Classic and indicative methods in the analysis
of the foot arch and foot loads in professional folklore dancers
on the basis of stabilographic tests

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Purpose: The proper shape of the foot determines its proper functioning and efficiency, which is significant as far as dancers are concerned. The aim of the study was to identify the arch of feet based on the Arch Index (AI), ability to maintain balance on the basis of stabilometric parameters and the distribution of loads acting on the feet of professional folk dancers. *Methods*: The study group was composed of 37 folk dancers and the reference group consisted of 56 healthy adults aged 19–45. Balance measurements were performed using the Zebris FDM-S measurement platform, Romberg test with eyes open. Test results were exported to the Matlab 2019b computing environment. The algorithm developed by the Authors in relation was used to calculate Arch Index for the right and left foot, for each test participant separately. *Results*: Statistical tests did not reveal statistically relevant differences between stabilometric parameters and loads affecting feet in the reference group and that of the dancers. The statistical tests revealed that the value of the AI differed significantly in the reference group and in the group of professional folk dancers ($p = 0.05$). The differences were also observed in the group of females ($p = 0.003$). No statistically relevant differences were observed in relation to the group of males ($p = 0.116$). The percentage of the feet with high arch in the group of dancers amounted to 26%; 33% of dancers' feet were classified as the feet with low arch. *Conclusions*: The feet of professional folk dancers have a statistically more arched foot than the reference group.

Key words: arch index, balance, folk dancers, foot

1. Introduction

Human foot plays an important static-dynamic function within the locomotor system. The morphological structure of the foot, particularly the proper shape of its longitudinal and transverse arches determine the proper functioning and efficiency of the foot [28]. This is of particular significance with regard to dancers due to the fact that, during landing, the foot becomes the first link of the biokinematic chain. The proper work of the foot increases the proper and safe absorption of shocks [9]. The publication by Spink [33] contains a statement that the changes in the structure of

feet affect their functionality and ability to maintain balance.

Ankles and feet of professional dancers are exposed to significant loads (static and dynamics loads) resulting from a dance technique [1], [3], [8]–[12], [14]. Juhyun and Kyungock [16] established that there were differences between the ground reaction force values (GRF) and subjective impressions depending on the type of foot and the structure of the internal arch support during a vertical jump performed from the second ballet position.

In spite of many existing methods used in the foot arch assessment, "the golden mean" has not been found yet [37]. Reference publications contain information on

various methods used for the assessment of the foot structure (arch), based on visual evaluation [6] or the evaluation of foot imprint and Arch Index (AI) [5].

The Arch Index (AI) is an important index used to assess the foot arch [40] as well as one of the most popular ones [2]. The AI, developed by Cavanagh and Rodgers [5], represents the proportion of the middle area of one third of the footprint to the entire area of the foot excluding toes. The higher the index, the flatter the foot. It has been demonstrated that the AI is very reliable [23], strongly correlated with the navicular height [20], [23] and angular measures [23], [39] defined on the basis of X-ray photographs as well as is sensitive to age-related differences in foot posture [32]. AI is correlated with the pressure under the metatarsus and during foot movements [22], [38] as well as movements of the foot during walking. However, the primary disadvantage of the AI is the fact that it requires the use of a graphic tablet or an optical scanner and imaging software enabling the precise, yet, time-consuming, calculation of the footprint area [21].

Although stabilographic tests concerning classical dancers are widely discussed in reference publications [17], [24], [30], [31], only a few publications refer to similar tests concerning professional folk dancers [7], [36]. Undoubtedly, folk dance can be regarded as a difficult (for male dancers) or very difficult (for female dancers) form of physical activity. Folk dancers should be very well prepared physically for the significant intensity of exercises present in this type of dance [19].

A significantly arched foot with a high longitudinal arch guarantees high aesthetics in classical ballet [13]. Dance teachers and dancers focus very much on the aesthetics of the foot. It is wondering whether the feet of dancers of different styles, including folklore, are more arched than feet in the control group (healthy adults). Can folk dance be a professional choice for those dancers who do not have high arched feet and therefore cannot be members of classical dance groups? Available reference publications do not contain information concerning the classification and the longitudinal arch of folk dancers' feet. There are no works analysing relationships between the longitudinal arch of the foot, loads acting on the foot and the maintaining balance in this professional group.

This study aimed to identify the arch of feet based on the Arch Index, ability to maintain balance on the basis of stabilometric parameters and the distribution of loads acting on the feet of professional folk dancers.

2. Materials and method

Participants

The study group was composed of 37 folk dancers (the Polish National Song and Dance Ensemble "Śląsk" in memory of Stanisław Hadyna, Poland) aged 19–45 (body mass: 61.9 ± 10.6 kg, body height: 1.71 ± 0.82 m, BMI: 21.1 ± 2.2 kg/m^2): 20 males (body mass: 70.4 ± 7.9 kg, body height: 1.78 ± 6.2 m, BMI: 22.5 ± 2.0 kg/m^2) and 17 females (body mass: 54.0 ± 5.3 kg, body height: 1.66 ± 5.8 m, BMI: 19.6 ± 1.5 kg/m^2).

Test inclusion criteria involved the professional nature of folk dance (dance as the only source of income, the lack of other occupations), a minimum 10-year long dancing career, the lack of chronic diseases as well as the lack of injuries of the ankle and foot 6 months before the performance of tests.

The reference group was composed of 56 healthy adults aged 20–30 (body mass: 65.5 ± 13.8 kg, body height: 1.71 ± 0.8 m, BMI: 22.3 ± 2.6 kg/m^2): 20 males (body mass: 76.3 ± 11.8 kg, body height: 1.78 ± 0.7 m, BMI: 23.3 ± 1.7 kg/m^2) and 36 females (body mass: 55.2 ± 12.1 kg, body height: 1.65 ± 5.2 m, BMI: 21.8 ± 2.1 kg/m^2). Reference group inclusion criteria involved the lack of defects within the locomotor system, the lack of visibly faulty posture, no surgeries within the spine and lower limbs or injuries sustained within the past 3 months.

Ethical statement

All of the persons agreed to their participation in the tests (performed in accordance with the principles of the Declaration of Helsinki). The study design was approved by the Bioethical Committee at the Poznań University of Medical Sciences before commencement of the study (decision no. 796/09).

Measurement protocol

Balance measurements were performed using the Zebris FDM-S (Zebris Medical GmbH, Isny, Germany) measurement platform. Sampling frequency of the platform amounted to 100 Hz. Balance tests (analysis of the position of the resultant pressure force of feet affecting the ground) was based on the Romberg test. During this test, a participant with arms placed freely along their body sides stands on both lower limbs, which are distanced from each other at the pelvis width. The Romberg test was performed with open eyes. Each test lasted 60 seconds. The analysed stabilometric parameters and percentage load exerted

on the feet were determined on the basis of a 30 second-long measurement (between the 15th and 45th second).

Test results were exported to the Matlab 2019b computing environment. The algorithm developed by the Authors in relation to the entire study group was used to calculate Arch Index values in relation to each recorded measurement exposure as well as in relation to the right and left foot of each test participant separately. The primary assumptions of the algorithm included the detection of the position of each foot on the platform, the segmentation of the pressure area of each foot (excluding toes) and the division of the foot into three areas (A, B and C), as shown in Fig. 1. The value of the Arch Index was calculated as the proportion of the instep area (B) to the area of the entire foot (A + B + C), in accordance with Eq. (1) [5].
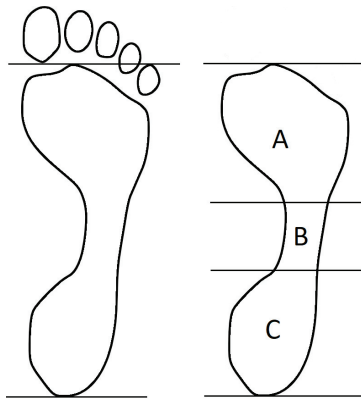

Fig. 1. Division of the foot area (excluding toes)
into 3 parts (A, B and C) to calculate Arch Index values

$$AI = B/(A + B + C) \qquad (1)$$

Each single 30 second-long measurement resulted in the obtainment of 3000 values of AI (100Hz * 30s). The results were averaged in relation to each foot of a given test participant.

In accordance with reference publications, on the basis of AI values, the foot arch can be classified as follows:
- $AI \leq 0.21$ – high arch,
- $0.21 < AI < 0.26$ – normal arch,
- $AI \geq 0.26$ – low arch/flat [20].

The platform used in the research measures the foot pressure distribution regardless of the way the foot is placed. The necessary condition is that the entire foot is on the platform (both feet during the measurement). The implemented proprietary algorithm detects the position of the toes and heels and then divides each foot into three parts. It is a repeatable process regardless of the position of the tested person. Additionally,

in order to reduce the impact of external noise, an averaging measurement window is used between 15 and 45 seconds of the test. During this time period, the measurement is continuous – the result is a database of 3000 measurement data related to the foot distributions for each participant. The results of the calculated AI values are averaged over the entire 30-second time window.

Analysed parameters

Parameters subjected to analysis were the following:
- path length (PL) [mm] – the entire length of the path covered by the COP (path covered by the centre of foot pressure on the ground during a measurement),
- ellipse area (EA) [mm²] – where the COP was located during a measurement (area of ellipse formed by 95% of the COP locations during a test),
- average percentage load acting on the right (R) and left (L) lower limb [%],
- average percentage load acting on the forefoot and hindfoot of the right and left lower limb [%],
- load symmetry index in relation the right and left lower limb, determined using formula (SI):

$$SI = \left| \frac{(L-R)}{0.5(L+R)} * 100\% \right|, \qquad (2)$$

where:
L – average percentage load acting on the left lower limb;
R – average percentage load acting on the right lower limb.
- Arch Index value (AI) in relation to the right and left foot.

Statistical analysis of test results

The test results were subjected to a statistical analysis. The quantitative variables of parameters were described using the average value, standard deviation as well as the minimum and maximum value. The normality of distribution was verified using the Shapiro–Wilk test. The occurrence of differences in the analysed parameters between the groups was analysed using the Student's *t*-test in relation to independent samples, or the Mann–Whitney *U*-test – depending on the normality of distribution of the analysed variables. The level of significance adopted in statistical analyses was $\alpha = 0.05$. Calculations were performed using Statistica 13.1 software programmes (StatSoft).

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3. Results

In Tables 1 and 2, the results concerning stabilo-metric parameters, percentage loads exerted on lower limbs, load symmetry index in relation to the right and left lower limb as well as the Arch Index in relation to the reference group and professional folk dancers are presented. Statistical tests did not reveal statistically relevant differences between stabilometric parameters and loads affecting feet in the reference group and that of the dancers. Despite the lack of statistically relevant intergroup differences in relation to stabilometric parameters, it was noticed that the values obtained for the reference group were characterised by greater scatter and that maximum values were higher. In relation to 10% of the people from the reference group, the area of ellipsis exceeded 100 mm^2 (in two cases, even 200 mm^2). The values of path length were similar in both groups. The tests did not reveal differences

Table 1. Test results concerning stabilometric parameters and percentage loads acting on lower limbs in relation to the entire reference group and the group of professional folk dancers

All group		Mean ± SD (min-max)	Reference vs. dancers
			p-value
PL [mm]	Reference	370 ± 86 (252–557)	0.08
	Dancers	335 ± 66 (206–474)	
EA [mm^2]	Reference	43 ± 46 (8–229)	0.26
	Dancers	37 ± 20 (9–92)	
L [%]	Reference	50.8 ± 4.2 (40.3–58.0)	0.822
	Dancers	50.6 ± 3.7 (42.5–57.1)	
R [%]	Reference	49.2 ± 4.1 (42.0–59.7)	0.822
	Dancers	49.4 ± 3.7 (42.9–57.5)	
SI [%]	Reference	13 ± 10 (0–39)	0.58
	Dancers	12.1 ± 8.3 (0.4–30.0)	
LF [%]	Reference	43.1 ± 11.8 (21.5–68.5)	0.1
	Dancers	47 ± 10 (27.5–69.2)	
LB [%]	Reference	56.9 ± 11.8 (31.5–78.5)	0.1
	Dancers	53 ± 10 (30.8–72.5)	
RF [%]	Reference	43.5 ± 12.2 (23.6–80.2)	0.081
	Dancers	47.7 ± 10 (26.9–67.6)	
RB [%]	Reference	56.5 ± 12.2 (19.8–76.4)	0.081
	Dancers	52.3 ± 10 (32.4–73.1)	
AI	Reference	0.257 ± 0.066 (0.096–0.367)	0.05*
	Dancers	0.237 ± 0.060 (0.082–0.347)	

* $p \leq 0.05$, PL – path length, EA – elipse area, L – average percentage load acting on the left lower limb, R – average percentage load acting on the right lower limb, SI – load symmetry index in relation the right and left lower limb, LF – average percentage load acting on the left forefoot, LB – average percentage load acting on the left hindfoot, RF – average percentage load acting on the right forefoot, RB – average percentage load acting on the right hindfoot, AI – arch index.

Table 2. Test results concerning stabilographic parameters, percentage loads acting on lower limbs and values of the AI in relation to the reference group and the group of professional folk dancers grouped according to gender

All group		Mean ± SD (min–max)	Reference vs. dancers
			p-value
Females			
PL [mm]	Reference	380 ± 91 (252–535)	0.773
	Dancers	345 ± 62 (239–471)	
EA [mm^2]	Reference	46 ± 43 (10–229)	0.28
	Dancers	41 ± 25 (9–92)	
L [%]	Reference	50.8 ± 4.4 (40.3–58.0)	0.94
	Dancers	50.7 ± 4.1 (43.6–57.1)	
R [%]	Reference	49.3 ± 4.4 (42.0–59.7)	0.94
	Dancers	49.4 ± 4.1 (42.9–56.4)	
SI [%]	Reference	13 ± 10 (0–39)	0.675
	Dancers	13.6 ± 9.0 (0.4–28.4)	
LF [%]	Reference	40.8 ± 11.5 (21.5–68.5)	0.117
	Dancers	46.1 ± 11.4 (27.5–64.5)	
LB [%]	Reference	59.2 ± 11.5 (31.5–78.5)	0.117
	Dancers	53.9 ± 11.4 (35.5–72.5)	
RF [%]	Reference	42 ± 10.8 (23.6–66.6)	0.163
	Dancers	46.4 ± 10.9 (26.9–67.6)	
RB [%]	Reference	58 ± 10.8 (33.4–76.4)	0.163
	Dancers	53.6 ± 10.9 (32.4–73.1)	
AI	Reference	0.269 ± 0.066 (0.096–0.367)	0.003*
	Dancers	0.219 ± 0.069 (0.086–0.347)	
Males			
PL [mm]	Reference	353 ± 75 (254–557)	0.24
	Dancers	326 ± 69 (206–474)	
EA [mm^2]	Reference	38 ± 53 (8–228)	0.056
	Dancers	34 ± 14 (10–64)	
L [%]	Reference	50.9 ± 3.4 (44.6–57.1)	0.777
	Dancers	50.6 ± 3.4 (42.5–56.0)	
R [%]	Reference	49.1 ± 3.4 (42.9–55.4)	0.777
	Dancers	49.4 ± 3.4 (44.0–57.5)	
SI [%]	Reference	13 ± 11 (0–39)	0.911
	Dancers	11.0 ± 7.6 (0.4–30.0)	
LF [%]	Reference	47.6 ± 11.4 (28.9–67.7)	0.942
	Dancers	47.8 ± 8.7 (30.9–69.2)	
LB [%]	Reference	52.4 ± 11.4 (32.3–71.1)	0.942
	Dancers	52.2 ± 8.7 (30.8–69.1)	
RF [%]	Reference	46.4 ± 14.4 (24.3–80.2)	0.529
	Dancers	48.9 ± 9.2 (34–64.9)	
RB [%]	Reference	53.6 ± 14.4 (19.8–75.7)	0.529
	Dancers	51.1 ± 9.2 (35.1–66)	
AI	Reference	0.236 ± 0.062 (0.101–0.361)	0.116
	Dancers	0.252 ± 0.047 (0.082–0.313)	

* $p \leq 0.05$, PL – path length, EA – elipse area, L – average percentage load acting on the left lower limb, R – average percentage load acting on the right lower limb, SI – load symmetry index in relation the right and left lower limb, LF – average percentage load acting on the left forefoot, LB – average percentage load acting on the left hindfoot, RF – average percentage load acting on the right forefoot, RB – average percentage load acting on the right hindfoot, AI – arch index.

as regards both groups in terms of loads acting on lower limbs. In the reference group, the load symmetry index for lower limbs in relation to 27% of test participants amounted to more than 20%, in relation to 60% of test participants amounted to more than 10%. Similarly, in the group of professional folk dancers, the load symmetry index (SI) for lower limbs in relation to 22% of test participants amounted to more than 20% and in relation to 51% of test participants, it amounted to more than 20%. The manner of exerting load on individual parts of the foot did not differ significantly between the group of professional folk dancers and the reference group ($p > 0.05$).

The statistical tests revealed that the value of the AI differed significantly in the reference group and in the group of professional folk dancers ($p = 0.05$). The differences were also observed in the group of females ($p = 0.003$). No statistically relevant differences were observed in relation to the group of males ($p = 0.116$).

In Figure 2, the percentage distribution of the AI values in the reference group and in the group of professional folk dancers is presented. In the reference group, 41% of the AI values revealed feet with the normal arch, 41% of the AI values revealed feet with the low arch, whereas 18% of feet were characterised by the high arch. In the group of professional folk dancers, a greater percentage of the results, i.e., 26%, indicated high-arch feet, with 38% of dancers' feet being classified as having the normal arch and 33% as feet with the low arch.
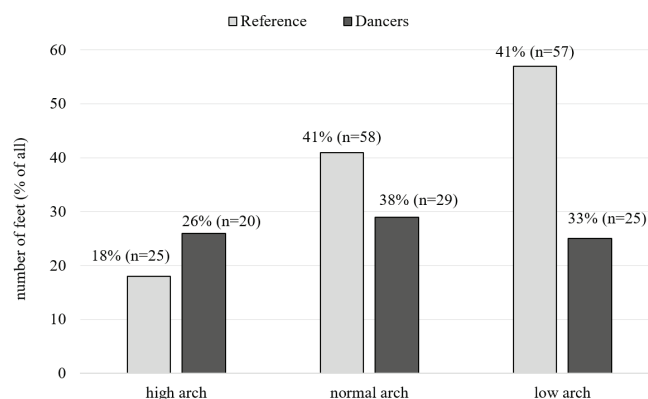

Fig. 2. Distribution of the AI in relation to feet
in the reference group and in the group of professional folk dancers

4. Discussion

The study aimed to identify the arch of feet on the basis of the Arch Index, ability to maintain balance on the basis of stabilometric parameters and the distribu-

tion of loads exerted on feet of professional folk dancers. The primary tests results revealed that: 1) AI values varied significantly in the reference group and in the group of professional folk dancers; 2) there were no statistically relevant differences between stabilometric parameters in relation to the reference group and the group of professional folk dancers; 3) there were no statistically relevant differences regarding percentage loads acting on lower limbs and in terms of the load symmetry index for the right and left lower limbs in relation to the reference group and the group of professional folk dancers.

In the following sections, possible explanations, interpretations and suggestions based on the data obtained in the tests are presented.

High foot arch versus professional dance

In the world of professional dance, there is a notion of the "perfect foot", i.e., with the high longitudinal arch. The "perfect foot" is every artist's dream and an admission ticket to renowned ballet schools [13]. The aesthetics of the high arch of the foot is important during barefoot dance as well as when dancing in points or traditional folk leather shoes[1]. The high foot arch translates into a beautiful foot profile at the final stage of a movement. However, the high arch of foot arch is more than just aesthetics.

People with high-arch feet usually have better jumping skills [40], which is of great importance as regards professional dancers. Feet with a very high arch are characterised by the smaller footprint area, where loads acting on the feet on a daily basis affect smaller areas. Zheng et al. [40] imply that high-arch feet could be nagging during long-distance walks. The longitudinal arch of the foot can be assessed using the AI. In our tests, in relation to the reference group, 41% of feet (designated using the AI) were classified as having the normal arch, subsequent 41% of feet were classified as having the low arch, whereas 18% of feet had the high arch. In relation to the group of professional folk dancers, 26% of the dancers had feet with the high arch, 38% of the dancers had feet with the normal arch and 33% of the dancers had feet with the low arch (Fig. 2). Because the above-presented test was the first one of its kind in relation to the group of dancers, it was not possible to confront our AI values with the tests performed in relation to other artists.

The educational path of professional folk dancers looks different to that followed by classical dancers [12]. A precondition for admission to a classical dance

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[1] Translators note: The authors referred especially to traditional leather shoes worn by Polish highlanders.

ensemble is graduation from the ballet school of general education. The aforesaid condition is not necessary in relation to folk dancers. Previous tests of classical dancers demonstrated that the high arch of the foot is an inborn feature which can only slightly be increased through ballet/technical exercises [13], primarily affecting feet muscles [10], [11].

The ankle and the foot of professional dancers are exposed to significant stresses and loads connected with dance techniques [3], [8], [12]. The above-named structures often sustain injuries [3]. Polish folk dancers have to be familiar with the fundamentals of classical dance and have a two-hour class every day. In cases of folk dancers performing in folk footwear (leather shoes, "officer's boots", highlander's leather shoes or shoes characteristic of a given culture) [27] are exposed to additional risks resulting from different height of the heel, various shoe materials and unpredictable ground during away-from-home performances. The difference in the structure and functionality of feet among folk and classical dancers was noticed by Oztekin et al. [27].

Stabilometry

Ability to maintain balance by dancers is a relatively frequent subject of publications, however, it refers to classical dancers [17], [24], [30]. According to reference publications, dancers have worse balance with their eyes closed [30]. Our tests revealed that, despite the lack of statistically relevant intergroup differences in relation to stabilographic parameters, the values obtained for the reference group were characterised by greater scatter. In addition, the maximum values were higher. Folk dance is a relatively unknown field. There were only two available reference publications concerning stabilometric tests of such groups and they referred to Estonian and Irish dancers [7], [36]. In our tests, in relation to nearly 10% of the dancers from the reference group, the area of ellipsis exceeded 100 mm^2, in two cases, even 200 mm^2. The average values of path length were similar in both groups, yet, regarding the group of folk dancers, the path length was on average 335 mm, whereas the ellipsis area amounted to 37 mm^2.

Väisa et al. [36] investigated the effect of 8-month long folk dance training on the static balance of young female dancers. They identified changes in the parameters of dancers' static balance in relation to disturbing factors and stressful situations. The tests revealed that the CoP movements of folk dancers in the anterio-posterior (AP) and medio-lateral (ML) dimensions measured in various conditions (eyes open – EO, eyes closed – EC) on the stable and unstable ground surface did not change significantly after 8-month long practical training. However, the static balance of young folk dancers assessed on the basis of the movement trajectory, velocity and CoP area improved significantly during the 8-month long training period. According to our observations, the balance of the folk dance artists did not reveal statistically relevant differences in relation to the reference group.

This fact probably resulted from the specific nature of recruitment to the folk dance ensemble and everyday movement-related exercises of the Polish artists. Folk dance was created by anonymous representatives of local culture as the expression and reflection of the movement and custom-related tastes, musicality as well as the sense of rhythm and temperament of people living in a given area [18]. Movement forms and music which accompanies them contain features confirming their old origins, elements of national identity as well as the continuity and permanence of a given dance culture. Polish folk dances performed by professional folk dance ensembles represent the richness of regional costumes, songs, dance tunes and collective dance movements performed in pairs. Unlike in classical dance, in folk dances, there are no typically balance-related tasks performed on small support planes [25]. In addition, the time of work in points is limited to maximum 90 minutes daily.

Similar results were obtained by Dewhurst et al. [7] performing tests concerning older female Scottish country dancers, who observed that the majority of stabilometric parameters did not differ between a group of folk dancers and a reference group. An exception was the velocity of deflections as in most of the tests, the aforesaid velocity was higher in the reference group ($p < 0.01$). During investigations involving a group of dancers in the parallel position and in the first classical position, Harmon et al. [15] noticed that the results suggest that superior balance and motor control in dancers may be limited to less innate dance-specific foot positions. In addition, Casabona et al. [4] concluded that, regarding dance training, the benefits resulting from improved stability were limited to a specific foot configuration, regardless of a degree of the posture difficulty or an element of the posture control.

According to Oreb et al. [26], the training process in folk dance is usually focused on the preparation for performances with the simultaneous negligence of motoric skills development. On the other hand, according to several authors, the application of training programmes for folk dancers produces visible results [7], [35], [36].

Distribution of pressure under feet

Measurements of the pressure under feet is useful for the assessment of foot pathology and loads exerted by the human body on feet in persons suffering from various types of faulty posture [28]. In people with pes cavus, the distribution of pressure during pedobarographic tests is lower under all parts of the foot [28]. In people with platypodia, the instep is exposed to significantly greater loads [29]. In the properly shaped foot during free standing, pressure is particularly exerted around three areas of stance, i.e., the area of calcaneal tuber, the head of the first metatarsal bone and the and the head of the fifth metatarsal bone (biomechanics of the human locomotor system). In healthy fit adults, approximately 60–70% of load should affect the hindfoot and the remaining 40–30% of load should act on the forefoot.

As a result, the COP is close to the ankle, which guarantees the minimisation of the activity of posterior muscles of the calf. Obviously, loads acting on feet vary depending on the manner of standing on two limbs or in the pointe position, which is typical of ballet dance [34]. The Romberg test performed by the Authors of this work did not reveal statistically relevant differences in the manner of loading the feet during the standing position in the group of folk dancers and in the reference group. In the reference group, the load symmetry index (SI) concerning the loading of lower limbs in relation to 27% of test participants amounted to more than 20%, whereas in relation to nearly 60% of test participants, it amounted to more than 10%. Similarly, in the group of professional folk dancers, in relation to 22% of test participants, the load symmetry index concerning lower limbs exceeded 20%, whereas in relation to 51% of test participants, the SI amounted to more than 20%. The manner of exerting loads on individuals parts of the foot (forefoot, instep and hindfoot) did not differ significantly between the group of professional folk dancers and the reference group ($p > 0.05$). The folk dancers exerted loads on their both feet in a manner similar to that in the reference group. Interestingly, unlike ballet dancers, professional folk dancers did not tend to exert loads on the forefoot [7], [31].

Limitation of this study and directions of further research

The main limitation of this study was that it only examined a group of folk dancers. It would be interesting to compare the determined parameters evaluating the foot arch, balance and foot loads between dancers of different dance styles (ballet, modern, folk).

It would be particularly interesting to check whether the value of the Arch Index is related to a professional career and to check if the balance parameters are related to the level of the foot arch. It is also interesting whether, apart from purely aesthetic values, the very arched foot has any biomechanical significance in particular dance styles.

5. Conclusions

Folk dance reference publications are scarce. This work constitutes the first study concerning the Arch Index and stabilometric parameters of Polish folk dancers. The performed tests and the analyses of the obtained results revealed that stabilometric parameters and loads acting on the feet did not differ significantly in the group of professional folk dancers and in the reference group. The values of the Arch Index used for the assessment of the foot arch differed significantly in the group of professional folk dancers in relation to the reference group. Lower AI values, indicating a more arched foot, were observed in the group of professional folk dancers. However, the percentage of the feet with high arch in the group of dancers amounted to 26%; 33% of dancers' feet were classified as the feet with low arch. Because of the fact that the high foot arch is an admission ticket to the ballet school, folk dance could be an alternative for those who wish to follow their dance career outside classical dance ensembles. We suppose that the method of determining the Arch Index based on measurements with the use of a dynamometric platform could be helpful in a quick, non-invasive foot classification during recruiting dancers to ballet schools and groups.

Acknowledgements

References

[1] AKSU N., ATANSAY V., AKSU T., DAMLA KARA Ş., KOÇULU S., KARALÖK I., *Overuse Injuries in Professional Anatolian Folk Dancers: A Descriptive Study Verified with MRI*, Med. Probl. Perform Art., 2017, 32 (3), 152–158.

[2] BIBROWICZ K., SZURMIK T., MICHNIK R., WODARSKI P., MYŚLIWIEC A., MITAS A., *Application of Zebris dynamometric platform and Arch Index in assessment of the foot*, Technol. Health Care, 2018, 26 (S2), 543–551.

[3] BRONNER S., MCBRIDE C., GILL A., *Musculoskeletal injuries in professional modern dancers: a prospective cohort study of 15 years*, J. Sport Sci., 2018, 36 (3), 1–9.

[4] CASABONA A., LEONARDI G., AIMOLA E., LA GRUA G., POLIZZI C.M., CIONI M., VALLE M.S., *Specificity of foot configuration during bipedal stance in ballet dancers*, Gait Posture, 2016, 46, 91–97.

[5] CAVANAGH P.R., RODGERS M.M., *The arch index: a useful measure from footprints*, J. Biomech., 1987, 20(5), 547–551.

[6] DAHLE L.K., MUELLER M., DELITTO A., DIAMOND J.E., *Visual assessment of foot type and relationship of foot type to lower extremity injury*, J. Orthop. Sports Phys. Ther., 1991, 14 (2), 70–74.

[7] DEWHURST S., PEACOCK L., BAMPOURAS T.M., *Postural stability of older female Scottish country dancers in comparison with physically active controls*, J. Aging Phys. Activ., 23 (1), 128–132.

[8] FORCZEK-KARKOSZ W., MICHNIK R., NOWAKOWSKA-LIPIEC K., VARGAS-MACIAS A., BAENA-CHICÓN I., GÓMEZ-LOZANO S., GORWA J., *Biomechanical description of Zapateado technique in flamenco*, Int. J. Env. Res. Pub. He., 2021, 18 (6), 2905.

[9] GORWA J., FRYZOWICZ A., MICHNIK R., JURKOJĆ J., KABACIŃSKI J., JOCHYMCZYK-WOŹNIAK K., DWORAK L.B., *Can we learn from professional dancers safe landing? Kinematic and Dynamic Analysis of the Grand Pas de Chat' Performed by Female and Male Dancer*, [in:] Proceedings of the Innovations in Biomedical Engineering, E. Tkacz, M. Gzik, Z. Paszenda, E. Piętka (Eds.), Springer International Publishing Cham., 2019, 925, 233–240.

[10] GORWA J., KABACIŃSKI J., MURAWA M., FRYZOWICZ A., *Which of the five classical ballet positions is the most demanding for the dancer's body? An electromyography-based study to determine muscular activity*, Acta Bioeng. Biomech., 2020, 22 (4), 3–14.

[11] GORWA J., KABACIŃSKI J., MURAWA M., FRYZOWICZ A., *On the track of the ideal turnout: Electromyographic and kinematic analysis of the five classical ballet positions*, PLoS One, 2020, 15 (3), e0230654.

[12] GORWA J., MICHNIK R.A., NOWAKOWSKA-LIPIEC K., JURKOJĆ J., JOCHYMCZYK-WOŹNIAK K., *Is it possible to reduce loads of the locomotor system during the landing phase of dance figures? Biomechanical analysis of the landing phase in Grand Jeté, Entrelacé and Ballonné*, Acta Bioeng. Biomech., 2019, 21 (4), 111–121.

[13] GORWA J., MICHNIK R., NOWAKOWSKA-LIPIEC K., *In Pursuit of the Perfect Dancer's Ballet Foot. The Footprint, Stabilometric, Pedobarographic Parameters of Professional Ballet Dancers*, Biology, 2021, 10 (5), 435.

[14] GORWA J., ZIELIŃSKI J., WOLAŃSKI W., MICHNIK R., LARYSZ D., DWORAK L.B., KUSY K., *Decreased bone mineral density in forearm vs. loaded skeletal sites in professional ballet dancers*, Med. Probl. Perform Art., 2019, 34 (1), 25–32.

[15] HARMON B.V., REED A.N., ROGERS R.R., MARSHALL M.R., PEDERSON J.A., WILLIAMS T.D., BALLMANN C.G., *Differences in Balance Ability and Motor Control between Dancers and Non-Dancers with Varying Foot Positions*, J. Funct. Morphol. Kinesiol., 2020, 5 (3), 54.

[16] JUHYUN K., KYUNGOCK Y., *The effects of the foot types and structures of the inner arch support bands on ground reaction force variables and sensations during 2 Nd Vertical Ballet Jump*, Korean Journal of Sport Biomechanics, 2017, 27, 25–33.

[17] LIN C.W., LIN C.F., HSUE B.J., SU F.C., *A comparison of ballet dancers with different level of experience in performing single-leg stance on retiré position*, Motor Control, 2014, 18 (2), 199–212.

[18] ŁOSAKIEWICZ J., TEPEREK R., *Report on folk dance and folk dance movement in Poland, The first dance congress*, Report, 2011, Accessed 20 May 2021. https://imit.org.pl/uploads/materials/files/kongres_tanca_raport.pdf

[19] MACIEJCZYK M., FEĆ A., *Evaluation of aerobic capacity and energy expenditure in folk dancers*, Human Movement, 2013, 14 (1), 76–81.

[20] MCCRORY J.L., YOUNG M.J., BOULTON A.J.M., CAVANAGH P.R., *Arch index as a predictor of arch height*, Foot, 1997, 7 (2), 79–81.

[21] MENZ H.B., FOTOOHABADI M.R., WEE E., SPINK M.J., *Visual categorisation of the arch index: a simplified measure of foot posture in older people*, J. Foot Ankle Res., 2012, 5, 10.

[22] MENZ H.B., MORRIS M.E., *Clinical determinants of plantar forces and pressures during walking in older people*, Gait Posture, 2006, 24, 229–236.

[23] MENZ H.B., MUNTEANU S.E., *Validity of 3 clinical techniques for the measurement of static foot posture in older people*, J. Orthop. Sports Phys. Ther., 2005, 35, 479–486.

[24] MICHALSKA J., KAMIENIARZ A., FREDYK A., BACIK B., JURAS G., SŁOMKA K.J., *Effect of expertise in ballet dance on static and functional balance*, Gait Posture, 2018, 64, 68–74.

[25] MIN-JUNG K., KYUNG-OCK Y., *The Biomechanical Analysis of Ballet Arabesque by Using Elastic Band*, Korean J. Sport Biomech., 2015, 25 (3), 265–274.

[26] OREB G., VLAŠIĆ J., ZAGORC M., *The Efficiency of Dance Training on Some Motor Abilities of Folk Dancers*, Sport Science, 2011, 4 (1), 96S100.

[27] OZTEKIN H.H., BOYA H., NALCAKAN M., OZCAN O., *Second-Toe length and forefoot disorders in ballet and folk dancers*, J. Am. Podiatr. Med. Assv., 2007, 97 (5), 385–388.

[28] PAUK J., EZERSKIY V., RASO J.V., ROGALSKI M., *Epidemiologic factors affecting plantar arch development in children with flat feet*, J. Am. Podiat. Med. Assn., 2012, 102 (2), 114–121.

[29] PAUK J., IHNATOUSKI M., NAJAFI B., *Assessing Plantar Pressure Distribution in Children with Flatfoot Arch: Application of the Clarke Angle*, J. Am. Podiatr. Med. Assoc., 2014, 104, 622–632.

[30] PERRIN P., DEVITERNE D., HUGEL F., PERROT C., *Judo, better than dance, develops sensorimotor adaptabilities involved in balance control*, Gait Posture, 2002, 15 (2), 187–94.

[31] RANGEL J.G., DIVINO NILO DOS SANTOS W., VIANA R.B., SILVA M.S., VIEIRA C.A., CAMPOS M.H., *Studies of Classical Ballet Dancers' Equilibrium at Different Levels of Development and Versus Non-Dancers: A Systematic Review*, J. Dance Med. Sci., 2020, 24 (1), 33–43.

[32] SCOTT G., MENZ H.B., NEWCOMBE L., *Age-related differences in foot structure and function*, Gait Posture, 2007, 26, 68–75.

[33] SPINK M.J., FOTOOHABADI M.R., WEE E., HILL K.D., LORD S.R., MENZ H.B., *Foot and ankle strength, range of motion, posture, and deformity are associated with balance and functional ability in older people*, Arch. Phys. Med. Rehabil., 2011, 92, 68–75.

[34] TORBA R.G., RICE D.A., *Pressure analysis of the ballet foot while en pointe*, Proceedings of the Twelfth Southern Biomedical Engineering Conference, 1993, 48–50.

[35] ÜNLÜ Y.H., *Examining the effects of strength building exercises on the stage perfomance of professional folk dancers*, 2017.

[36] VÄISA L., ERELINE J., PÄÄSUKE M., KUMS T., *The effect of Estonian folk dance practice on static balance performance in young females*, Acta Kinesiologiae Universitatis Tartuensis, 2020, 26, 61–71.

[37] WONG C.K., WEIL R., BOER E., *Standardizing foot-type classification using arch index values*, Physioth. Can., 2012, 64 (3), 280–283.

[38] XIONG S., GOONETILLEKE R.S., WITANA C.P., WEERASINGHE T.W., AU E.Y., *Foot arch characterization: a review, a new metric, and a comparison*, J. Am. Podiatr. Med. Assoc., 2010, 100 (1), 14–24.

[39] YALÇIN N., ESEN E., KANATLI U., YETKIN H., *Evaluation of the medial longitudinal arch: a comparison between the dynamic plantar pressure measurement system and radiographic analysis*, Acta Orthop. Traumatol. Turc., 2010, 44, 241–245.

[40] ZHENG T., YU Z., WANG J., LU G., *A New Automatic Foot Arch Index Measurement Method Based on a Flexible Membrane Pressure Sensor*, Sensors, 2020, 20 (10), 2892.