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Investigation of Foot Biomechanics in 5-15 Years Old Children Performing Gymnastics

5-15 Yaş Arası Cimnastik Yapan Çocuklarda Ayak Biyomekaniğinin İncelenmesi

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ABSTRACT

Gymnastics is a basic sport branch consisting of eight disciplines and is recommended to be taught to children at an early age. Our study aimed to evaluate the foot biomechanics and static plantar pressure of children aged 5-15 years who were performing rhythmic and artistic gymnastics. The study included 58 (19 Men/39 Women) child gymnasts and aged 5-15 years. Sociodemographic form, static plantar pressure analysis in bipedal position with pedobarography device, hallux valgus angle measurement (HVA), navicular drop test (NDT) and subtalar pronation angle measurement were performed respectively. The measurements were performed in the same way by an experienced expert. IBM Statistical Package for Social Sciences Version 26.0 (SPSS inc, Chicago, IL, USA) statistical programme was used. Tests were analyzed pairwise with Pearson correlation ($p \leq .05$). The mean age was 7.43±2.37 years, height 124.68±16.97 cm, weight 27.39±11.39 kg and body mass index (BMI) 16.99±3.22 kg/m^2. There was no significant difference between weighted and unweighted in NDT results. In pedobarography analysis, hindfoot percentages were higher than forefoot percentages in static bipedal positions. A positive correlation was found between HVA and subtalar angles (p=0.00). In children performing artistic and rhythmic gymnastics, lateral ankle sprain may be observed due to a pronation tendency in subtalar angles. In addition, in the static bipedal position, distortions occurred in the bipedal static force center because the percentage of hindfoot pressure in plantar pressures was higher than the forefoot. Studies with foot-ankle exercises are needed for these.

Keywords: Gymnastics, pedobarography, foot biomechanics

ÖZ

Cimnastik, sekiz disiplinden oluşan temel bir spor branşıdır ve çocuklara erken yaşta öğretilmesi önerilmektedir. Çalışmamızda 5-15 yaş arası ritmik ve artistik cimnastik yapan çocukların ayak biyomekaniği ile statik plantar basıncının değerlendirilmesi hedeflenmiştir. Çalışmaya yaşları 5-15 arasında 58 (19 Erkek/39 Kadın) çocuk cimnastikçi dahil edildi. Çocuklara, sırasıyla sosyodemografik form, pedobarografi cihazı ile bipedal pozsiyonda statik plantar basınç analizi, halluks valgus açısı ölçümü (HVA), navikular drop testi (NDT) ve subtalar pronasyon açısı ölçümü yapıldı. Ölçümler deneyimli bir uzman tarafından herkese aynı şekilde uygulandı. IBM Statistical Package for Social Sciences Version 26.0 (SPSS inc, Chicago, IL, USA) statistical program was used. Testler Pearson korelasyonu ile çift yönlü olarak analiz yapıldı. ($p \leq ,05$). Yaşları ortalaması 7,43±2,37 yıl, boyları 124,68±16,97 cm, kilogramları 27,39±11,39 kg ve vücut kütle indeksleri (VKİ) 16,99±3,22 kg/m^2 bulunmuştur. NDT sonuçlarında ağırlıklı ve ağırlıksız arasında anlamlı bir fark görülmemiştir. Pedobarografi analizinde statik bipedal pozisyonda arka ayak yüzdeleri, ön ayak yüzlerine göre daha fazla bulundu. HVA ile subtalar açılar arasında pozitif yönlü korelasyon bulunmuştur (p=0.00). Artistik ve ritmik cimnastik yapan çocuklarda, subtalar açılarda pronasyona yönelim olduğundan dolayı lateral ayak bileği burkulması gözlemlenebilir. Ayrıca statik bipedal pozisyonda plantar basınçlarında arka ayak basınç yüzdeliği ön ayağa göre fazla bulunduğundan bipedal statik kuvvet merkezinde bozulmalar meydana gelmiştir. Bunlara yönelik ayak-ayak bileği egzersizleri ile çalışmalara ihtiyaç bulunmaktadır.

Anahtar Kelimeler: Cimnastik, pedobarografi, ayak biyomekaniği

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Introduction

Gymnastics is accepted as a basic sport branch worldwide. It consists of eight different disciplines: artistic gymnastics, rhythmic gymnastics, trampoline gymnastics, double mini trampoline gymnastics, tumbling, acrobatic gymnastics, parkour and aerobic gymnastics. Therefore, it is emphasized that gymnastics should be consciously taught to children from preschool (Mengütay, 1998). Various studies show that gymnastics is accepted as the basis of sports. Basic skills such as speed, strength and flexibility play an important role in gymnastics (Kesilmiş, 2012). The literature shows that athletes who have received gymnastics training at a young age are superior in these basic skills. In addition, the flexibility level of gymnastics athletes is quite high compared to other branches (Gallahue & Donnelly, 2003).

Nowadays, gymnastics, which has high spectator pleasure and creates excitement in the audience, is a sport branch that requires the use of all muscles. Gymnastics consists of flexibility, strength, endurance, speed, coordination and body control exercises with or without instruments. Gymnastics has a great effect on the motor development of children (Malina et al., 2003). The concept of sport is generally considered as inter-team or individual competitions; therefore, it may be difficult to consider gymnastics as an athletic activity. However, as in other sports, in gymnastics, the athlete tries to show his/her best performance by exhibiting all his/her abilities (Mengütay, 1998). Gymnastics provides the development and active working of muscles and joints by using the body's natural movements. It is one of the important physical activities that support the acquisition of endurance, flexibility, agility, coordination and motor skills. In gymnastics, movements such as running, jumping and rolling increase the body's flexibility. In addition, flexion, reaching and stretching movements directly affect psycho-motor development in children. It is important for children to learn how to move and control their bodies for their cognitive and social development. Since gymnastics requires multiple muscle movements and coordination, it supports the development of basic motor characteristics such as coordination, attention, balance, and flexibility (Mülazımoğlu & Bruninks-Oseretsky, 2006). In addition, it enables the fulfillment of the functions of muscles and joints and develops physical and psychological abilities together (Bencke et al., 2002).

The foot and ankle have 7 tarsal bones (calcaneus, talus, navicular, cuboid, and 3 uniforms), 5 metatarsal bones, and 14 phalanges. The foot is analyzed in three main sections: forefoot, midfoot, and hindfoot. These sections define foot and ankle deformities and functions (Kanatlı et al., 2003). The foot is a complex structure consisting of 26 bones, 33 ligaments and numerous joints, which is in the most distal part of the body and provides our contact with the earth. The foot absorbs shocks during activities such as running, walking, jumping, and pushing the body forward. The sole contains three arches: the medial longitudinal arch, lateral arch, and transverse arch. The height of the medial longitudinal arch varies between 15-18 mm, and the height of the lateral arch varies between 3-5 mm. Plantar flexion and dorsi flexion movements are observed in the ankle; some inversion and adduction movements occur during plantar flexion, and eversion and abduction movements occur during dorsi flexion (Şener & Erbahçeci, 2016). In the bipedal position, 60% of the body weight is distributed on the heel and 40% on the metatarsal heads. While 1/3 of this 40% load is concentrated on the first metatarsal, the remaining part is equally distributed to the other metatarsal heads. The midfoot carries 8% load, the forefoot 28% and the toes 4% (11). Plantar pressure measurements evaluate foot and ankle functions. Pedobarography is a method that dynamically measures the pressures on the plantar surface of the foot. These measurements are used to examine the foot structure, determine pressure changes, and detect lower extremity pathologies (Orlin & McPoil, 2000). Thanks to technological advances, these measurements can be performed statically and dynamically utilizing platforms with sensors and computers (Hurkmans et al., 2003). Static plantar pressure analysis involves standing motionless for a certain period. This method obtains data such as pressure and loading values, plantar contact surface, maximum and average pressure on both extremities and the support surface. These data provide information about foot deformities (Thavets et al., 2005; Ünver & Bek, 2014).

When the studies in the literature were analyzed, it was found that shoulder injuries were frequently encountered in female artistic gymnasts. However, it has been reported that more detailed studies are needed to determine the risk factors of these injuries (Hinds et al., 2019). Afterward, ankle and wrist injuries are frequently encountered (Goulart et al., 2016). However, detailed data cannot be found in these studies. This study aimed to investigate the relationship between static plantar pressures and foot biomechanics in gymnastic children aged 5-15.

Methods

Participants

The inclusion criteria were that the child be between the ages of 5 and 15 and do artistic and rhythmic gymnastics. The exclusion criteria were having had any lower extremity surgery in the last year and having any neurological or psychiatric problems. The study's sample size was calculated using the G*Power 3.1.9.7 program to include 58 individuals with 80% power (Sobera et al., 2015). Ethical approval was obtained from Çankırı Karatekin University Ethics Committee Institutional Review Board within protocol June 05, 2024-14. In addition, this study adhered to the principles outlined in the Declaration of Helsinki. All participants gave informed consent, and written informed consent was obtained from the participants' families. The evaluations were conducted face-to-face.

Evaluations

Sociodemographic Form: It includes items such as height, weight and gender.

Pedobarography Plantar Pressure Measurement: Plantar pressures were measured statically in the bipedal position, and the percentage distributions of the right and left foot, forefoot, and hindfoot were calculated (Figure 1). These measurements were performed using the AS Foot Scan (Analysis System, Istanbul, Turkey). The device has a sensor area of 400mm x 400mm, 2288 sensors (1.4 sensors/cm²) and a data rate of 200 to 400Hz. The delay rate is <3%.

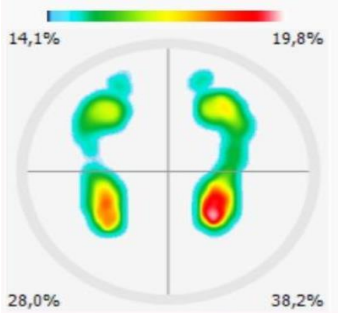

Figure 1. Plantar pressure analysis in static pedorabarography device

Hallux Valgus Angle Measurement: The pivot point of the goniometer should be placed on the medial projection of the metatarsophalangeal joint. The fixed arm should extend parallel to the medial aspect of the first metatarsal (Figure 2). The mobile arm should be placed parallel to the medial aspect of the first proximal phalanx. The measured acute angle is recorded as the angular severity of the deformity (Karabıcak et al., 2015).

Figure 2. Hallux Valgus Angle measurement with goniometer

Navicular Drop Test: While the patient is standing in a bipedal position, he/she is positioned to carry full weight along the lower extremity, and the subtalar joint is kept in a neutral position. The most prominent part of the navicular tuberosity is marked and the distance to the support surface is measured. After the patient is asked to relax, the movement of the navicular in the sagittal plane is measured with a ruler. If the difference between the measurements is less than 5 mm, it is considered as pes cavus, and if it is greater than 10 mm, it is considered as pes planus (Menz, 1998).

Subtalar pronation: The angle between the calcaneus's midpoint and the Achilles tendons long line is measured with a

goniometer while the person is standing on a high platform. This measurement determines the angle between the calcaneus's midpoint and the Achilles tendon (Jastifer & Gustafson, 2014).

Statistical Analysis

IBM Statistical Package for Social Sciences Version 26.0 (IBM SPSS Corp., Armonk, NY, USA) statistical program was used. Pearson test analysis was used in the study and statistical significance was taken as $p \leq .05$ for all two-way measurements.

Results

Of the 58 children who participated in the study, 19 were male and 39 were female. BMI scores were found to be normal.

Sociodemographic data are given in detail in Table 1.

Table 1.
Sociodemographic Data

	N	Mean	SD (±)
Age (years)	58	7.43	2.37
Height (cm)	58	124.68	16.97
Kilogram (kg)	58	27.39	11.39
BMI	58	16.99	3.22

BMI; Body mass index, N; number of participants, SD; Standard deviation.

According to the children's NDT results, there was no medial transverse posterior drop because there was less than 10 mm difference between the unweighted and weighted calculations in both feet. These results are given in Table 2.

Table 2.
NDT Data of the Children Performing Gymnastics

	N	Mean	SD (±)
R.F NDT Weightless	58	5.27	1.43
L.F NDT Weightless	58	5.20	1.34
R.L NDT Weighted	58	4.27	1.38
L.F NDT Weighted	58	4.36	1.27

NDT: Navicular Drop Test, R.F: Right Foot, L.F: Left Foot, SD: Standard Deviation

When the percentages of the plantar pressures of the children performing gymnastics in the static bipedal position were analyzed, it was found that the percentage plantar pressures of the hindfoot were higher than the percentage plantar pressures of the forefoot in both feet. Related data are given in Table 3.

Table 3.
Plantar Pressure Analysis Results in a Static Bipedal Position of the Children Performing Gymnastics

	N	Mean	SD (±)
R. Forefoot (%)	58	15.89	6.39
R. Hindfoot (%)	58	30.27	7.97
L. Forefoot (%)	58	18.10	5.66
L. Hindfoot (%)	58	35.74	8.58

R: Right, L: Left, SD: Standard Deviation

When the HVA and subtalar angles of the children were analysed, it was found that hallux valgus angles were normal but subtalar angles were towards pronation. Related values are given in Table 4.

Table 4.
Subtalar Angle Data with HVA of the Children Performing Gymnastics

	N	Mean	SD (±)
R.F HVA (°)	58	14.34	2.77
L. F HVA (°)	58	14.72	2.37
R.F Subtalar pronation (°)	58	6.48	1.69
L.F Subtalar pronation (°)	58	6.39	2.44

HVA; Hallux Valgus, F: Right Foot, L.F: Left Foot, (°): Angle, SD: Standard Deviation

In the correlation analysis performed between HVA and subtalar angles of the children performing gymnastics, a moderate positive correlation was found (p=0.00). Table is given in Table 5.

Table 5.
Correlation Analysis Performed Between HVA and Subtalar Angles of the Children Performing Gymnastics

	L.F Subtalar pronation (°)	R.F Subtalar pronation (°)	L.F HVA (°)	R.F HVA (°)
L.F Subtalar pronation (°)	-	-	-	-
R.F Subtalar pronation (°)	.571*	-	-	-
L.F HVA (°)	.699	,564*	-	-
R.F HVA (°)	.662*	,637*	,849*	-

F: Right Foot, L.F: Left Foot, p<0.05*

Discussion

As a result of the analysis of the HVA of the children who performed gymnastics, it was found that they did not have hallux valgus. Hallux valgus is called positive when the HVA is 15° and above (Samoto et al., 2000). Hallux valgus is rare in children. However, it is more common in girls than boys and the cause is unknown. In addition, the probability of hallux valgus appearing bipedal is 87% (Coughlin & Jones, 2007). Casado et al. included 1768 children aged 5-17 years in the study conducted in 2023. In the study, BMI was divided into three groups as normal, overweight and obese according to age. Hallux

valgus deformity and pes planus were observed in overweight individuals. It was reported that the rate of hallux valgus surgery was high in overweight children at a later age (Martín-Casado et al., 2023). Other studies reported that hallux valgus was more likely to be observed in children with high BMI (Tasatan & Tekin, 2024; Tomaru et al., 2020). In our study, BMI was ideal in children who performed gymnastics; accordingly, low medial arch and hallux valgus deformity were not observed.

When the subtalar angles are analyzed, it is said that there is a tendency towards subtalar pronation with angles of 5° and above (Jastifer & Gustafson, 2014). Since gymnastics is a type of exercise with a tendency to stretch, it is thought that there is an increase in the subtalar angle especially due to the flexibility in the peroneal longus and brevis muscles. In addition, it is thought that a high subtalar angle increases the possibility of ankle injury during gymnastics (Charpy et al., 2023).

When the foot percentage distributions were analyzed, hindfoot pressures (%) were found to be higher than forefoot pressures (%). When the literature was examined, it was found that there should not be much difference between forefoot and hindfoot percentage distributions (Tuna et al., 2004). This is because children performing gymnastics are in development due to their age and the structural features of the shoes they wear, and changes in their pressures can be observed because they exercise on different surfaces during gymnastics (Pérez-Soriano et al., 2010).

A positive correlation was found between HVA and subtalar angles. In a review study conducted in 2016, Cheron et al. examined the differences between sports regarding the diagnoses and anatomical regions with the highest probability of injury. This study analyzed football, handball, orienteering, running, dance, and gymnastics. It was found that the lower leg region was affected more frequently than the upper leg region in all sports. Another important finding was that foot injuries were more common in gymnastics than in other sports. The reason for this was observed to be the high loads on the foot during gymnastics and impaired foot biomechanics (Chéron et al., 2016). In another study conducted in 2015, Sobera et al. determined the incidence of foot and ankle deformities in trampoline and artistic gymnasts. A total of 20 participants, 10 acrobatic gymnasts (trampoline) and 10 artistic gymnasts aged 6-14 years, were included in the study. Subtalar pronation angle was determined as the angle of the superior calcaneal tendon and the longitudinal heel axis, while Clarke angles were determined by podoscopy. A statistically significant higher subtalar pronation angle was observed in the trampoline group compared to the artistic gymnastics group. As a result of the study, considering the prevalence of foot and ankle deformities in both gymnastics disciplines, it was emphasized that this situation should be considered by coaches from an early age during gymnastics training (Sobera et al., 2015).

Conclusion and Recommendations

There was a tendency towards pronation in the subtalar angle of the foot of rhythmic and artistic gymnastic children aged 5-15 years. A positive correlation was found between HVA and subtalar angle. In addition, when the plantar pressure was analyzed in a static bipedal position, the hindfoot's percentage pressure was higher than the forefoot. Therefore, lateral ankle injuries can be observed in these individuals.

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Hakem Değerlendirmesi: Dış bağımsız.
Yazar Katkıları: Konsept- G.A; Tasarım- S.S; Denetim- S.S; Kaynaklar- B.Ü; Malzemeler- G.A; Veri Toplama ve/veya İşleme- S.S, H.S; Analiz ve/veya Yorum- Y.Y; Literatür Taraması- G.A; Yazma- G.A, S.S, B.Ü
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Informed Consent: Written consent was obtained from the families of all participants who participated in the study.
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References

Abdul Razak, A. H., Zayegh, A., Begg, R. K. & Wahab, Y. (2012) Foot plantar pressure measurement system: A review. *Sensors. 12*(7):9884-9912. doi: 10.3390/s120709884.

Balıkçı, Ş. (2022). Investigation of the effect of 8-week rhythmic gymnastics-based training on some strength and balance parameters of 4–6-year-old children. Istanbul.

Bencke, J., Damsgaard, R., Saekmose, A., Jorgensen, P., Jorgensen, K. & Klausen, K. (2002). Anaerobic power and muscle strength characteristics of 11 years old elite and non-elite boys and girls from gymnastics, team handball, tenis and swimming. *Scandinavian Journal of Medicine & Science in Sports; 12*:171-178. doi: 10.1034/j.1600-0838.2002.01128.x.

Charpy, S., Billard, P., Dandrieux, P. E., Chapon, J., & Edouard, P. (2023). Epidemiology of injuries in elite women's artistic gymnastics: a retrospective analysis of six seasons. *BMJ Open Sport & Exercise Medicine, 9*(4), e001721. https://doi.org/10.1136/bmjsem-2023-001721

Chéron, C., Le Scanff, C., & Leboeuf-Yde, C. (2016). Association between sports type and overuse injuries of extremities in children and adolescents: a systematic review. *Chiropractic & Manual Therapies*, 24, 41. https://doi.org/10.1186/s12998-016-0122-y

Coughlin, M. J., & Jones, C. P. (2007). Hallux valgus: demographics, etiology, and radiographic assessment. *Foot & Ankle International, 28*(7), 759–777. doi: 10.3113/FAI.2007.0759.

Gallahue, D. L. & Donnelly, F. C. (2003). Developmental physical education for all children (4th ed.). Champaign, IL: Human Kinetics

Goulart, N. B. A., Lunardi, M., Waltrick, J. F., Link, A., Garcias, L., Melo, M. de. O., Oliva, J. C. & Vaz, M. A. (2016). Injuries prevalence in elite male artistic gymnasts. *Revista Brasileira de Educação Física e Esporte*, 30, 79-85. doi: 10.1590/1807-55092016000100079

Hinds, N., Angioi, M., Birn-Jeffery, A., & Twycross-Lewis, R. (2019). A systematic review of shoulder injury prevalence, proportion, rate, type, onset, severity, mechanism and risk factors in female artistic gymnasts. *Physical Therapy in Sport*, 35, 106-115. doi: 10.1016/j.ptsp.2018.11.012.

Hurkmans, H. L. P, Bossman, J. B. J., Benda, E., Verhaar, J. A. N. & Stam, H. J. (2003). Techniques for measuring weight-bearing during standing and walking. *Clinical Biomechanics. 18*(7):576-589. doi: 10.1016/s0268-0033(03)00116-5.

Jastifer, J. R., & Gustafson, P. A. (2014). The subtalar joint: biomechanics and functional representations in the literature. *Foot (Edinburgh, Scotland), 24*(4), 203–209. https://doi.org/10.1016/j.foot.2014.06.003

Kanatli, U., Yetkin, H. & Bolukbasi, S. (2003). Evaluation of the transver se metatarsal arch of the foot with gait analysis. *Archives of Orthopaedic and Trauma Surgery, 123*(4):148-50. doi: 10.1007/s00402-002-0459-7.

Karabicak, G. O., Bek, N., & Tiftikci, U. (2015). Short-term effects of kinesiotaping on pain and joint alignment in conservative treatment of hallux valgus. *Journal of Manipulative and Physiological Therapeutics, 38*(8), 564–571. doi: 10.1016/j.jmpt.2015.09.001.

Kesilmiş, İ. (2012). The effect of gymnastics training on growth and biomotor skills in 4–6-year-old children. Master Thesis Mersin University Institute of Educational Sciences, Mersin.

Malina, R. M., Bouchard, C. & Bar-Or, O. (2003). Grawth, Maturation, and Physical Activity. Human Kinetic.

Martín-Casado, L., Aldana-Caballero, A., Barquín, C., Criado-Álvarez, J. J., Polonio-López, B., & Marcos-Tejedor, F. (2023). Foot morphology as a predictor of hallux valgus development in children. *Scientific Reports, 13*(1), 9351. https://doi.org/10.1038/s41598-023-36301-2

Mengütay, S. (1998). Teaching methods and help forms of basic technical movements. Ankara

Menz, H. B. (1998). Alternative techniques for the clinical assessment of foot pronation. *Journal of the American Podiatric Medical Association, 88*(3), 119–129. https://doi.org/10.7547/87507315-88-3-119

Mülazımoğlu, Ö. & Bruninks-Oseretsky (2006). Motor competency testinin validity, reliability study and the effect of gymnastics training program applied to five-six age group children on motor development (Doctoral Dissertation), Ankara,

Orlin, M. N. & McPoil, T. G. (2000). Plantar pressure assessment. *Physical Therapy. 80*(4):399-409.

Pérez-Soriano, P., Llana-Belloch, S., Morey-Klapsing, G., Perez-Turpin, J. A., Cortell-Tormo, J. M., & van den Tillaar, R. (2010). Effects of mat characteristics on plantar pressure patterns and perceived mat properties during landing in gymnastics. *Sports Biomechanics, 9*(4), 245–257. https://doi.org/10.1080/14763141.2010.537675

Samoto, N., Higuchi, K., Sugimoto, K., Tanaka, Y., & Takakura, Y. (2000). Electromyographical evaluation of the effect on the active abduction exercise of the big toe for hallux valgus deformity. *The Japanese Society for Surgery of the Foot*, 21, 12-6.

Şener, G. & Erbahçeci, F. (2016). Kinesiology and Biomechanics. Hipokrat Bookstore. Ankara

Sobera, A., Sobera, M., & Kleszyk, K. (2015). Foot and ankle deformity in young acrobatic and artistic gymnasts. *Human Movement, 16*(3), 130-136. doi: 10.1515/humo-2015-0034

Tasatan, E., & Tekin, E. A. (2024). Relationship between hallux valgus interphalangeal deformity and the recurrence of ingrown toenail in children. *Journal of the American Podiatric Medical Association, 114*(2), 21-217. https://doi.org/10.7547/21-217

Thavets, J. G., Liu, X. C., Tassore, C. & Klein, S. (2005). Corraltion of the foot radiographs with foot function and analyzed by plantar pressure distribution. *Journal of Pediatric Orthopaedics, 25*(2):249-252.

Tomaru, Y., Kamada, H., Tsukagoshi, Y., Nakagawa, S., Tanaka, K., Takeuchi, R., Mataki, Y., Kimura, M., Miyakawa, S., & Yamazaki, M. (2020). Determining the relationship between physical status and musculoskeletal injuries in children: a cohort study. *Journal of Rural Medicine: JRM, 15*(3), 116–123. https://doi.org/10.2185/jrm.2020-015

Tuna, H., Yıldız, M., Celtik, C., & Kokino, S. (2004). Static and dynamic plantar pressure measurements in adolescents]. *Acta Orthopaedica et Traumatologica Turcica, 38*(3), 200–205.

Ünver, B. & Bek, N. (2014). Effect of insert to plantar contact areas and pressure distribution. *Turkish Journal of Physiotherapy and Rehabilitation.25*(2):86-92.

Xiao, S., Shen, B., Zhang, C., Xu, Z., Li, J., Fu, W., & Jin, J. (2023). Effects of tDCS on Foot Biomechanics: A Narrative Review and Clinical Applications. *Bioengineering (Basel, Switzerland), 10*(9), 1029. https://doi.org/10.3390/bioengineering10091029