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The Relationship Between Functional Hopping Performance and Foot Posture Index in Elite Female Handball Players

Elit Kadın Hentbolcularda Fonksiyonel Sıçrama Performansı ile Ayak Postür İndeksi Arasındaki İlişki

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ABSTRACT

The study aimed to determine the relationship between anatomical foot posture and functional jump performance in elite female handball players. The study was performed according to a randomized repeated measures crossover design. Twenty-nine volunteer elite female handball players (age 19.62 ± 1.18 years, height 174.31 ± 5.93 cm, weight 64.62 ± 5.08 kg, and BMI 21.29 ± 1.70 kg/m²) participated in the study. Single leg hop for distance (SH), triple leg hop for distance (TH), crossover leg hop for distance (CH), medial side triple hop (MSTH), 90° medial rotation hop (MRH), single leg vertical jump (SLVJ), and counter movement jump (CMJ) tests were performed to determine the functional jump performance of the subjects. In addition, the foot posture of the subjects was evaluated with the Foot Posture Index (FPI-6). The normality of the data was tested using the Shapiro-Wilk test, and it was found that they followed a normal distribution. Paired Samples T-Test and One-Way ANOVA test were used in the comparison analyses. The relationship between variables was evaluated using the Pearson Correlation test. Significant differences existed between the dominant (DS) and non-dominant (NDS) sides in SH, TH, MSTH, and MRH tests. No significant difference was found between jump test limb symmetry indexes (LSI). There was no significant difference between DS and NDS sides in FPI total scores, but significant relationships existed between some FPI-6 criteria and jump tests. Although the results showed that the subjects had differences in functional performance on the DS and NDS, the LSI values were within the safe range. In addition, it can be said that foot posture affects functional jump performance in elite-level female handball players.

Keywords: Foot posture, functional tests, handball

ÖZ

Çalışmanın amacı, elit kadın hentbolcularda anatomik ayak postürü ile fonksiyonel sıçrama performansı arasındaki ilişkiyi belirlemekti. Çalışma randomize tekrarlı ölçümler çapraz tasarımına göre gerçekleştirildi. Çalışmaya yirmi dokuz gönüllü elit kadın hentbol oyuncusu (yaş 19.62 ± 1.18 yıl, boy 174.31 ± 5.93 cm, ağırlık 64.62 ± 5.08 kg ve VKİ 21.29 ± 1.70 kg/m²) katıldı. Deneklerin fonksiyonel sıçrama performanslarını belirlemek için mesafe için tek bacak sıçrama (SH), mesafe için üçlü bacak sıçrama (TH), mesafe için çapraz bacak sıçrama (CH), medial yan üçlü sıçrama (MSTH), 90° medial rotasyon sıçrama (MRH), tek bacak dikey sıçrama (SLVJ) ve counter movement jump (CMJ) testleri uygulandı. Ayrıca, deneklerin ayak postürleri Ayak Postür İndeksi (FPI-6) ile değerlendirildi. Verilerin normalliği Shapiro-Wilk testi ile sınandı ve normal dağılım sergiledikleri görüldü. Karşılaştırma analizlerinde Paired Samples T-Testi ve One-Way ANOVA testi kullanıldı. Değişkenler arasındaki ilişki Pearson Korelasyon testi ile değerlendirildi. SH, TH, MSTH, MRH testlerinde dominant (DS) ve dominant olmayan (NDS) taraflar arasında anlamlı farklılıklar vardı. Sıçrama testlerinde uzuv simetri indeksleri (LSI) arasında anlamlı bir fark bulunmadı. FPI toplam puanlarında DS ve NDS tarafları arasında anlamlı bir fark yoktu, ancak bazı PFI-6 kriterleri ile atlama testleri arasında anlamlı ilişkiler vardı. Sonuçlar, deneklerin DS ve NDS'deki fonksiyonel performanslarında farklılıklar olduğunu gösterse de, LSI değerleri güvenli aralıktaydı. Ayrıca, elit seviye kadın hentbolcularda ayak duruşunun fonksiyonel sıçrama performansı üzerinde etkisi olduğu söylenebilir.

Anahtar Kelimeler: Ayak postürü, fonksiyonel testler, hentbol

Introduction

Handball is an Olympic sport that involves short-term and high-intensity actions such as sudden changes of position and direction, jumping, lateral sliding, throwing, and repeated sprints (Hermassi et al., 2018; Madruga-Parera et al., 2021). Handball players' optimal performance of specific actions, especially in the offensive direction, depends on the lower extremity strength and power potential (Zsakai et al., 2024). Therefore, symmetrical or asymmetrical weakness in lower extremity elements can lead to impaired kinematics, decreased performance, and disability problems. Because impairments in neuromuscular functions are often associated with symmetrical or asymmetrical muscle weakness, this causes some morphological changes and pathologies (Yang et al., 2022).

Lower extremity muscle strength and function are the most important success criteria for the athletic population (Cadens et al., 2023). Although there are many methods to assess these parameters, single leg hop tests (SLHT) and counter movement jump test (CMJ) are the most widely used (Drid et al., 2019). Whereas traditional methods include only straightforward movement patterns, SLHTs reveal functional strength in multidirectional movement patterns. Therefore, its ability to represent sportive movement patterns is high, and its results are more reliable (Dingenen et al., 2019). In addition, since SLHT detects asymmetric force conditions between extremities, it is very functional in rehabilitation and preventing injuries (Butler et al., 2024).

On the other hand, research shows that lower extremity pathologies are closely related to foot posture (Buldt et al., 2018). The foot posture index (FPI-6) classifies changes in foot shape as pes planus (pronation), pes rectus (neutral), or pes cavus (supination) (Lugade & Kaufman, 2014; Robb & Perry, 2024). The FPI-6 is widely used in clinical research because it has demonstrated strong reliability and validity in characterizing the relationship between static foot posture and dynamic lower leg movement (McLaughlin et al., 2016; Redmond et al., 2006). However, there are insufficient studies in the literature examining the relationship between foot postures and functional performance levels of athletes (Huang et al., 2019; Lopezosa-Reca et al., 2018). Therefore, the combined use of FPI-6, CMJ, and SLHT will be an important evaluation criterion to determine the relationship of functional performance with foot posture and the possible injury risks of athletes. The current study is critical in demonstrating the relationship between anatomical foot postures and functional jump performances of the handballers and filling this gap in the literature.

The study aimed to investigate the relationship between anatomical foot posture and functional jump performance in elite female handball players. We hypothesize that foot posture variability, such as pes planus or pes cavus, will be associated with lower extremity functional jump performance.

Methods

Participants

29 elite level female handball players (age= 19.62 ± 1.18 years; height= 174.31 ± 5.93 cm; weight= 64.62 ± 5.08 kg and body mass index= 21.29 ± 1.70 kg/m²) participated in the study. The inclusion criterion was that the participants had at least 4 years of league-level athlete history. In addition, the study did not include athletes with a history of lower extremity injury in the last 6 months.

Study Design

The study was conducted using a crossover experiment design with random repeated measurements. Subjects visited the laboratory 4 times at 24-hour intervals. During their first visit, the subjects were informed about the study and shown the measurements to be made. Participants who agreed to participate in the study signed an informed consent form. At the same time, height, weight, and BMI measurements were performed with the Gaia 359 Plus Bodypass analyzer (Jawon Medical Co., Ltd., Seoul, South Korea). In the other visits, Foot Posture Index analysis (FPI-6), six different Single Leg Hop Test (SLHT) and counter movement jump (CMJ) tests were performed according to the protocols. A 10-minute warm-up and 5-minute stretching exercises were performed before the measurements.

This study complied with the ethical principles stated in the Declaration of Helsinki (World Medical Association, 2013). Ethics committee approval was obtained from Ordu University Clinical Research Ethics Committee (Date: November 24, 2023, protocol no: 2023/311).

Evaluation Tools

Foot Posture Index (FPI-6)

FPI-6 measured participants' foot posture in multiple planes and anatomical segments (Redmond et al., 2006). Six criteria were used to evaluate FPI-6: talar bone arch changes, supra and infra lateral malleolus curvatures, inversion and eversion position of the heels in the anterior plane, talonavicular joint bulging, medial longitudinal arch structure, abduction and adduction of the forefoot on the rearfoot. Posture images obtained using digital photography were analyzed for each criterion as pronation dominance (+1 to +2) and supination dominance (-1 to -2) with a standard score range of -2 to +2. In the final evaluation of the scores obtained in the analysis, a score of 0 was considered neutral, positive values as pronation predominance, negative values as supination predominance, and results other than +2 to -2 were considered pathological.

Single Leg Hop Tests (SLHT)

SLHT was applied on a 0.3m wide and 30cm long starting strip drawn on a flat ground and a 15cm wide and 6m long strip extending vertically from the middle of it. A warm-up protocol was performed before the tests. Participants were subjected to three repeated main tests for each test, and their best jump distance was recorded. In the tests, the success criterion was determined as the participants remaining in complete stabilization on their landing legs for 3 seconds. Participants' arm and leg movements were not restricted during the test (Munro & Herrington, 2011; Peebles et al., 2019). In the Single leg hop for distance (SH) and Triple hop for distance (TH), subjects stood on one foot in the center of the starting baseline. Subjects jumped 1 step in SH and three consecutive steps in TH, landing on the same leg along the vertical line. In the Crossover hop for distance (CH), subjects stood on one foot in the center of the starting line and performed three jumps laterally in the landing directions by crossing the opposite of the first jumped foot. In the Medial side triple hop for distance (MSTH), subjects stood on one leg with the medial part of the foot at the baseline and performed three consecutive jumps in the medial direction. In the 90° medial rotation hop (MRH), subjects stood on one foot in the center of the starting line with the medial part of their foot on the starting line, performed right-angled medial rotation, and jumped on one leg. The distance between the subject's heel line and the starting point was measured and recorded in cm during successful repetitions in SLHTs (Dingenen et al., 2019; Munro & Herrington, 2011; Peebles et al., 2019).

Single Leg Vertical Jump (SLVJ)

The test was performed on a Sargent jump analyzer (HELMAS system, OnFit, Seoul, Korea). The subjects stood on one leg for a while in a deep squat and jumped vertically to reach maximum height. The test was repeated three times for both legs. The subjects' arm swinging was released during the test, and the highest jumps performed were recorded (Hopper et al., 2008).

Counter Movement Jump (CMJ)

The subjects were told to stand with their feet shoulder-width apart and hands on their hips. Subjects were instructed first to squat and then jump as high as possible. No arm swinging was allowed during the jump. The success criterion was determined as the subjects' ability to stay balanced on their legs for 3 seconds on landing. Subjects performed three repetitions with 15-second rest intervals on the measuring device (HELMAS, Onfit, Seoul, Korea), and the highest level was determined (Heishman et al., 2020).

Statistical Analysis

Data analyses were conducted using IBM SPSS Statistics version 22.0 (IBM SPSS Corp., Armonk, USA). We represented our data using means and standard deviations. We looked at histograms and conducted the Shapiro-Wilk test to check whether the data were normally distributed. A paired Sample T test was used for pairwise comparisons, and a One Way ANOVA test was used to compare three or more groups. The Pearson Correlation test evaluated the relationship between variables. All our statistical tests were two-tailed, and we set our threshold for statistical significance at $p<.05$.

Results

Table 1.
Descriptive data of subjects

	Min.	Max.	Mean	SD
Height (cm)	160.00	185.00	174.31	5.93
Weight (kg)	55.00	75.00	64.62	5.08
Age (year)	18.00	26.00	19.62	1.18
Training age (year)	4.00	8.00	6.29	1.10
BMI (kg/m^2)	18.12	25.21	21.29	1.70
DS_SLVJ (cm)	6.00	21.00	12.31	3.45
NDS_SLVJ (cm)	6.00	19.00	11.69	3.12
CMJ (cm)	14.00	42.00	25.66	5.27
DS_SH (cm)	119.00	260.00	151.41	26.07
NDS_SH (cm)	92.00	242.00	144.93	25.00
DS_TH (cm)	342.00	576.00	459.52	55.88
NSD_TH (cm)	283.00	606.00	431.59	67.13
DS_CH (cm)	249.00	484.00	378.10	61.67
NDS_CH (cm)	227.00	500.00	370.52	66.58
DS_MSTH (cm)	261.00	458.00	344.41	50.43
NDS_MSTH (cm)	199.00	475.00	306.62	60.58
DS_MRH (cm)	88.00	169.00	125.93	17.15
NDS_MRH (cm)	81.00	164.00	115.83	16.98
DS_FPI TOTAL	-4.00	4.00	-0.72	2.07
NDS_FPI TOTAL	-6.00	5.00	-0.69	2.41

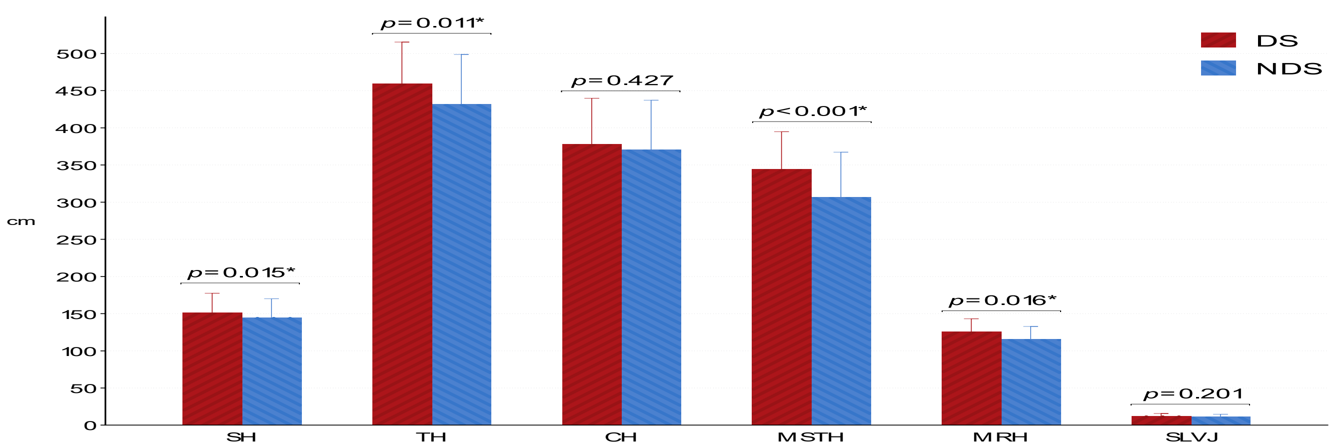
SH: single leg hop for distance; TH: triple leg hop for distance; CH: crossover leg hop for distance; MSTH: medial side triple hop test; MRH: 90° medial rotation test; SLVJ: single leg vertical jump; BMI: body mass index; CMJ: counter movement jump; FPI Total; foot posture index score (FPI-6); Min: minimum; Max: maximum; SD: standart deviation

Table 1 shows the subjects' demographic information, SLHTs, and FPI-6 scores on DS and NDS sides and CMJ values.

Figure 1 shows the comparison results of the subjects' DS and NDS functional performances. As a result of the comparison, it was found that there were significant differences between DS and NDS in favor of DS in SH (t=2.579; *p*=.015), TH (t=2.725; *p*=.011), MSTH (t=4.788; *p*=.000), and MRH (t=2.553; *p*=.016) tests. There was no significant difference between DS and NDS in SLVJ (t=1.308; *p*=.201) and CH (t=.806; *p*=.427) tests.

Figure 1.

Comparison of single-leg hop performances of the subjects (DS vs NDS)



SH: single leg hop for distance; TH: triple leg hop for dinstance; CH: crossover leg hop for distance; MSTH: medial side triple hop test; MRH: 90° medial rotation test; SLVJ: single leg vertical jump; *$p<.05$

Table 2.
Comparison of LSIs revealed by subjects in SLHTs

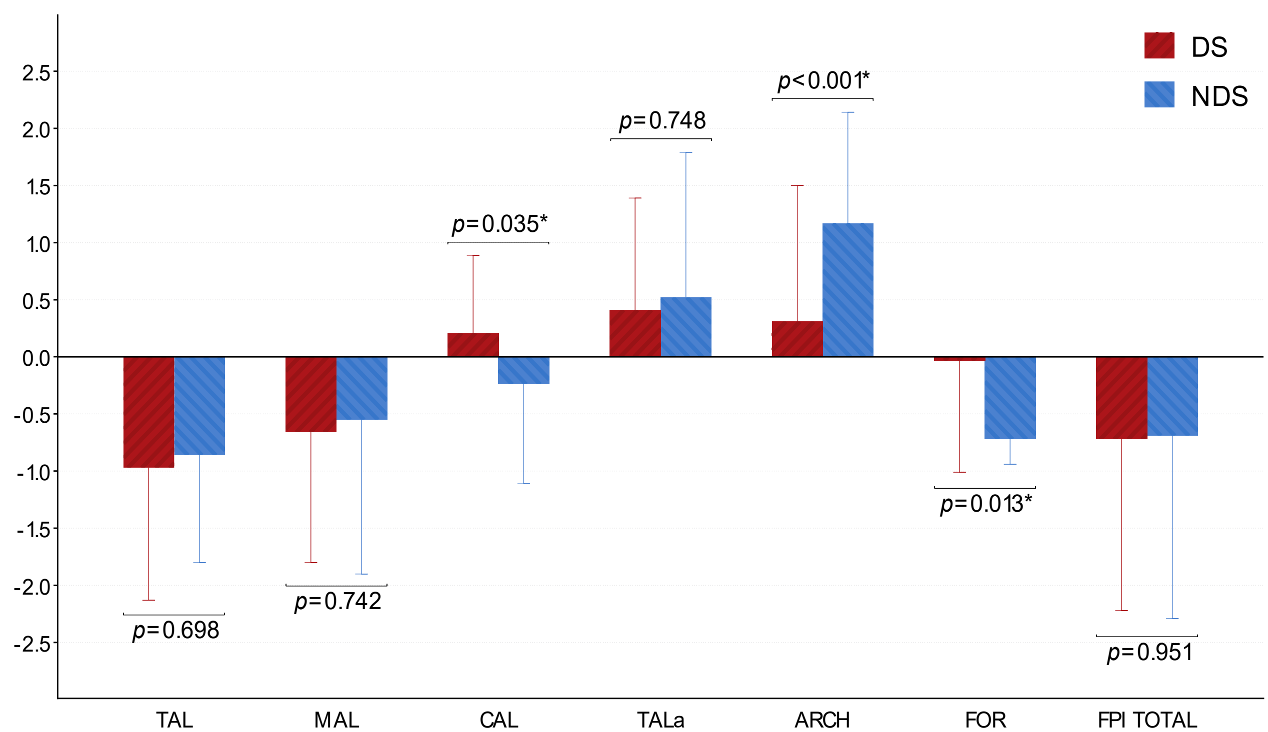
	Mean ± SD (%)	%95 CI		F	*p*
		LB	UB		
SH	96.1 ± 9.4	64.79	110.92	1.320	.258
TH	94.21 ± 10.97	56.83	117.33		
CH	98.92 ± 15.57	59.42	140.56		
MSTH	90.12 ± 12.29	64.69	113.03		
MRH	93.43 ± 17.39	60.45	142.05		
SLVJ	97.47 ± 20.15	57.14	145.45		

SD: standart deviation; LB: lower bound; UB: upper bound; SH: single leg-hop for distance; TH: triple leg hop for dinstance; CH: crossover leg hop for distance; MSTH: medial side triple hop test; MRH: 90° medial rotation test; SLVJ: single leg vertical jump

Table 2 shows the asymmetry rates by comparing the strength values of the subjects on the dominant (DS) and non-dominant side (NDS) found by SLHTs. When the results are evaluated, there is no significant difference between the limb symmetry indexes (LSI=left limb distance/proper limb distance [%]) of the subjects in the functional performance tests (p>.05).

Figure 2 shows the comparison analysis of the subjects' DS and NDS foot posture indexes. As a result of the comparison, there were significant differences between the inversion and eversion position of in anterior plane of the heels (t=-2.218; p=.035), medial longitudinal arch structure (t=4.870; p=.000) and abduction and adduction of the forefoot on rearfoot (t=-2.669; p=.013) values, while no significant difference was found in the other values (p>.05).

Figure 2.
Comparison of foot posture indexes of the subjects (DS vs NDS)



TAL: talar bone arch changes; MAL: supra and infra lateral malleolus curvatures; Cal: inversion and eversion position of in anterior plane of the heels; TALa: talonavicular joint bulging; ARCH: medial longitudinal arch structure; FOR: abduction and adduction of the forefoot on rearfoot; FPI Total ; foot posture index score (FPI-6); *p<.05

Figure 3 shows the correlation analysis between DS functional performance test results and FPI-6 scores of the subjects. According to the analysis results, there was a moderate positive correlation between MRH and MAL (r=.380; *p*=.042). There was a moderate negative correlation between SLVJ and TALa (r=-.418; *p*=.024) and between TH and ARCH (r=-.371; *p*=.047). There was no significant relationship between the other values (*p*>.05).

Figure 3.

Correlation between participants' FPI-6 scores and SLHTs performance (DS)

	SH	TH	CH	MSTH	MRH	SLVJ
TAL	0.160	-0.233	0.038	-0.003	-0.022	-0.091
MAL	0.073	0.188	0.283	0.143	0.380 *	0.035
CAL	-0.117	0.164	0.186	-0.035	0.060	-0.136
TALa	-0.170	-0.360	0.107	0.097	-0.128	-0.418*
ARCH	-0.115	-0.371*	-0.119	-0.108	-0.181	0.303
FOR	-0.022	-0.023	0.008	0.014	0.155	0.045
FPI TOTAL	-0.080	-0.341	0.221	0.058	0.130	-0.072

* $p<0.05$ r= -1.0 -0.5 0 0.5 1.0

r= correlation coefficient

Figure 4 shows the correlation analysis between NDS functional performance test results and FPI-6 scores of the subjects. The results showed a moderate negative correlation between SH and TALa (r=-.401; *p*=.031) and between TH and ARCH (r=-.391; *p*=.036). In addition, there was a moderate negative correlation between the participants' FOR scores and MSTH (r=-.466; *p*=.011), MRH (r=-.415; *p*=.025), and SLVJ (r=-.533; *p*=.003). The other values had no significant relationship (*p*>.05).

Figure 4.

Correlation between participants' FPI-6 scores and SLHTs performance (NDS)

	SH	TH	CH	MSTH	MRH	SLVJ
TAL	-0.161	-0.209	-0.306	-0.070	-0.150	-0.285
MAL	0.035	0.056	0.133	-0.021	0.161	0.034
CAL	-0.163	0.238	0.183	0.137	0.243	-0.344
TALa	-0.401*	-0.094	-0.224	-0.152	0.046	0.105
ARCH	-0.065	-0.391*	-0.294	-0.294	-0.427	0.149
FOR	0.178	0.246	0.174	0.466*	0.415*	0.533*
FPI TOTAL	-0.267	-0.068	-0.156	0.036	0.165	0.137

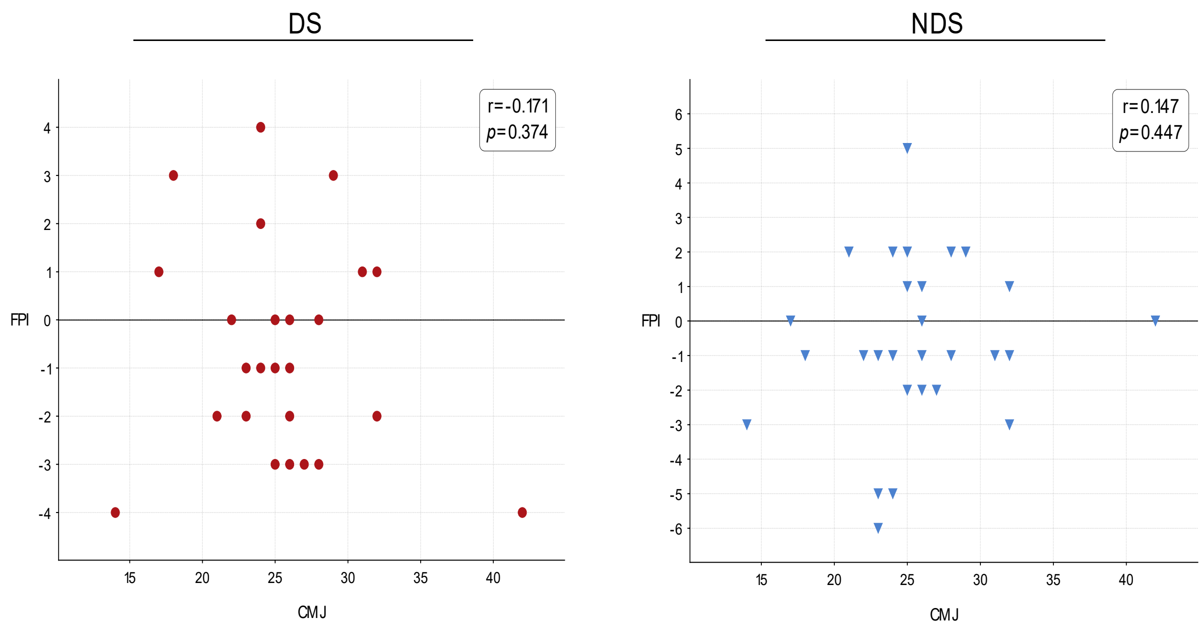
* $p<0.05$ r= -1.0 -0.5 0 0.5 1.0

r= correlation coefficient

Figure 5 shows the correlation analysis between participants' FPI-6 and CMJ performance. According to the results, no statistically significant relationship was found (*p*>.05).

Figure 5.

Correlation between participants' FPI-6 and CMJ performance



CMJ; counter movement jump; FPI: foot posture index (FPI-6); DS: dominant side; NDS: non-dominant side

Discussion

The study aimed to determine the relationship between anatomical foot posture and functional jump performance in elite female handball players. Several significant findings were identified in the present study. The results showed significant differences between the DS and NDS sides in the SH, THD, MSTH, and MRH tests in favor of the DS side, while there were no significant differences in the other SLHTs. However, the LSIs between the lower limbs of the subjects were found to be within normal ranges (LSI>% 90%), and the athletes were not at risk of injury under normal conditions. On the other hand, there were no significant deformation differences between the DS and NDS in the FPI total scores of the subjects, but there was a supination foot dominance. In addition, when the relationship between the SLHT performance of the athletes and the six criteria of FPI-6 values was examined, it was found that there were significant positive (MRH and MAL on DS) and negative correlations (TH and ARCH, SLVJ and TALa on DS; SH and TALa, TH and ARCH, FOR and MSTH, MRH, SLVJ on NDS), but there was no significant correlation between CMJ scores and FPI-6.

SLHTs permit a realistic assessment of the results between the lower limbs because they are similar to the movement patterns practiced during exercise regarding muscle activation and functionality (Di Paolo et al., 2022; Hopper et al., 2008). In addition, these tests have verified validity and reliability, such as computer-based tests (Measson et al., 2022; Munro & Herrington, 2011). Many studies with lower extremity performance tests in athletic populations have demonstrated superiority of the DS side over the NDS side, similar to the present study (Dauty et al., 2020; Yılmaz et al., 2020). This result can be explained by the participants' morphological characteristics (body height and body mass), genetic predispositions, and the effect of training processes. In addition, these differences not only occur in the forward SLHTs (such as SH and TH) but also in the medial SLHTs (such as MRH and MSTH). This result is critical as it provides information about the athletes' knee strength and hip abductor and rotator muscles. Because it has been reported that medial SLHTs activate the hip abductor and rotator muscles, and these muscles contribute more to knee power generation than forward SLHTs (Yılmaz et al., 2020).

On the other hand, handball players' extremities on both sides must be equally competent to improve their on-court performance (Jones & Bampouras, 2010) because team handball involves short-duration and high-intensity specific actions (such as jumping, acceleration, and deceleration) in offense and defense. This makes it imperative that the NDS extremities of athletes produce at least as much force and power as the DS sides.

This study's average LSI rate from six SLHTs was 95.04%. Similarly, studies on healthy subjects or athletes have reported rates between 90% and 100% (Madsen et al., 2020; Munro & Herrington, 2011). Although bilateral strength differences were detected in the present study, LSIs were within the normal range. This showed that the subjects were not likely to be disabled under normal conditions. In a study that used forward and medial tests on healthy athletes, the mean LSI was 100.65%, which is similar to our results (Dingenen et al., 2019). In addition, although multidisciplinary studies on healthy athletes showed bilateral asymmetric strength in the lower extremities, mean LSI values were within normal ranges (Carrasco-Fernández et al., 2023).

On the other hand, some studies on elite and healthy athletes have found that asymmetry indices are outside safe limits (Drid et al., 2019; Ermiş et al., 2019). However, the researchers emphasized that the factor that affected this result was unclear, but it could be due to branch-specific conditions such as training effects and specific actions. However, another study emphasized that if LSI values are outside the safe range between the two limbs, the athletes cannot perform their sports without eliminating the factors that cause it (Skandalis et al., 2020).

The FPI total scores obtained in the current study showed a similar mean score of -0.72 (SD=2.07) on the DS side and -0.69 (SD=2.41) on the NDS side. This result also showed supination dominance in both feet. Similarly, Martínez-Nova et al. (2014) examined the foot postures of handball players and found that the players had supination foot dominance (-0.4 ± 6.9). This is an important risk factor for injury. Because the most common lower extremity injuries in the athletic population are lateral ankle sprain and patellar tendinopathy, which is associated with supine feet (Lopezosa-Reca et al., 2020), this is also very important in terms of performance parameters. The results in the current study showed negative correlations between TALa , ARCH, and FOR criteria and SLHTs. This showed that morphologic structure disorders in the foot postures of handball players negatively affected functional performance. Researchers have argued that supination foot dominance reduces concentric plantar flexion strength (Huang et al., 2019; Kataria et al., 2020). Of course, there are also studies in the literature that contradict the results of the current study. For example, a similar study was conducted on volleyball players, and it was found that the athletes had pronation foot dominance (Kahraman, 2023). This result showed that repetitive movements specific to different sports can lead to different morphological disorders in players' feet due to stress associated with overuse.

On the other hand, the results of the present study showed that there were significant differences between DS and NDS feet in CAL, ARCH, and FOR criteria of FPI-6. The jump shots, which are used extensively in handball, are mostly made with the NDS side (Belcic et al., 2023). Therefore, there may be more deformation in the NDS foot than in the DS side due to the high level of pressure with overuse. The fact that the foot on the NDS side shows a higher deformation level than the other foot in the analysis results supports this interpretation.

The present study had no significant relationship between the subjects' DS and NDS FPI total scores and CMJ performance. This suggests that the relationship between foot postures and the bipedal jump performance of handball players is unclear. Although some studies accept the relationship between foot posture and lower extremity injuries, they argue that the relationship with muscle activations in bipedal jump tests remains unclear (Aggarwal et al., 2020; Lopezosa-Reca et al., 2018).

When the results obtained in the study are compared with the literature, it is seen that our study has some limitations. For example, we only focused on the foot in lower limb deformation. However, deformities in the metaphyseal and epiphyseal regions of the tibia are associated with the knee proximally and the ankle distally. Therefore, the study can be extended to include tibial deformations.

Conclusion and Recommendation

The results of the present study showed that morphologic abnormalities in the foot posture of elite female handball players may lead to poor functional performance. In addition, although there was asymmetrical strength development between the lower extremities of the athletes, this asymmetry was found to be within a safe range. Finally, it is recommended to regularly evaluate all postural structures that may be hurt by short-term and high-intensity actions (such as jumping), which are very important in handball.

Etik Komite Onayı: Bu çalışma için etik komite onayı Ordu Üniversitesi'nden (Tarih: 24 Kasım 2023, Karar No: 311) alınmıştır.
Hasta Onamı: Çalışmaya katılan tüm katılımcılardan yazılı onam alınmıştır.
Hakem Değerlendirmesi: Dış bağımsız.
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