ORIGINAL ARTICLES

Barometric and Spatiotemporal Gait Differences Between Leading and Nonleading Feet of Handball Players

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Background: Side-to-side stress imbalance has been suggested as a risk factor for injury in unilateral sports. The leading leg is suggested to be essential in sports rehabilitation for the return of athletes to the playground. The main aim of this study was to evaluate the dynamic pedobarometric and spatiotemporal gait differences between the leading and nonleading feet of male handball players.

Methods: Thirty healthy elite male handball players (mean ± SD: age, 31.7 ± 2.99 years; height, 177.5 ± 6.0 cm; weight, 78.9 ± 6.3 kg; body mass index, 25.0 ± 0.7) participated in this study; all of the participants are backcourt and pivot handball players. The assessments were performed using the Tekscan Walkway pressure sensor to detect and compare the variables of interest between the leading and nonleading feet during normal walking at a self-selected speed.

Results: Maximum force, peak pressure (total and forefoot pressure), foot width, single-limb support time, and step velocity are significantly increased in the leading foot compared with the nonleading foot. In addition, maximum force, foot width, and total peak pressure showed moderate positive significant correlations with body mass index.

Conclusions: The differences in the pedobarometric and spatiotemporal gait parameters may result from the physiologic and mechanical demands that are put on the leading foot of handball players, which need more rehabilitation attention and protection to avoid expected injuries. (J Am Podiatr Med Assoc 112(5), 2022)

In team handball, the players develop different throwing mechanisms that vary in leg movements, force, and pressure. These different leg movements tend to change the upper body mechanics and influence player performance.[1] The jump-throw technique is the most frequently applied mechanism (>75%) in team handball.[2] Jump height is important for the jump-throw technique in team handball to reach the high vertical level required to throw the ball over the block of the opposing players. Upper body mechanics and ball movement velocity in the jump-throw technique were dissimilar when take-off from one (the leg opposite the throwing arm) or two lower extremities, and ball tossing with take-off from the lower extremity opposite the tossing arm permits maximum ball speed.[3] Throwing technique is the result of consecutive muscle stimulation, energy transfer, torque production, generation of different joint angular velocities from proximal to distal in the lower limbs' kinetic chain, and propagation through the trunk and the upper limbs.[3,4] The higher efficiency of throwing velocity in handball is attributed to the better power and force output skills of the lower and upper extremities along with a more free fatty mass.[5] This tends to put greater demands on the lower extremities, especially the leading one, which is usually the leg opposite the shooting arm.

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The use of one lower extremity over the other may lead players to experience muscle imbalance in unilateral sports such as volleyball and handball.[6,7] This muscle imbalance and the asymmetrical joint forces may be related to high training loads and regularly repeated unilateral movements.[8] Muscle imbalance then increases the incidence of injury.[5,9] Besides, various physiologic attributes for different handball playing positions are required: pivot and backcourt handball players should be taller and heavier than the other handball players on the team and should show higher strengths than wing players.[10–12] Handball players have an unequal upper body weight distribution that relates to the percentage of body weight distribution on their feet during standing.[5] More years of handball playing can be noticed in an asymmetrical posture of the upper body and in an uneven body weight distribution in male handball players.[5]

Most of the previous studies analyzing handball players' posture focused on asymmetrical posture of the trunk and upper limb rather than on lower-limb asymmetry.[6,10–12] Ohlendorf et al[5] assessed the static plantar pressure and force distribution of handball players but did not assess the dynamic plantar force and pressure. Dynamic plantar force and pressure inequality delivers valuable information for rehabilitation and exercise to avoid body imbalance and injuries. Several previous studies have used the Tekscan Walkway system to evaluate athletic gait performance and reduce the incidence of injuries.[13–15] Limited knowledge exists about dynamic foot barometric and spatiotemporal gait asymmetry of handball players. In addition, foot pressure and force in correlation with body mass index (BMI) in professional male handball players have not been studied previously.

The purposes of this study were to examine the dynamic foot pressure and force differences and the degree of spatiotemporal asymmetry between the leading and nonleading feet of elite male handball players. Furthermore, the foot forces and pressures correlated with the BMI. The null hypothesis states that there is no differences in dynamic pressure, force, and spatiotemporal parameters between the leading and nonleading feet of handball players and no relation between BMI and dynamic foot force and pressure distribution.

Materials and Methods

Participants

Thirty healthy elite male handball players (17 backcourt players and 13 pivot players) were carefully chosen randomly from different teams in Al-Ahly Sporting Club of Egypt (mean ± SD: age, 31.7 ± 2.99 years; height, 177.5 ± 6.0 cm; weight, 78.9 ± 6.3 kg; and BMI [calculated as the weight in kilograms divided by the square of the height in meters], 25 ± 0.7). Twenty-five participants were right-handed and five were left-handed. The study inclusion criteria were as follows: 1) participate in the same competitions; 2) have the same activity levels; 3) train five times a week for 90 min each time (they also attend 60 min of obligatory physical fitness classes 4 days per week; none of the players had stopped playing for >2 weeks through the year before joining this study); 4) are backcourt (n = 22) or pivot (n = 8) players; and 5) have minimum training experience of 20 years (the maximum was 28 years), without participation in other sports. Participants with a history of less than 1 year of lower- or upper-extremity injuries or deformed lower-limb and foot joints, upper or lower back injuries, scoliosis, recognized congenital spine deformities, postural irregularity (eg, leg length variation), and balance disorder were excluded from study participation. Before the gathering of data, each player signed a written informed consent form after approval of the institutional review board of Faculty of Physical Therapy, Cairo University (Approval No. REC/012/002892), and the study was conducted in accordance with the Declaration of Helsinki.

Study Design

A cross-sectional study was performed to analyze the barometric (force and pressure distribution) and spatiotemporal gait (single-leg support time and step velocity) differences between leading and nonleading feet of handball players. Relationships were analyzed between BMI and foot width, foot force, and pressure distribution because these are well-known risk factors for flat feet and other foot problems.

Instrumentation

Asymmetry between leading and nonleading feet is a key indicator for abnormalities considered to be risk factors for any kind of injuries. Therefore, the Tekscan Strideway pressure measurement system with VersaTek cuffs (model #7.01x; Tekscan Inc, Norwood, Massachusetts) was used. This system offers objective information on static and dynamic gait and barefoot force and plantar pressure, in addition to temporal (time) and spatial (distance) parameters for a comprehensive gait analysis. The

Tekscan Walkway system is 1.8 m long. It contains four pressure-sensing mats (model 3150/3150E) with a total of 9,152 sensors. The frequency of acquisition is 62.5 Hz. Moreover, the system has two cords: one USB cord attached to the computer (for data collection and analysis) and one power cord. The system setup is efficient and streamlined.

Also, the software can automatically discriminate the left foot from the right foot. Furthermore, the device provides heat mapping during the test to detect foot pressure and force intensities. At the end of the test, the device delivers a detailed data analysis in the form of tables and graphs showing the spatiotemporal, foot force, and pressure data collected during the examination. The device reliability and validity have been demonstrated by previous research work.[16–18] The features of this device and software are provided on the Tekscan Web site (http://www.tekscan.com/products-solutions/systems/strideway-system).

Procedure

Before collection of the variables of interest, each participant stood on a scale to measure the body weight and height. In addition, the BMI was calculated. Foot width and length were detected manually using measurement taps, and all of the measurements were conducted by one examiner to ensure the reliability of these measurements. The system was provided with participants' weight for calibration. The calibration of each MatScan sensor before capturing data is mandatory. All of the measurements were collected in a quiet room with a comfortable temperature. Each handball player was asked to stand in front of the Walkway system in their normal and habitual standing foot position. The player started walking with two steps before walking on the Walkway mat to ensure that he reach normal gait before capturing the required data. These first two steps tend to eliminate the need for the examiner to discard the initial steps taken by participants or to clean up the collected data during data analysis. The participant walked barefoot across the Strideway system at normal walking speed for three trials, with each foot fully contacting one of the four sensors twice along the Walkway. The leading foot of the participant was defined as the pivot foot that is commonly used by players in throw with run-up, and it is often the foot opposite the throwing hand.[19] For each variable of interest, the average of three successful trials of free walking was obtained and analyzed.

Data Analysis

The data were analyzed with IBM SPSS Statistics for Windows, Version 20.0 (IBM Corp, Armonk, New York) to detect outliers.The test of normality was proved by the Shapiro-Wilk test ($P > .05$) to detect the normality of distributions for anthropometric data and each variable of interest. Descriptive analysis was conducted for each variable, and mean ± SD values were obtained. The t test for paired samples was used to compare the variables of interest, and the level of significance was set at $P < .05$. The bivariate correlation (Pearson product-moment correlation coefficient) was used to test the relationships between each variable of interest, and the test was two-tailed. The correlation was significant at the 0.01 and 0.05 levels.

Results

Descriptive Analysis

As explained in the previous section, the descriptive statistics for demographic data such as age, height, weight, BMI, and width and length of the leading and nonleading feet were sensibly measured and analyzed using IBM SPSS Statistic for Windows. The mean ± SD, SEM, and range of values are presented for demographic data. In addition, the t test for paired samples was used for foot dimensions (Table 1). T1

The *t* Test for Paired Samples for Variables of Interest

The t test for paired samples showed significant differences in the total peak plantar pressures ($P < .001$) and forces ($P < .001$) between the leading and nonleading feet of handball players. Moreover, there was a significant difference in forefoot plantar pressure between the leading and nonleading feet of the participants ($P < .001$). Also, hindfoot pressure showed a significant difference between the feet of handball players ($P = .026$). The spatiotemporal parameters (single-leg support time [$P < .001$] and step velocity [$P < .001$]) showed significant differences between the leading and nonleading legs of the participants (Fig. 1 and Table 2). F1T2

Pearson Product-Moment Correlation Coefficient

The Pearson product-moment correlation coefficient showed a moderate positive significant correlation

Table 1. Demographic Data for the 30 Study Participants and Paired *t* Test for Foot Dimensions

Variable	Mean ± SD	SEM	Range	*P* Value
Age (years)	31.7 ± 2.99	0.55	27–38	–
Height (cm)	177.5 ± 6.05	1.10	169–186.5	–
Weight (kg)	78.9 ± 6.34	1.16	70–89	–
Body mass index[a]	25 ± 0.71	0.128	24–26	–
Nonleading foot width (cm)	8.91 ± 0.69	0.127	8–10	<.001[b]
Leading foot width (cm)	9.09 ± 0.70	0.128	8–10	
Nonleading foot length (cm)	25.87 ± 0.58	0.106	25–26.8	.281
Leading foot length (cm)	25.89 ± 0.58	0.105	25–26.8	

[a]Calculated as the weight in kilograms divided by the square of the height in meters.
[b]Statistically significant ($P < .05$).

between BMI and the width of the leading and nonleading feet of handball players. Moreover, a moderate positive significant correlation was detected between BMI and the maximum force of the leading and nonleading feet of the players. Furthermore, there were weak-to-moderate positive nonsignificant correlations between BMI and the total peak, forefoot, and hindfoot pressures, except the relation between BMI and the total peak pressure of the leading foot showed a moderate positive significant correlation (Table 3). T3

Discussion

The present study compared the spatiotemporal gait parameters (single-leg support time and step velocity), dynamic plantar pressures, and force distributions between the leading and nonleading feet of elite male handball players. In addition, the correlations among the BMI, foot width, dynamic plantar pressures, and forces were detected in this study. The author selected variables that detect the amount of mechanical stress put on the leading feet of handball players due to asymmetrical distribution of body weight (effect of laterality) during dynamic situation. The results of this study showed statistically significant increases in spatiotemporal gait parameters, dynamic foot pressures, and force distributions in the leading foot compared with the nonleading foot of the handball players. Moreover, there were moderate positive significant correlations among BMI, foot width, and dynamic plantar forces of the feet. In addition, a moderate positive significant correlation was detected between BMI and the total dynamic peak pressure of the foot.

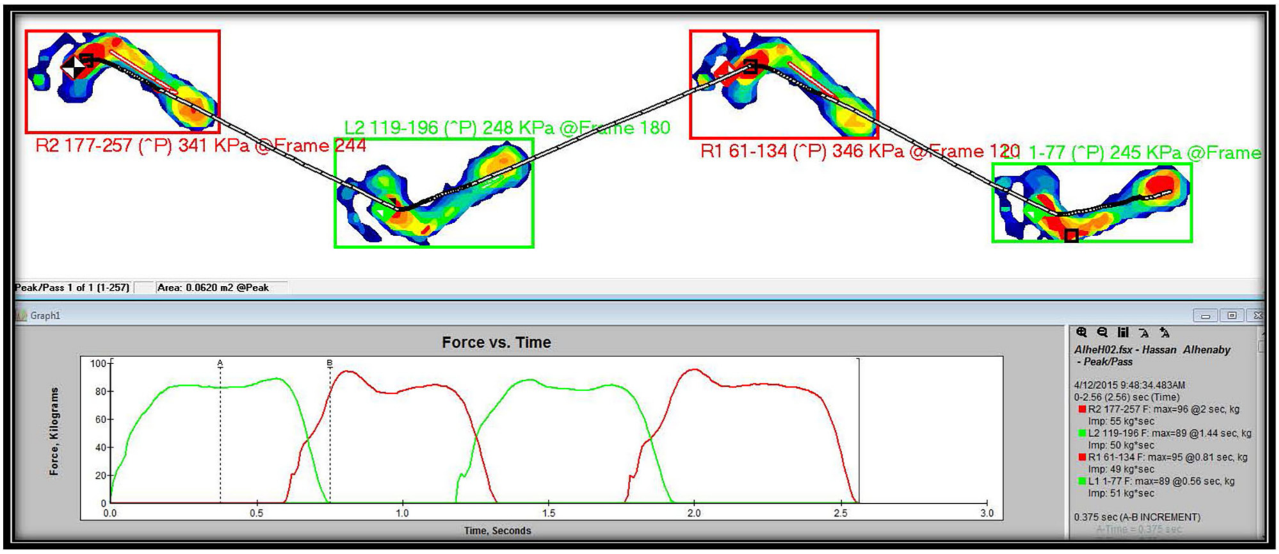

Figure 1. The total peak pressure and maximum force of one trial for the leading and nonleading feet of a left-handed handball player (right leading foot). It shows more pressure and force on the leading foot and more pressure concentration on the forefoot areas.

Table 2. The *t* Test for Paired Samples for Variables of Interest

Variable	Leading Foot	Nonleading Foot	*t* Value	*P* Value
Maximum force (% BW)	110.8 ± 8.2	107.4 ± 8.7	5.3	<.001[a]
Total peak pressure (kPa)	276.7 ± 5.2	256.3 ± 10.5	13.8	<.001[a]
Forefoot peak pressure (kPa)	292.7 ± 7.2	286.6 ± 5.9	9.8	<.001[a]
Hindfoot peak pressure (kPa)	268.8 ± 7.1	268.1 ± 7.5	2.4	.026[a]
Single-leg support time (% GC)	34.7 ± 1.99	32.2 ± 2.95	5.4	<.001[a]
Step velocity (m/sec)	0.60 ± 0.04	0.56 ± 0.036	6.97	<.001[a]

Note: Data are given as mean ± SD.
Abbreviations: BW, body weight; GC, gait cycle.
[a]Statistically significant ($P < .05$).

Table 3. Pearson Product-Moment Correlation Coefficients for BMI and the Other Variables of Interest

	BMI	
Variable	*r*	*P* Value
Foot width (LF)	0.639	<.001[a]
Foot width (NLF)	0.631	<.001[a]
Maximum force (LF)	0.624	<.001[a]
Maximum force (NLF)	0.578	.001[a]
Total peak pressure (LF)	0.446	.013[b]
Total peak pressure (NLF)	0.328	.077
Forefoot pressure (LF)	0.242	.197
Forefoot pressure (NLF)	0.214	.256
Hindfoot pressure (LF)	0.038	.843
Hindfoot pressure (NLF)	0.101	.596

Abbreviations: BMI, body mass index; LF, leading foot; NLF, nonleading foot.
[a]Correlation is significant at the 0.01 level.
[b]Correlation is significant at the 0.05 level.

Athletic posture has been the main focus of many researchers, especially in unilateral overhead games such as handball, volleyball, and tennis.[20–22] The significant increases in the plantar foot pressure and forces in the leading foot may result in asymmetrical body weight distribution and posture in handball players.[5] A study by Grabara[23] showed asymmetrical position of the shoulder blades and pelvic alignment from the frontal plane in adolescent handball players. Also, a study by Oyama et al[24] showed more scapular protraction and internal rotation in the leading hand than in the nonleading hand in tennis players. The handball player repeatedly throws the ball with one leading upper extremity (an estimated ~48,000 throws per season), and such weighty, one-handed overload may cause long-term posture abnormalities and asymmetrical weight distribution.[25] Asymmetrical trunk movements that are routine in sports and are always performed in the same movement direction are harmful and can cause postural defects. Dynamic postural asymmetry is usually associated with alteration in joint mobility and muscle strength on the right and left sides of the body.

The results of this study agree with those of Ohlendorf et al,[5] who found a significantly higher load on the leading foot of backcourt and pivot players than on the nonleading foot compared with wing handball players; this result could be due to backcourt and pivot players being taller and heavier than the other players in team handball. This also confirmed the effect of weight gain on the plantar pressure and force distribution. Moreover, Ohlendorf et al[5] found that the hindfoot of handball players carried more pressure than the forefoot, and this was opposite the finding of the present study. On the other hand, a study of healthy men that compared leading and nonleading foot plantar pressures and forces confirmed that the total dynamic plantar pressure was mainly concentrated on the forefoot during normal walking speed. Although the results showed no significant difference between leading and nonleading feet, this may be because the sample used in this study was not from athletes.[23] Also, Imamura et al[26] found a significant difference in dynamic maximum vertical force between the leading and nonleading feet of healthy men; in addition, the study detected a significant positive correlation between maximum vertical force and body weight. This agrees with the result of the present study of a significant difference in dynamic maximum force between the leading and nonleading feet and a significant positive correlation between maximum force and BMI.

The total peak pressure of the leading foot showed a moderate positive significant correlation with BMI, and the other pressure distributions showed weak positive nonsignificant correlations. This may be because an increase in foot width (foot area) with increasing body weight tends to increase foot forces. This result is in agreement with the result of another study of adults that showed a strong positive significant correlation between foot width and contact foot area with increasing BMI in obese adults.[27] However, a study by Martínez-Nova et al[28] showed that handball players had more foot supination compared with basketball players and runners and determined the cause to be that handball players are in continuous lateral displacement and pivoting on the playing floor but their knees and feet move toward the supination position. Also, the jumping techniques in handball playing are more horizontal, with more tendencies toward lateralization.

Although, to our knowledge, there is a lack of studies on spatiotemporal gait differences between the leading and nonleading feet of handball players. Kinetic chain investigation studies of handball throwing techniques found strong correlations between throwing velocity and different joint positions during the acceleration phase of playing.[1,29] The present study showed a statistically significant difference in step velocity between leading and nonleading feet, and the result confirmed the increase of leading foot step velocity. The present result is in agreement with other studies that confirmed the strong relation between ball-throwing velocity and lower-extremity strength and velocity that allowed the leading foot more step velocity and single-leg support time through most of the throwing technique, which is known as step running throw.[30,31]

The ability to throw a ball at high velocity is supposed to be due to a ball-throwing mechanism, upper and lower body strength and power, and timing of body segment sequencing. The overhead ball-throwing technique is very complicated, with many body segments and different body joints contributing in a proximal to distal sequence. A study by Chaouachi et al[32] showed that bilateral jumping of handball players did not strongly associate with sprint times. Nevertheless, all of the unilateral leg jump techniques strongly correlated with different sprint times of different distances. The single greatest prognosticator of 5- and 30-m sprint times was the jump with the leading leg in elite male handball players. The movements elaborated in sprinting and the 5-jump test need fast stretching and higher-velocity leg muscle contractions, which might clarify this strong relation. This result is in agreement with the present results that indicated a significant increase in step velocity of the leading foot of handball players that tends to increase jump-throw technique efficiency, and this may reflect on the normal walking of the players. Moreover, a previous study proved that the bone mineral density of the leading leg (the contralateral leg to the throwing hand) of child handball players is more than that of their counterparts who do only physical education activities. This may be because the leading leg (the contralateral leg to the throwing hand) in handball players is mainly engaged in take-off and landing activities, and this may increase the weightbearing time and stimulate bone formation.[33] This result agrees with the present result that indicated greater single-support time of the leading foot than the nonleading foot.

The present study had many limitations, including the lower number of participants. Also, it did not include handball players from all of the various playing positions (only the backcourt and pivot players were included). In addition, only male elite handball players were included in this study, and it is recommended to include players of both sexes in future studies. Moreover, it is recommended to include all of the spatiotemporal gait parameters and kinetic and kinematic analyses in future studies to give a complete picture of the difference between leading and nonleading feet during normal walking. Furthermore, all of these variables of interest are recommended to be analyzed during the real activity of handball players (during running, change of direction, take-off, and throwing) inside the playing court to differentiate between leading and nonleading feet.

Conclusions

Handball players showed a greater laterality effect on their leading and nonleading feet by changing the plantar pressure and force distributions between both feet. Leading feet had greater plantar pressure distribution, with more pressure concentration at the forefoot. In addition, moderate positive significant correlations were detected among BMI, foot width, plantar pressure, and force distribution. Also, the results of this study demonstrated the statistically significant increases in step velocity and single-leg support time of the leading foot compared with the nonleading foot that are required during the performance of a more efficient step-throwing technique. The results of this study give attention to the need to provide more care for the leading foot of handball players because it carries more load than the nonleading foot and is exposed to more opportunities for injury.

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