Barometric and spatiotemporal gait differences between leading and non-leading feet of handball players

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Abstract

Background: Side-to-side stress imbalance has been suggested as a risk factor for hurts in unilateral sports. The leading leg is suggested to be essential in sports rehabilitation and return of athletes to the playground. **Purpose:** The main aim of the current study was to evaluate the dynamic pedo-barometric and spatiotemporal gait differences between the leading and non-leading feet of male handball players. **Methods:** 30 healthy, elite male, handball players aged from 27 to 38 years old (mean =31.7±0.54), all of the handball players are from the backcourt and pivot players. All assessments were performed using the Teckscan walkway pressure sensor, the maximum plantar force, peak pressure, single limb support time, and gait velocity were detected and compared between the leading and non-leading foot during the normal walking with self-selected speed. Three consecutive trials were detected to provide the quantitative data. **Results:** the maximum force, peak pressure (total and forefoot pressure), foot width, single-limb support time, and step velocity have significant increases in the leading foot compared with the non-leading foot. In addition, the maximum force foot width, and total peak pressure showed significantly moderate positive correlations with body mass index. **Conclusion:** the differences in the pedo-barometric and spatiotemporal gait

parameters may return to the physiological and mechanical demands that put on the leading foot of handball players which give more attention to rehabilitation and protection of the leading foot to avoid any expected injuries.

Keywords: Pedo-barometric evaluation, Spatiotemporal gait parameters, Handball, Leading foot.

Introduction:

In handball team, the players develop different throwing mechanisms that vary in the leg movements, forces and pressures. These different leg movements tend to change in the upper body mechanics and influence the players' performance [1]. The jump-throw technique is the most frequently applied mechanism (>75%) in handball team [2]. Jump height is significant for the jump-throw technique in handball team to reach a high vertical level that required to throw the ball over the block of the opposite players. Upper body mechanics and ball movement velocity in the jump-throw technique were dissimilar when take-off from one (the leg opposite or leg from the throwing arm) or two lower extremities, while the ball tossing with take-off from one lower extremity opposite to the tossing arm permits the maximum ball speed [3]. Throwing technique is the result of consecutive muscle stimulation, energy transfer, torque production, the generation of different joint angular velocities from proximal to distal in the lower limbs' kinetic chain and propagates through the trunk and the upper limbs [3, 4]. The higher efficiency of throwing velocity in handball attributes 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 to the shooting arm.

The use of one lower extremity over the other may leads to muscle imbalance in unilateral sports like volleyball and handball players [6,7]. This muscle imbalance and asymmetrical joint forces may be returned to high training loads and regularly repeated unilateral movements [8]. Muscle imbalance then rises the incidence of injury [5,9]. Besides, various physiological stresses for different handball playing positions are required such as; pivot and backcourt handball players should be taller and heavier than the other handball players in the team and show higher strengths than wing players [10, 11, 12]. Handball players have an unequal upper body weight distribution which relates to the percentage of body weight distribution on their feet during standing [5]. More years of handball plying can be noticed in an asymmetrical posture of 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 the lower limb asymmetry [6, 10,11,12]. Alfonso et al [13] study the foot posture of handball players rather than asymmetrical foot force and pressure distribution and their relation to BMI. Ohlendorf et al [5] assessed the static plantar pressure and force distribution of handball players but not assessed 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. Limited knowledge exists about the dynamic feet barometric and spatiotemporal gait

asymmetry of handball players. In addition, the feet pressure and force in correlation to the Body Mass Index (BMI) in professional male handball have not been studied previously.

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

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Material and Methods:

Participants:

The participants included 30 healthy elite male handball players carefully chosen randomly from different teams in Al-Ahly National Club of Egypt [Age (SD) = 31.7(±2.99) years, Height (SD) = 177.5 (±6) cm, Weight (SD) =78.9 (±6.3) kg, BMI(SD) = 25 (±0.7)]. The other inclusive criteria for enrolling the participants involved i) the handball players should participate in same competitions ii) they should have the same activity levels iii) they should have joined 5 times training sessions a week for 90 minutes each session. Moreover, they attend 60 minutes of obligatory physical fitness classes held 4 days per week. None of players stopped to play for more than two weeks through the year before joining this study. iv) they should belong to the same handball playing positions [backcourt (22) and pivot players (8)].

v) their minimum training experience was 20 years and the maximum was 28 years without participation in any other kind of sports. vi) all of them were right-handed except only 5 of them (they were left-handed). Participants with history less than one year of lower or upper extremity injuries or deformed lower limb and foot joints, upper or lower back injuries, scoliosis, a recognized congenital spine deformities, postural irregularity (e.g. leg length variation), and balance disorder were excluded from the participation in this study. Before the gathering of data, each player signed a written consent form after the approval of the review board of ethics committee of Faculty of Physical Therapy, Cairo University (Egypt), and the study was conducted in accordance with the Declaration of Helsinki.

Study design

A Cross-Sectional Study was performed to analyze the barometric (forces and pressures distribution) and spatiotemporal gait (single leg support time and step velocity) differences between leading and non-leading feet of handball players. Relationships were recognized among the BMI, feet width, feet forces, and pressure distribution, as these are well known as risk factors to flatfeet and other feet problems.

Instrumentation

Asymmetry between leading and non-leading feet is a key indicator for any abnormalities that considered as a risk factor for any kind of injuries. So, the Tekscan Walkway™ Pressure Measurement System VersaTek Cuff Baseds was used. This system offers objective information on static and dynamic gait and barefoot force and plantar pressure, in addition temporal (time) and spatial (distance) parameters for a comprehensive gait analysis. Tekscan Walkway™ system (South Boston, Massachusetts, USA, Model #7.01x) is 1.8 meter long. It contains 4 MatScan Sensor (3150 / 3150E) and the total number of sensors is 9152. The frequency of acquisition is 62.5 Hz. Moreover, the system has two cords, one USB cord attach to the computer software (for data collection and analysis) and one power cord, the system set up is efficient and streamlined.

Also, the software can automatically discriminate the left foot from the right foot. Furthermore, the device provides heat-map during the test to detect the 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 that collected during examination. The device reliability and validity were detected by many previous research work [13, 14, 15] The features of this device and software are existing on this website (www.tekscan.com/products-solutions/systems/strideway-system).

Procedure

Before the collection of the variables of interest, each participant stand on weight and height scale to detect the body weight and height. In addition, the BMI was calculated from the body height and weight. Each foot width and length were detected manually using measurement taps. The system was provided with subjects' weight for calibration. The calibration of each MatScan Sensor before the capturing of the data is mandatory. All measurements were collected in quiet and comfortable room temperature. Each handball player was asked to stand in front of the walkway system with normal and habitual standing foot position. The player started his walking with two steps before the real walking on the walkway mat to ensure the participants reach their normal gait before capturing the required data. These first two steps tend to eliminate the need of examiner to discard initial steps were taken by 123 participants or clean up the collected data during data analysis. The participant walked barefooted across the strideway system with normal walking speed for 3 trials and each foot should be fully contact one of the 4 sensor twice along the walking. The leading foot of the participant was defined as the pivot foot that commonly used by players in throw with run-up and it is often the opposite foot to the throwing hand [16]. The average of each interested variable of three successful trials of free walking was detected and analyzed.

Data analysis

The data were explored by using Statistical Package for Social Sciences (SPSS) version 20.0 to detect any outlier. The test of normality was proved by the Shapiro-Wilk test ($P > 0.05$) to detect the normality of distributions for anthropometric data and each variable of interest. Descriptive analysis was conducted for each variable, and their mean value and standard deviation (SD) were obtained. The paired sample t-test was used to compare between the variables of interest and the level of significance was set at $p<0.05$. The bivariate correlation (Pearson 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 of demographic data such as age, height, weight, BMI, and width and length of leading and non-leading foot were sensibly measured and analyzed using the SPSS. The mean, standard deviation (SD), standard error of the mean (SEM), and maximum/minimum values are presented for demographic data. In addition, the paired sample t –test was detected for feet dimensions as shown in Table1.

Table 1. Demographic data of participants (n= 30) and paired t test of foot Dimensions

Variables	Mean (±SD)	SEM	min/max 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 (kg/m^2)	25 (± 0.71)	0.128	24-26	-
Non-leading Foot width (cm)	8.91 (± 0.69)	0.127	8-10	0.000*
Leading Foot width (cm)	9.09 (± 0.70)	0.128	8-10	
Non-leading Foot length(cm)	25.87 (± 0.58)	0.106	25-26.8	0.281
Leading Foot length (cm)	25.89 (± 0.58)	0.105	25-26.8	

* statistically significant results ($p < 0.05$)

Paired sample t-test for variables of interest

The paired sample t-test showed statistical significant differences in the total peak plantar pressures and forces ($p = 0.000$ and $p = 0.000$, respectively) between the leading and non-leading feet of handball players. Moreover, there was a statistical significant difference in the forefoot plantar pressure between the leading and non-leading feet of the participants (p= 0.000). Also, the hindfoot pressure showed statistical significant difference between the both feet of handball players (p= 0.026). The spatiotemporal parameters (single leg support time and step velocity) showed statistical significant differences between the leading and non-leading leg of the participants (p= 0.000 and p= 0.000, respectively) as shown in Figure1 and Table2.

Table 2. Paired sample t-test of Variables of interest

Variables	LF Mean (±SD)	NLF Mean (±SD)	t-values	p-values
Maximum force (%BW)	110.8(±8.2)	107.4(±8.7)	5.3	0.000*
Total Peak Pressure (KPa)	276.7(±5.2)	256.3(±10.5)	13.8	0.000*
Fore-foot Peak Pressure (KPa)	292.7(±7.2)	286.6(±5.9)	9.8	0.000*
Hind-foot Peak Pressure (KPa)	268.8(±7.1)	268.1(±7.5)	2.4	0.026*
Single Support Time (%GC)	34.7(±1.99)	32.2(±2.95)	5.4	0.000*
Step Velocity (m/sec)	0.60(±0.04)	0.56(±0.036)	6.97	0.000*

* statistically significant results (p < 0.05); LF: Leading foot; NLF: Non-Leading Foot; BW: Body Weight; GC: Gait Cycle.

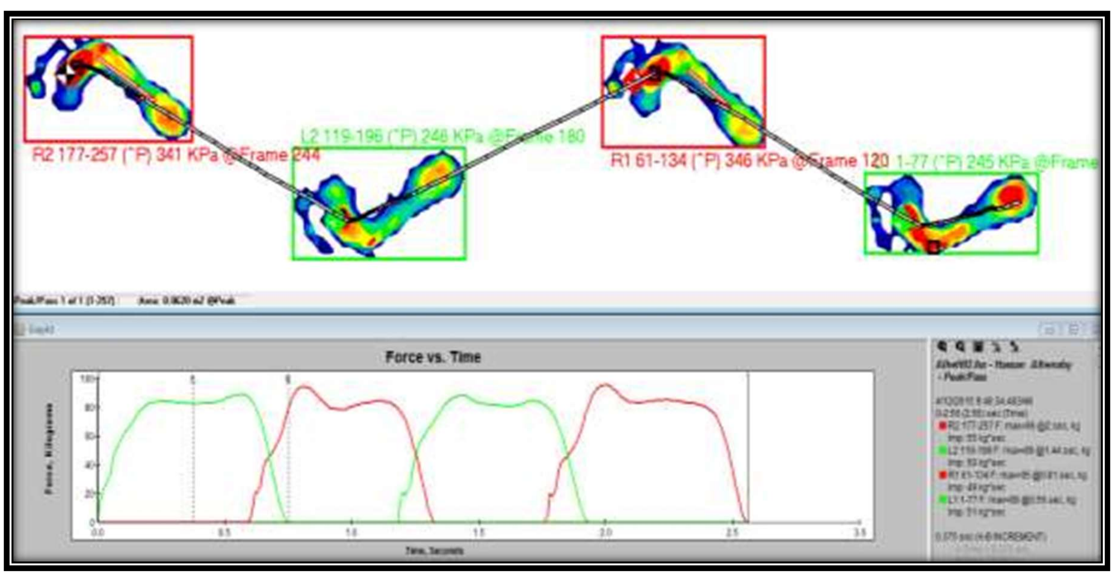

Figure1. The total peak pressure and maximum force of one trial for leading and non-leading feet of left-handedness handball player (right leading foot). It shows more pressure and force

on the leading foot and more pressure concentration on the fore-foot areas.

Person product correlation coefficient

The Pearson product correlation coefficient showed a moderate positive significant correlation between the BMI and the foot width of leading and non-leading feet of handball players. Moreover, a moderate positive significant correlation was detected between the BMI and the maximum force of the leading and non-leading feet of the players. Furthermore, there were from weak to moderate positive non-significant correlations between the BMI and the total peak pressure, the forefoot, and the hindfoot pressure except the relation between the BMI and the total peak pressure of the leading foot showed a moderate positive significant correlation. as shown in the table 3.

Table 3. Person product correlation coefficient among the BMI and the other variable of interests

Variables	BMI
Leading Foot width	**r** = .639, P =.000**
Non-Leading Foot width	**r** = .631, P =.000**
Maximum force (LF)	**r**= .624, P = .000**
Maximum force (NLF)	**r**= .578, P = .001**
Total Peak pressure(LF)	**r**= .446, P = .013*
Total Peak pressure(NLF)	**r**= .328, P = .077
Fore-foot pressure(LF)	**r**= .242, P = .197
Fore-foot pressure(NLF)	**r**= .214, P = .256
Hind-foot pressure(LF)	**r**= .038, P = .843
Hind-foot pressure(NLF)	**r**= .101, P = .596

* Correlation is significant at the 0.05 level; **correlation is significant at the 0.01 level;LF: Leading foot; NLF: Non-Leading Foot

Discussion

The current study compare the spatiotemporal gat parameters (single leg support time and step velocity), dynamic plantar pressures and forces distribution between the leading and non- leading feet of elite male handball players. In addition, the correlations among the BMI, foot width, and dynamic plantar pressures and forces were detected in this study. The author selected variables that detect the amount of mechanical stresses that 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 statistical significant increases of spatiotemporal gait parameters, dynamic foot pressures and forces distribution in the leading foot compared with non-leading foot of the handball players. Moreover, there were significant moderate positive correlations among BMI, feet width, and dynamic plantar forces of the feet. In addition, a significant moderate positive correlation was detected between the BMI and the total dynamic peak pressure of the feet.

Athletic posture has been the main focus of many researchers especially in unilateral overhead games like handball, volleyball, and tennis playing [17,19]. The significant increases in the plantar foot pressure and forces in the leading foot may return to asymmetric body weight.

The results of this study agree with those of Ohlendorf et al [5] that found a significant a higher load on the leading foot of backcourt and pivot players than the non-leading foot in comparison to the wing handball players this returned to the backcourt and pivot players are taller and heavier than the other players in handball team. 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 to the finding of this study. On the other hand, a study performed on normal adult male to compare between the leading and non-leading 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 non-leading feet but this may return to the sample used in this study was not from athletes [23]. Also, Imamura et al. [23] found a significant difference in the dynamic maximum vertical force between the leading and non-leading feet in normal male adult person, in addition the study detected a significant positive correlation between the maximum vertical force and body weight, this agree with the result of our study that detect a significant difference in the dynamic maximum force between the leading and non-leading feet and a significant positive correlation between the maximum force and BMI.

The total peak pressure of the leading foot showed a significant moderate positive correlation with the BMI while the other pressure distribution showed weak positive non-significant correlation this may return to increase the foot width (foot area) with increasing the body weight that tends to increase the foot forces. This result come in agreement with the results of other study conducted on adult subject that showed a strong positive significant correlation between the foot width and contact foot area with increasing BMI in obese adult subjects [24]. However, a study conducted by Martı´nez-Nova et al. [25] showed that handball players had more foot supination in comparison with basketball and runner players and returned the cause of being the handball players in a continuous lateral displacement and pivoting on the playing floor that but their knees and feet move towards supination position. Also, the jumping techniques in handball playing are more horizontal, with more tendencies to lateralization.

Although, to the author's knowledge, there is lack of study that conducted on spatiotemporal gait differences between the leading and non-leading 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 [26, 27]. The result of this study showed statistical significant difference in step velocity between Leading and non-leading feet and the result confirmed the increase of leading foot step velocity. Our result come in agreement with other studies who confirmed the strong relation between the throwing ball velocity and lower extremities' strength and velocity that acquired the leading foot more step velocity and single leg support time through the most throwing technique which known as step running throw [28, 29].

The ability to throw a ball at high velocity is supposed to be due to: ball throwing mechanism, upper and lower body part strength and power, timing of body segment sequencing. The overhead ball throwing technique is very complicated with many body segments and different body joints contributing to be performed in a proximal to distal sequence. As study conducted by Chaouachi et al. [30] showed that bilateral jumping of handball players did not strongly associate with any times of the sprint. Nevertheless, all of the unilateral leg jump techniques strongly correlated with different sprint times of different distances. The single greatest prognosticator of 5-meter and 30-meter 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 more-velocity leg muscular contractions, which might clarify this strong relations. This result come in agreement of our results that indicated the significant increase in step velocity of the leading foot of hand ball 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 (BMD) of leading leg (contralateral leg to throwing hand) of child handball players is more than their counterpart of child who do only physical education activities. This returned to leading leg (contralateral leg to throwing hand) in handball players is mainly engaged in take-off and landing activities and this may increase the weight bearing time that stimulates the bone formation [31]. This result agree with our result that indicated the more single support time of leading foot than the non-leading foot.

The current study demonstrated many limitations which include the lower number of participants. Also, it didn't include the handball players in all various playing positions (only the backcourt and pivot players). In addition, the only male elite handball players were included in this study and it is recommended to include both gender in the future studies. Moreover, it is recommended to include all the spatiotemporal gait parameters, kinetic and kinematic analysis in the future studies to give a complete picture about the difference between the leading and non-leading feet during normal walking. Furthermore, all these variables of interest is recommended to be analyzed during the real activity of handball players (during running, change direction, take-off, and throwing) inside the playing court to differentiate between the leading and non-leading feet.

Conclusion

Handball players showed a greater laterality effect on their leading and non-leading feet by changing the plantar pressure and force distribution between both feet. The leading feet had a greater plantar pressure distribution with more pressure concentration at the forefoot. In addition, the moderate significant correlations were detected between the BMI, foot width, plantar pressure and force distribution. Also the results of this study demonstrated the statistical significant increases in the step velocity and single leg support time of leading foot than the non-leading foot which is required during the performance of more efficient step-throwing technique. The results of this study attracted the attention to provide more care for the leading feet of handball players as they carry more load than the non-leading foot and expose to more incidence of injures.

Acknowledgement

The authors would like to thank all Handball players who participated in this study patiently.

Conflict of interest

There is no any financial support or any conflict of interest to declare.

References

1- Wagner, H, Pfusterschmied, J, von Duvillard, S P, Müller E. Performance and kinematics of various throwing techniques in team-handball. Journal of sports science & medicine, 10(1), 73–80, 2011.

2- Wagner H, Kainrath S, Müller E. Coordinative and tactical parameters of the throw in team-handball. Relationship between experience, throwing quality and selected technical and tactical parameters. Leistungssport 38, 35-42, 2008.

3- Wagner H, Finkenzeller T, Würth S, Von Duvillard S P. Individual and team performance in team-handball: a review. Journal of sports science & medicine, 13(4), 808–816, 2014.

4- Roach NT, Venkadesan M, Rainbow MJ, and Lieberman D. Elastic energy storage in the shoulder and the evolution of high-speed throwing in Homo. Nature 498, 483-486, 2013.

5- Ohlendorf D, Salzer S, Haensel R. et al. Influence of typical handball characteristics on upper body posture and postural control in male handball players. BMC Sports Sci Med Rehabil 12, 4, 2020. https://doi.org/10.1186/s13102-020-0156-2

6- Wang HK, Cochrane T. Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. J Sports Med Phys Fitness 41:403–10, 2001.

7- Soderman K, Alfredson H, Pietila T, et al. Risk factors for leg injuries in female soccer players: a prospective investigation during one out-door season. Knee Surg Sports Traumatol Arthrosc 9:313–21, 2001.

8- Grabara M. Comparison of posture among adolescent male volleyball players and non-athletes. Biology of sport, 32(1), 79–85, 2015.

9- Niemuth PE, Johnson RJ, Myers MJ, et al. Hip muscle weakness and overuse injuries in recreational runners. Clin J Sport Med 15:14–21, 2005.

10- Povoas SC, Ascensao AA, Magalhaes J, Seabra AF, Krustrup P, Soares JM, et al. Physiological demands of elite team handball with special reference to playing position. J Strength Cond Res. 28(2):430–42, 2014.

11- Michalsik LB, Madsen K, Aagaard P. Technical match characteristics and influence of body anthropometry on playing performance in male elite team handball. J Strength Cond Res 29(2):416–28, 2015.

12- Michalsik LB, Aagaard P, Madsen K. Locomotion characteristics and match-induced impairments in physical performance in male elite team handball players. Int J Sports Med 34(7):590–9, 2013.

13- Coda A, Carline T, Santos D. Repeatability and reproducibility of the Tekscan HR-Walkway system in healthy children. Foot 24, 49–55, 2014.

14- Zammit G V, Menz HB, Munteanu SE. Reliability of the TekScan MatScan® system for the measurement of plantar forces and pressures during barefoot level walking in healthy adults. J. Foot Ankle Res. 3, 11, 2010.

15- Arafsha F, Hanna C, Aboualmagd A, et al., InstrumentedWireless SmartInsole System for Mobile Gait Analysis: A Validation Pilot Study with Tekscan Strideway. Journal of sensor and actuators network. J. Sens. Actuator Netw 7, 36, 2018.

16- Eriksrud O, Sæland FO, Federolf PA, Cabri J. Functional Mobility and Dynamic Postural Control Predict Overhead Handball Throwing Performance in Elite Female Team Handball Players. Journal of Sports Science and Medicine 18, 91-100, 2019.

17- Barczyk-Pawelec K, Bańkosz Z, Derlich M. Body postures and asymmetries in frontal and transverse planes in the trunk area in table tennis players. Biol Sport 29:129–134, 2012.

18- Varekova R, Vareka I, Janura M, Svoboda Z, Elfmark M. Evaluation of postural asymmetry and gross joint mobility in elite female volleyball athletes. J Hum Kinet 29:5–13, 2011.

19- Grabara M. A comparison of the posture between young female handball players and non-training peers. J Back Musculoskelet Rehabil 27(1):85–92, 2014.

20- Grabara M. Posture of adolescent male handball players compared to non-athletes. Baltic Journal of Health and Physical Activity 9(3):76-86, 2017.

21- Oyama S, Myers J B, Wassinger CA, Daniel Ricci R, Lephart SM. Asymmetric resting scapular posture in healthy overhead athletes. Journal of athletic training, 43(6), 565–570, 2008. https://doi.org/10.4085/1062-6050-43.6.565

22- Pieper HG. Humeral torsion in the throwing arm of handball players. Am J Sports Med 26:247–253, 1998.

23- Imamura M, Imamura ST, Salornao O, et al., Pedobarometric Evaluation of the Normal Adult Male Foot. Foot & Ankle InternationalNol. 23, 9, 2002.

24- Youssef EF, Shanb AA, Ameer AA, Shanab ME. Impact of body weight on shifting of foot pressure among adult subjects. Acta of Bioengineering and Biomechanics 22(2), 2020.

25- Martı´nez-Nova A, Go´mez-Bla´zquez E, Escamilla-Martı´nez E, et al. The Foot Posture Index in Men Practicing Three Sports Different in Their Biomechanical Gestures. Journal of the American Podiatric Medical Association. 104 (2), 2014.

26- Van den Tillaar R and Ettema G. A three-dimensional analysis of overarm throwing in experienced handball players. Journal of Applied Biomechanics 23, 12-19, 2007.

27- Wagner H, Pfusterschmied J, von Duvillard SP, Muller E. Performance and kinematics of various throwing techniques in team-handball. Journal of Sports Science and Medicine 10, 73-80, 2011.

28- Marques MC, González-Badillo JJ. In-season resistance training and detraining in professional team handball players. Journal of Strength and Conditioning Research, 20(3), 563-571, 2006.

29- Alves A, Marques MC. Throwing velocity predictors in elite team handball players. Journal of Human Sport and Exercise 8(3). 2013.

30- Chaouachi A, Brughelli M, Levin G. Anthropometric, physiological and performance characteristics of elite team-handball players. Journal of Sports Sciences 27(2): 151–157, 2009.

31- Vicente-Rodriguez C, Dorado C, Perez-Gomez J, et al. Enhanced bone mass and physical fitness in young female handball players. Bone 35, 1208 – 1215