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ORIGINAL ARTICLE

The Effect of Foot Postures and Biomechanical Parameters of the Foot-ankle Segment on Static Balance in Amateur Female Futsal Players

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ABSTRACT

Background. Balance is a critical component in athletic performance, particularly in sports like futsal, where rapid changes in direction and stability are essential. Foot posture and the biomechanical properties of the foot-ankle complex have been hypothesized to influence balance. However, the relationship between these factors and balance performance in amateur female futsal players remains unclear. **Objectives.** The study aimed to analyze the relationship between foot postures, foot-ankle biomechanical parameters (such as muscular strength, ankle range of motion, passive subtalar inversion-eversion range, calcaneal position), and static balance skills in 54 amateur female futsal players. **Methods.** Static balance was assessed using the Flamingo and Stork tests. Muscular strength of crural and femoral muscles was measured by ankle and knee flexion/extension maximal voluntary concentric contraction torque (MVCCT) at 60˚/s with an isokinetic dynamometer. No significant correlation was found between foot postures (asymptotic significance >0.05) and foot-ankle biomechanical properties with balance performance (Pearson correlation coefficients <0.5). **Results.** A moderate correlation existed between ankle plantar flexor strength and the Stork test (Spearman correlation coefficient =0.6). **Conclusion.** There was no significant relationship between foot-ankle biomechanical parameters and balance scores (Spearman correlation coefficients <0.5). The study concluded that foot type and biomechanical parameters do not correlate with balance performance, though muscle strength is emphasized in maintaining postural stability during the Stork test.

KEYWORDS: ***Postural Control, Foot Biomechanics, Athletic Performance, Balance.***

INTRODUCTION

Theoretical definition of the human balance is the ability of the body to maintain any postural position with as little effort as possible by keeping the gravity line, drawn perpendicular to the ground from the body's center of mass, within the support surface formed by the body's points of contact with the ground (1). The balance motor skill is classified into two main categories: static and dynamic balance. Static balance involves maintaining a specific postural position on a stable surface, while dynamic balance involves maintaining a specific one on a moving surface (2). The body utilizes three strategies while maintaining postural positions, including the ankle strategy, which involves ankle movements to keep the center of gravity on the support surface without being subjected to any postural destabilizing forces from outside the body (3). The two functional tests commonly used to assess this strategy are the Flamingo and Stork single-leg balance tests (4). These tests are utilized not only to evaluate the static balance proficiency of

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healthy individuals, which is a component of Physical fitness, but also to evaluate the recovery of athletes after sports injuries by improving weakened balance motor skills resulting from sports injuries (5, 6). In addition, athletes with weak balance scores, especially those who have experienced injuries in the foot-ankle segment, are more likely to encounter secondary injuries (7), and these tests are used to improve their balance skills in training (5, 8-10).

When discussing the biomechanical structure of the foot-ankle segment, various kinetic and kinematic data related to the foot-ankle segment, such as range of motion and muscle forces, are examined under this concept. In addition, foot posture, an outcome of the foot's biomechanical parameters, is also considered a biomechanical parameter (11). The foot posture, defined by the shape created when weight is applied to the foot, is primarily analyzed in three categories based on the relative line formed by the calcaneus, talus, navicular, medial, middle, and lateral cuneiforms and the medial three metatarsal bones known as the medial arch. The position of the navicular tuberosity, considered the apex of the medial arch, serves as the reference point for classifying foot posture. For example, in pes cavus, the medial arch does not change its shape when weight is applied to the foot, whereas in pes planus, this arch flattens towards the ground as if it has a highly flexible structure. In the pes rectus, the average flexibility of the medial arch demonstrates a moderate level compared to the pes cavus and planus. The foot with pes cavus posture is relatively rigid and transmits the ground forces passing through it directly to the upper segments without being affected by these forces.

In contrast, the foot with pes planus posture shows flexible behavior and absorbs some of the forces encountered by changing its shape (12, 13). Based on this information, it can be suggested that foot posture may particularly affect specific motor performances, such as explosive movement patterns or balance, especially in bipedal positions. For instance, during the push-up phase of jumping, the foot's medial arch elevates and stabilizes, providing a stable and rigid base for transmitting muscle forces through the ground. However, individuals with pes planus foot profiles may experience difficulty achieving the proper function of the medial arch, which can compromise stability and force transmission during activities such as the push-up phase of jumping (12). In addition, when considering postural control, mainly static postural control, a flexible and dynamic foot-ankle segment is more conducive to displaying reactive movements continuously undergoing dorsal and plantar flexion to maintain the gravitational line over the support surface (13). Given these principles of kinesiological understanding, it is reasonable to expect that foot-ankle biomechanics could influence balance skills, but this situation has sometimes resulted in favor of static balance skills (14-16), while in others, it has favored dynamic balance skills (17-19). However, unlike balance skills, certain studies suggest no significant relationship between explosive movement patterns and foot postures (20-22).

This study aimed to investigate the influence of the biomechanical properties of the foot-ankle segment on static postural stability. Specifically, it aimed to determine whether variations in foot postures, influenced by these biomechanical properties, impact an individual's ability to maintain balance in a static position. Additionally, an assessment was made of the potential contributions of other factors known to affect balance, such as the strength of the muscles in the lower leg (crural and femoral muscles), the range of motion in the ankle joint (dorsal-plantar flexion), passive subtalar inversion and eversion range of motions and resting calcaneal position instance, to better understand their interplay with foot biomechanics concerning postural stability.

The study's limitations include the exclusive focus on young female athletes, which may limit the generalizability of the results to other populations, such as males or non-athletes. Additionally, the study did not assess dynamic balance, which might have provided further insights into the relationship between foot posture and balance skills. Future research could explore these areas, including longitudinal studies, to observe how changes in foot posture over time might impact balance performance in different contexts.

MATERIALS AND METHODS

Participants. The study included 54 young amateur female futsal players from the Faculty of Sports Sciences at Düzce University. All participants were between 18 and 24 years old and had no history of lower extremity injuries. They were selected based on their active involvement in amateur futsal training and their ability to provide informed consent. The inclusion criteria ensured that participants were healthy, free from conditions that might affect balance or biomechanical measurements, and able to comply with the study's procedures. Participants were excluded if they had any previous lower extremity injuries, medical conditions that could impact balance or biomechanics, or could not adhere to the study protocols. The study was conducted before the start of the futsal season when players were in a less optimal physical state due to the off-season period. This timing was strategically chosen to minimize the effects of peak fitness on the study's outcomes and establish a baseline assessment before the competitive season. All participants provided informed consent following the Declaration of Helsinki, and the University Institutional Review Board approved the study.

Instruments. Anthropometric measurements, including height, weight, and age, were obtained using the Tanita SC-330 and Seca Stadiometer. The active range of motion of the talocrural joint and passive subtalar joint range of motion were measured on a patient table using a goniometer. The navicular drop test was conducted to classify foot posture, with measurements taken using a ruler. The Isomed 2000 device (D. and R. Ferstl GmbH, Hemau, Germany) was utilized to determine ankle and knee extension-flexion isokinetic peak momentum force. A stopwatch was employed for the Stork balance test, while a wooden stick with a height of 50 cm and widths of 3 cm and 5 cm was used for the Flamingo single-leg balance test.

A stepladder and goniometer were also used to measure the neutral stance calcaneal position. The participants were instructed on how the tests and measurements would be conducted and not to consume alcohol, engage in strenuous exercise within 24 hours, eat anything within 3 hours, or have a full bladder 30 minutes before testing. All tests were conducted in the Physical Therapy and Rehabilitation Unit of Düzce University Hospital on a single day and performed on both legs.

Navicular drop test. The navicular drop test classified foot types as pes cavus, pes rectus, and pes planus. Initially, participants were positioned on a patient table with their feet on a stepladder without placing weight on them (Figure 1-A). The subtalar joint neutral position was established by palpating the medial and lateral heads of the talus at an equal level. In this position, the vertical distance between the navicular tubercle and the ground was measured in millimeters using a ruler (Figure 1-B). Subsequently, participants were asked to stand on the stepladder with weight-bearing, and the distance between the ground and the navicular tubercle was measured again. The difference between the measurements taken in the weight-bearing and non-weight-bearing positions was recorded. After three measurements, the average distance was calculated and recorded as the test's result. Foot types were then classified based on these results: 4 mm and below were classified as pes planus, 5-8 mm as pes rectus, and 9 mm and above as pes cavus (23, 24).

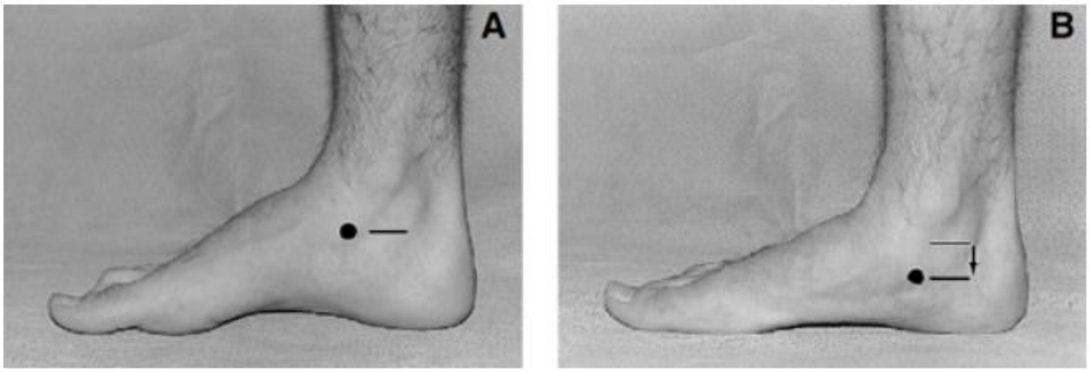

Figure 1. Measurement of navicular drop (25).

Ankle range of motion. The range of ankle dorsal-plantar flexion was measured by putting the goniometer's stationary arm on the fibula shaft's lateral surface, and the mobile arm was placed onto the lateral surface of the fifth metatarsal shaft (Figure 2). During the measurements, the participants were placed in a supine position. The knee was extended at 0 degrees extension, and care was taken to ensure that the participants did not move their knees during the measurement. They were instructed to push their foot down as much as possible for the plantar flexion and pull up for the dorsal flexion. After three measurements, average scores were recorded (16).

Passive subtalar inversion and eversion measurements. The passive subtalar inversion-eversion measurements of the right and left ankles were taken in the prone position on a patient table. The hips and knees were extended, with the feet hanging off the table's edge. Two lines were drawn, one bisecting the posterior surface of the lower leg and the other bisecting the posterior surface of the calcaneus. The stationary arm of the goniometer was aligned over the bisection line of the lower leg. The mobile arm of the goniometer was aligned over the bisection line of the calcaneus. The total subtalar range of motion was determined by passively moving the calcaneus to its end point of motion. Measurements were taken at the end range of the eversion (Figure 3-A) and inversion (Figure 3-B) motion using the goniometer (26).

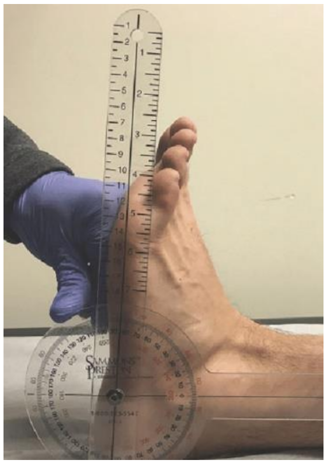

Figure 2. Method for measuring dorsal and plantar ankle range of motions (27).

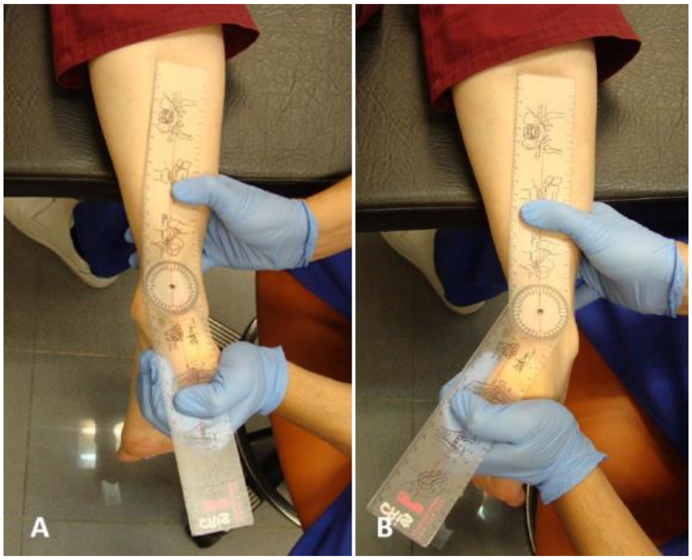

Figure 3. Passive subtalar eversion (A) and inversion (B) measurement (28).

Calcaneal position in resting stance. The participants were positioned prone on the patient table with their feet hanging off the edge to measure the calcaneal position in a resting stance. The medial and lateral borders of the calcaneus were palpated, and then a transverse line was drawn (Figure 4). Later, a perpendicular line was drawn to the line, bisecting the calcaneus in half. The participants were told to stand on a stepladder in a relaxed stance. The goniometer mobile arm was placed online with the transverse draw, and the stationary arm was placed parallel to the base of the stepladder in the frontal plane. After three measurements, average angle degrees were recorded, and measurements were repeated for the other extremity (29).

Figure 4. Calcaneal position in resting stance (28).

Stork balance test. Many balance assessment tests are used in studies, but for this research, the Stork and Flamingo static balance tests were selected to evaluate static postural stability due to their practicality and functional relevance. The participants were assessed under both open and closed-eye conditions. In the Stork balance test, the participants were positioned on an exercise mat after removing their shoes, with their hands on the hips. The non-supporting foot was placed against the inside knee of the supporting leg. The participants were given one minute to practice balance. They then raised the heel to balance on the ball of the foot, and the stopwatch was started as the heel lifted from the floor. The stopwatch was stopped if any of the following occurred: the hand (s) came off the hips, the supporting foot swiveled or moved in any direction, the non-supporting foot lost contact with the knee, or the heel of the supporting foot touched the floor (Figure 5). The total time in seconds was recorded, and the best time from three attempts was used for scoring. The scores were classified as follows: excellent (5 points) for times ranging above 50 seconds, good (4 points) for times ranging between 40-50 seconds, average (3 points) for times ranging between 25-39 seconds, weak (2 points) for times ranging between 10-24 seconds, and very weak (1 point) for times below 10 seconds (30).

Flamingo balance test. In the Flamingo balance test, participants stood on a beam without shoes and received assistance in maintaining balance by holding the instructor's hand. While balancing on their preferred leg, the free leg was flexed at the knee, bringing the foot close to the buttocks (Figure 5). The stopwatch was started as the instructor released the participant's hand, and timing continued until the person lost balance (either by falling off the beam or releasing the held foot). The number of falls or losses of balance within 60 seconds of balancing was recorded. If the number of falls exceeded 15 times within the first 30 seconds, the test was terminated, and a score of zero was given (4).

Maximum voluntary concentric contraction torque measurement. For knee measurements, the participants were seated on the seat of the Isomed 2000 with the hip joint at approximately 85 degrees (0 degrees representing full extension). The distal shin pad of the dynamometer was attached 2-3 cm proximal to the lateral malleolus using a strap, while the dynamometer leverage joint axis was aligned with the lateral femoral condyle (Figure 6). Participants were instructed not to flex their torso and to hold onto support arms placed at both edges of the seat. A strap was applied across the mid-thigh to minimize extraneous movements. Measurements were conducted at a 60-degree/second angular velocity, with a 30-second recovery time between trials. The range of motion for knee testing was between 10 degrees of extension and 90 degrees of flexion, starting in the 90-degree flexion position. Participants were seated supine on the device for ankle measurements, with unwanted lower extremity movements limited using a knee supporter. The participants received online visual feedback of the instantaneous dynamometer torque on a computer screen. Before trials, participants warmed up by cycling for 5 minutes on a fitness bike without resistance.

For maximum voluntary concentric contraction torque of ankle dorsal and plantar flexion, the device's seat was adjusted to a 30-degree flexed position to place participants in a semi-recumbent position. As with the knee measurements, the distal shin pad of the dynamometer was attached 2-3 cm proximal to the knee using a strap, and the dynamometer leverage joint axis was aligned with the lateral malleolus. A support was placed on the knee in a restrictive manner to prevent extraneous knee movements. Participants wore their sports shoes, which were tightly secured onto the footplate of the dynamometer leverage arm, with the leverage axis aligned with the lateral malleolus (Figure 6). Before the trial started, the ankle was positioned in a neutral position. The range of motion for ankle testing was between 12 degrees of dorsal flexion and 35 degrees of plantar flexion, beginning in the neutral position of the ankle. Each test for the knee and ankle involved ten repetitions to determine the maximum voluntary concentric contraction torque score (Willems et al., 2002); the values were divided by weight and multiplied by 100 to normalize the data of maximum torque (in Newton-meters) (31, 32).

Figure 5. Flamingo (A) and Stork (B) balance tests (33).

Data analysis. All statistical analyses were performed using IBM SPSS Statistics version 21. The impact of the foot postures on the static balance tests was analyzed using the Kruskal-Wallis H test. The Paired Simple T-Test was applied to compare the Flamingo scores between individuals with pes rectus and pes planus foot postures, as those with pes cavus foot posture could not achieve the desired scores in the Flamingo test. The Spearman correlation coefficient was applied for the correlation analysis between muscle strength and static balance scores. The Pearson correlation coefficient was applied for the correlation analysis between the biomechanical parameters of the right and left sides and balance test scores. A significance level of 0.05 was used for all analyses.

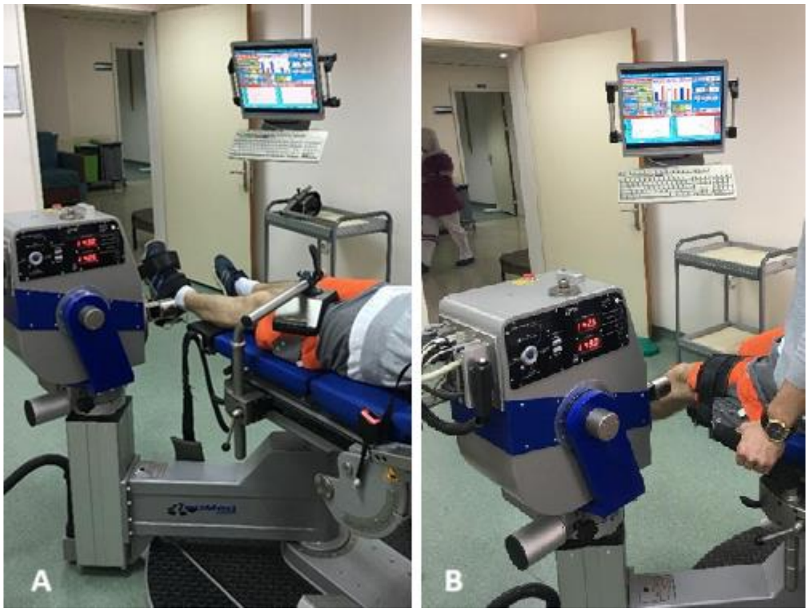

Figure 6. Maximum voluntary concentric contraction torque measurement (A. Ankle B. Knee).

RESULTS

The balance test scores conducted with eyes closed were consistently low during the study evaluation. Therefore, these scores were excluded from the analysis (Table 1; Table 2).

Tables 3 and 4 indicate that foot posture does not confer an advantage to participants with different foot postures in maintaining postural stability during both tests.

Table 1. Physical characteristics of the participants (n=54)

Age (year±sd)	min-max	Height (cm±sd)	min-max	Weight (kg±sd)	min-max
20.1±2.1	18-24	160.9±7.5	158-175	52.7±6.2	48-62

sd: Standard deviation.

Table 2. The mean range of motion for the foot-ankle segment's joint movements and the mean isokinetic force values for the knee and the ankle joint

Variables	Mean±sd
Right Passive Subtalar Inversion	32±9 º
Left Passive Subtalar Inversion	34±10 º
Right Passive Subtalar Eversion	9±7 º
Left Passive Subtalar Eversion	7±5 º
Right Calcaneal Position Resting in Standing	-2±6 º
Left Calcaneal Position Resting in Standing	-2±6 º
Right Knee Flexion IMVCC	173±34 Nm
Right Knee Extension IMVCC	296±70 Nm
Right Ankle Dorsal Flexion IMVCC	26±7 Nm
Right Ankle Plantar Flexion IMVCC	148±23 Nm
Left Knee Flexion IMVCC	135±30 Nm
Left Knee Extension IMVCC	214±49 Nm
Left Ankle Dorsal Flexion IMVCC	30±6 Nm
Left Ankle Plantar Flexion IMVCC	150±24 Nm
Right Ankle Dorsal Flexion ROM	10±5 º
Left Ankle Dorsal Flexion ROM	10±7 º
Right Ankle Plantar Flexion ROM	55±8 º
Left Ankle Plantar Flexion ROM	57±8 º

sd: Standard deviation; º: Degrees; Nm: Newton meter (torque value).

Table 3. Foot postures and balance scores of the right foot

Foot Postures	Right Flamingo (EO)	Left Stork (EO)
Pes cavus (n=9)	0	2.6±1.5
Pes rectus (n=20)	1.8±1.2	2.3±1.0
Pes planus (n=15)	1.2±1.3	1.6±0.5
p-value	*>0.05	#>0.05

*: Asympt sig <0.05 for Kruskal Wallis H Test, ± Standart deviation; #: Asympt sig <0.05 for Paired Samples T-Test, ± Standart deviation; EO: Eyes-open.

Table 4. Foot posture and balance scores of the left foot

Foot Postures	Right Flamingo (EO)	Left Stork (EO)
Pes cavus (n=10)	0	3.0±2.8
Pes rectus (n=19)	1.5±2.5	2.6±0.8
Pes planus (n=15)	3.1±5.8	2.1±1.4
p-value	*>0.05	#>0.05

*: Asympt sig <0.05 for Kruskal Wallis H Test, ± Standart deviation; #: Asympt sig <0.05 for Paired Samples T-Test, ± Standart deviation; EO: Eyes-open.

As observed in Tables 5 and 6, plantar muscle strength emerges as the primary factor for segmental stabilization of the foot-ankle segment in the Stork balance test. The Stork test was assumed to offer a distinct kinematic perspective where postural control necessitates plantar flexor muscle force for stability. Other muscular parameters are required to maintain the perpendicular projection of the gravity center on the support base with minimal effort.

Tables 7 and 8 demonstrate no correlation between the biomechanical parameters of the foot-ankle segment and the results of the balance tests.

Table 5. Right lower extremity isokinetic maximum voluntary concentric contraction torque (IMVCC) and balance correlation analyze

Variables	Right Flamingo (EO)		Right Stork (EO)	
	p	r	*p*	r
Right Knee Flexion IMVCC	*0.047*	0.3	*0.003*	0.3
Right Knee Extension IMVCC	*0.026*	0.2	*0.014*	0.4
Right Ankle Dorsal Flexion IMVCC	*0.026*	0.2	*0.001*	0.2
Right Ankle Plantar Flexion IMVCC	*0.883*	0.07	*0.018*	0.6

Numbers in Table 5 are Spearman correlation coefficients <0.5 confirmed no relationship; EO: Eyes-open.

Table 6. Left lower extremity isokinetic maximum voluntary concentric contraction torque (IMVCC) and balance correlation analyze

Variables	Left Flamingo (EO)		Left Stork (EO)	
	p	r	*p*	r
Left Knee Flexion IMVCC	*0.600*	-0.1	*0.302*	0.2
Left Knee Extension IMVCC	*0.413*	0.2	*0.500*	0.1
Left Ankle Dorsal Flexion IMVCC	*0.007*	0.3	*0.712*	-0.06
Left Ankle Plantar Flexion IMVCC	*0.402*	0.2	*0.001*	0.6

Numbers in Table 6 are Spearman correlation coefficients <0.5 confirmed no relationship; EO: Eyes-open.

Table 7. Biomechanical parameters of the right foot-ankle segment and balance correlation analyze

Variables	Right Flamingo (EO)		Right Stork (EO)	
	p	r	*p*	r
Right Passive Subtalar Inversion	*0.739*	0.04	*0.473*	-0.1
Right Passive Subtalar Eversion	*0.477*	-0.1	*0.770*	0.04
Right Ankle Dorsal Flexion ROM	*0.618*	-0.07	*0.473*	-0.1
Right Ankle Plantar Flexion ROM	*0.153*	-0.2	*0.131*	0.2
Right Calcaneal Position Resting in Standing	*0.001*	0.4	*0.557*	-0.08

Numbers in Table 7 are Spearman correlation coefficients <0.5 confirmed no relationship; EO: Eyes-open.

Table 8. Biomechanical parameters of the left foot-ankle segment and balance correlation analyze

Variables	Left Flamingo (EO)		Left Stork (EO)	
	p	r	*p*	r
Left Passive Subtalar Inversion	*0.737*	-0.05	*0.473*	0.1
Left Passive Subtalar Eversion	*0.473*	0.1	*0.657*	0.06
Left Ankle Dorsal Flexion ROM	*0.473*	-0.1	*0.023*	0.3
Left Ankle Plantar Flexion ROM	*0.770*	-0.04	*0.737*	-0.05
Left Calcaneal Position Resting in Standing	*0.023*	-0.3	*0.770*	0.04

Numbers in Table 8 are Spearman correlation coefficients <0.5 confirmed no relationship; EO: Eyes-open.

DISCUSSION

As observed in Table 1, the participants' overall physical characteristics appear to be relatively homogeneous. Additionally, the participant group's participation in amateur sports contributed to a more accurate evaluation of the study's outcomes. In such sports scientific studies, the high level of youthfulness and physical fitness among participants is believed to reduce the number of variables affecting the measurements and facilitate the interpretation of results. Evaluating the measurement data gathered in the study, the most notable finding in Tables 3 and 4 appears to be that participants with pes cavus foot profiles could not complete the Flamingo balance test. On the contrary, while no particular foot posture seems to have an advantageous effect on balance scores in the Stork balance test, the participants with pes cavus foot posture exhibited higher average scores than other foot postures. The pes cavus foot posture, resulting from increased tension in the plantar fascia, leads to a varus position of the calcaneus, making the foot more rigid. In this case, especially during weight center shifts while standing on one foot, the foot-ankle segment cannot increase or decrease the support surface to compensate for this change. Therefore, merely manipulating the center of gravity with minor muscle contractions may not be sufficient to maintain balance (34). The same foot posture turns into an advantage in the Stork balance test. Although this advantage may not create a significant difference among different foot postures, it is observed that having the intended plantar fascia tension in the Stork test position reflects on balance scores. Based on the data, it can be observed that foot posture does not significantly affect individuals' static single-leg balance performance in both the Flamingo and Stork balance tests. The Flamingo and Stork, static balance tests were selected because tests conducted on a single leg would more effectively assess individuals' balance performance, given that the test positions involve postural positions where ankle balance strategies are effectively utilized (35, 36). It appears that these two balance tests represent their unique postural positions. Both positions involve tests challenging neuromuscular coordination while standing on one leg (37).

When reviewing relevant studies, it becomes apparent that foot posture or type exerts a discernible influence on balance motor skills, particularly concerning dynamic balance. For instance, Tsai investigated a cohort ranging from 18 to 31 years old (19), finding that pes planus foot posture resulted in weak scores in a single-leg balance posture. Cote focused on participants aged 18 to 22 (16), and although there was no significant difference between pes planus and pes cavus, pes planus had higher scores than pes cavus in the Star excursion balance test (SEBT). Al Abdulwahab and Kachanathu studied participants aged 18 to 30 (14), and their research using computerized static balance tests revealed no significant difference between the foot posture groups. Cobb restricted their research to individuals aged 18 to 26 (15), and the study indicated that pes planus requires more effort for static balance. In Ghorbani's study, participants aged between 18 and 25 were enrolled, and the use of the Romberg test to assess individuals with pes planus and pes rectus foot postures showed that individuals with pes planus had better scores. However, it is essential to note that this study primarily measured body sway rather than balance (38).

When considering the influence of different age groups and the unique variables affecting them, conducting a comprehensive comparative analysis on foot posture and balance motor skills based on the literature is challenging and requires a thorough examination. Factors such as participants' demographic or physical characteristics, the variety of tests used, or the different methods employed to determine foot posture allow hypotheses related to the study subject to be continuously tested in various ways. This can make it challenging to arrive at a definitive conclusion that describes the relationship between these variables. In this study, it was observed that the foot posture did not significantly affect the balanced motor skills of participants who were young and physically fit compared to their peers. However, this result does not necessarily contradict existing literature. The fact that participants were physically fit may suggest that any accompanying disadvantages of foot posture could be compensated for with better neuromuscular effort. This implies an implicit compensation mechanism at play. In this context, it can be argued that mechanical disadvantages are potentially compensated for with better neuromuscular coordination. This raises questions about whether this compensation mechanism creates an extra energy burden for individuals.

It is known that muscle strength is essential for maintaining any postural position (22, 39, 40). During the design phase of the study, it was decided to measure the lower extremity muscle strengths of the individuals to distinguish whether any advantage provided by a foot profile in static balance was indeed due to foot biomechanics or if it was influenced by underlying muscle strength. Following the observation, there was no apparent effect of the foot biomechanical structure on static balance skill among the participants, but as observed in Tables 5 and 6, the muscular strength of dorsal flexors moderately affects the Stork balance skill. This finding originates from the postural position required by the Stork test. During the Flamingo balance test, participants do not maintain standard dorsal and plantar flexor muscle lengths in the test position. Typically, during this test, the plantar flexor muscles lengthen while the dorsal flexor muscles shorten to maintain ankle and knee stability for balance, responding by contracting reactively to changes in the center of gravity. However, in the Stork balance test position, participants engage in an isometric contraction of the plantar flexors, which suggests that individuals with stronger plantar flexor muscles or those with a segment that generates less effort to rotate the ankle in the plantar flexor direction are more likely to maintain the balance position for a longer duration. In their study, Ertuğrul and Özbar (41) found that the two tests did not equally represent static balance. Although both tests measure the ability to maintain a stable postural position, the requirements for neuromuscular coordination or muscle contraction strength in postural control differed. A correlation analysis between muscle strength and balance scores was added to enrich the study.

The relationship between muscle strength and balance motor skills may vary depending on participant profiles. For example, the loss of muscle strength experienced by elderly individuals with aging can increase the risk of falls (42, 43). However, as individuals age decrease, they are generally believed to have average muscle strength and more effective neuromuscular coordination on balance. However, this does not mean that balance skills are independent of muscle strength, primarily when evaluated from a balanced perspective. Static balance, in particular, appears to be an activity that requires less effort than dynamic balance, and as the intensity of the activity increases, muscle strength becomes a more effective variable (39, 44, 45). This study examines whether muscle strength directly influences balance. After the possible effect of foot posture, muscle strength behind foot postures has been evaluated. However, in both cases, it has been observed that static balance is not directly affected by either foot posture or muscle strength.

The contribution of visual input to balance performance is a significant factor, as previous studies have highlighted (46, 47). In the study, only a few participants could produce scores in the Flamingo test with their eyes closed; in the Stork test, all received weak and very weak scores. Therefore, these data were not included in the study's statistical analysis.

Following ankle injuries, limited range of motion can significantly contribute to balance deficits (48, 49). Interventions to improve restricted ankle movements have been found to enhance balance and range of motion (18, 50). Notably, in the study, none of the participants had a history of ankle injury or exhibited limited dorsiflexion within 45-90 degrees (51). Furthermore, the ankle dorsiflexion degrees among all participants were not restricted and followed a normal distribution, suggesting that ankle range of motion and balance scores were not correlated. It is theorized that passive subtalar range of motion (PSTROM) and calcaneal position in standing (CPIS) are related to foot posture (52, 53). Typically, these parameters are utilized for foot-type classification (54). Increased passive subtalar eversion and calcaneal eversion in standing can lead to a drop in the medial longitudinal arch, resulting in a flat foot. This alteration in foot structure may influence sensorimotor reactions in the ankle-foot segment (54). Therefore, PSTROM and CPIS were included in the study as independent parameters. No correlation or interaction was observed between the foot profile and static balance test scores, nor was any correlation found between the parameters underlying the foot profile and static balance test scores, including a joint range of motion in the study aimed to identify potential unforeseen outcomes contrary to the anticipated results that could lead to exploring a new research topic.

The study's limitations include the exclusive focus on young female athletes, which may limit the generalizability of the results to other populations, such as males or non-athletes. Additionally, the study did not assess dynamic balance, which might have provided further insights into the relationship between foot posture and balance skills. Future research could explore these areas, including longitudinal studies, to observe how changes in foot posture over time might impact balance performance in different contexts.

CONCLUSION

In conclusion, it can be suggested that specific biomechanical requirements are necessary for the stability of certain static postural positions. However, regarding foot posture, the observed outcomes diverge from theoretical approaches. This is primarily attributed to individuals compensating for the disadvantages associated with different foot postures through various kinematic strategies. It is suggested that more comprehensive studies be conducted to identify these strategies.

APPLICABLE REMARKS

- This study suggests that athletes with a pes cavus foot structure should focus on training programs that enhance their somatosensory system, which shapes motor control and visual systems.

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AUTHORS' CONTRIBUTIONS

Study concept and design: Ertuğrul Çakır. Acquisition of data: Ertuğrul Çakır. Analysis and interpretation of data: Ertuğrul Çakır. Drafting the manuscript: Ertuğrul Çakır. Critical revision of the manuscript for important intellectual content: Ertuğrul Çakır. Statistical analysis: Ertuğrul Çakır. Administrative, technical, and material support: Ertuğrul Çakır. Study supervision: Ertuğrul Çakır.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

The author(s) declare(s) that there are no financial interests or conflicts of interest related to the material in this manuscript.

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ETHICAL CONSIDERATION

Informed consent was obtained from each participant in this study. The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki, as reflected in the prior approval by the institution's human research committee (Ethics Committee Report Number: 2017-37, Düzce University).

ROLE OF THE SPONSOR

No sponsors or funding organizations were involved in the study's design and conduct, data collection, management, and analysis, or the manuscript's preparation, review, and approval.

ARTIFICIAL INTELLIGENCE (AI) USE

No AI or AI-assisted technologies were used in the writing process, data analysis, or the creation or alteration of images and figures in this manuscript.

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