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CORRELATION BETWEEN FOOT ARCH TYPE AND BALANCE PERFORMANCE

POVEZANOST MED OBLIKO STOPALNEGA LOKA IN RAVNOTEŽJEM

ABSTRACT

This study aimed to investigate the correlations between different foot arch types and balance performance. Forty-four Faculty of sport students completed the single-leg body sway balance test and single-leg landing tests using force plates, and single-leg foot-type tests using a pedobarometry platform with both the left and right legs. Spearman correlation coefficients were determined between the foot arch index and landing test results, as well as between the foot arch index and body sway test results. For the landing test results, we found statistically significant positive correlations between the arch index and the time to stability, calculated based on centre of pressure (COP) data for both legs (left: *rho* = 0.39, $p < 0.05$; right: *rho* = 0.34, $p < 0.05$). For the body sway test results, statistically significant negative correlations were found between the arch index and the frequency of COP path changes for both legs (left: *rho* = -0.39, $p < 0.05$; right: *rho* = -0.41, $p < 0.05$). Vertical force, COP path, and velocity were not correlated with the arch index results, regardless of the test. Our results suggest that participants with a lower foot arch needed more time to stabilize the movement of the body's COP after single-leg landing. Furthermore, participants with a lower arch index maintained single-leg balance with more frequent corrections of the body's COP. Based on our findings, we conclude that the foot arch height partially determines single-leg balance performance. Future studies are warranted to identify common muscle characteristics underpinning both balance test performance and arch index results.

Keywords: arch index, landing, body sway, footprint, flat foot

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IZVLEČEK

Namen naše študije je bil raziskati povezanost med višino stopalnega loka in rezultati testov ravnotežja. Štiriinštirideset študentov Fakultete za šport je izvedlo test enonožne stoje in test pristanka na eni nogi na pritiskovni plošči ter meritve višine stopalnega loka na pritiskovni blazini za levo in desno nogo posebej. Spearmanov korelacijski koeficient je bil izračunan med rezultati stopalnega indeksa in rezultati testa enonožne stoje ter med rezultati stopalnega indeksa in enonožnega pristanka. Za test enonožnega pristanka smo ugotovili statistično značilno pozitivno povezanost med rezultati stopalnega indeksa in časom do vzpostavitve stabilnega položaja, izračunanim iz podatkov oprijemališča sile reakcije podlage (OSRP) za obe nogi (leva: *rho* = 0.39, $p < 0.05$; desna: *rho* = 0.34, $p < 0.05$). Za test enonožne stoje smo ugotovili statistično značilno negativno povezanost med rezultati stopalnega indeksa in frekvenco sprememb smeri gibanja OSRP za obe nogi (leva: *rho* = -0.39, $p < 0.05$; desna: *rho* = -0.41, $p < 0.05$). Rezultati vertikalne sile reakcije podlage, poti OSRP in hitrosti premikanja OSRP niso bili povezani z rezultati stopalnega indeksa. Glavni ugotovitvi naše raziskave sta, da so preizkušanci z nižjim stopalnim lokom potrebovali več časa za stabilizacijo telesa po enonožnem pristanku in da so preizkušanci z nižjim stopalnim lokom vzdrževali ravnotežje na eni nogi z večjo frekvenco sprememb smeri OSRP. Naši rezultati kažejo, da je stopalni lok povezan z nekaterimi spremenljivkami ravnotežja. Dodatne študije so potrebne, da bi ugotovili, katere mišice in njihove lastnosti so odgovorne za višino stopalnega loka in hkrati uspešnost pri izvedbi ravnotežnih nalog.

Ključne besede: stopalni indeks, pristanek, enonožna stoja, odtis stopala, plosko stopalo

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https://doi.org/10.52165/kinsi.30.3.19-30

INTRODUCTION

The foot is one of the most important parts of the human body. Despite its significance, it is often overlooked in training or rehabilitation (Dawe & Davis, 2011). The human foot is unique, composed of numerous bones and joints, and secured by three layers of ligaments. The bones of the human foot are arranged to form three strong arches: two longitudinal and one transverse (Wright et al., 2011), known as the medial, lateral, and transverse arches (Gwani et al., 2017). Foot arches play a crucial role in supporting body weight and absorbing ground reaction forces generated during weight-bearing activities.

The height of the medial longitudinal arch (referred to as "the arch" hereafter) plays a significant role in ankle muscle strength and physical performance. Research indicates that individuals with high arches tend to exhibit lower ankle muscle strength, particularly in plantarflexion and inversion, compared to those with medium arch height (Zhao et al., 2017). Conversely, individuals with normal medial longitudinal arches demonstrate higher muscle strength than those with pes planus, a condition characterized by a flattened arch (Zhao et al., 2017). Furthermore, Zhao et al. suggest that the lower arch with greater ankle muscle strength may be an adaptation to weight support and shock absorption. Engaging in foot exercises, such as calf raises and arch lifts, can positively impact foot arch height and ankle joint torque, maintaining the relationship between arch height and ankle muscle strength while minimizing the relationship with maximum eversion torque (Unver et al., 2020). Additionally, foot arch-related muscle strength training has been shown to reduce the incidence of ankle sprains among athletes, emphasizing the importance of adequate muscle strength in injury prevention (Fujitaka et al., 2012). These findings highlight the intricate relationship between foot arch height and ankle strength, underscoring the importance of maintaining optimal muscle strength for overall foot and ankle health.

Moreover, foot arch height plays a crucial role in determining balance among individuals, especially dancers (Unver et al., 2020). Studies have shown that individuals with higher foot arches tend to exhibit superior dynamic balance abilities, toe flexor strength, and postural stability compared to those with lower arches (Matsumoto & Yamamoto, 2022). Therefore, assessing foot arch height is essential in optimizing balance and performance in various physical activities.

Cobb et al. (2014) found that a high medial longitudinal foot arch was associated with decreased mediolateral control of single-limb stance. Additionally, Jankowicz-Szymańska et al. (2015)

discovered that better balance was observed in adolescents with a higher medial longitudinal arch of the foot. Hajirezayi et al. (2019) found that individuals with a neutral foot arch performed better in maintaining control of posture and balance, while the flat-foot group exhibited the weakest balance. High-arch and low-arch types are also associated with lower extremity injuries, although the strength of this relationship is low (Tong & Kong, 2013). However, the balance and foot arch type assessment procedures used in previous studies are not standardized, leading to contradictory results. Therefore, our study aimed to investigate the correlations between different foot arch types, assessed through footprint analysis using pedobarometry, and two of the most commonly used balance and stability tests in the literature: the body sway test and the landing test. To emphasize the impact of muscle function on balance performance and arch index, the tests were performed single-legged. Based on the results of previous studies and the assumption that muscles maintaining a high foot arch during single-leg stance also contribute to single-leg stance and landing stability, we hypothesized that participants with a higher foot arch height would demonstrate better balance performance during single-leg balance tasks.

METHODS

Experimental Protocol

The data were collected in a single visit. The experimental protocol included a short warm-up, followed by single-leg body sway test, single-leg landing test, and single-leg pedobarometric footprint assessment. The participants underwent the measurements in a randomized order. The protocol for this study was conducted in accordance with the latest revision of the Declaration of Helsinki. The experimental procedures of this study were reviewed and approved by the University of Ljubljana, Faculty of Sport Ethics Committee (reference number: 40:2023).

Participants

Forty-four Faculty of Sport students (21 men, 23 women) voluntarily participated in the study. The average height of the participants was 176 cm (SD = 8.0), the average body weight was 69.77 kg (SD = 12.0), and the average foot length was 26 cm (SD = 2 cm). The inclusion criteria for participants were the absence of any musculoskeletal injuries or pain syndromes within the last year, as well as the absence of any medical conditions that could potentially be exacerbated by the measurement procedures. Participants were instructed to avoid any strenuous activity two days prior to testing. Before the measurements, participants were thoroughly informed about the details of the protocol and were required to sign an informed consent form.

Single-leg body sway test

The body sway was assessed during a barefoot single-leg stance on a force plate (9260AA, Kistler, Winterthur, Switzerland). Participants were required to stand on one leg in the centre of the force plate. The knee of the standing leg was to be extended but not locked (i.e., no hyperextension). The hip of the free leg was positioned at 0 degrees, with the thigh parallel to the standing leg and the knee flexed at 90 degrees, ensuring it did not touch the standing leg (see Figure 1). Participants were instructed to look at a fixed point (a black dot on a white wall at approximately eye level and about 4 meters away). Their hands had to remain on their hips. Each leg was tested three times for 30 seconds, with 60-second breaks between repetitions. For each trial, participants assumed the single-leg position, and the examiner started the data acquisition after about 1 second. Both legs were assessed alternately, with the starting leg randomized among participants. The foot position was kept constant across repetitions. If participants lost balance, moved their hands, or jumped in place, the test was repeated.

Ground reaction force data were collected at a sampling frequency of 1000 Hz and automatically low-pass filtered (Butterworth, 2nd order, 10 Hz) using the manufacturer's MARS software (version 4.0; Kistler, Winterthur, Switzerland). The data were further processed in the same software to derive the outcome variables of interest. The average of the three repetitions was used for further analysis of all outcome variables. We obtained the mean centre of pressure (COP) path, velocity, and frequency in the anterior-posterior (AP) and medio-lateral (ML) directions. The COP path was defined as the average amount of COP sway, calculated as the total length of the COP trajectory divided by the number of direction changes. Velocity was calculated as the length of the trajectory divided by the measurement time. COP frequency was defined as the number of COP oscillations (direction changes) in the AP or ML direction divided by the measurement time.

Figure 1. Single-leg body sway test setup.

Single-leg landing test

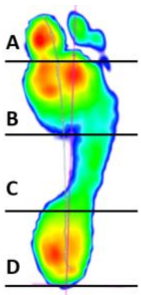
The landing task began with participants standing on a platform that was 25 cm high. They were instructed to stand upright, place their hands on their hips, and look straight ahead. To initiate the task, they lifted the tested leg off the surface and positioned it over the edge of the box, before dropping it down to land in a single-leg stance on a force plate placed directly in front of the box (see Figure 2). Participants were required to keep their knee and hip in a neutral position upon losing contact with the box. The opposite leg had to be bent at the knee to prevent it from touching the ground. Participants were instructed to stabilize themselves as quickly as possible and maintain their balance for approximately six seconds. If participants lost their balance and touched the floor with the opposite leg, the trial was repeated. Each leg was tested in an alternating order, with three trials performed for each leg and 60 seconds of rest between trials.

The same as for the body sway test, ground reaction force data were collected at a sampling frequency of 1000 Hz and automatically low-pass filtered (Butterworth, 2nd order, 10 Hz) using the manufacturer's MARS software (version 4.0; Kistler, Winterthur, Switzerland). The data were then automatically processed within the same software to derive the outcome variables of interest. The average of the three repetitions was used for further analysis of all outcome variables. We obtained the time to stabilization from the centre of pressure (COP) data, as well as the peak vertical force, COP amplitude, and velocity data in the anterior-posterior (AP) and medial-lateral (ML) directions. The time to stabilization was determined based on the total, ML, and AP COP movement paths using sequential estimation. Specifically, an algorithm was employed to calculate a cumulative average of the COP data points in a series, adding points sequentially. The cumulative average was then compared with the overall mean of the series. The series was considered stable when the sequential average remained within 0.25 of the standard deviation of the overall mean. Peak force was defined as the peak vertical force value measured during the time of assessment. The COP amplitude was defined as the average of the peak amplitudes of the COP sway during the measurement period. Velocity was calculated as the total length of the trajectory divided by the measurement time. All variables were calculated for 5-second time windows following the landing.

Figure 2. Single-leg landing test setup.

Pedobarometric test

Participants were required to stand on one leg for 10 seconds on the pedobarometry platform (VCP1600 Pressure Plate, Voxel Care) to capture foot scan images (see Figure 3) based on the pressure distribution of the foot sole. The test was conducted barefoot and on a single leg. Each leg was tested three times. The arch index was calculated as the ratio of the area of the middle third of the footprint to the total footprint area, excluding the area under the toes. Participants' foot arch height characteristics were then categorized into three groups: normal medial arch height (0.21 to 0.28), high medial arch height (<0.21), and low medial arch height (>0.28) (Menz et al., 2012). The average of the three repetitions for each leg was used for further analysis.



Notes. The arch index was calculated from pressure areas using the formula: C / (B+C+D-A).

Figure 3. Foot print obtained using pedobarometry.

Statistical analyses

Descriptive statistics were calculated for all variables. Prior to testing our main hypothesis, intra-session reliability among three repetitions of arch index results was assessed using the intraclass correlation coefficient (ICC2.1) (Koo & Li, 2016) and the coefficient of variation (CV%) (Hopkins, 2000). CV values < 10% were deemed acceptable (Cormack et al., 2008). The ICC values were interpreted according to the following guidelines: ICC2.1 < 0.5 indicates poor reliability, 0.5 ≤ ICC2.1 ≤ 0.75 indicates moderate reliability, 0.75 < ICC2.1 ≤ 0.9 indicates good reliability, and ICC2.1 > 0.90 indicates excellent reliability (Koo & Li, 2016). Spearman correlation coefficients were then calculated between the foot arch index (normal, high, low) and landing test results, as well as between the foot arch index and body sway test results for each leg separately. The strength of association was interpreted as insignificant (rho < ±0.2), low (±0.2 < rho < ±0.4), moderate (±0.4 < rho < ±0.7), high (±0.7 < rho < ±0.9), and very high (rho > ±0.9) (Akoglu, 2018). Statistical analyses were performed using SPSS (Version 26, IBM, Armonk, NY, USA), with the level of significance set at $p < 0.05$.

RESULTS

Descriptive statistics of the test results are presented in the Table 1.

The reliability results of the arch index showed good relative (left: ICC2.1 = 0.85; right: ICC2.1 = 0.88) reliability, but unacceptable (> 10%) values of CV (left: CV = 35%; right: CV = 32%).

Table 1. Descriptive statistics of the foot arch index, landing test and body sway test measures.

Test	Variable	Left leg			Right leg		
		n	***M***	***SD***	***n***	***M***	***SD***
Pedobarometry	Arch index	44	0.19	0.07	44	0.20	0.06
Landing	Time from COP (s)	43	1.36	0.57	43	1.08	0.67
	Peak force (N)	43	1902.88	683.88	43	1906.50	620.80
	Amplitude AP (mm)	43	30.14	5.29	43	31.50	4.35
	Amplitude ML (mm)	43	74.53	17.62	43	72.50	17.80
	Velocity AP (mm/s)	43	72.51	13.26	43	73.80	18.59
	Velocity ML (mm/s)	43	175.21	36.18	43	178.59	67.67
Body sway	Path AP (mm)	44	715.52	185.32	44	716.40	188.75
	Path ML (mm)	44	820.23	194.90	44	818.40	182.63
	Velocity AP (mm/s)	44	23.85	6.18	44	23.88	6.29
	Velocity ML (mm/s)	44	27.34	6.50	44	27.28	6.09
	Frequency AP (Hz)	44	4.27	0.77	44	4.37	0.73
	Frequency ML (Hz)	44	5.38	1.51	44	5.20	1.25

Notes. *n* = 44; *M* = mean; *SD* = standard deviation; AP = anterior-posterior; ML = medio-lateral; COP – centre of pressure

In Table 2, the results of the correlation analysis between the foot arch index and landing test results are presented. Statistically significant positive correlations were found between the arch index and the time to stability for both legs (left: rho = 0.39, $p < 0.05$; right: rho = 0.34, $p < 0.05$). The amplitude, peak force, and velocity variables were not significantly correlated with the arch index results.

Table 2. The Spearman correlation coefficient results between foot indexes and landing test results.

Leg	Variable	Amplitude AP	Amplitude ML	Peak force	Time (COP)	Velocity AP	Velocity ML
Left	*rho*	-0.04	0.07	0.05	**0.39**	-0.16	-0.03
	p	0.79	0.65	0.73	**<0.01**	0.31	0.86
Right	*rho*	-0.20	-0.04	-0.12	**0.34**	-0.22	-0.11
	p	0.21	0.82	0.43	**<0.05**	0.17	0.50

Notes. *n* = 43; *rho* = Spearman correlation coefficient; *p* = statistical significance; AP = anterior-posterior; ML = medio-lateral; COP – centre of pressure

In Table 3, the results of the correlation analysis between the foot arch index and body sway test results are presented. Statistically significant negative correlations were found between the arch index and the frequency of COP path changes for both legs (left: rho = -0.39, $p < 0.05$; right: rho = -0.41, $p < 0.05$). The CoP path, velocity, and frequency variables were not significantly correlated with the arch index results.

Table 3. The Spearman correlation coefficient results between foot indexes and body sway test results.

Leg	Variable	Path AP	Path ML	Velocity AP	Velocity ML	Frequency AP	Frequency ML
Left	*rho*	0.05	-0.01	0.05	-0.01	**-0.39**	-0.25
	p	0.74	0.95	0.74	0.95	**<0.01**	0.10
Right	*rho*	0.09	-0.05	0.09	-0.05	**-0.41**	-0.17
	p	0.55	0.77	0.55	0.77	**<0.01**	0.29

Notes. *n* = 43; *rho* = Spearman correlation coefficient; *p* = statistical significance; AP = anterior-posterior; ML = medio-lateral; COP – centre of pressure

DISCUSSION

Our study aimed to investigate the correlations between different foot arch types, assessed through footprint analysis using pedobarometry, and two widely used balance and stability tests in the literature: the body sway test and the landing test. In the body sway test, we found statistically significant negative correlations between the arch index and the frequency of COP path changes for both legs. In the landing test, statistically significant positive correlations were observed between the arch index and the time to stability for both legs. Vertical force, COP path, and velocity did not show any correlation with the arch index in either test. These results partially support our hypothesis that a higher foot arch would be associated with better balance performance during single-leg balance tasks. However, only one of the six analyzed balance performance variables in each test proved to be sensitive to foot arch height. Specifically, the findings suggest that participants with lower foot arches required more time to stabilize their body's COP after a single-leg landing. Additionally, participants with a lower arch index maintained single-leg balance with more frequent corrections of the body's COP.

The Spearman correlation coefficient between the foot arch index and the dynamic balance landing test showed statistically significant positive correlations between the arch index and the time to stability, calculated based on COP data for both legs (left: rho = 0.39, $p < 0.05$; right: rho = 0.34, $p < 0.05$). Moreover, statistically significant negative correlations were found between the arch index and the frequency of COP path changes for both legs (left: rho = -0.39, $p < 0.05$; right: rho = -0.41, $p < 0.05$). Based on these results, we can partially confirm our hypothesis that participants with a higher arch index would demonstrate better balance performance during single-leg balance tasks due to similar muscle tasks during both tests. Specifically, it could be speculated that muscles that maintain a high foot arch in single-leg stance also contribute to single-leg body sway and landing stability results. In addition, high foot arch anatomy might provide better conditions for muscle function due to more optimized length-tension relationship of the muscles (Chang et al., 1999).

Only one of the six analysed result variables of each balance test was found to be correlated with the foot arch height results, regardless of the leg. In other words, it seems that the arch index differently underpins particular balance performance parameters, which might reflect different balance control strategies. The time to stabilization after single-leg landing task performance depends on proprioceptive feedback, pre-programmed muscle patterns, and reflexive and voluntary muscle responses, as indicated by a previous study (Wikstrom et al., 2005). Our results showed that participants with a lower foot arch needed more time to stabilize COP after the landing, meaning that the previously mentioned mechanisms were less effective. On the other hand, a higher arch height might influence time to stability due to better evertor muscle capabilities, preventing foot pronation and consequently dynamic valgus knee position (Jamaludin et al., 2020).

In the single-leg body sway test, the foot indices on the left and right feet were negatively correlated with the variable AP frequency. It could be speculated that participants with a lower arch index maintained single-leg balance with more frequent corrections of the body's COP, which might be a consequence of a lack of stiffness in the longitudinal medial arch. Nevertheless, our interpretation relies on speculations as we found no studies examining the sensitivity of particular balance performance variables for muscle characteristics assessment, presumably due to the complexity of the ankle joint and the synergistic behaviour of multiple muscle groups controlling the movement of the joint.

Moreover, these results also raise the question of whether a higher frequency of COP during single-leg stance reflects good or bad balance performance in healthy participants. A higher number of corrections at smaller amplitude changes of the COP path might also be an indicator of a good response to loss of balance or stability during standing and landing tasks, respectively. We speculate this while negative correlation was found between frequency of COP and arch index results, but positive correlation was found between time to stabilization and arch index results, meaning that participants with a high arch index stabilized faster after the landing. Therefore, we would also expect them to perform better in the single-leg body sway test.

The strengths of our study were controlled balance testing procedures, previously validated in the literature (Kozinc & Šarabon, 2021; Meras Serrano et al., 2023). However, our study has several limitations that need to be mentioned. This study was conducted on a relatively small, physically active sample, so the generalization of findings to the general population is limited. Additionally, the findings cannot be extrapolated to a population with injuries, as the participants in this study were healthy and without acute or chronic injuries. In the future, it would also be important to compare correlations between dynamic foot analysis (foot scans during walking or running) and dynamic balance. Moreover, low heterogeneity between foot arch results could also limit the power of the correlation analysis. In general, 40% of participants were classified into the group with a high foot arch, following procedures in the literature (Menz et al., 2012). Moreover, during the tests, participants were not instructed to maintain a high arch or stable foot position. Therefore, muscle characteristics might not have been measured, but rather anatomical foot characteristics were assessed. This might be a limitation of foot arch type measurements in general, as there are no standardized procedures in terms of instructions to participants when performing the foot scans using pedobarometry.

Furthermore, we did not measure strength or navicular bone height in particular, therefore the sensitivity of the foot scan results using pedobarometry might lack sensitivity to differences between participants and, consequently, to different functional performance measures of the foot. Because the pedobarometric device used in this study has not been previously utilized in research settings, we verified its reliability before the correlation analyses. The reliability results of the arch index showed good relative reliability, but unacceptable (> 32%) values of CV. Based on these results, we can conclude that more than three repetitions should be averaged to improve the signal-to-noise ratio of the results in our study. Lower reliability might lower the validity of the arch index results, therefore lowering the power of the correlation analyses. Importantly, in clinical practice and in future studies, more than three repetitions should be averaged to obtain trustworthy absolute values of arch index results. Future reliability studies might also be beneficial to confirm our claims.

CONCLUSION

In summary, we found that participants with flat feet needed more time to stabilize after the single-leg landing task. Moreover, participants with flat feet maintained single-leg balance with more frequent corrections of the body's COP. No differences in the reliability of the arch index results and correlation analysis between arch indices and balance performance test results were found between both legs. Based on our findings, we conclude that the foot arch index partially determines single-leg balance performance. Future studies are warranted to identify common muscle characteristics underpinning both balance test performance and arch index results. Moreover, for future use, we suggest that researchers carefully consider the number of repetitions needed for each measurement to reduce the impact of measurement variability of the foot arch index.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

Akoglu, H. (2018). User’s guide to correlation coefficients. *Turkish Journal of Emergency Medicine, 18*(3), 91–93. https://doi.org/10.1016/j.tjem.2018.08.001

Chang, Y.-W., Su, F.-C., Wu, H.-W., & An, K.-N. (1999). Optimum length of muscle contraction. *Clinical Biomechanics, 14,* 537–542.

Cobb, S. C., Bazett-Jones, D. M., Joshi, M. N., Earl-Boehm, J. E., & James, C. R. (2014). The relationship among foot posture, core and lower extremity muscle function, and postural stability. *Journal of Athletic Training, 49*(2), 173-180.

Cormack, S. J., Newton, R. U., McGulgan, M. R., & Doyle, T. L. A. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal of Sports Physiology and Performance, 3*(2), 131–144. https://doi.org/10.1123/ijspp.3.2.131

Dawe, E. J., & Davis, J. (2011). (vi) Anatomy and biomechanics of the foot and ankle. *Orthopaedics and Trauma*, *25*(4), 279-286.

Fujitaka K, Fujitake S, Kita T, Hashimoto M, Otuki S, Okubo M, Hon K. (2012). The Effect of the Foot Arch Related Muscle Strength Training on the Incidence of Ankle and Foot Injuries in Male College Soccer Players. *Rigakuryoho Kagaku, 27*(3), 263–7.

Gwani, A. S., Asari, M. A., & Ismail, Z. M. (2017). How the three arches of the foot intercorrelate. *Folia Morphologica*, *76*(4), 682-688.

Hajirezayi, P., Ghasemi, G., Arghavani, H., & Sadeghi-Demneh, E. (2019). Comparison of postural control factors, static and dynamic balance in students with different foot arches. *Journal of Paramedical Sciences & Rehabilitation, 8*(2), 69-76.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*(1), 1–15. https://doi.org/10.2165/00007256-200030010-00001

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise, 41*(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

Jamaludin, N. I., Sahabuddin, F. N. A., Najib, R. K. M. R. A., Bahari, M. L. H. S., & Shaharudin, S. (2020). Bottom-up kinetic chain in drop landing among university athletes with normal dynamic knee valgus. *International Journal of Environmental Research and Public Health, 17*(12), 1–10. https://doi.org/10.3390/ijerph17124418

Jankowicz-Szymanska, A., Mikolajczyk, E., & Wardzala, R. (2015). Arch of the foot and postural balance in young judokas and peers. *Journal of Pediatric Orthopaedics, 24*(5), 456-460.

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine, 15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Kozinc, Ž., & Šarabon, N. (2021). The effects of leg preference on transient characteristics of body sway during single-leg stance: a cross-sectional study. *Frontiers in human neuroscience*, *14*, 617222.

Matsumoto M, Yamamoto K. Effect of Medial Longitudinal Arch Height on Static and Dynamic Balance Among UiTM Female Athletes. (2022). *J Phys Ther Sci., 34*, 135–9. https://doi.org/10.1007/978-981-15-3270-2_7

Menz, H. B., Fotoohabadi, M. R., Wee, E., & Spink, M. J. (2012). Visual categorisation of the arch index: a simplified measure of foot posture in older people. *Journal of Foot and Ankle Research, 5*(1), 1-7.

Šarabon, N., Rosker, J., Loefler, S., & Kern, H. (2010). Sensitivity of body sway parameters during quiet standing to manipulation of support surface size. *Journal of Sports Science & Medicine, 9*(3), 431.

Tong, J. W., & Kong, P. W. (2013). Association between foot type and lower extremity injuries: systematic literature review with meta-analysis. *Journal of Orthopaedic & Sports Physical Therapy, 43*(10), 700-714.

Unver, B., Selici, K., Akbas, E., & Erdem, E. U. (2020). Foot posture, muscle strength, range of motion, and plantar sensation in overweight and obese. *Journal of applied biomechanics*, *37*(2), 87-94.

Wikstrom, E. A., Tillman, M. D., Smith, A. N., & Borsa, P. A. (2005). A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *Journal of Athletic Training*, *40*(4), 305-309.

Zhao, X., Tsujimoto, T., Kim, B., & Tanaka, K. (2017). Association of arch height with ankle muscle strength and physical performance in adult men. *Biology of sport*, *34*(2), 119-126.