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Original Article

Is there any weakness in sports performance in volleyball athletes regarding the correlation between foot posture index and lower limb functional hopping performance?

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Abstract

Objective: The aim of the study was to investigate the relationship between 1RM calf raise, countermovement jump (CMJ), and functional hop performance with foot posture index (FPI).

Methods: Twenty-six volleyball athletes were evaluated in this study. Foot posture index was evaluated with six-item criteria; talar head palpation, curves above and below the malleoli, calcaneus inversion/eversion, talonavicular congruence, medial longitudinal arch high, and forefoot abduction/adduction. Single hop, triple hop, crossover hop for distances, medial side triple hop, 90° medial rotation hop, single-leg vertical jump, 6m. timed hop, 1RM calf raise, and CMJ were measured in this study.

Results: All measurements were tested on both right and left side. Significant differences were found in single hop (p = 0.016), triple hop (p = 0.005), medial side triple hop (p = 0.001), medial rotation hop (p = 0.020) in single leg vertical jump, and FPI for right and left sides (p < 0.001, p < 0.005). There were significant differences when comparing the limb symmetry indexes (LSI%) calculated from hop tests. When the correlations between FPI and hop tests were found significant, correlation and no significant correlations were found between left side and FPI.

Conclusion: This study has shown that young female volleyball players may produce low hop performances due to the asymmetric structure relationship FPI scores.

Level of Evidence IV; Therapeutics Studies; Cases Series.

Keywords: Athletes; Foot; Exercise test; Posture; Volleyball.

Introduction

Many neuromuscular dysfunctions are characterized by muscle weakness; in some cases, weakness is symmetrical, others asymmetrical[1]. Specifically, lower limb muscle injury implicated feet with improper foot posture and muscle weakness, such as pes planus and pes cavus. Furthermore, a systematic review showed lower limb muscle pathologies had reported significant relationships between foot posture, medial tibial stress syndrome, patellofemoral joint pain, and patellar tendinopathy[2]. However, the lower limb muscle mechanism linking foot posture injury remains unclear on movement muscle dynamometry, including various hopping tests, jumps tests, and lower leg strength performance[3,4].

Lower limb strength training and heavy stress conditions can cause improper foot posture, plantar fasciitis pain, lowered medial longitudinal arch, and plantar region strain; it is lower limb muscle performance related to foot posture indexes (FPI) in all athletes[5,6]. Variable foot deviation and rotation on functional hopping performances may indicate strength losses and changes in foot posture accompanying both plantar fascia strain and ankle injury in both feet[3,4].

Study performed at the Ondokuz Mayıs University.

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Although the strength function of the lower limb helps absorb more foot force during the propulsion phases[6,7], the torque required for the subtalar joints depends on the medial longitudinal arch and dynamic plantar pressure postural control[8]. A study reported that foot posture is organized by the absorptive rotation of lower limb muscle performance for spring energy return in the foot in intrinsic plantar activation[9]. Indeed, active muscle-tendon resistance to the pressing workout of the lower limb muscle and absorbed muscle activity creates strain to flexion-extension workouts for foot postural gain[8]. Furthermore, functional hopping performance and lower limb strength activities are typically 45°/90°/140° knee-ankle longitudinal postural position, and plantar muscle activation in ankle flexion-extension generates strain from ground reaction force in, for example, single-leg hop test (SLHT)[4,10-12]. During SLHT performances, strength loads affecting a single lower leg may change foot pressure. Investigating the lower limb muscle performance in the athletic population may be essential for evaluating FPI during the ground reaction phases[13]. Therefore, functional ankle stability and intrinsic plantar strength may be related to FPI for performance differences[14,15]. One study Lopezosa-Reca et al.[3] reported basketball players and showed altered FPI. However, more foot supinated is associated with ankle-patella injury according to the player's position.

Foot posture index was produced in response to foot position variety and foot injury model of clinical settings and were created from six-item criteria for a quick, easy, and reliable method. Although evaluation of FPI for rehabilitation is common, it has not been associated with time to injury during athletic performances in athletes[3,16]. Current literature has reported FPI related to foot plantar muscle changes, injuries, and muscle-tendon strain in athletes[17,18]. However, previous studies have not focused on differences in foot posture for lower limb calf raise strength performance, jump tests, and functional hop performance during the stay until active contraction to maintain foot posture[16,17]. Foot posture index evaluation is internal validity and laboratory-based measurement in a standing position for lower limb performance applied in athletes[19]. Moreover, FPI includes multivariate performances in all workout stages within multiple techniques and references rearfoot and forefoot evaluation items[18,20]. This study reported the relationship between the lower limb muscle-tendon complex and functional performance on the FPI.

The main aim of this study was to reveal the correlations between foot pressure, strain, and intrinsic activations with functional hop performance, 1 RM calf raise, and CMJ in young volleyball players.

Our hypothesis is that multiple-direction leg mechanical workouts may show different postural deformity variability, i.e., pronation and supination weakness effects. Thus, FPI was investigated in the volleyball athlete's lower limb muscle mechanical workout variability, and foot deformities may be expected in the strength performing.

Methods

Subject

The study was obtained from Ondokuz Mayıs University Clinical Research Ethics Committee under the number 2022-69.

Twenty-six female volleyball athletes were recruited for this study, age 15.62 ± 1.18 years, height 172.34 ± 6.11 cm, and weight 62.19 ± 5.6 kg. In addition, calf raise 1RM 38.55 ± 9.15 kg and CMJ 23.07 ± 5.28 cm were measured for all athletes. The following inclusion criteria were at least three years of league experience. The exclusion criteria were serious femur, patella, knee, and ankle injuries within one week. The written consent form was signed by all athletes included in the study.

Experimental approach to the problem

This study reported the multivariate foot pressure or types for muscle-tendon strengthening and postural foot deformities[21]. Foot posture indexes such as pressure, strain, and deformity can occur during mechanical workouts of muscle weakness performances. In this direction, our research includes six functional hop performances; single hop (SH) and triple hop (TH), crossover hop (CH) for distance, medial side triple hop test (MSTH), 90° medial rotation hop (MRH), single leg vertical jump (SLVJ), 6m. timed hop (6mTH), countermovement jump (CMJ), and 1 RM calf raise were designed to examine the relationship within FPI criteria. The subjects visited the laboratory one time, including a 10-minute warm-up. The athlete's height, weight, and body mass index (BMI) were measured, and detailed information was given. The SLHT, FPI, CMJ, and 1 RM calf raise measurements were applied in sports training condition. Between the applications, the total training sections were performed in one hour, including all 26 female volleyball players.

Procedures

Foot posture index (FPI) measurement

The FPI is based on rearfoot and barefoot evaluation[22]. Previous studies showed an intraclass correlation coefficient (0.90–0.97) similar to other studies[21]. Foot posture index items were included in six criteria: 1) talar bone arch changes, 2) supra and infra lateral malleolus curvatures, 3) inversion and eversion position of in anterior plane of the heels, 4) talonavicular joint bulging, 5) medial arch longitudinal unity and 6) abduction and adduction of the forefoot on rearfoot. Foot posture index was resolved in the standing digital photography method in 50 cm. Between final scores -2 and +2 are within standard limitation. Supination predominance (+1 to +2) and pronation predominance (-1 to -2). The result scores were obtained in all categories. Results evaluated from supination or pronation difference angle of the longitudinal alignment leg in vertical are (+1) and (-1), standard deviation (+1), potential abnormal (+2), and other results are pathological[23] (Figure 1).

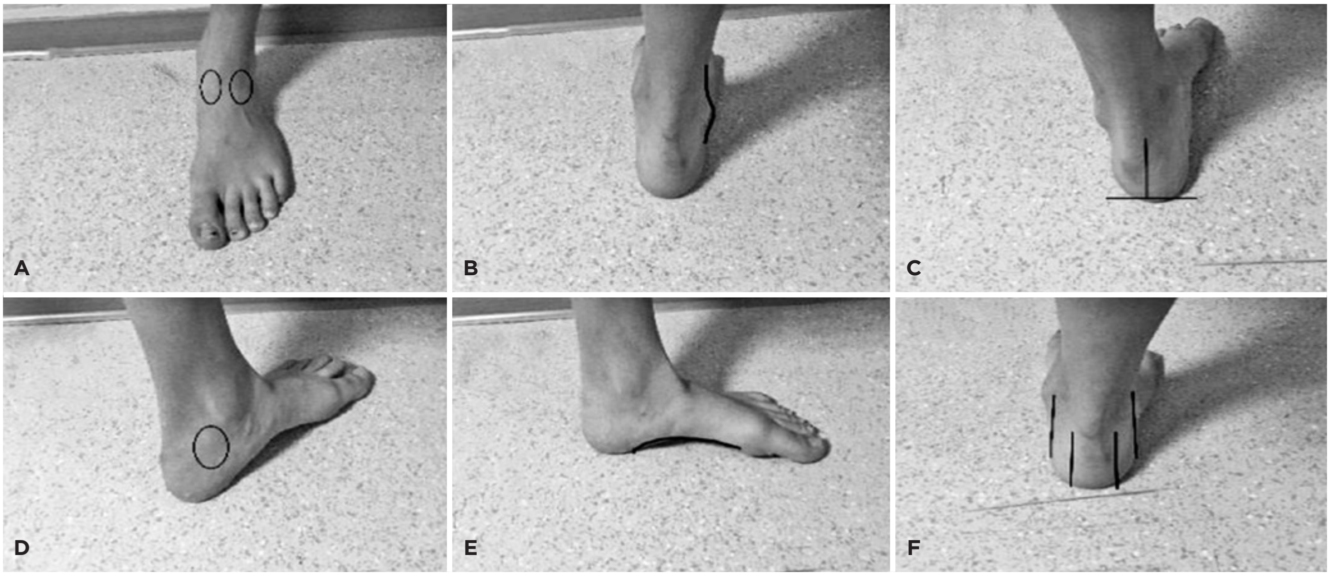

Figure 1. FPI six item criteria evaluations: A) Talar head palpation, B) Curves above and below the malleoli, C) Calcaneus inversion/eversion, D) Talanovicular congruence, E) Medial longitudinal arch high, F) Forefoot abduction/adduction.

1RM calf raise

Among the different lower limb calf muscle-tendon unit techniques, the calf raises muscle weakness strength test allows plantar flexors strength, strain, and pressure to increase muscle energy through absorption(24). Calf raise workouts were conducted on a seated ergometer against maximum strength between upward and downward techniques (ProWellness, LX-50A, TR). Posture techniques were adjusted from 90° knee postural position during strength repetition. All calf raise workouts were conducted 10 min warm-up, then 1RM was performed in three stages 50% of 1RM (1 and 2 rep), 80% of 1RM (1 and 3 rep), and 100% of 1RM (1 and 2 rep) with 10 s and 30 s of rest(25).

Single-leg vertical jump (SLVJ)

Dominant and non-dominant SLVJ performance is countermovement jump performance 180° evaluation of the unilateral lower extremity performance. Single-leg vertical jumps were performed with an infrared jumping device (Inf, SW03, Photocell Stopwatch, TR). The subject was asked to perform a single-leg right or left vertical countermovement jump from a stable upright position. The hip and knee of the nonincluded leg were kept at the mid-shaft height at a 90° flexion postural position. Arm swing was not limited during the jump(26).

Countermovement of jump (CMJ) without arm swing

The CMJ starts upright, performing the first downward movement by bending the knees and hands on the hips with the highest possible jump without the arms swinging. All subjects conducted 2-3 attempts on the jump measuring device and rested for 10 seconds between jumps (Inf, SW03, Photocell Stopwatch, TR). During the CMJ, the high was individual selection(27).

The functional hop performances

The starting line is a 0.3 m strip, and a 6 m long 15 cm wide strip was drawn perpendicularly from the middle of the two strips. The participants were informed how to perform the SH test. In the SH test, subjects started on one foot at the marked starting line and, when ready, jumped as far as participants could to land horizontally on the same leg. The successful attempt was detected between the resulting baseline and the participant's heel level and recorded in cm. In the TH test, they stood on one leg at the starting line and, when ready, jumped forward three times horizontally without stopping. The length between the starting line and the heel where they fell was recorded in cm. Before the tests, they were given three trials for each test. After the trials, they performed three main tests, and the successful performance in the test was determined to land on one leg with complete stability and stay for three seconds. Subjects rested for 30 seconds between trials. The use of arms movement during the test was allowed, and there were no restrictions(4). The subjects then stood on one leg at the starting line and finished in the fastest possible time the 6mTH performance started from the line and ended when the heel touched the first place where it crossed the finished line. All subjects were tested three times, and a 2 min rest interval was given for rest between each test. The test was recorded in seconds with a standard stopwatch. The best time from the three tests was recorded in seconds. The use of arms was allowed, and there were no restrictions[28]. The CH test was three forward jumps and the distance was recorded in cm. The first jump started diagonally opposite the foot used and continued laterally to the side of the fall. For each test, the subjects repeated three times. After the trials, there were three main tests. The successfull performance in the test was determined toland on the leg with complete stability and stay for three seconds. The best jump distance was recorded in cm. Subjects rested for 30 seconds between trials[29]. For the MHST test, the medial aspect of the participant's feet to be jumped was brought to a perpendicular position to the jumping direction. Participants were asked to perform three consecutive jumps on the same foot. The distance of three consecutive jumps was measured as the distance between the medial part of the foot in the starting position and the medial part of the foot in the finishing position[12]. The MRH test ensured that the medial side of the participant's feet to be jumped was perpendicular to the jumping direction. Participants were allowed to perform a perpendicular angle medial rotation with a single jump and complete the jump parallel to the jump direction. The foot's position at the start of the jump was maintained, and at the end of the jump, the foot's position was allowed to deviate by no more than 10° from the jump direction. Jumps other than these cases were considered invalid. Jumping distance was measured between the medial part of the foot in the starting position and the toes in the finishing position[12].

Statistical Analyses

All analyses were performed using SPSS 22.0 for Windows (SPSS Inc., Chicago, Illinois, US). Descriptive data were presented as mean, standard deviation, median, minimum, and maximum. The shapiro-Wilk test was used to evaluate normal distribution. The paired sample t-test was used to compare sets of dependent variables and evaluated differences from the lower limb symmetry index. The Spearman rank test was used for correlations between variables. A two-sided p-value less than $p < 0.05$ was considered statistically significant.

Results

Comparisons of the functional hop performance on the right and left sides are presented in Figure 2. Significances were found in SH ($p = 0.016$), TH ($p = 0.005$), MSTH ($p < 0.001$), and MRH ($p = 0.020$) on the right side, but no significance was found in the CH, SLVJ, and 6mTH tests ($p > 0.05$).

When the FPI scores on the right and left sides were evaluated statistically, significance was found in calcaneus inversion/eversion ($p = 0.040$), medial longitudinal arch high ($p < 0.001$), and forefoot abduction/adduction ($p < 0.001$), but no significance was found in talar head papation, curves above and below malleoli, talanovicular congruence, and total FPI scores ($p > 0.05$) (Figure 3).

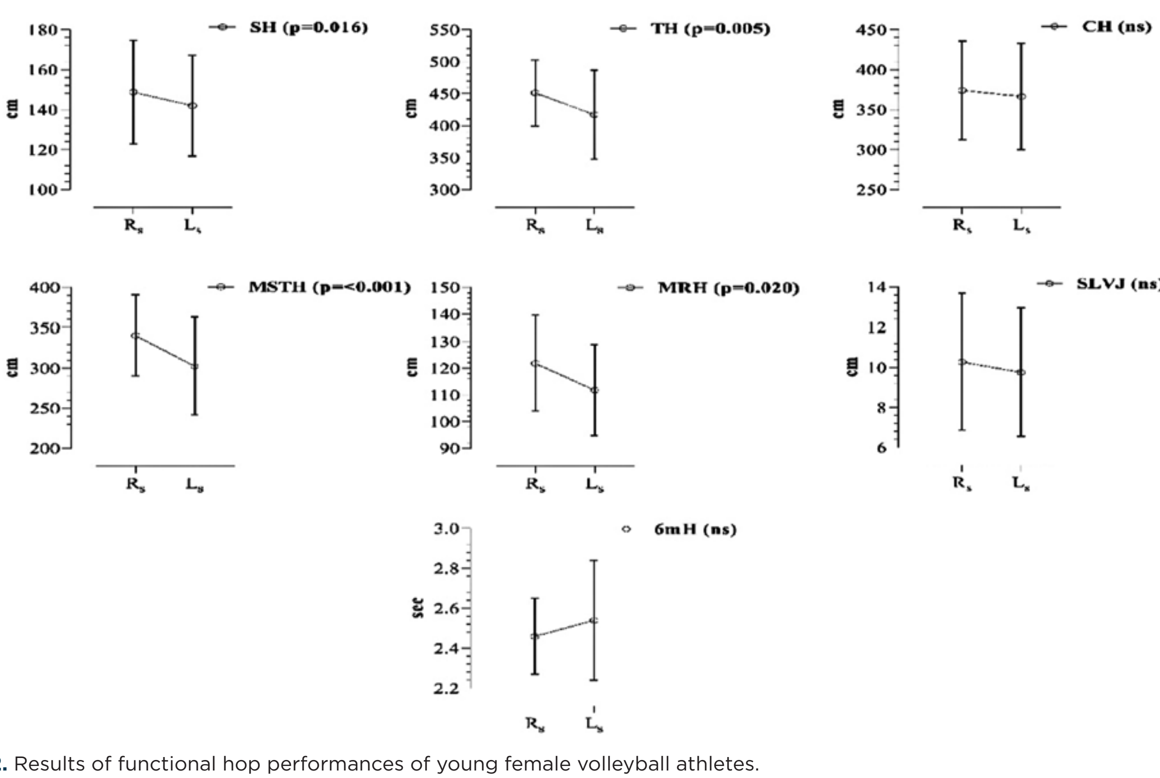

Figure 2. Results of functional hop performances of young female volleyball athletes.

Rs: Right-side; Ls: Left-side; SH: single-leg hop for distance; TH: triple leg hop for distance; CH: crossover leg hop for distance; MSTH: medial side triple hop test; MRH: 90° medial rotation test; SLVJ: single leg vertical jump; 6mH: 6 m. timed hop test.

The significant differences among the groups as LSI% and mean functional hop performances are SH 147 cm, TH 150 cm, CH 360 cm, MSTH 329 cm, MRH 170 cm, 6mTH 2.45 s, and SLVJ 10.5 cm (Figure 4).

When the LSI values from functional hop performance were compared, a statistically significant difference was found only between MSTH and 6mTH ($p < 0.05$). It is seen that other LSI ratios did not reveal a significant difference between each other ($p > 0.05$) (Table 1).

When the correlations between the scores from FPI and functional hop performance on the right side were evaluated, significant positive correlation relationships were found only at curves above and below the malleoli, SH ($r = 0.387$, $p = 0.038$), and MRD ($r = 0.372$, $p = 0.047$). No significance was found between the other parameters ($p > 0.05$) (Table 2).

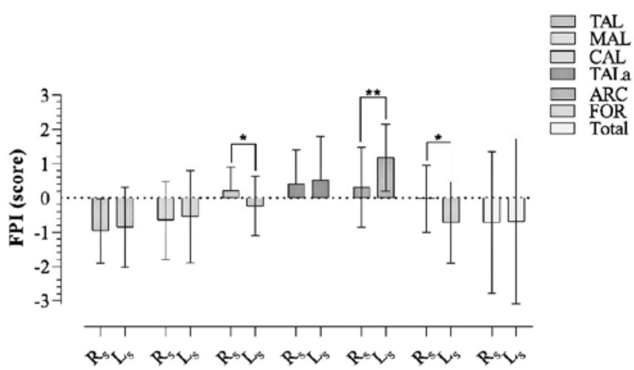

Figure 3. Results of foot posture index (FPI) of young female volleyball athletes.

TAL: Talar head palpation; MAL: Curves above and below the malleoli; CAL: Calcaneus inversion/eversion; TALa: Talanovicular congruence; ARC: Medial longitudinal arch high; FOR: Forefoot abduction/adduction; Total score of foot posture, *p < 0.05; **p < 0.01.

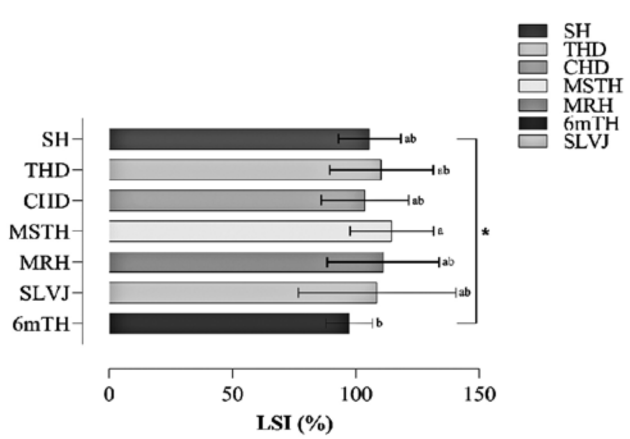

Figure 4. Results of limb symmetry index (LSI%) of young female volleyball athletes.

When the correlations between the scores obtained by the subjects from the results of FPI and functional hop performance on the Ls were evaluated. There were significant positive correlations were found between forefoot abduction/adduction, SLVJ ($r = 0.477$, $p = 0.009$), TH ($r = 0.450$, $p = 0.014$), MSTH ($r = 0.399$, $p = 0.032$), and MRH ($r = 0.407$, $p = 0.029$). No significance was found between the other parameters ($p > 0.05$) (Table 3).

Calf raise 1RM 38.55 ± 9.15 kg and CMJ 23.07 ± 5.28 were measured for volleyball players. The relationship between FPI total scores with 1 RM calf raise left foot ($r = -0.284$; $p = 0.136$), right foot ($r = -0.113$; $p = 0.558$), and CMJ parameters lef foot ($r = -0.147$; $p = 0.445$) and right foot ($r = 0.119$; $p = 0.538$) was evaluated by Pearson correlation. There were no significant correlations between 1 RM calf raise and CMJ parameters with FPI ($p > 0.05$).

Discussion

Performance evaluation of functional hop performance and countermovement jumps in lower limb muscle groups showed multidirectional different muscle-tendon dynamics and FPI criteria typically occurring on talar head position and talonavicular prominence, foot type of volleyball players predominance over others. Our results showed that SLHT performances with FPI scores associated with severe overuse injuries are inclined to occur in more pronated feet. In addition, calcaneus inversion/eversion, medial longitudinal arch high, and forefoot abduction/adduction indexes affected SLHT's results on the right and left side, but our total scores compared to runners, basketball, and handball players showed the most pronated predominance[21]. Thus, CMJ and 1RM calf raise performances caused increased arch highs because of functional hop performance with the medial plantar musculature under stress conditions and strain propulsion phases.

Lower limb strength-force on volleyball players, such as strain, determines muscle performance results during functional hop performance techniques, and absorbed reaction foot angles produce peak muscle force gain, preventing FPI injury risk formation[4,16]. One study found that sprinters have 26% normal foot posture, 34% pronated, and 40% highly pronated foot posture in the dominant foot[8]. Indeed, muscle strain weakness is usually symmetrical and asymmetrical in functional performance. Likewise, pronated feet displaying eversion or inversion are related to medial arch high postural control in all athletes[18]. In the study where the researchers examined the FPI total scores of swimmers and football players with at least ten years of training history, they reported that the swimmers were pathologic results, for example, 6.45 (high pronation) and the footballers were in the normal range.

Additionally, the mean difference between left foot and lower limb injury in the population was (-4.27), and the mean difference in right foot value of (-4.16)[16]. Another risk of injury in FPI resulted in 2.66 more supinated in all basketball athletes. However, center players had a 5.15 standard deviation

Table 1. Correlation between functional hop performance and foot posture indexes of young female volleyball players – right side

	SLVJ		SH		TH		CH		MSTH		MRH		6mTH	
	r	p	r	p	r	p	r	P	r	p	r	p	r	p
TAL	-0.079	0.685	0.049	0.802	-0.089	0.647	0.039	0.840	0.022	0.911	0.105	0.589	-0.247	0.196
MAL	-0.100	0.606	0.387	**0.038***	0.328	0.082	0.266	0.163	0.178	0.357	0.372	**0.047***	0.125	0.519
CAL	-0.198	0.302	-0.312	0.496	0.021	0.912	0.174	0.367	-0.082	0.673	0.008	0.967	-0.118	0.543
TALa	-0.278	0.144	-0.120	0.536	-0.357	0.058	0.104	0.591	0.113	0.560	-0.133	0.492	-0.033	0.864
ARC	0.270	0.156	-0.087	0.655	-0.210	0.275	-0.090	0.642	-0.088	0.650	-0.140	0.470	-0.238	0.214
FOR	0.097	0.618	-0.122	0.528	-0.134	0.489	0.076	0.696	-0.030	0.877	0.288	0.129	-0.273	0.151
$Total_R$	-0.050	0.795	0.057	0.767	-0.166	0.391	0.227	0.235	0.126	0.516	0.273	0.152	-0.247	0.196

*Spearman rank correlation $p < 0.05$.

Table 2. Correlation between functional hop performance and foot posture indexes of young female volleyball players – left side

	SLVJ		SH		TH		CH		MSTH		MRH		6mTH	
	r	p	r	p	r	p	r	P	r	p	r	p	r	p
TAL	-0.288	0.129	0.016	0.933	-0.328	0.083	-0.333	0.079	-0.143	0.460	-0.095	0.624	-0.200	0.298
MAL	0.095	0.625	0.138	**0.476**	0.253	0.185	0.186	0.334	0.003	0.989	0.240	0.210	-0.071	0.716
CAL	-0.289	0.128	0.155	0.423	0.372	0.154	0.154	0.425	0.169	0.380	0.211	0.271	-0.143	0.459
TALa	0.033	0.866	-0.213	0.267	-0.195	0.311	-0.174	0.367	-0.192	0.319	0.078	0.688	-0.220	0.251
ARC	0.180	**0.351**	-0.036	0.852	-0.137	0.476	-0.105	0.588	-0.218	0.256	-0.153	0.427	-0.029	0.251
FOR	0.477	**0.009****	0.243	0.203	0.450	**0.014***	0.169	0.382	0.399	**0.032***	0.407	**0.029***	0.276	0.147
$Total_L$	0.140	0.468	0.045	0.817	0.075	0.699	-0.142	0.464	-0.016	0.936	0.287	0.131	-0.123	0.525

**Spearman rank correlation $p < 0.05$.

Table 3. Correlation between 1 RM calf raise, CMJas, and foot posture indexes of young volleyball players

	$FPI\ Total_R$		$FPI\ Total_L$	
	r	p	r	p
Calf raise (1RM)	-0.284	0.136	-0.113	0.558
CMJ	-0.147	0.445	0.119	0.538

FPI: Total score of foot posture index; R: Right side; L: Left side; CMJ: Countermovement jump without arm swing; 1RM: one-repetition maximum.

that occurred muscle strain activity in different foot posture scores[3].

Normative mean values of FPI scores among adult volleyball athletes have accepted four values. In a study of volleyball players, one player supinated in lower limb posture, and four had highly pronated foot posture in medial arch morphologic[19]. Therefore, FPI values of special (-0.68) left foot, (-0.72) right foot postural pronated deformation of the forefoot, and rearfoot adduction/abduction specifical were obtained in their study. This shows that talus head position is related to biomechanical jump performances and asymmetries, as stated by the researchers[12,17]. In addition, comparing other sports branches, i.e., handball, runners, and basketball, showed that talar head, talonavicular predominance, and medial longitudinal arch congruence had different scores. This shows that FPI can explain the responses to supination postural control in functional hop performances and lower extremity strengths[21]. This may be due to the ground reaction force, solid muscle strength, plantar fascia loading, elastic energy storage predicting dynamic plantar pressure in knee and ankle inversion, supinated foot posture, and lower extremity overuse during multidirectional CH, MSTH, and MRH[28]. In forward or vertical hop performance tests such as SH, TH, and SLVJ, it may be due to the reaction force on the ground, supinated foot posture, and lower extremity overuse. In our study, the different correlations between FPI scores and functional hop performance suggest that they differ according to the conditions mentioned. Other studies and literature reported that the supinated foot is related to CMJ and SLVJ performance; all plantar symmetry and anterior muscle contraction parameters may not risk athletes. No injury has been implicated in excessively pronated feet as a risk factor, such as in our study.

Many FPI scores are characterized by muscle contraction and strengthening; specifically, lower limb muscle foot posture adds medial longitudinal arch highest. Furthermore, significant ecological values of medial-lateral muscle strength and weakness are linked to mechanical force performance. Additionally, hopping performance is still unclear in the training performances of volleyball athletes. In this condition, lower limb strength generally can cause stress conditions in abnormal FPI, plantar fasciitis, lower medial longitudinal arch, and plantar region strain obtained from CMJ and 1RM calf raise related to hop functional performance. Clinical deviations of foot rotation movement on foot functional performances may indicate strength unloading.

Moreover, the lower limb strength function helps absorb more distance hop performance during propulsion phases and more foot force during the propulsion phases; the unloading knee and ankle torque movement required for the subtalar joints depends on the medial longitudinal arch[7,8]. Therefore, our foot posture is crucial to lowering limb muscle performance rotation movements for energy formation in intrinsic muscle activation[9]. Indeed, pressing workouts of muscle activity occurred flexion-extension workouts for foot postural displacement are postural position and plantar muscle activation generated from leg strength as in 6mTH, CH, and MSTH[4,10,12]. The functional performance changes in foot pronation and supination length related to FPI for volleyball athletes and basketball players showed more foot supination and position differences[3]. FPI by strength coaches, therapists, and rehabilitation is commonly applied. However, sports performance examinations have not been applied to individual performance characteristics in the athlete population[16]. Common investigations have investigated FPI and limb strength hop performances in previously focused measurements on differences between active contraction and optimal performances[17].

Moreover, FPI should be examined in a standing position for other sports activities[19]. In addition, when the results of the studies are evaluated, it has been revealed that the FPI rates of the athletes may vary not only depending on the lower extremity strength and foot anatomy but also depending on the muscle volumes, activations, and rehabilitation processes after anterior cruciate ligament reconstruction (ACLR) and calf injuries. The fact that SLHTs reveal different activations in the lower extremity muscles in studies and that SLHTs applied in different directions after ACLR reveal different limb symmetry indexes supports this interpretation.

When our research results were evaluated with the literature findings, it was seen that some significant limitations of the current study emerged. Especially in our current study, FPIs and hops, CMJ, and 1 RM calf raise tests were performed without any kinematic analysis. Making kinematic evaluations in future studies to reveal more detailed findings is crucial. In addition, studies to evaluate the foot and lower extremity anatomy with radiological imaging will provide more apparent evidence for possible relationships. Also, the number of subjects could be higher.

Conclusions

This research has shown that young female volleyball players may produce low hop performances due to the asymmetric structure relationship FPI scores. Continuous follow-up is recommended, especially in volleyball players where jumping and hop performances in different directions are essential, to clarify these results and evaluate the possible negative results in hop performances due to foot posture of lower leg and extremity. This study also concluded that most supination predominance foot patterns to sport performance and lower limb functional hopping performance during sport activities, but further studies are required to encourange these findings.

Authors' contributions: The author contributed individually and significantly to the development of this article: YK *(https://orcid.org/0000-0001-5297-0445) Concept designer, data collection, analysis and interpretation, literature search, writing. The author read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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