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Foot Symmetry and Plantar Pressure Characteristics in Elite Taekwondo Athletes; Preferred and Non-Preferred Foot Comparison

Elit Tekvando Sporcularında Ayak Simetrisi ve Plantar Basınç Karakteristikleri; Tercih Edilen ve Edilmeyen Ayak Karşılaştırması

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ABSTRACT Objective: The aim of this study was to investigate differences in plantar pressure characteristics between preferred and non-preferred foot in elite taekwondo athletes. **Material and Methods:** The study population consisted of 11 elite taekwondo athletes ages ranged between 19.16±2.72 years. To determine preferred foot, they were also asked which leg they preferred to kick a ball. Plantar pressure distributions were measured by pedobarography device. The relative pressure-loads (%) between preferred and non-preferred foot determined with static pedobarographic measurements while subject stand on the pressure plate. The dynamic pedobarographic measurements were performed to investigate plantar pressure distribution, temporal characteristics and peak pressure asymmetry between preferred and non-preferred foot. **Results:** There was no statistically difference between preferred and non-preferred foot with regard to static measurement results. No significant differences were found between foots for temporal characteristics and peak pressure underneath the ten anatomical areas. The absolute impulse underneath the second metatarsal was significantly higher at preferred foot while absolute impulse of lateral heel was higher at non-preferred foot. The relative impulse of second metatarsal and third metatarsal were also significantly higher at preferred foot. Peak pressure asymmetry was found in favor to non-preferred foot. **Conclusion:** The finding of present study indicates that the peak pressure beneath the preferred and non-preferred foot is not symmetrical. Peak pressure asymmetry finding indicates that preferred and non-preferred foot should be assessed and trained separately to prevent sports injury in taekwondo.

Keywords: Foot symmetry; plantar pressure; symmetry index; taekwondo

ÖZET Amaç: Bu çalışmanın amacı elit tekvando sporcularında tercih edilen ve edilmeyen ayaktaki plantar basınç karakteristiklerinin farklılıklarını araştırmaktır. **Gereç ve Yöntemler:** Çalışma grubu yaşları 19,16±2,72 yıl olan 11 elit tekvando sporcusundan oluşmaktadır. Tercih edilen ayağın belirlenmesi için bireylere topa hangi ayakla vurdukları soruldu. Plantar basınç dağılımı pedobarografi cihazı ile ölçüldü. Tercih edilen ve edilmeyen ayağa olan basınç yüklenmesi (%) birey platform üzerinde statik olarak ayakta dururken belirlendi. Tercih edilen ve edilmeyen ayaktaki plantar basınç dağılımı, temporal karakteristikler ve pik basınç asimetrisini araştırmak için dinamik pedobarografik ölçümler gerçekleştirildi. **Bulgular:** Statik ölçüm sonuçlarına göre tercih edilen ve edilmeyen ayaklara olan yük dağılımı istatistiksel olarak farklı değildi. Ayaklar arasında, temporal karakteristikler ve on anatomik bölge altındaki pik basınçlar bakımından anlamlı farklılıklar bulunmadı. Mutlak impals değeri tercih edilen ayakta ikinci metatars altında anlamlı olarak daha yüksek iken, tercih edilmeyen ayakta topuk lateralinde daha yüksek idi. Göreceli impals değeri ise tercih edilen ayakta, 2. ve 3. parmak altında tercih edilmeyen ayağa göre daha yüksekti. Pik basınç asimetrisi tercih edilmeyen ayak lehine idi. **Sonuç:** Bu çalışmanın sonuçları tercih edilen ve edilmeyen ayaktaki pik basınçların simetrik olmadığını ortaya koymuştur. Pik basınç asimetri bulguları, tekvandoda spor yaralanmalarının önlenmesi için tercih edilen ve edilmeyen ayağın ayrı ayrı değerlendirilmesi ve antrene edilmesi gerektiğini göstermiştir.

Anahtar Kelimeler: Ayak simetrisi; plantar basınç; simetri indeksi; tekvando

Taekwondo is a Korean traditional martial art that mainly focuses on fast, high and spinning kick. While one foot is used to kick, the other foot has a crucial role on postural control and stability. Most researchers have consensus upon the fact that preferred leg/foot is responsible for manipulating an object or kicking, whereas non-preferred leg/foot provides stabilizing support.[1-3] Asymmetry can be classified into three types as morphological, functional and dynamical.[4] Morphological and functional asymmetries of joints or extremities can cause the unsuitable management of body movement.[5] These asymmetries are important internal risk factors and precipitate to lower extremity injury.[6] It is denoted that symmetry between lower extremities are considerable for elite taekwondo athletes who may acquire an advantage for attacks and also defense against opponents.[7,8] Furthermore, it has also been reported that existing symmetry between preferred and non-preferred foot may avoid muscle imbalance and prevent sport injuries.[9,10] Brophy et al. reported that limb preferences serve as an etiological factor with regard to anterior cruciate ligament (ACL) injuries.[11] Functional asymmetry, very important for combative sports, is defined as a variance in frequency of use, accuracy of movement and consistent task discrepancy between the limbs.[4,12] The symmetry index has been used along with the assessment of functional asymmetry in gait kinematic and kinetic parameters, ground reaction force of gait and running.[13-17] This index defined by Robinson et al. has been widely used to quantify symmetry and it has been found to be cheap, useful, and easily applicable and results are presented clearly.[18]

Since preferred and non-preferred leg could be different from each other in nature, it might be acceptable to think that plantar pressure distribution data of preferred foot can be distinct from non-preferred foot. Plantar pressure data provide comprehensive information about plantar pressure distribution on the areas loaded under the foot and timing of rollover processes.[19,20] Measurements of plantar pressure also provide information about foot and ankle functions. Besides, objective and helpful information can be obtained through investigation of plantar pressure symmetry for the rehabilitation programs to avoid lower extremity imbalance and also to maintain postural stability.[3,21,22] It can be speculated that good balance and appropriate pressure distribution are necessary for weight bearing and weight shifting while performing kicks, transition and defense.[7,22,23] Although most of the researches focus on the injury rates and types, literature provides a lack of studies that investigate the causes of lower extremity injuries in taekwondo. Since injury rates in taekwondo are higher than the other full-contact and collision sports it would be necessary to develop specific approaches to reduce the number and the severity of competition injuries in taekwondo.[24,25] Therefore, the main purposes of this study were to compare the differences in plantar pressure characteristics between preferred and non-preferred foot and to investigate the existence of an asymmetry in elite taekwondo athletes.

MATERIAL AND METHODS

THE SUBJECT

Eleven national team taekwondo athletes ages ranged between 19.16±2.72 years participated in this study during the period of January through April 2013. All athletes participated in taekwondo competitions at the national level at least one time and all of them were injury-free. Subjects were excluded from the study if they had a history of any diseases and lower extremity injuries that may affect gait mechanics at the time of the study or in the preceding six months. All participants were required to fill out a Physical Fitness Readiness Questionnaire (PAR-Q).[26] To determine preferred foot, they were also asked which leg they preferred to kick a ball.[27] Ethical approval was taken from the local Clinical Research Ethics Committee and an informed consent was also obtained from all participants.

PLANTAR PRESSURE ASSESSMENT

Plantar pressure data were collected at a sampling frequency of 300 Hz using the pressure plate (0.5 m × 0.4 m, with 4,096 resistance sensitive sensors, 4 sensors/cm^2) (Footscan® RSscan International, Olen, Belgium). The pressure plate was calibrated for each subject, according to instructions of the manufacturer, using their bodyweight recorded before each test session. Subjects were asked to stand still on the plate with their head upright, facing straight ahead and their arms at their sides to make a static recording of both feet to determine the relative pressure-loads (%) between preferred and non-preferred foot while standing. Subsequently, for dynamic plantar pressure measurements, all subjects asked to walk barefoot for 10 times at their preferred walking speed over the pressure plate, alternating with the left and right foot. Average values of three valid trials gathered from left and right foot were analyzed to ensure adequate reliability of pressure data.[28] Dynamic data were recorded at the stance phase of gait.[29] All data were analyzed by the Footscan 7 gait 2nd generation software. According to De Cock et al. temporal plantar pressure variables measured with the Footscan pressure plate are reliable with ICC values >0.75.[20]

Ten anatomical pressure areas were semiautomatically identified according to the geometric criteria, based on the peak pressure footprint. These areas were: medial and lateral heel (HM and HL), midfoot (MF), metatarsal areas (M1-M5), hallux (T1) and the remaining toes (T2-5) (Figure 1). Total contact time, peak pressure (PP), absulute impulses (pressure time integrals) and relative impulses (as % of summed impulses) beneath these areas were calculated.[20,30] Peak pressure point outs the local high pressures of the plantar skin and soft tissue. However, regional impulse (pressure time integral) unites the amplitude and duration of loaded pressure. It also has been revealed to be worthful index for the qualification of localized foot loading and comprehending of foot function.[32,33]

For each walking performance, total foot contact time and five temporal characteristics of foot rollover were determined: first foot contact (FFC), first metatarsal contact (FMC), forefoot flat (FFF), heel-off (HO) and last foot contact (LFC). Based on these five events, total foot contact time could be separate into four phases: initial contact phase (ICP; from FFC to FMC), forefoot contact phase (FFCP; from FMC to FFF), foot flat phase (FFP; from FFF to HO) and forefoot push-off phase (FFPOP; from HO to LFC).[20]

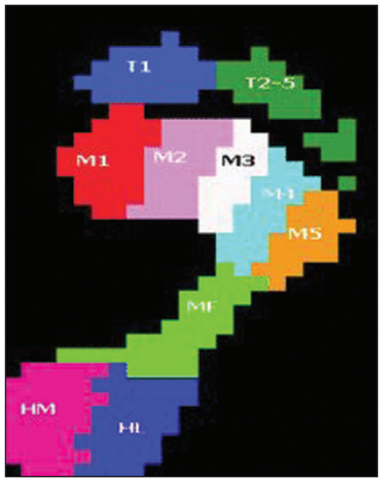

FIGURE 1: The location of ten anatomical sub-areas on the peak pressure footprint (Footscan software 7, RsScan International).
HM: Medial heel; HL: Lateral heel; MF: idfoot; M1-M5, metatarsal areas, T1: hallux; T2-5: remaining toes.

The symmetry index for peak pressure was calculated according to the following formula.[18] This index was used to verify the degree of asymmetry between the preferred and non-preferred foot for plantar pressure characteristics.

$$\text{Symmetry index} = \frac{2 \text{ x (preferred foot-non preferred foot)}}{\text{(preferred foot + non preferred foot)}} \text{ x } 100$$

The average of symmetry index of the group was analyzed and data were presented as means (SD). Zero, represented perfect symmetry between the preferred and non-preferred foot, positive percentage values indicate asymmetry favoring the preferred foot and negative percentage values indicate asymmetry favoring the non-preferred foot.[34]

STATISTICS

Shapiro Wilk test was carried out to test convenience of normal distribution for permanent data. According to the results obtained from this test, parametric methods were used as necessary. Otherwise nonparametric methods were used. If the distribution assumption was provided, summary statistics for permanent data were summarized as mean (standard deviation, SD), if not, statistics were presented as median (minimum-maximum). For paired sample comparison, if assumption was provided, paired sample t test was used. If not provided, Wilcoxon test was used. Statistical analysis was performed using the Statistical Package for Social Sciences, version 11.5 (SPSS, Inc,Chicago, IL) and MedCalc version 11.5.0. $p<0.05$ was considered statistically significant.

TABLE 1: Descriptive characteristics of participants (Mean (SD)).

N=11	Mean (SD)
Age (years)	19.36 (2.46)
Body weight (kg)	60.90 (8.21)
Body height (cm)	172.77 (6.09)
BMI (kg/m^2)	20.35 (2.07)
Training duration (years)	10.27 (2.90)

RESULTS

Descriptive characteristics of participants are listed in the Table 1. All athletes have the same weekly training hours (2 hr/day/week).

No statistically significant differences were found between the preferred and non-preferred foot relative pressure-loads (%) in the static pedobarographic measurements (48.18±3.4% and 51.81±3.4% respectively, p=0.107).

During the mid-stance phase, mean and standard deviations for peak pressure, absolute impulse and relative impulse result of the different regions for both preferred and non-preferred foot across all 11 athletes are presented in Table 2. Peak pressures of M1 for preferred and non-preferred foot were 2.35 (0.80-7.35) N/cm^2 and 2.95 (1.65-6.70) N/cm^2 respectively, (p=0.091). Absolute impulses of M1 were similar in both preferred and non-preferred foot, 0.65 (0.2-2.0) and 0.70 (0.40-1.90), respectively, (p=0.538). Relative impulses of M1 were also similar in both preferred and non-preferred foot (8.33 (2.56-25.64) and 8.00 (4.57-21.71), respectively, (p=0.534). No significant differences were found between foots in the peak pressure underneath the ten anatomical areas. The absolute impulse underneath the M2 was significantly higher at preferred foot (p=0.048) while absolute impulse of lateral heel was higher at non-preferred foot (p=0.038; Table 2). The relative impulse of M2 and M3 were also significantly higher at preferred foot (p=0.001 and p=0.006).

No perfect peak pressure symmetry between preferred and non-preferred foot was observed. The asymmetries of peak pressure were found in the favor of non-preferred foot except at the region of T1, T2-4 and M2. The highest asymmetry was found at M1 area (-28.87%±52.46) and followed by M5 (-7.99 % ± 60.81) and HM (-5.75%±16.89) (Figure 2).

TABLE 2: The peak pressure (PP), absolute impulses (AI; pressure time integrals) and relative impulses (RI; as % of summed impulses) of preferred and non-preferred foot.

	Peak Pressure (N/cm^2)		Absolute Impulse (N.s/cm^2)		Relative Impulse (%)	
	Preferred	Non-Preferred	Preferred	Non-Preferred	Preferred	Non-Preferred
T1	3.15 (0.99)	3.06 (0.94)	0.60 (0.30)	0.50 (0.22)	6.81 (3.56)	5.18 (2.59)
T2-5	1.00 (0.65)	1.02 (0.70)	0.15 (0.14)	0.14 (0.14)	1.84 (1.71)	1.46 (1.35)
M1	2.68 (1.77)	3.40 (1.42)	0.70 (0.47)	0.79 (0.43)	7.81 (4.39)	8.37 (4.71)
M2	5.72 (1.29)	5.58 (1.06)	1.55 (0.34)	1.42 (0.25)*	17.58 (2.77)	14.46 (2.05)*
M3	7.02 (1.87)	7.19 (1.63)	2.03 (0.61)	1.95 (0.56)	22.71 (4.82)	19.38 (3.32)*
M4	5.33 (2.09)	5.75 (2.34)	1.62 (0.86)	1.61 (0.75)	17.84 (7.34)	15.59 (5.70)
M5	2.50 (1.05)	2.82 (1.36)	0.70 (0.38)	0.69 (0.31)	7.84 (3.60)	6.78 (2.55)
MF	1.43 (0.29)	1.59 (0.50)	0.35 (0.16)	0.38 (0.13)	4.23 (2.35)	4.02 (1.80)
HM	5.57 (0.90)	5.89 (0.90)	1.10 (0.29)	1.27 (0.27)	12.47 (2.18)	13.03 (3.06)
HL	5.16 (1.00)	5.18 (0.81)	1.03 (0.30)	1.15 (0.25)*	11.52 (2.22)	11.68 (1.98)

The data presented are mean values (SD). * $p<0.05$. T1: hallux; T2-5: Remaining toes; M1-M5: Metatarsal areas; MF: Midfoot; HM: Medial heel; HL: Lateral heel.

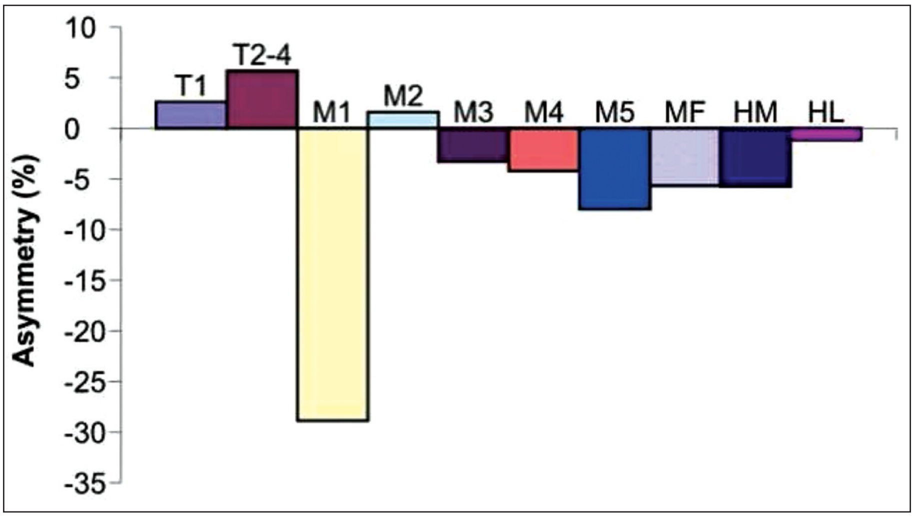

FIGURE 2: Averaged symmetry index (%) of peak pressure. Zero represent symmetry between preferred and non-preferred foot; positive percentage values represent higher peak pressure in the preferred foot, and negative percentage value represent higher peak pressure in the non-preferred foot.
HM: Medial heel; HL: Lateral heel; MF: Midfoot; M1-M5: Metatarsal areas; T1: hallux; T2-5: Remaining toes.

Mean and S.D. of temporal characteristics of the foot roll-over during walking are presented in Figure 3. There were no statistically differences between preferred and non-preferred foot neither in total contact time (686±55 ms and 686±48 ms, respectively) nor in temporal characteristics (p>0.05).

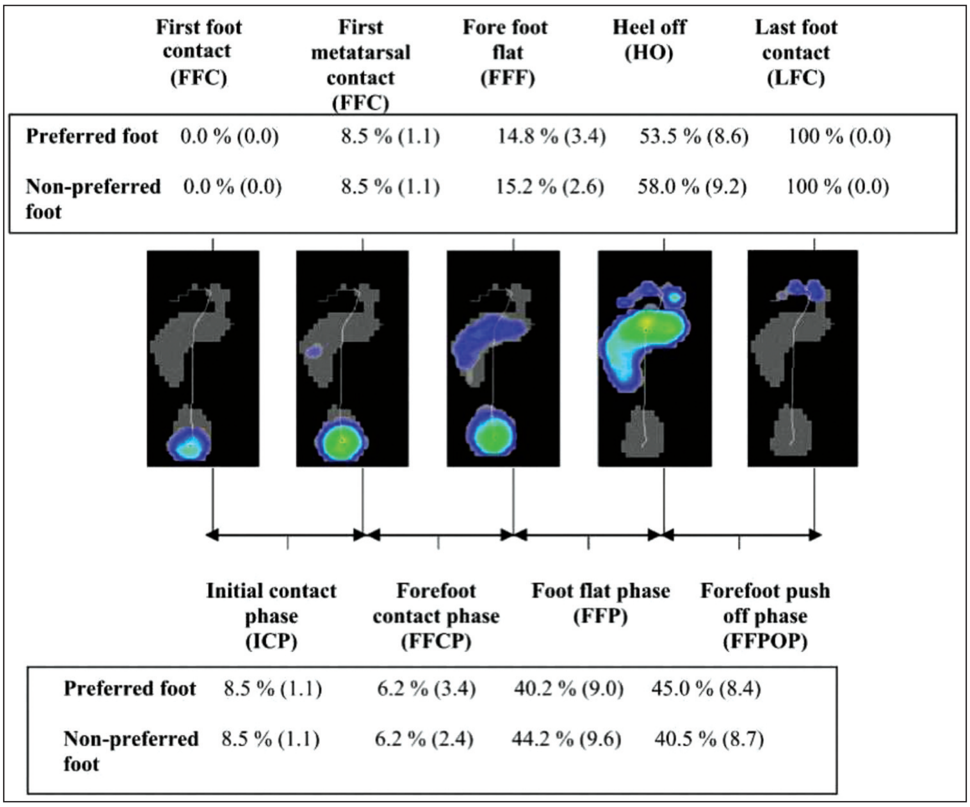

FIGURE 3: Mean (SD) timing of five distinct instants and phases relative to total foot contact time.

Initial contact phase during walking begins with FFC (0%) and ends up after 8.5% at FMC, which is the start of the FFCP and responsible for the following 6.2% of stance phase for both feet. The foot maintains contact with the ground till FFF is at 14.8% for preferred foot and 15.2 for non-preferred foot. Then, for preferred foot 40.2% and for non-preferred foot 44.2% of total foot contact time, the foot was at the FFP. After HO, the remaining duration of total foot contact time, the FFPOP, ended with 45.0% for preferred foot and 40.5% for non-preferred foot.

DISCUSSION

The current study intended to analyze the differences of plantar pressure and temporal characteristics between preferred and non-preferred foot in elite taekwondo athletes. Plantar pressure assessments are commonly used both in biomechanical research and clinical practice to evaluate the interaction between foot and plantar surface during the gait cycle. In generally, only one foot analyzed for plantar pressure investigation according to the previous data supposed that there were no significant differences between the right and left foot in pedobarographic assessment and gait biomechanics.[35,36]

While dynamic pedobarography provides insight into the plantar pressure parameters during dynamic activities such as walking and running, static pedobarography gives plantar pressure data in standing position.[19] In this study, there were no significant differences between preferred and non-preferred foot regarding the relative pressure-loads (%) in static condition. This means that taekwondo athletes show similar weight distribution at both feet. Similarly, this report revealed that in dynamic condition (walking), peak pressures beneath the preferred and non-preferred foot was not statistically different. The highest PP values were found under the M2, M3, M4 heads and heel zones at both feet. These findings are in agreement with the studies of Bryant et al. and Hughes et al.[33,37]

Metatarsalgia may occur as a result of repetitive loading on metatarsal heads. Unbalanced distribution of load may be a reason of stress fractures and may lead to high pressure on metatarsal heads.[36] The results of this study showed that the absolute impulse of M2 was significantly higher at preferred foot. The second metatarsal is the most frequently fractured bone and carries the greatest loads during gait, compared to the other metatarsals.[38] It was declared that M2 has an important weight-bearing function on load distribution in the forefoot.[39,40] Restricted normal range of motion of M2 in the tarsometatarsal joint, compared to a flexible first ray may clarify the higher absolute impulse underneath M2.[20,39] Together with the longer contact duration of M2 during rollover, this may be the part of the explanation for higher impulse of M2.[20] By means of these specific features, M2 has become a crucial propulsive structure. It is believed that increased pressured beneath the foot areas will be lead to some mechanical foot problems such as metatarsalgia.[36] Metatarsal injuries and fractures are relatively common injury that may affect the foot function and performance.[41,42] The M2 and M3 are prone to stress fractures if subject has a low or collapsed longitudinal arch or other foot disabilities. These pathologies change the weight bearing of the foot because of the extreme stress loading on these metatarsals.[41]

The heel was divided in two zones as medial and lateral heel for the purpose of performed more detailed analyses. In this study the absolute impulse of lateral heel was higher at non-preferred foot. It was indicated that higher impulse underneath the lateral side of heel was related with functionally unstable ankles.[43] On the other hand, in a research that investigated the relationship between gait biomechanics and inversion sprains it was presented that peak pressure and the impulse at the heel were not significantly different between controls and the inversion sprain group.[30] Foot and ankle injuries do not only occur during walking or running but also be seen during lateral cutting and side-shuffle movements and landing from a jump. Sadeghi et al. stated that preferred limb is more responsible for forward propulsion, whereas non-preferred limb has an important role for support and stability during walking in young people.[44,45] As the preferred foot is the attack foot and non-preferred foot is responsible for postural control and stability in taekwondo athletes, higher absolute impulse value of M2 against to preferred foot and higher absolute impulse value of lateral heel against to non- preferred foot should be considered to avoid injuries. It was also suggested that limb preference might be an important factor in the etiology of some pathology of knee.[11] On the grounds of these results, it would be reasonable to plan an exercise program and rehabilitate the preferred and non-preferred foot independently.

Furthermore, according to result of this study, the symmetry index for peak pressure indicated that no perfect symmetry between the preferred and non-preferred foot, which ranged from -28 to 5. The asymmetry seen in the healthy people indicates that foot function of normal foot may require a little degree of plantar pressure asymmetry.[41] However, there is no normal range of asymmetry for plantar pressure distribution to compare the result of asymmetry. The peak pressure asymmetries were found in the favor of non-preferred foot except beneath the T1, T2-4 and M2 areas. Although there were no significant differences between preferred and non-preferred foot with regard to peak pressure distribution, this asymmetry indicates more loading on non-preferred foot responsible for postural control and stabilization. To our knowledge, there is no study that investigated plantar pressure distribution differences and also asymmetry between preferred and non-preferred foot in taekwondo athletes. Some researchers investigated the differences between legs in respect to only kinematics characteristics. According to Tang et al., the symmetric abilities are very crucial for being elite in taekwondo.[8] In general, these athletes have preference of one dominant specific leg to kick during training and competition, which does not let us to classify this sport as asymmetric.[8] Pedzich et al. stated higher stroke force values on the preferred side during side-kick (yop-chagi) and spinning back kick (dwit-chagi).[46] In line with, Peng et al. demonstrated that the preferred leg was faster than non-preferred leg during roundhouse kick (Peng CT. [The difference of strength and the speed, balance between the dominant and non-dominant leg during the roundhouse kick of taekwondo athletes] Unpublished doctoral dissertation, 2006). On the contrary, it was detected that there was no statistically differences between preferred and non-preferred leg in movement time and kicking speed during the same kick type.[8] In addition, there were also no statistically differences between two legs in hip angular velocity, knee angular velocity and ankle angular velocity in Tang et al.'s study.[8] The differences between these results of the researches may be caused by the age differences of athletes and procedure used during the data collection.

Another purpose of the current study was to compare the temporal characteristics of foot roll-over during walking in preferred and non-preferred foot at taekwondo athletes. The outcome of this study indicated that all temporal variables relative to the total foot contact duration were similar for preferred and non-preferred foot. Both preferred and non-preferred foot spend similar time in all phases. Gait is generally supposed to be symmetrical. In previous researches, it was detected that there was no statistically differences between right and left legs with regard to spatio-temporal variables (stride, swing and stance duration) during walking at self-selected speed.[47,48] Comparing the current findings with literature about foot roll-over in walking at healthy adults revealed some similarities and differences. During self-selected walking the ICP in our study and in the study of Blanc et al. has almost similar relative duration (8.5% and 8.8% respectively).[49] However, FFCP was shorter in our study (6.2% against 29.1% in Blanc's study), which means that metatarsal contact from lateral to medial occurs faster. Our data also differs from normative data for healthy adults in that it has an earlier HO (53.5% for preferred foot and 58% for non-preferred foot against 64% in walking).[49] This result implies a comparatively faster weight transfer from hind foot to forefoot. In the present study, an earlier weight transfers from hind foot to fore foot occurred during walking, as well as a faster weight shift from lateral to medial. Although temporal characteristics of foot roll-over during walking were not statistically different in boot feet, there were some differences according to normative data stated by Blanc et al. We concluded that this difference might be originated from the athletic characteristics of our subjects.[49]

CONCLUSION

The finding of present study indicates that the peak pressure beneath the preferred and non-preferred foot is not symmetrical. In general, higher pressure is determined in the non-preferred foot. High plantar pressure is known to be crucial for the occurrence of foot pathology. On the grounds of the symmetry is important in respect to provide an advantage during in both kicking and defending at training/competition in elite taekwondo athletes, the preferred and non-preferred foot should be evaluated separately for rehabilitation/exercise programs to reduce the bilateral differences and also to avoid injuries in taekwondo.

Conflict of Interest

Authors declared no conflict of interest or financial support.

Authorship Contributions

***Concept:** Figen Dağ, Ayhan Taner Erdoğan; **Design:** Figen Dağ, Ayhan Taner Erdoğan; **Supervision:** Figen Dağ, Ayhan Taner Erdoğan, Uğur Dal; **Data collection and/or processing:** Figen Dağ, Ayhan Taner Erdoğan; **Analysis and/or interpretation:** Figen Dağ, Ayhan Taner Erdoğan, Didem Derici Yıldırım, Uğur Dal; **Literature Search:** Figen Dağ, Ayhan Taner Erdoğan; **Writing manuscript:** Figen Dağ.*

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