Analysis of foot structure in young recreational female ballet dancers

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Summary

Study aim: The human foot is an essential element of the locomotor system. It plays a key role in both the dynamics and the statics of the whole lower limb. The normal structure of the foot determines its mechanical function. During growth and formation of the foot structure, sport activity plays an important role.

The aim of this study was to analyse the structure of the foot in ballet dancers aged 6 to 14 years compared with a clinical reference peer group that did not do ballet.

Material and methods: The study involved 120 girls aged 6 to 14 years (mean age 9.6, sd. 2.4). Sixty of them formed the study group of ballet dancers, and the other 60 formed the reference group. To conduct the measurements, the computer podoscope CQ-ST produced by the CQ Elektronik System, connected to a portable computer, was used.

Results: A few differences were found between the foot structure in young female ballet dancers and their peers. A statistically significant difference was found in the hallux valgus α angle. The left foot of the examined ballet dancers was found to have a larger hallux valgus. A statistically significant correlation was found between the length of time of ballet training and the increase in the α angle values of the left foot and the right foot in the ballet group.

Conclusions: Ballet dancing in childhood may increase the risk of developing hallux valgus, with the tendency of worsening with training time.

Key words: Ballet dance – Foot – Deformations – Children

Introduction

The human foot is an essential element of the locomotor system. When in contact with the ground, it transports the mass of the whole body. Apart from this supportive function, it also performs an important propulsive function in gait. It adapts to the uneven surface of the ground, which allows body balance to be maintained in changing external conditions. The foot participates in cushioning shocks, thus protecting the nervous system, the spine, and the internal organs from microinjuries [14].

Playing such divergent functions requires combining stiffness, which allows for stability, and elasticity, which allows for the dynamic work of the system. The function of the foot depends on its morphological structure. The essential elements here are the foot arches [4, 11, 15].

The human foot in the process of its development is subjected to numerous external factors that can either

hinder or stimulate the normal development of the arches. The key factors in forming the structure are the type of physical activity undertaken, the kinds of movements required by this activity, the training time, and the training intensity [9, 30].

In professional ballet training, the feet are subjected to considerable loads for several years. The extreme forces affecting the developing system of muscles, ligaments, and joints often lead to overload and microinjuries, which may lead to foot deformations. Many researchers regard ballet dancing as one of the activities that put serious strains on the motor system and damage the foot structure in the long term [1, 6, 10, 11, 19, 23, 24, 30].

The structure and function of the feet are the subjects of interest of specialists of several fields: anatomy, anthropology, biomechanics, radiology, orthopaedics, and physiotherapy [2]. This reveals how complex the structure is and how challenging it is to assess. Unfortunately, it also results in considerable discrepancies in methods and

scientific techniques applied. The multitude of tools leads to obtaining results that are difficult to compare. To avoid measurement errors, as well as accusations of a lack of objectivity or repeated trials, in our study we decided to use computer equipment for foot diagnostics. It combined the traditional methods of measurements and the state-of-the-art achievements of information technologies. The equipment is a perfected and developed version of a traditional podoscopic test based on the photogrammetric Moire's method, and it is very well suited for screening tests. Additionally, it is non-invasive, pain-free, and quick to administer [3].

A sufficiently early assessment of the foot structure may play an essential role in foot deformation prevention and correction. The use of standardised measurement methods ensures objectivity of obtained results. Observation of foot development and changes during the years of ballet training can lead to better understanding of loads occurring in the lower leg during this activity and provide an answer how to train in a safer way. Therefore, the aim of this study was to analyse the foot structure in female ballet dancers aged 6 to 14 years in relation to a peer clinical reference group consisting of girls who did not do ballet.

Experimental

The study involved 120 girls aged 6 to 14 years of a mean age of 9.6 ± 2.4 years, mean body height of 137.2 ± 14.6 cm, and mean body mass of 32.9 ± 11.8 kg. The ballet group consisted of 60 girls who participated in ballet dancing lessons 2–3 times a week for 1.5 h at two ballet schools in southern Poland. The reference group consisted of 60 girls who did not do any special physical activity. The clinical reference group girls were chosen so that their age, body mass, and height matched their ballet

dancer counterparts. This allowed us to compare the two groups in the further process of the study. We did not find statistically significant differences between the groups regarding the above-mentioned body features. The girls did ballet for 2 to 10 years, with a mean of 4.3 ± 2.0 years.

The measurements were taken with a CQ-ST podo-scope produced by CQ Elektronik System. It is equipped with a digital camera and connected to a computer with relevant software for foot-parameter analysis. The computer program allowed for both three-dimensional foot structure assessment and determination of foot geometry indices necessary for foot diagnosis and treatment and provided information on load-bearing zones. Weight and height were measured using the height–weight scale. Information regarding the age of beginning of training and its intensity was taken from surveys conducted among the dancers. All dancers had demi-pointe or pointe training.

We obtained consent to conduct the measurements from the ethics committee, institutions in which we conducted the measurements, the girls themselves, and the girls' parents.

The girls were asked to step with both their bare feet onto the podo-scope, with their eyes directed forward and their arms along their bodies. The measurements were taken by the same technician, at the same time of the day (i.e. in the afternoon), and in similar weather conditions. The figure below presents the measurement station (Fig. 1). On the basis of the photograms of each of the subjects, we determined foot structure indices. Then we compared the results of the dancers with the results of the reference group. The figures below present the indices for foot assessment [19]. The Wejsflog index (ratio of foot length and foot width) was used for transversal foot arch assessment (Fig. 2).

Fig. 1. Registering the planum of the feet during the measurement [own foto]

Fig. 2. Wejsflog index – assessment of transversal foot arch [own drawing]

l – foot length – measured between the extreme points on the heel and toe I/II; w – foot width – measured in the widest area of the forefoot

Fig. 3. Clarke's angle – assessment of longitudinal arch [own drawing]

Fig. 4. The Alpha, beta, and gamma angles – assessment of toes and heel position [own drawing]

For longitudinal arch evaluation, Clarke's angle was used (Figure 3).

Clarke's angle – angle between the line that joins the more internal point of the forefoot and the more internal point of the rearfoot (AB) and the line that joins the more internal point of the forefoot with the deeper part of the footprint (C).

The study also evaluated alpha, beta, and gamma angles (Fig. 4).

The alpha angle (the angle of the valgus deformity of toe I) – between a tangent drawn to the medial foot edge (a) and a tangent drawn from the point at the widest place of the forefoot to the inner edge of the hallux (b).

The beta angle (the angle of the varus deformity of toe V) – by a tangent drawn to the lateral foot edge (c) and a tangent drawn from the point at the widest place of the forefoot to the outer edge of toe V (d).

The gamma angle (the heel angle) – between two tangents drawn to the inner and outer foot edge (a, c).

To analyse the feet, we used the following classifications:

1. The Wejsflog index [19]
 - 2–2.43 – denotes transversely flat feet
 - 3–2.44 – denotes normal transversal arches
2. Clarke's angle [16]
 - $\geq 30^\circ$ – flat foot
 - 31° – 41° – lowered arches
 - 42° – 54° – normal foot
 - $\leq 55^\circ$ – high arched foot
3. Hallux valgus angle alpha [15]
 - $> 0^\circ$ – hallux varus
 - 0 – 9° – normal hallux
 - $< 9^\circ$ – hallux valgus
4. Angle of varus deformity of toe V β [15]
 - $> 0^\circ$ – valgus deformity of toe V
 - 0 – 5° – normal toe V
 - $< 5^\circ$ – varus deformity of toe V
5. Heel angle γ [15]
 - $> 15^\circ$ – excessive transversal arches
 - 15 – 18° – normal foot
 - $< 18^\circ$ – transversally flat foot.

The results were processed with the Statistica 10.0 software. To analyse them, we used Student's t-test, the Mann-Whitney U-test, and the Pearson correlation coefficient. The Shapiro-Wilk test was used in estimating the normality of the distribution of variables and the equality of variances was assessed by Levene's test. The statistical significance level was set at $\alpha = 0.05$.

Results

Most of the girl ballet dancers had normal transversal foot arches. We found lowered transversal foot arches only in 11.7% of right feet and 15% of left feet. The Clarke's angle analysis revealed that 55% of dancers had normal longitudinal arches in the right foot, and 51.7% had normal longitudinal arches in the left foot. Comparison of results between dancers and the reference group is presented in Table 1.

Table 1. The assessment of longitudinal foot arch (Clarke's angle) – the dancers and reference group populations

Variable	Study group		Reference group		t	p
	$\bar{x} \pm SD$	Me	$\bar{x} \pm SD$	Me		
CL right	47.5 $\pm$ 23.6	47.0	44.8 $\pm$ 11.8	46.0	0.77	0.4441
CL left	45.7 $\pm$ 24.2	46.3	43.9 $\pm$ 11.9	45.9	0.51	0.6120

Table 2. Comparison of halux valgus in the dancers and reference group population

Variable	Study group		Reference group		t	p
	$\bar{x} \pm SD$	Me	$\bar{x} \pm SD$	Me		
Alpha right	5.3 $\pm$ 5.9	5.3	4.5 $\pm$ 5.9	4.5	0.68	0.4949
Alpha left	6.7 $\pm$ 5.6	7.1	4.4 $\pm$ 6.7	3.5	2.0	0.0476

Table 3. Comparison of of varus deformity of toe V (beta) – the dancers and reference group population

Variable	Study group		Reference group		t	p
	$\bar{x} \pm SD$	Me	$\bar{x} \pm SD$	Me		
Beta right	11.2 $\pm$ 6.8	10.9	10.7 $\pm$ 8.6	10.8	0.34	0.7370
Beta left	12.2 $\pm$ 7.0	11.4	11.1 $\pm$ 6.6	9.6	0.92	0.3605

Table 4. Comparison of the heel angle (gamma) – the dancers and reference group population

Variable	Study group		Reference group		t	p
	$\bar{x} \pm SD$	Me	$\bar{x} \pm SD$	Me		
Gamma right	15.4 $\pm$ 2.3	15.3	15.5 $\pm$ 2.7	15.6	–0.20	0.8443
Gamma left	15.4 $\pm$ 2.5	15.4	15.1 $\pm$ 2.9	15.0	0.64	0.5228

We found a normal hallux (the alpha angle) in 66.7% of right feet and 50% of left feet. We found hallux valgus in 20% of girls in the right foot and as many as 38.3% in the left foot. Comparison of results between dancers and the reference group is presented in Table 2.

Varus deformity of toe V was common in the dancers group. Only 11.7% of subjects had normal toe V. In the dancers group 53.3% of right feet and 51.7% of left feet had normal transversal arches. These arches were excessive in 35% of right feet and 38.3% of left feet. Comparison of results of varus deformity of toe V between dancers and the reference group is presented in Table 3. Comparison of the heel angle (gamma) of both groups is presented in Table 4.

Discussion

The foot, through its structure that combines the maximum stability with great mobility, is able to support the mass of the body, transport loads, and adapt to the different

structures it may walk upon. However, the motor abilities of the foot are dependent on its healthy morphological structure. Divergent factors that affect the foot over a person's lifespan, especially the physical activity undertaken, particularly at an early age, result in constant changes to the foot's structure [15, 25]. Underestimation of the foot's crucial role in the kinematic structure of the lower limb results in repeated injuries that hinder quick recovery and physical ability and activity [18].

Numerous authors have focused on how various sports disciplines affect foot structure. Furgał and Adamczyk reported that children who do sports have the best foot structure [9]. Still, some sports disciplines may overstrain the locomotor system. There are several reports on the most common injuries in dancers [8, 9, 26] and several analyses on forces that affect particular joints in the course of dancing dynamics [13, 18]. Unfortunately, the studies available largely concern adult dancers. It therefore seems advisable to analyse the foot structure of child dancers, as it may prove crucial to the planning of future training and in injury prevention.

The reports presented below on injuries in dancing unanimously prove that the lower limbs when subjected to the action of extreme forces are exposed to overstrain. Among 476 students (aged 10 to 21 years) of the Royal Swedish Ballet School in Stockholm, over the seven years analysed, the most common cause of injury was overstraining of the lower limb, as it constituted 76% of all injuries and equalled 0.8 injuries per 1,000 hours of dancing. The foot was most often affected by overstraining [15]. A study conducted in the Australian Ballet School proved a similar tendency; injuries there affected mostly the foot and the spine [6]. Other authors confirmed these findings [7, 12]. Steinberg, who examined 569 dancers aged 8 to 16 years, found that 90% of them had injuries of the lower limb, followed by injuries of the spine [27]. It is therefore easy to agree with Kennedy, who estimated that 95% of dancers professionally active for a year or more are highly likely to suffer from foot injury [11].

It therefore seems legitimate to examine the feet of young ballet dancers as early as possible. Determining individual elements in statics may prove helpful in prevention of the above-mentioned injuries. This is because the foot is the first element of the limb that contacts the ground while the body is in movement. Although our study did not find any significant differences between the feet of child dancers and their non-dancing peers, we noticed several tendencies in their foot structure. Both Steinberg and Leanderson point to the need to introduce prevention training for the youngest dancers, as dancers are not only artists but also professional sportspeople [15, 27].

The problem of the hallux is an issue discussed by several authors. 'En pointe' or 'demi-pointe' dance requires the dancers to dynamically support their body mass on their toes, at maximum plantarflexion at the ankle, with simultaneous extension of the metatarsophalangeal joints, which may lead to weakening of ligaments and consequently to hypermobility within the foot. This may cause secondary valgus deformity of toe I. Common problems of dancers are the osteophytes of the metatarsophalangeal joint of toe I [1], instability of this joint [21, 24], degenerative disorders [12], and instability (first ray) within the first metatarsal cuneiform joint [5].

Our study revealed that hallux valgus was a common deformity in the studied children and that it affected 38% of left feet and 20% of right feet. We also found a significant correlation between the alpha angle values of the right and the left foot and the training time. It is interesting that the deformity is more common in the left foot. It may be related to the movement technique or the special style of individual dancers. This phenomenon certainly requires further biomechanical analyses.

It is certain that there are numerous risk factors, apart from tight footwear and extreme positioning of the foot in ballet, that may lead to the development of hallux valgus.

These are age, female sex, genetics, muscular balance disorders, or the inborn structure of the foot. Technical mistakes in training and too early introduction of pointe work may also lead to the development of hallux valgus [8]. However, there are increasingly common opinions of specialists on the subject that it is not the age, training time, and range of mobility of the ankle that should determine the start of training on the tips of toes, and that this decision should be based rather on functional criteria: stability of the trunk and the lower limbs with the pelvis, particularly the feet, and muscle strength of the areas particularly prone to overstraining [5, 22, 29]. Our study supports this functional trend. Also, our study is an attempt at screening that would allow for injury prevention in child dancers.

The literature provides information on changes to the arches of the foot. Figures performed by ballet dancers often require non-physiological positioning of the foot, huge elasticity of ligament structures, and great muscle strength. They require multiple repetitions of extreme movements generating huge forces within the foot, which after considerable training time may lead to significant foot deformities [15]. Still, studies on the subject are not unanimous. Some reports seem to be contradictory and lead to contrasting conclusions. Therefore, undertaking this subject seems legitimate, especially considering that the dancers are children who engage in a demanding physical activity.

In her study on the body posture of female ballet dancers, Pelc found that the second most common disorder was foot arch deformities; they were found in 46% of her subjects [20]. Makarczuk reached similar conclusions in a study involving 728 ballet dancers. She observed excessive longitudinal foot arches in ballet dancers when compared to non-dancers [28]. Yakut et al. observed a similar phenomenon: ballet dancers had excessive longitudinal arches and lowered transversal arches in comparison to the clinical reference group [30]. Our study revealed normal longitudinal foot arches, with Clarke's angle values of 42–54°, in more than 50% of subjects. A small percentage (16.7%) of the studied dancers had lowered or excessive longitudinal foot arches, and only a few dancers had flat feet. A comparison of Clarke's angle values between the ballet dancers and the clinical reference group did not reveal statistically significant differences. The analysis of transversal foot arches with the Wejsflog index found normal arches in most of the dancers. Similarly, we did not find statistically significant differences in transversal arches between the ballet dancers and the reference group.

According to the obtained results, the feet of young female ballet dancers did not significantly differ from the feet of their peers. Other studies seem to confirm our results [28]. However, training time, and therefore training strain and the increase in difficulty of the evolutions performed,

accompanied by certain anatomical predispositions and the absence of suitable prophylaxis, may lead to numerous injuries and deformities that may be prevented if suitable training is implemented. The suitable training would provide a perfect means of foot care, as the feet for dancers are 'the instruments on which their art depends' [11].

A strong advantage of our study is the fact that it is based on young dancers aged 6 to 14 years, as we tried to fill a certain gap in the available literature. As Steinberg [27] observed, studies of this kind usually are based on professional adult dancers, thus leaving the youngest dancers out of the range of scientific research and consequently denying them reliable knowledge that may serve their health and security. We also succeeded in finding a relatively large group of ballet dancers that is homogeneous in terms of the morphological structure and training done; it is not easy to find such a group within this discipline.

The material we present has some limitations. There were some adolescent girls among the ballet dancers, and the processes related to puberty may have distorted the results to some extent. Moreover, the measurements were taken in static conditions. Since ballet is a dynamic form of activity, it may be useful to apply some more sophisticated measurement forms to use in dynamic conditions. Still, our intention was to conduct screening that would be feasible to repeat and easily accessible for ballet coaches in order to enable them to control the security of the students in their charge. Also, the changes observed in static conditions would manifest in dynamic conditions too, and they indicate the elements that should be considered when undertaking further studies in dynamic conditions.

The aim of application of the tests presented is as early as possible detection of changes to the foot in young dancers. As the changes may predispose towards early degenerative disorders or injuries, the results of the tests would allow for implementation of a prevention exercise plan for this age group and the administration of strain and training forms appropriate for the functional state of the students. It was our intention to considerably raise the safety of this beautiful and sophisticated form of art and sport, ballet.

Conclusions

1. Recreational ballet dancers had a similar foot structure to their non-dancing peers.
2. The valgus deformity of the hallux was greater in dancers and worsened with ballet training time.

Conflict of interest: Authors state no conflict of interest.

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