanical power and strength of each of these joints causes impairment in sending afferent sensory information to the central nervous system, thereby impairing the postural control [45]. Hence, in the feet abnormalities, the segments and joints should receive attention plus neuromuscular coordination exercises. The latter part is important because, in addition to correcting the abnormalities, we could also observe improvement in postural control in these people. Exercise protocols aimed at correcting foot abnormalities cause the activation of motor neurons in a group of muscles and joints for performing an action and its adaptation to the environmental context [46]. Also, neuromuscular coordination exercises cause enhanced coordination and integration of motor units, co-contraction of agonist muscles, and increased inhibition of antagonist muscles. This eventually leads to improved neuromuscular responses and hence enhanced static and dynamic balance [47].

## 5. Conclusion

The results of our review paper reveal that flat and high-arch people have weaker postural control compared to normal people. They also show that flat-foot people had weaker postural control measured on force plates. However, no difference was observed between the two groups in terms of static and dynamic balance. There was also no difference in dynamic balance between normal people and subjects with flat foot and high-arch deformities. To achieve more accurate results, further studies are required.

## Ethical Considerations

### Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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### Authors' contributions

All authors equally contributed to preparing this article.

### Conflict of interest

The authors declared no conflict of interest.

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