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# The Relationship between Plantar Pressure Distribution and Balance in Adolescent Taekwondo Athletes

## Adolesan Taekwondo Sporcularında Plantar Basınç Dağılımı ile Denge Arasındaki İlişki

Research Article / Araştırma Makalesi

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## Abstract

The purpose of this research was to examine the relationship between plantar pressure distribution and balance in adolescent taekwondo athletes. Twenty-three adolescent taekwondo athletes participated in the study voluntarily. Pedobarographic method was used to determine the plantar pressure and plantar force. Flamingo balance test for static balance and lower quarter Y balance test for dynamic balance were applied. Pearson correlation test was used to determine the relationship between plantar pressure distribution and balance. A moderate significant negative relationship between the non-dominant leg static balance and the plantar pressure at the forefoot of the athletes (r=-.466, p=.025), and a moderate significant positive relationship with the plantar pressure at the rearfoot (r=.466, p=.025) was determined. There was a moderate positive correlation between the dynamic balance ability and the dynamic plantar force during walking in the anterior direction (r=.552, p=.008) and a high positive correlation in the posteromedial direction (r=.656, p<.001) in the dominant leg; moderate positive correlation (r=.483, p=.020) in the posteromedial direction and moderate positive correlation in the posterolateral direction (r=.437, p=.037) was observed in the non-dominant leg of participants. As a result, plantar pressure distribution and force were associated with static and dynamic balance in adolescent taekwondo athletes. It is recommended that plantar pressure data should not be ignored during the developmental period in adolescent taekwondo athletes, possible plantar disorders should be followed and balance exercises should be added to training in order to have optimal plantar pressure distribution.

Keywords: Taekwondo, Dynamic balance, Static balance, Plantar pressure, Pedobarography

## Öz

Bu araştırmanın amacı adolesan taekwondo sporcularında plantar basınç dağılımı ile denge arasındaki ilişkinin incelenmesidir. Araştırmaya yirmi üç adolesan taekwondo sporcusu gönüllü olarak katılmıştır. Plantar basınç ve plantar kuvvetini belirlemek amacıyla pedobarografik yöntem kullanılmıştır. Statik denge için flamingo denge testi ve dinamik denge için alt ekstremite Y denge testi uygulanmıştır. Plantar basınç dağılımı ve denge arasındaki ilişkinin belirlenmesi için Pearson korelasyon testi kullanılmıştır. Sporcuların baskın olmayan bacak statik denge ile ayakların ön kısmına uyguladıkları plantar basınç arasında orta düzeyde anlamlı negatif ilişki (r=-.466, p=.025) ve ayakların arka kısmına uyguladıkları plantar basınç arasında orta düzeyde anlamlı pozitif ilişki (r=.466, p=.025) tespit edilmiştir. Katılımcıların dinamik denge performansı ile yürüyüş esnasındaki dinamik plantar kuvvet arasında baskın bacak anterior yönde orta düzey (r=.552, p=.008) ve posteromedial yönde yüksek pozitif ilişki (r=.656, p<.001); baskın olmayan bacakta posteromedial yönde orta düzey (r=.483, p=.020) ve posterolateral yönde orta düzey pozitif ilişki (r=.437, p=.037) elde edilmiştir. Sonuç olarak adölesan taekwondocularda plantar basınç dağılımı ve kuvvetinin, statik ve dinamik denge ile ilişkilidir. Adölesan taekwondocularda, gelişim döneminde plantar basınç verilerinin göz ardı edilmemesi, olası ayak taban rahatsızlıklarının takip edilmesi ve plantar basınç dağılımının optimal olması için denge çalışmalarının antrenmanlara eklenmesi önerilmektedir.

Anahtar Kelimeler: Taekwondo, Dinamik denge, Statik denge, Plantar basınç, Pedobarografi

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## Introduction

Taekwondo is a martial art that incorporates kicking and punching techniques practiced in Korea and includes competitions in the poomsae and kyorugi categories (Haddad, Ouergui, Hammami & Chamari, 2015). In the kyorugi competition of taekwondo, in 3 rounds (2 minutes per round) for a total of 6 minutes, the athletes hit their opponents powerfully and quickly within the framework of the rules. 80% of taekwondo skills are related to kick strokes, so kickings increase the demands of lower extremity strength (Ball, Nolan & Wheeler, 2011). This lower extremity strength is an important factor for the proper application of techniques during competition (Aziz, Tan & Teh, 2002; Ball et al., 2011).

Taekwondo athletes exhibit a lot of asymmetrical activity during training and competition when applying quick kick techniques. Therefore, unilateral stance stability is very important for taekwondo athletes. In addition, the ability of balance and postural control is a decisive factor for the performance of taekwondo athletes in competitions. Taekwondo athletes change their body position and distance from the opponent by stepping in different directions during competitions as well as kicking and their attacks against the opponents must contain balanced movement patterns (Pieter & Heijmans, 2000; Rabello et al., 2014). Athletes must not fall to the ground in order not to lose points (Canbolat Güder, 2022). Besides, uncontrolled and sudden movements may increase the possibility of injury in athletes. Hence, it is important for them to develop their balance ability for high performance (Güder & Günay, 2019; Leong, Fu, Gabriel & Tsang, 2011; Suzana & Pieter, 2009; Yoon, Sung & Park, 2015). In taekwondo competitions, due to the contact with the opponent and the compelling technical movement patterns, the athletes' attempt to score points by jumping, sliding or turning with their foot towards the opponent's trunk or upper body while standing on one foot depends on the balance ability of the athletes. This situation also affects the technical skill of the athlete (Falco et al., 2009; Pieter & Heijmans, 2000).

Especially in sports events, the function of the foot sole has gained greater importance (Ackland, Elliott & Bloomfield, 2009). The foot sole is designed for strength, flexibility and coordinated movements. The main role of these body parts is to transfer the force so that motor activities such as walking, running and jumping can ocur (Wong et al., 2007). Most of the force in the body is produced by the pressure exerted by the foot on the ground, and continues through all segments such as muscles, joints and bones (Rad & Aghdam, 2012). In this context, it is necessary to understand the relationship between foot structure and motor function. Variations in structure and associated function among individuals have the potential to affect the abilities of elite athletes (van Werkhoven & Piazza, 2017). There is a strong relationship between maximal pressure increase on the foot sole and excessive body sway to the right or left, poor balance, weakening of the sensory functions of the lower limbs, deterioration and increasing age (Lord, Ward, Williams & Anstey, 1994).

Plantar pressure differences caused by unbalanced anatomical positions are the reason of anomalies in the human body and muscle joint system. These repetitive abnormal effects are also the primary cause of spinal disorders and an association has been found with increased pressure in various areas of the foot sole (Park et al., 2009). Although there are studies examining plantar pressure (Mocanu, Iordan, Mocanu, Cojocaru & Nechifor, 2021a; Mocanu, Murariu, Iordan & Sandu, 2021b; Zvonar, Lutonska & Reguli, 2012) and balance (Morales et al., 2018; Pirani et al., 2014; Zago et al., 2015) in other combat sports, interestingly there are very few studies on plantar pressure (Entezari, Memar & Kakavand, 2017) and balance (Choi, Jung & Park, 2021; Rabello et al., 2014) in taekwondo athletes. In some studies, the effect of different training programs on balance in taekwondo players was investigated (İpekoğlu et al., 2018, Tayshete, Akre, Ladgaonkar & Kumar, 2020, Yoon et al., 2015). To the best of authors' knowledge there was no study examining the relationship between plantar pressure and balance in taekwondo. However, the determination of foot sole deformities and plantar pressure in adolescent athletes in the developmental period can be an important predictor for both health status and taekwondo performance in later ages of the athletes. For this reason, it is necessary to investigate these parameters and to determine the relationship between them. We hypothesized that there was significant relationship between plantar pressure and balance in adolescent taekwondo players. Therefore, in this study, it was aimed to determine the relationship between plantar pressure and balance in adolescent taekwondo players.

## Methods

### *Participants*

A total of 23 taekwondo athletes ($n_{girls}$=12, and $n_{boys}$=11) aged 11-14 participated in the study voluntarily. Inclusion criteria for the study were (a) to be a taekwondo athlete between the ages of 11-14 (to be an athlete in the little or youth category) (b) to have at least 6 months of training experience (c) to regularly participate in taekwondo training three days a week for the last six months. Exclusion criteria in the study were (a) not participating in any of the tests (b) existing musculoskeletal disorders or physical disability, which may affect the research data, (c) previous lower extremity surgery. The study started with 24 athletes, and one female participant was excluded because she was not included in the dynamic plantar strength test. Before the measurement, the dominant legs of the athletes were questioned. Kicking legs are considered the dominant leg. While the dominant leg of a boy and a girl from the

participants was left, the dominant legs of all remaining athletes were right.

### Data Collection

Plantar pressure distribution and balance measurements were taken with bare foot before two training units on two different days. Static plantar pressure and dynamic plantar force were measured in one training session, followed by static balance and dynamic balance on the next training day, respectively. Each participant was informed about the test protocol and familarization was performed before the measurements.

In order to determine the characteristics of the participants, body height was measured with a SECA brand stadiometer (Seca, Hamburg, Deutschland) which has a scale that displays measurements in millimetres, and body mass was measured with a bioimpedance analyzer (Tanita BF350, Tanita Corporation, Arlington Heights, IL, USA) with a sensitivity of 0.1 kg.

### Plantar Pressure Distribution and Plantar Force

Plantar pressure distribution and plantar force of the participants were obtained by pedobarographic method with FootScan device (RS Scan FootScan v9 hı IvI, RS Scan International, Belgium). This device consists of a flat mat (1 m long and 50 cm wide) laid on the ground and a software synchronized with this mat. On this mat, the athletes first performed a standing upright posture and were asked not to move during this time. Percentages of plantar pressure distribution according to foot regions (as forefoot and rearfoot) in standing upright stance was recorded and evaluated as static plantar pressure data. All data were taken separately for both the dominant and non-dominant sides at once. The parameters included in the static plantar pressure are distribution of forefoot, rearfoot and total pressure (Figure 1) on one side, and forefoot plantar pressure on both sides (= dominant + non-dominant side forefoot plantar pressure) and rearfoot plantar pressure on both sides (= dominant + non-dominant side rearfoot plantar pressure).

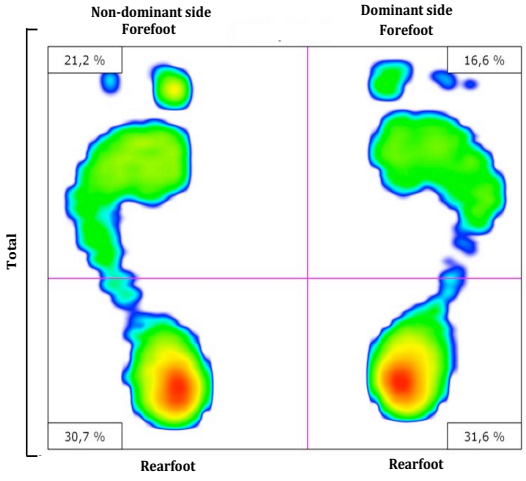


**Figure 1.** Forefoot, rearfoot and total plantar pressure distribution

For dynamic plantar force, participants were asked to walk forward on this mat. During this walk, it was stated that they should not alter their gait and be comfortable. Among the plantar force data obtained depending on time during walking, the highest force (peak force) was recorded in Newton (N) unit as the plantar force parameter of the participants. This data was determined separately for both the dominant and non-dominant side.

### Static Balance

Flamingo balance test was used for static balance. While the participants were balancing with one foot on a metal balance beam, they bent the other foot back from the knee, pulled it towards the hip and held it with the hand on the same side. In this position, the athletes tried to stay in balance while maintaining her body integrity, and as soon as the correct position was achieved, the time was started with a stopwatch. Participants were asked to maintain this steady state for 1 min. When the balance is lost (if the foot is left while holding it with the hand, falling from the balance board, touching the ground with any part of the body, etc.), the timer was stopped. When the athlete got on the balance beam and regained his balance, the time was restarted from where he left off. The test continued in this way for one minute, and the number of times the athlete stopped the timer for one minute was recorded as the static balance score. After this test was completed for one side, it was applied to the other side as well. After the test was applied to both sides, it was repeated two more times and the average of three trials was recorded.

### Dynamic Balance

Lower quarter Y balance test (YBT; Move2Perform, Evansville, IN) was used for dynamic balance according to criteria described by Plisky et al. (2009). In this test, the athletes were asked to lie on the Y-shaped strip on the floor (angle of 135 degrees between the anterior and posterior directions and 90 degrees between the posterior directions) while balancing with one foot, while reaching out in the directions (anterior, posteromedial, posterolateral) determined with the other foot. Maximum reach percentage normalized by dividing reach distances by leg length. The composite score was calculated by dividing the sum of the three directions by three times the leg length. Dynamic balance was applied 3 times in each direction. Scores were recorded separately for the dominant and non-dominant leg. Internal reliability of this test was reported as excellent (ICC=0.88–0.99, p≤0.01) (Feizolahi & Azarbayjani, 2014).

### Data Analysis

Data analysis was performed using SigmaPlot 11.0 (Systat Software, Inc., San Jose, USA) software. The normality of the distribution of the data was determined by the Shapiro Wilk test. Descriptive statistics of the data are presented in tables with mean, standard deviation, minimum value, maximum

value and 95% confidence interval (CI). Pearson correlation test was used to determine the relationship between static balance and static plantar pressure, dynamic balance and dynamic plantar force. If the correlation coefficient is less than 0.2, it is considered as a very weak relationship or no relationship, a weak relationship between 0.2-0.4, a moderate relationship between 0.4-0.6, a high relationship between 0.6-0.8, and a very high relationship if it is greater than 0.8. The significance level was accepted as 0.05.

### *Ethics Statement*

Before the measurements, the athletes were instructed about the research and written informed consent was taken from their parents. The study was performed according to the World Medical Association Declaration of Helsinki and approved by the Ethics Commission of Gazi University (Research Code: 2022-1221).

## Findings

The characteristics of the participants are presented in Table 1.

**Table 1.** Characteristics of the participants

| | Mean±SD | Min | Max | 95%CI |
|---|---|---|---|---|
| Age (years) | 12.0±1.3 | 11 | 14 | 11.5-12.5 |
| Age of experience (years) | 2.5±2.1 | 0.6 | 9 | 1.6-3.4 |
| Body height (cm) | 149.3±11.2 | 128 | 167.9 | 144.7-153.9 |
| Body mass (kg) | 44.2±13.0 | 24 | 77.5 | 38.9-49.5 |

Participants applied higher pressure to the ground on the non-dominant side (23.3±8.1% in the forefoot, 30.1±6.0% in the rearfoot, 52.2±5.0% in the total, respectively) compared to the dominant side (20.7% in the forefoot, 27.1±% in the rearfoot, 47.8±5.0% in the total, respectively) in static stance (Table 2).

**Table 2.** Static balance and static plantar pressure distiribution of the adolescent taekwondo athletes

| | Mean±SD | Min | Max | 95%CI |
|---|---|---|---|---|
| ***Static balance*** | | | | |
| Dominant (no. of falls) | 14.6±4.8 | 5.7 | 25.3 | 12.6-16.6 |
| Non-dominant (no. of falls) | 14.7±4.3 | 7.3 | 23.0 | 12.9-16.5 |
| **Plantar pressure distribution** | | | | |
| *Non-dominant foot* | | | | |
| Forefoot | 23.3±8.1 | 10.7 | 49.1 | 20.0-26.6 |
| Rearfoot | 30.1±6.0 | 18.2 | 41.9 | 27.6-32.6 |
| Total | 52.2±5.0 | 42.1 | 59.1 | 50.2-54.2 |
| *Dominant foot* | | | | |
| Forefoot | 20.7±5.2 | 12.2 | 34 | 18.6-22.8 |
| Rearfoot | 27.1±5.9 | 16.7 | 38.9 | 24.7-29.5 |
| Total | 47.8±5.0 | 40.9 | 57.9 | 45.8-49.8 |
| *Forefoot in both feet* | 42.8±9.1 | 26.2 | 61.5 | 39.1-46.5 |
| *Rearfoot in both feet* | 57.2±9.1 | 38.5 | 73.8 | 53.5-60.9 |

In adolescent taekwondo athletes, no significant relationship was found between static balance and static plantar pressure in the dominant and non-dominant legs. A moderate significant negative relationship (r=-.466, p=0.025) between the non-dominant leg static balance and the plantar pressure applied to the forefoot of the athletes (r=-.466, p=0.025), and a moderate significant positive relationship with the plantar pressure applied to the back of the feet (r=0.466, p=0.025) was determined (Table 3).

**Table 3.** The relationship between static balance and static plantar pressure of adolescent taekwondo athletes

| | Static balance | | | |
|---|---|---|---|---|
| | Dominant | | Non-dominant | |
| ***Plantar pressure (%)*** | r | p | r | p |
| Dominant | -.093 | .673 | -.290 | .179 |
| Forefoot | .387 | .068 | .226 | .300 |
| Rearfoot | .360 | .092 | -.308 | .152 |
| Total | -.367 | .085 | -.466 | .025 |
| Forefoot *in both feet* | .367 | .085 | .466 | .025 |
| Rearfoot *in both feet* | -.093 | .673 | -.290 | .179 |

Non-dominant leg dynamic balance of adolescent taekwondo athletes was higher than dominant leg in all directions. Participants' dynamic plantar strength was minimally higher on the non-dominant side than on the dominant side (613.7±163.6 N vs. 610.3±149.2 N, respectively) (Table 4).

**Table 4.** Static balance and static plantar force of the adolescent taekwondo athletes

| | Mean±SD | Min | Max | 95%CI |
|---|---|---|---|---|
| ***Dynamic balance*** | | | | |
| Dominant | | | | |
| Anterior (cm) | 60.3±7.1 | 48 | 74 | 57.4-63.2 |
| Posteromedial (cm) | 65.8±10.8 | 47 | 87 | 61.4-70.2 |
| Posterolateral (cm) | 61.5±10.0 | 40 | 81 | 57.4-65.6 |
| Anterior reach (%) | 78.7±7.0 | 65.3 | 98.4 | 75.8-81.6 |
| Posteromedial (%) | 85.8±12.1 | 62.7 | 111.1 | 80.8-90.7 |
| Posterolateral (%) | 80.2±12.5 | 61.5 | 98.4 | 75.1-81.3 |
| Composite score | 81.5±9.3 | 63.6 | 102.6 | 77.7-85.3 |
| Non-dominant | | | | |
| Anterior (cm) | 62.0±7.9 | 47 | 76 | 58.8-65.2 |
| Posteromedial (cm) | 66.6±11.0 | 50 | 83 | 62.1-71.1 |
| Posterolateral (cm) | 61.6±11.5 | 40 | 80 | 56.9-66.3 |
| Anterior reach (%) | 81.5±9.9 | 62.7 | 111.3 | 77.5-85.6 |
| Posteromedial (%) | 87.3±12.6 | 66.7 | 122.6 | 82.2-92.5 |
| Posterolateral (%) | 80.7±13.9 | 53.3 | 114.5 | 75.1-86.4 |
| Composite score | 83.2±11.3 | 60.9 | 116.1 | 78.6-87.8 |
| ***Plantar force*** | | | | |
| Dominant (N) | 610.3±149.2 | 396 | 904.3 | 549.3-671.3 |
| Non-dominant (N) | 613.7±163.6 | 332.5 | 1015.6 | 546.8-680.6 |

There was a moderate positive correlation between the dynamic balance ability and the dynamic plantar force during walking in the anterior reach (r=0.552, p=0.008) and a high positive correlation in the posteromedial reach (r=0.656, p<0.001) in the dominant leg; moderate positive correlation (r=0.483, p=0.020) in the posteromedial reach and moderate positive correlation in the posterolateral reach (r=0.437, p=0.037) was obtained in the non-dominant leg of participants (Table 5).

**Table 5.** The relationship between dynamic balance and dynamic plantar force of adolescent taekwondo athletes

| | Plantar force (N) | | | |
|---|---|---|---|---|
| | Dominant | | Non-dominant | |
| ***Dynamic Balance*** | r | p | r | p |
| Anterior (cm) | 0.552 | 0.008 | 0.396 | 0.061 |
| Posteromedial (cm) | 0.656 | <0.001 | 0.483 | 0.020 |
| Posterolateral (cm) | 0.393 | 0.070 | 0.437 | 0.037 |
| Anterior reach (%) | 0.167 | 0.458 | -0.003 | 0.989 |
| Posteromedial (%) | 0.409 | 0.059 | 0.206 | 0.345 |
| Posterolateral (%) | 0.143 | 0.527 | 0.202 | 0.355 |
| Composite score | 0.552 | 0.008 | 0.396 | 0.061 |

## Discussion

In this study, it was aimed to determine the relationship between plantar pressure distribution and balance in adolescent taekwondo athletes. Plantar pressure distribution and plantar strength were significantly associated with static and dynamic balance performance in adolescent taekwondo athletes. Although plantar pressures show individual differences in the participants, plantar disorders were determined in half of them (Figure 2).

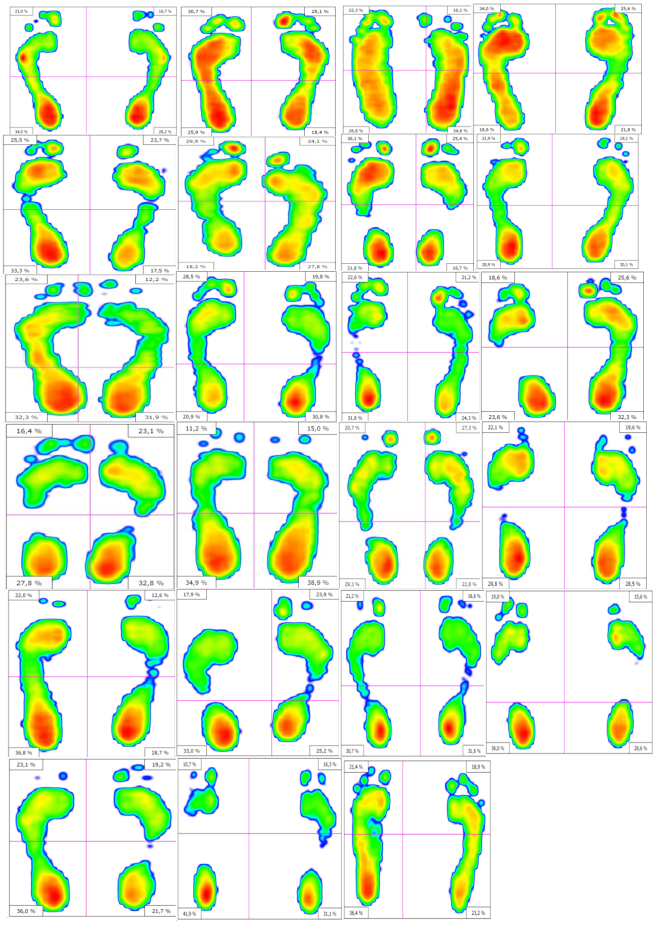

**Figure 2.** Plantar pressure distributon of the taekwondo athletes

Demirbüken et al. (2019) reported that gender and age factors have an effect on toe plantar pressure in adolescents. It has also been predicted that plantar pressure changes in early adolescence may cause further deterioration of the foot. In our study, plantar pressure data were not evaluated based on the gender factor, but this study is support our results since we detected various plantar disorders in adolescent athletes. In addition to age and gender factors, it is thought that the causes of plantar presuure differences and deformities in the participants may be genetic factors (El et al., 2006; Lin, Lai, Kuan & Chou, 2001), obesity (Adoración, Esquivel, Tomás, Buenafé & Moreno, 2008; Mickle, Steele & Munro, 2006; Pfeiffer, Kotz, Ledl, Hauser & Sluga, 2006), lower extremity disorders (Sabharwal, Zha & Edgar, 2008), and shoe preference (Yurt, 2011).

In the only study examining plantar pressure in taekwondo athletes, it was found that plantar pressure increased in the heel and 3-5 metatarsals in female taekwondo athletes, the lowest pressure was in the 2-5 toes, lower limb dominant vs. nondominant asymmetry has been reported (Entezari et al., 2017). These findings also confirm our research. We also found high rearfoot pressure and asymmetric plantar pressure in our study. We associate the most important factor affecting this with the mostly asymmetrical display of technical movements in taekwondo (increased stance on one foot, more frequent activities with the dominant kicking leg, etc.). Mocanu et al. (2021a) found the higher normal bilateral foot in U13 karate do athletes, while the incidence of various plantar imbalances was higher over the age of 13. It is also reported that forefoot plantar pressure increases compared to the dominant foot due to the long-term use of the non-dominant foot as a support base, especially during kicks, with increasing age (Mocanu et al., 2021b).

According to previous studies, as the dynamic balance performance increases, the strength of the lower extremity muscle groups increases. Increasing the strength in the lower extremity increases the force applied to the floor (Pekel & Aydos, 2022). In our study, as the plantar force increases, the dynamic balance reach distance increases. Balance performance in athletes is related to hip muscles strength, foot and ankle muscle strength, abductor and adductor muscle group strength (Chtara et al., 2018), and a decrease in balance performance occurs in case of lack of strength in the specified muscle groups (Chtara et al., 2018; Doğan, Korkmaz, Güzel, 2021; Düzcesoy Kalender, 2018; Yılmaz Menek & Tarakcı, 2022). It has been reported that individuals with reduced hip abduction muscle strength show reduced medio-lateral postural stability and use the ankle strategy (control of postural sway from the foot and ankle) to maintain balance during tasks performed on one leg (Lee & Powers, 2014). The positive relationship between the non-dominant side abductor isometric muscle strength and the dominant side anterior reaching in male soccer players shows that the increase in the strength of

the contralateral abductor muscles increases the amount of anterior reaching in the other extremity (Doğan et al., 2021). Taekwondo athletes, like soccer players, perform a lot of asymmetrical activities. In sports disciplines where asymmetrical activities are intense, many activities are in the form of the dominant extremity performing the activity while the support leg is on the ground (Pieter & Heijmans, 2000; Pinniger, Steele, & Groeller, 2000). From this point of view, it is thought that with the abductor muscle strength of the non-dominant leg, the person will remain more stable on one foot and it will be easier for the dominant foot to reach forward without losing balance. In the light of all this information, it is thought that plantar pressure and force is associated with balance performance for sports disciplines with asymmetrical activity.

## Conclusion

As a result, there is a significant relationship between dynamic plantar force and dynamic balance reach distance in the dominant leg (anterior and posteromedial direction) and non-dominant leg (posteromedial and posterolateral directions). Participants with a high static balance error score for the non-dominant leg showed that forefoot plantar pressure in both feet was lower than the rearfoot plantar pressure distribution. Various plantar anomalies (pes cavus, pes planus, hallux valgus, subtalar valgus) have been seen in adolescent taekwondo athletes. The number and group of participants is the main limitation of this current study. We recommend examining different disciplines and sedentary groups with a larger number of participants in future studies. Furthermore, in order to report that our findings are due to taekwondo, it may be necessary to compare the findings with another sport discipline that does not show similar technical characteristics or with a sedentary group in further studies. In our study, we emphasize the importance of plantar pressure analysis in adolescent taekwondo players in terms of balance and athlete development, which are important parameters for their sports performance and health. Therefore, we think that taekwondo trainers should also consider the plantar pressure distribution in the development of balance and that they can follow the performance of their athletes with plantar pressure and balance control, as well as appropriate trainings to be included in their training programs.

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### Conflict of Interest

The authors report no conflict of interest.

### Author Contributions

Research Idea: YA, EC; Research Design: YA, EC; Analysis of Data: EC; Writing: YA, EC; Critical Review: EC

## References

1. **Ackland, T. R., Elliott, B., & Bloomfield, J.** (2009). *Applied anatomy and biomechanics in sport (2. ed)*. Auckland: Human Kinetics.
2. **Adoración, M. V., Esquivel, J. M., Tomás, C., Buenafé, A., & Moreno, L.** (2008). Foot structure in overweight and obese children. *International Journal of Pediatric Obesity*, *3*(1), 39-45.
3. **Aziz, A. R., Tan, B., & Teh, K. C.** (2002). Physiological responses during matches and profile of elite pencak silat exponents. *Journal of Sports Science & Medicine, 1*(4), 147.
4. **Ball, N., Nolan, E., & Wheeler, K.** (2011). Anthropometrical, physiological, and tracked power profiles of elite taekwondo athletes 9 weeks before the Olympic competition phase. *The Journal of Strength & Conditioning Research, 25*(10), 2752-2763.
5. **Canbolat Güder, B.** (2022). *Taekwondocularda 12 haftalık kor egzersizlerinin statik denge kor kuvveti anaerobik güç sürat ve çevikliğe etkisinin incelenmesi* (Doktora Tezi). Gazi Üniversitesi Sağlık Bilimleri Enstitüsü, Ankara.
6. **Choi, D. S., Jung, E. N., & Park, M. H.** (2021). Comparison of balance ability and physical fitness according to the growth period in taekwondo players. *Journal of Exercise Rehabilitation, 17*(5), 354-361.
7. **Chtara, M., Rouissi, M., Bragazzi, N. L., Owen, A. L., Haddad, M., & Chamari, K.** (2018). Dynamic balance ability in young elite soccer players: implication of isometric strength. *Journal of Sports Medicine and Physical Fitness*, *58*(4), 414-420.
8. **Demirbüken, I., Ozgül, B., Timurtas¸, E., Yurdalan, S. U., Dinçer Çekin, M., & Polat, G.** (2019). Gender and age impact on plantar pressure distribution in early adolescence. *Acta Orthopaedica et Traumatologica Turcica*, *53*, 215-220.
9. **Doğan, F. E., Korkmaz, N., & Güzel, N. A.** (2021). Futbolcularda kalça izometrik addüktör ve abdüktör kas kuvvet oranının dinamik denge ile ilişkisi. *Spor Hekimliği Dergisi*, *56*(4), 180-185.
10. **Düzcesoy Kalender, H.** (2018). *Farklı ayak postür indeksi'ne sahip sporcuların ayak bileği kuvvet, mobilite, esneklik ve plantar basınç değerlerinin karşılaştırılması* (Yüksek Lisans Tezi). Eskişehir Osmangazi Üniversitesi Sağlık Bilimleri Enstitüsü, Eskişehir.
11. **El, O., Akcali, O., Kosay, C., Kaner, B., Arslan, Y., Sagol, E., … Peker, O.** (2006). Flexible flatfoot and related factors in primary school children: A report of a screening study. *Rheumatology International*, *26*(11), 1050-1053.
12. **Entezari, S., Memar, R., & Kakavand, M.** (2017). Effect of taekwondo on plantar pressure distribution symmetry in dominant and none-dominant limb. *Research in Sport Medicine and Technology, 15*(13), 17-24.
13. **Falco, C., Alvarez, O., Castillo, I., Estevan, I., Martos, J., Mugarra, F., & Iradi, A.** (2009). Influence of the distance in a roundhouse kick's execution time and impact force in taekwondo. *Journal of Biomechanics*, *42*(3), 242-248.
14. **Feizolahi, F., & Azarbayjani, M.** (2014). Comparison of static and dynamic balance in amateur male athletes. *The Scientific Journal of Rehabilitation Medicine, 3*(4), 89–98.

15. **Güder, F., & Günay, M.** (2019). Sub-elit taekwondocuların statik denge düzeyleri müsabaka başarılarında etkili midir? [Does static balance levels of sub-elite taekwondo players was effective on their competition success?]. *International Journal of Contemporary Educational Studies*, *5*(1), 89-98.
16. **Haddad, M., Ouergui, I., Hammami, N., & Chamari, K.** (2015). *Physical training in taekwondo: generic and specific training. Performance Optimization in Taekwondo: From Laboratory To Field*, OMICS Group eBooks, California, USA.
17. **İpekoglu, G., Karabiyik, H., Er, F., Suveren Erdogan, C., Cakir, E., Koz, M., Baltaci, G., & Colakoglu, F. F.** (2018). Does bosu training affect on dynamic and static balance in adolescent taekwondo athletes?. *Kinesiologia Slovenica, 24*(1), 5-13.
18. **Lee, S. P., & Powers, C. M.** (2014). Individuals with diminished hip abductor muscle strength exhibit altered ankle biomechanics and neuromuscular activation during unipedal balance tasks. *Gait & Posture, 39*(3), 933-938.
19. **Leong, H. T., Fu, S. N., Gabriel, Y. F., & Tsang, W. N.** (2011). Low-level taekwondo practitioners have better somatosensory organisation in standing balance than sedentary people. *European Journal of Applied Phisiology*, *11*(1), 1787-1793.
20. **Lin, C. J., Lai, K. A., Kuan, T. S., & Chou, Y. L.** (2001). Correlating factors and clinical significance of flexible flatfoot in preschool children. *Journal of Pediatric Orthopedics*, *21*(3), 378-382.
21. **Lord, S. R., Ward, J. A., Williams, P., & Anstey, K. J.** (1994). Physiological factors associated with falls in older community-dwelling women. *J. of the American Geriatrics Society*, *42*(10), 1110-1117.
22. **Mickle, K. J., Steele, J. R., & Munro, B. J.** (2006). The feet of overweight and obese young children: Are they flat or fat? *Obesity*, *14*(11), 1949-1953.
23. **Mocanu, G. D., Iordan, D. A., Mocanu, M. D., Cojocaru, M., & Nechıfor, A.** (2021a). Investigation of plantar pressure and plantar imbalances in the static phase of karate do athletes. *Balneo and PRM Research Journal, 12*(2), 133-144.
24. **Mocanu, G. D., Murariu, G., Iordan, D. A., & Sandu, I.** (2021b). Analysis of the influence of age stages on static plantar pressure indicators for karate do practitioners (preliminary report). *Applied Sciences, 11*(16), 7320.
25. **Morales, J., Ubasart, C., Solana-Tramunt, M., Villarrasa-Sapiña, I., González, L. M., Fukuda, D., & Franchini, E.** (2018). Effects of rapid weight loss on balance and reaction time in elite judo athletes. *International Journal of Sports Physiology and Performance, 13*(10), 1371-1377.
26. **Park, J. H., Noh, S. C., Jang, H. S., Yu, W. J., Park, M. K., & Choi, H. H.** (2009, December). The study of correlation between foot-pressure distribution and scoliosis. *Paper presented at the 13th International Conference on Biomedical Engineering*, *pp.* 974-978. Springer, Berlin, Heidelberg.
27. **Pekel, A. Ö., & Aydos, L.** (2022). Erken ergenlikte spor eğitiminin adım uzunluğuna etkisi [The effect of sports education on stride length in early adolescence]. *Bozok International Journal of Sport Sciences, 3*(2), 74-85.
28. **Pfeiffer, M., Kotz, R., Ledl, T., Hauser, G., & Sluga, M.** (2006). Prevalence of flat foot in preschool-aged children. *Pediatrics*, *118*(2), 634-639.
29. **Pieter, W., & Heijmans, J.** (2000). *Scientific coaching for olympic taekwondo. 22-27.* (2. ed). Aachen: Meyer and Meyer Sport.
30. **Pinniger, G. J., Steele, J. R., & Groeller, H.** (2000). *Does fatigue induced by repeated dynamic efforts affect hamstring muscle function?. Medicine and Science in Sports and Exercise, 32*(3), 647-653.
31. **Pirani, M. A., Miri, H., Hemayattalab, R., Dabagh Nikookheslat, S., Haidari Moghadam, R., Khoshdast, M., & Mahdiloo, M.** (2014). Comparison between balance and reaction time in Iranian elite karate athletes. *Journal for Research in Sport Rehabilitation, 1*(2), 49-57.
32. **Plisky, P. J., Gorman, P. P., Butler, R. J., Kiesel, K. B., Underwood, F. B., & Elkins, B.** (2009). The reliability of an instrumented device for measuring components of the star excursion balance test. *North American Journal of Sports Physical Therapy, 4*(2), 92–99.
33. **Rabello, L. M., Macedo, C. D. G., Gil, A. W., Oliveira, M. R., Coelho, V. A., Silva, G. B., & Silva, R. A.** (2014). Comparison of postural balance between professional tae kwon do athletes and young adults. *Fisioterapia e Pesquisa*, *21*(2), 139-143.
34. **Rad, A. G., & Aghdam, E. M.** (2012). The medical insole effects in kinetic patterns of vertical jumping for heading between flatfoot male football players. *Annals of Biological Research*, *13*(1), 162-169.
35. **Sabharwal, S., Zhao, C., & Edgar, M.** (2008). Lower limb alignment in children: Reference values based on a full-length standing radiograph. *Journal of Pediatric Orthopaedics*, *28*(7), 740-746.
36. **Suzana, M. A., & Pieter, W.** (2009). Motor ability profile of junior and senior taekwondo club athletes. *Brazilian Journal of Biomotricity*, *3*(4), 325-331.
37. **Tayshete, I., Akre, M., Ladgaonkar, S., & Kumar, A.** (2020). Comparison of effect of proprioceptive training and core muscle strengthening on the balance ability of adolescent taekwondo athletes. *International Journal of Health Sciences and Research, 10*(6), 268-79.
38. **Van Werkhoven, H., & Piazza, S. J.** (2017). Foot structure is correlated with performance in a single-joint jumping task. *Journal of Biomechanics*, *57*, 27-31.
39. **Wong, P. L., Chamari, K., Chaouachi, A., De, W. M., Wisløff, U., & Hong, Y.** (2007). Difference in plantar pressure between the preferred and non-preferred feet in four soccer-related movements. *British Journal of Sports Medicine*, *41*(2), 84.
40. **Yılmaz Menek, M., & Tarakcı, D.** (2022). Kalça çevresi kas kuvveti denge ve fonksiyonu etkiler mi? [Does the hip muscle strength affect balance and function?]. *Sağlık Akademisi Kastamonu*, *7*(1), 100-111.
41. **Yoon, S. D., Sung, D. H., & Park, D.** (2015). The effect of active core exercise on fitness and foot pressure in taekwondo club students. *The Journal of Physical Therapy Science*, *27*(2), 509-511.
42. **Yurt, Y.** (2011). *Okul öncesi dönemdeki çocuklarda ayakkabı uygunluğunun değerlendirilmesi* (Yüksek Lisans Tezi). Hacettepe Üniversitesi Sağlık Bilimleri Enstitüsü, Ankara.
43. **Zago, M., Mapelli, A., Shirai, Y. F., Ciprandi, D., Lovecchio, N., Galvani, C., & Sforza, C.** (2015). Dynamic balance in elite karateka. *Journal of Electromyography and Kinesiology, 25*(6), 894-900.
44. **Zvonar, M., Lutonska, K., & Reguli, Z.** (2012). Influence of combative sports on state of plantar pressure. *Ido Movement for Culture. Journal of Martial Arts Anthropology, 12*(1), 30-5.