Antropomotoryka. Journal of Kinesiology and Exercise Sciences
JKES 86 (29): 19-27, 2019

(1.2) DOI: 10.5604/01.3001.0014.1273

ANALYSIS OF THE DISTRIBUTION OF FOOT FORCE ON THE GROUND BEFORE AND AFTER A KINAESTHETIC STIMULATION

Jarosław Jaszczur-Nowicki [1], **Dariusz Kruczkowski** [2], **Joanna Magdalena Bukowska** [1]

[1] Department of Tourism, Recreation and Ecology, University of Warmia and Mazury in Olsztyn, Poland
[2] Elbląg University of Humanities and Economics in Elbląg, Poland

Authors' contribution:
A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

Keywords: foot, stabilometry, subpararographic platform, stability

Abstract:

Aim. Analysis of the distribution of foot force on the ground in children before and after kinaesthetic stimulation.

Materials and methods. Research was conducted from April 11 to May 22, 2019, in two groups of children aged 7-12. The experimental group (E) consisted of children attending dance classes, while the control group (C) comprised their peers undergoing mandatory physical educations classes. To obtain answers to the posed research questions, the tests were carried out using a sub-pararographic mat. The results were analysed using the Statistica program. The authors are aware that some of the results obtained are nonparametric data, therefore, the non-parametric Mann-Whitney U test and the Kolmogorov-Smirnov test were used. Considering further results analysed via the Student's *t*-test, non-parametric data were analysed for this test.

Results. There were statistically significant differences between the average results of the subjects at the level of $p < 0.05$ occurring before the introduction of kinaesthetic stimulation. Distribution of forces on the metatarsal bones of the left foot ($p \leq 0.04$), the tarsus bones of the left foot ($p \leq 0.0078$), the toes of the right foot ($p \leq 0.0039$) and the metatarsal bones of the right foot ($p \leq 0.03$). However, after stimulation, a statistically significant difference at the level of $p \leq 0.0076$ occurred in the distribution of forces on the bones of the toes of the right foot. Analysing the average results, statistically significant differences were observed for COP distance ($p \leq 0.0001$) and the area of the body's barycentre ellipse ($p \leq 0.01999$).

Conclusions. Dance practiced in childhood significantly affects the postural stability of the body and the distribution of forces on the ground. It was also noticed that when performing fast movements, there were noticeable differences in the body posture of dancing and non-dancing children.

Introduction

A concept relating to the entirety of human motor operations is motor ability. By this term, we can define a moving person in space, as a result of changes in the structure of the body or parts of the body relative to each other. Motor ability can also be understood as all the conditions and manifestations, as well as the needs and motor behaviours of a human [1]. It forms with his/her biological movement and the laws of ontogenesis. The traits inherited from parents, natural and social environment, lifestyle and exercise have additional impact on human development [2]. Too little or complete cessation of physical activity causes regression of the level of motor skills. Therefore, through regular physical activity, a person is able to train his/her motor skills [3].

The pre-school period is particularly favourable for the dynamic development of motor skills. During ontogenesis, a child's dimensions, weight and proportions, which shape the muscles and movement pattern, undergo changes. It is assumed that a child already at the age of seven has mature and shaped gait [4]. In the process of phylogenesis, humans freed their upper limbs from the requirement of postural support and has become two-legged, constantly struggling to maintain "safe" body posture in static and dynamic conditions [5].

The foot is a key element that allows to balance the position of the body in static spatial conditions. The foot also plays the role of a driving mechanism that gives the body propulsion during locomotion. The correct function of the feet is conditioned by their morphological structure and, in particular, by the correct formation of the transverse and longitudinal arch, which results in the correct shape of the foot. Forming elastic and strongly sprung arches perform a protective and shock-absorbing function against other body systems, while supporting the whole body [6,7].

A non-deformed foot rests on the ground at three points, the first metatarsal bone, the fifth metatarsal bone and the calcaneal tumour [8].

An active and stable foot is one that adapts and reacts in unpredictable and new situations in a short time, and along with postural control in a one-legged position, these are basic skills that allow proper management during loss of balance. Formation of the longitudinal arch in the foot is the result of evolution and adaptation to a two-legged position [9].

The body is the essence of content transfer in dance while performing difficult and complex movements. The ability to combine movements is the ability to coordinate individual movements and the phases occurring between them. The ability to maintain balance is an important element for the efficiency of dance activities. This is possible due to static and dynamic balance. The first - static - allows to maintain a balanced position of the body, the second - dynamic - permits maintaining and regaining balance during motor activities and after their completion [10].

Considering the fact that motor skills should be shaped as early as at a pre-school age, and dance is a discipline requiring exceptional coordination from the dancer particular emphasis should be placed on this aspect of human motor development. The authors present the results of experimental research, thanks to which the influence of dance on the sense of balance in children was analysed.

The aim of the study was to analyse the distribution of foot strength on the ground in children before and after kinaesthetic stimulation. In addition, the following research questions were formulated:

1. Which indicators of the distribution of foot forces on the ground in children, before and after kinaesthetic stimulation, differentiate the studied groups?
2. Are there differences in the sense of balance among training and non-training children?

Analysing the content of the literature, the authors hypothesized that kinaesthetic stimulation affects the distribution of foot forces on the ground of children practicing and not practicing dance in a diverse way.

Materials and methods

The research was conducted from April 11 to May 22, 2019, at two Olsztyn dance clubs: Powerdance and Eranova and at Jan Liszewski's Primary School No. 29 in Olsztyn. The study involved n=24 dancers aged 7-12 and n=33 primary school students from grades 2 and 3 who did not attend a dance course, constituting the control group.

The research was conducted from April 11 to May 22, 2019, at two Olsztyn dance clubs: Powerdance and Eranova and at Jan Liszewski's Primary School No. 29 in Olsztyn. The study involved n=24 dancers aged 7-12 and n=33 primary school students from grades 2 and 3 who did not attend a dance course, constituting the control group.

Table 1. Numerical characteristics of the studied groups

	Age		Body mass		Body height	
	E*	**C****	**E**	**C**	**E**	**C**
MD	8.73	9.15	31.27	31.29	133.42	137.33
SD	1.39	0.36	9.72	4.46	10.342	5.25

***E – experimental group; **C – control group**

Source: authors' research

As it can be seen in Table 1 presented above, the average age and average body mass in both study groups were similar, within the range of 9 years and 31 kilograms, respectively. However, in the case of body height, the control group was characterised by a higher average value (close to 4 centimetres) compared to the experimental group.

Prior to the study, the consent of the parents, school headmaster and instructors was obtained for the study.

In order to verify the hypothesis, tests were carried out using a subarithographic mat. The mat is a computer diagnostic device enabling the assessment of foot defects, testing the distribution of pressure forces on the plantar side of the foot as well as neurological, orthopaedic and diabetological parameters. The test is non-invasive and does not require prior preparation from the patient. The mat has 2,304 sensors that collect measurements for 20 seconds and then transfer them to a computer using the Biomech Studio program.

During the tests, the following measurement order was adopted:

1. Explanation of the purpose and essence of research.
2. Measurements of the child's body height and mass.
3. Measurements of the distribution of forces on the ground using a subararographic mat, consisting in maintaining stable posture with arms placed along the trunk for 20 seconds. The subject stood barefoot on the mat.
4. Kinaesthetic stimulation by having the child perform 6 turns around their axis, 3 behind the right shoulder and 3 behind the left.
5. Re-measuring the distribution of forces on the ground.

The study groups were characterised in terms of age, body mass andheight, distribution of foot force on the ground and stabilometric parameters.

The results were analysed using Statistica 13.1, Excel and the Biomech Studio programs. Parametric and nonparametric tests were used to assess statistically significant differences between the groups. The authors are aware that some of the results obtained are non-parametric data, therefore, the Mann-Whitney U test and the Kolmogorov-Smirnov test were used.

Considering further results analysed via the Student's *t*-test, non-parametric data were analysed for this test.. Values of $p<0.05$ were considered statistically significant.

Results

The tested parameters were the average force distribution on the ground before and after kinaesthetic stimulation. When analysing the results of the tests presented in Table 2, it can be seen that even prior to kinaesthetic stimulation, the majority of parameters have statistically significant differences. The Kolmogorov-Smirnov test

Table 2. Average force distribution regarding particular segments of the foot before kinaesthic stimulation

	Experimental group		**Control group**		**Kołmogorov-Smirnov test**	**Mann-Whitney U test**	**Student's *t*-test**
Variable	**MD**	**SD**	**MD**	**SD**	***p***	***p***	***p***
toes of left foot	0.434	0.107	0.407	0.158	p > .100	0.929	0.469
metatarsus of left foot	0.136	0.099	0.9	0.119	**p < .050**	**0.04**	0.127
tarsal bone of left foot	0.43	0.142	0.503	0.154	**p < .025**	**0.008**	0.073
toes of right foot	0.476	0.091	0.547	0.082	**p < .005**	**0.004**	**0.003**
metatarsus of right foot	0.141	0.105	0.8	0.099	**p < .025**	**0.03**	**0.03**
tarsal bone of right foot	0.383	0.077	0.374	0.081	p > .100	0.765	0.648

Level of statistical significance p≤0.05

Table 3. Average force distribution regarding particular segments of the foot after kinaesthic stimulation

	Experimental group		**Control group**		**Kołmogorov-Smirnov test**	**Mann-Whitney U test**	**Student's *t*-test**
Variable	**MD**	**SD**	**MD**	**SD**	***p***	***p***	***p***
toes of left foot	0.469	0.0609	0.482	0.0979	p > .100	0.272	0.557
metatarsus of left foot	0.137	0.1087	0.87	0.0954	p > .100	0.104	0.071
tarsal bone of left foot	0.395	0.0762	0.431	0.1096	p > .100	0.196	0.168
toes of right foot	0.489	0.0933	0.564	0.0969	p < .100	**0.008**	**0.005**
metatarsus of right foot	0.126	0.1037	0.93	0.0938	p > .100	0.344	0.221
tarsal bone of right foot	0.385	0.0696	0.343	0.1096	p < .100	0.101	0.108

Level of statistical significance p ≤ 0.05 and the Mann-Whitney U test demonstrated differences in the case of pressure on the metatarsal bone and the tarsus of the left foot as well as on the toes and metatarsus of the right foot. The Student's **t**-test at 55 degrees of freedom, further confirmed the statistically significant differences in pressure on the toe bones ($p \leq 0.0034$) and the metatarsus ($p \leq 0.0297$) of the right foot.

After applying kinaesthetic stimulation (Tab. 3, Fig. 1), a statistically significant difference was only found in the distribution of forces on the right toes at $p \leq 0.0076$

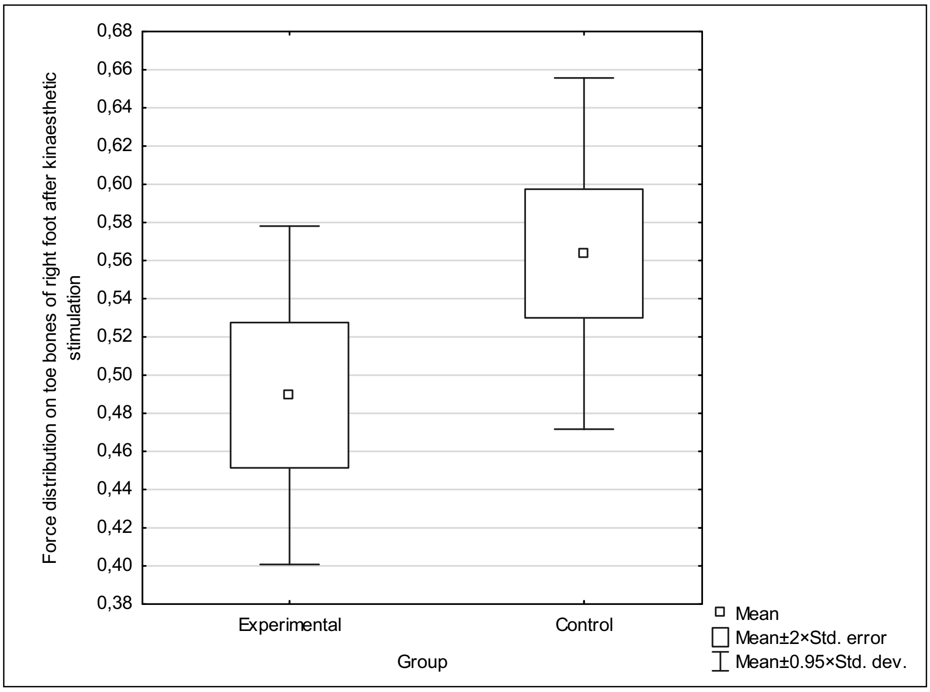

Figure 1. Force distribution on toe bones of right foot after kinaesthetic stimulation

Source: authors' research

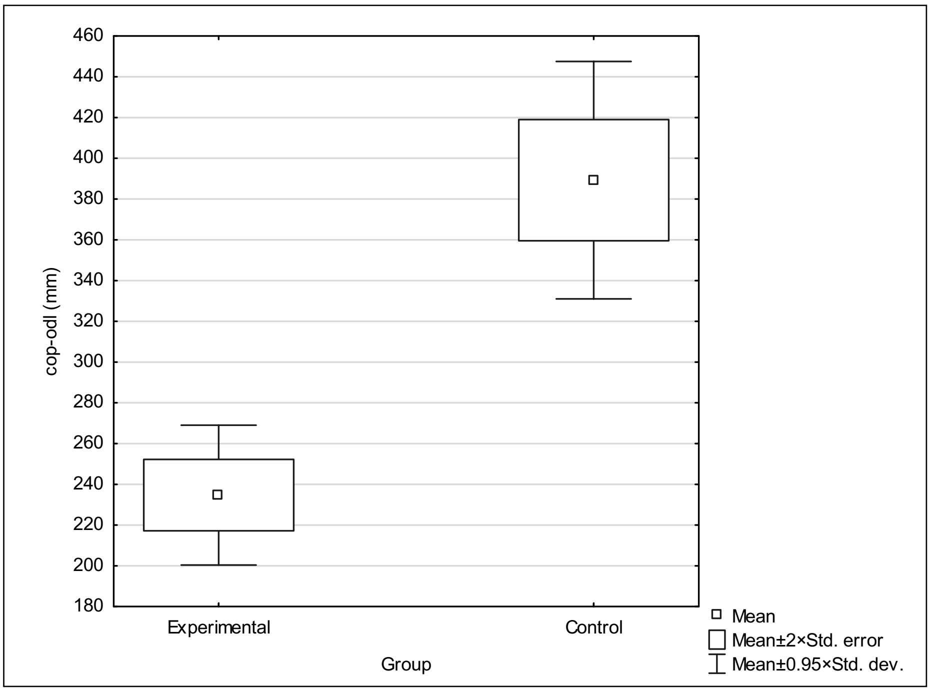

Figure 2. Average range between extreme deviations in the body's centre of gravity

Source: authors' research

(Mann-Whitney U test) and $p \leq 0.00534$ (Student's *t*-test). The Kolmogorov-Smirnov test showed statistically non-significant differences.

Figures 2 and 3 demonstrate the results of the average distance COP (distance of the centre of foot pressure on the ground) and the average speed of displacement of the centre of gravity of the subjects. The above parameters were selected due to the large discrepancy between the groups and statistical significance at the level of $p \leq 0.000$.

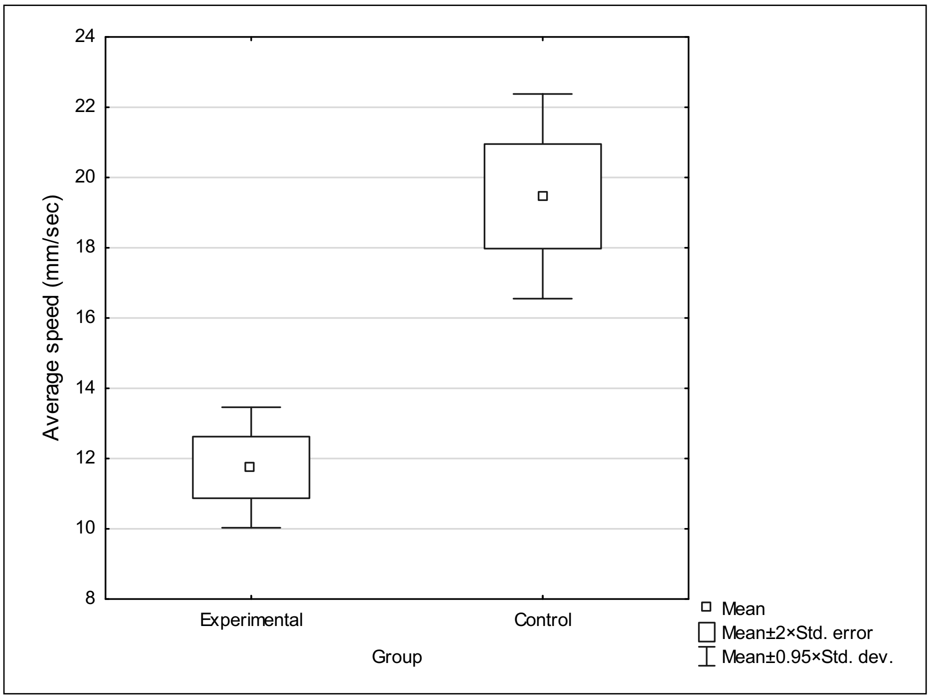

Figure 3. Average speed between extreme deviations of the body's centre of mass

Source: authors' research

Table 4. Stabilometric evaluation after applying kinaesthetic stimulation, conducted using the Student's *t*-test

	Experimental group		**Control group**		***t***	***p***
Variable	**MD**	**SD**	**MD**	**SD**		
cop-distance (mm)	**234.7**	**85.74**	**389.27**	**170.82**	**-4.07**	**0.000**
cop-bars (mm^2)	**547.07**	**493.01**	**1255.46**	**1382.9**	**-2.40**	**0.020**
p-bars (mm^2)	195.05	223.28	346.85	385.3	-1.73	0.090
l-bars (mm^2)	123.34	141.63	346.76	556.91	-1.92	0.061
cop-lsf	**1.05**	**1.2**	**0.55**	**0.35**	**2.27**	**0.027**
cop-speed (mm/sec)	**11.75**	**4.29**	**19.46**	**8.54**	**-4.06**	**0.000**
cop-x (mm)	0.46	1.11	0.08	1.35	1.12	0.266
cop-y (mm)	-1.78	1.71	-1.23	2.17	-1.02	0.311
SD X	**4.43**	**3.08**	**6.6**	**3.53**	**-2.42**	**0.019**
SD Y	**6.77**	**4.22**	**10.13**	**5.84**	**-2.40**	**0.020**
x-max-c	**10.61**	**5.48**	**19.23**	**19.11**	**-2.14**	**0.037**
x-min-c	**-11.12**	**8.65**	**-20.56**	**13.14**	**3.06**	**0.003**
y-max-c	15.46	**8.51**	**31.78**	**18.18**	**-4.08**	**0.000**

y-min-c	-15.34	12.11	-20.54	11.91	1.62	0.112
x-max-p	3.18	4.32	10.34	24.92	-1.39	0.170
x-min-p	-9.26	23.75	-12.68	38.59	0.38	0.702
y-max-p	28.66	63.17	46.52	50.38	-1.19	0.240
y-min-p	-14.8	13.42	-21.61	13.58	1.89	0.066
x-max-l	5.75	8.48	7.35	7.35	-0.76	0.449
x-min-l	-6.57	14.83	-8.75	13.4	0.58	0.564
y-max-l	**20.13**	**15.42**	**32.76**	**25.83**	**-2.13**	**0.037**
y-min-l	-18.86	16.33	-22.87	15.85	0.93	0.356

Level of statistical significance $p \leq 0.05$

cop-dist – distance between extreme deflections of the body's centre of gravity,
cop-bars – surface of deflections of the body's centre of gravity,
l-bars – left foot deflection area,
p-bars – right foot deflection area,
cop-x – deflection coordinate in the frontal plane ("+" to the right, "-" to the left),
cop-y – deflection coordinate in the sagittal plane ("+" forwards, "-" backwards),
cop-speed – deflections speed of body's centre of gravity,
cop-lsf – ratio of the distance between extreme deflections to the deflection surface,
x max – maximal deflection of the centre of gravity in the frontal plane ("b" - body, "r" - right foot, "l" - left foot),
x-min – minimal deflection of the centre of gravity in the frontal plane ("b" - body, "r" - right foot, "l" - left foot),
y-max – maximal deflection of the centre of gravity in the sagittal plane ("b" - body, "r" - right foot, "l" - left foot),
y-min – minimal deflection of the centre of gravity in the sagittal plane ("b" - body, "r" - right foot, "l" - left foot).

Stabilometric evaluation following kinaesthetic stimulation showed that the average values of all variables, regardless of the level of statistically significant differences, were significantly higher in the control group than in the experimental group. In Table 4, all analysed parameters are presented. The average surface regarding deflections in the research group for the right foot was 195.05 mm^{2}and for the left 123.34 mm^2. The average surface area of the dancers' centre of gravity was 547.07 mm^2. In the control group, the values were: for the right foot: 346.85 mm^2; for the left foot: 346.76 mm^2, and for the centre of gravity, 1255.46 mm^2. At 55 degrees of freedom, statistically significant differences at the highest degree ($p \leq 0.003$) occurred for: the distance between extreme deflections of the body's centre of gravity, average deflection speed of body's centre of gravity, and the maximal deflection of body's centre of gravity in the sagittal plane forwards and in the frontal plane, to the left. A smaller level of significance of differences ($p \leq 0.027$) was demonstrated by comparing the parameters determining the surface of the body's centre of gravity, the ratio of the distance between the extreme deflection to and deflection surface, and also, the average deviation of COP in both the frontal and sagittal planes. The lowest level of differences ($p \leq 0.037$) was found between the values of maximal deflection of the body's centre of gravity in the frontal plane to the left and comparing the values of maximal deflection of the body's centre of gravity of the left foot in the sagittal plane to the right.

Discussion

In its original form, balance reactions, the task of which is to maintain or restore balance in a given position, appear around 6-8 months of age. Between the age of 18 and 24 months, balance reactions are fully developed and remain active throughout human life.

Many health and environmental factors influence the process of shaping human balance during growth. Correct balance control is possible thanks to the precise neuromuscular coordination of all body segments [11].

Swaying posture requires constant activity of the musculoskeletal system, variability in postural muscle tension. The lower leg muscles, which enable ankle movements and foot pressure on the ground, have a special role in this task. Maintaining stable, upright posture, requires the integration of stimuli from three systems: visual, vestibular and proprioceptor [12,13].

For people who practice qualified sport, their health may depend on many factors, such as the knowledge, skills and sensitivity of the coach leading the sports training. The possibility of applying corrective methods and training measures is possible thanks to body posture diagnostics. It is an important criterion for assessing loads in asymmetrical sports. In such areas, it is recommended to introduce comprehensive training units and improve the functional balance of individual muscle groups. [14]

Dancers undergo motor training at a high skill level, thanks to which their body is able to compensate for vestibular disorders [15]. They present less ankle-hip coordination variation that can contribute to increased stability, neuromuscular control and their ability to perform complex tasks that require balance [16]. Dance training improves the sensorimotor control functions underlying static and dynamic balance. Dancers are said to have lower body oscillation power, which is less dependent on vision to control posture [17]. Full body rotation is a particularly complex movement because it involves stabilising and mobilising balance components. Dancers should maintain upright stance and balance until the end of the turn. Proper balance during each phase of rotation can be maintained by developing coordination of the shoulder girdle with the hip girdle. It is also associated with lower limb stability [18]. It should be borne in mind that dance training improves balance, movement awareness and body orientation in relation to the surrounding ground [19].

Ibuki A. et al. [20] undertook examination of the characteristics of the centre of pressure and fluctuations in the centre of body mass in ballet dancers and a control group not attending dance classes. To perform the test, both groups had three standing positions: standing on both legs, one-legged posture and standing on toes. Statistically significant differences were noted when standing on one leg. For two-legged and toe posture, no statistically significant differences were noted. In the case of the position standing on two legs, which was analysed by the authors of this study, statistically significant differences occurred at the level of $p \leq 0.019993$.

In the research by Michalska J. et al. [21], the authors analysed the balance and stability of 13 ballet dancers and 13 students not attending dance classes. The inclusion criteria were no injuries in the last 2 years and no neurological problems. An additional criterion for dancers was 5 years of experience in classical ballet. The experimental procedure consisted of 2 trials. The first was to maintain stable body posture on the platform with the arms placed along the body. During the study, participants focused on a designated point 3 meters away from the patient.

The next test consisted of 3 phases: I - upright position, II – maximal forward body tilt, III – standing and maintain maximal forward leaning position. The tests were repeated 3 times and lasted for 30 seconds. In the analysis of the results, the authors rejected the results of the second phase of the test because of its short duration. As a result of the performed tests, the dancers were characterised by much higher values of all variables compared to the control group. The authors of this work obtained the same results after applying kinaesthetic stimulation. The mean values of all variables, regardless of the level of statistically significant differences, were much higher than in the control group.

Piątek E. et al. took up similar research issues [22]. The authors examined the morphological structure of the feet of young disco dancers and subjects of a control group, which were girls who did not practice any sport. The examination consisted of free standing without shoes or socks, resting the entire surface of the foot on the podoscope. The morphological structure, toe position and longitudinal and transverse arches were analysed. Both Piątek E. et al. as well as the authors of this work in their research did not find statistically significant differences in foot typology among dancing and non-dancing groups.

Zabrocka and Sawczyn, in the results of research among dancers, noticed a greater increase in the examined feature between the I and the II stage of research than between the II and III. This allows to conclude that at the initial stage of training, greatest development of motor coordination occurs in dancers. The research results showed great diversity in the manifestation of motor coordination between training and non-training children. Children practicing dance sports were characterised by a higher level of coordination abilities. Therefore, it can be assumed that the measures of the training process in sport dance had impact on the formation of coordination abilities. [23]

Bruyneel came to a similar conclusion. This author examined 2 groups of dancers, the younger (age 8 and 16 years old) and the adult group (age 17 and 30 a). In both groups, the ground reaction forces to the antero-posterior and medial parts of the feet were assessed. Comparable studies were performed by Frączek and Wojciechowska, both studies indicating that, compared to adults, young dancers were characterised by instability combined with an increase in the number of oscillations and a decrease in variability separating swinging was also noted. Moreover, the younger group was less effective in controlling balance. The results indicate that this may be related to the number of hours performing dance, which were different in both groups [24,25].

The results obtained by the authors mentioned above as well as the authors of this study provide the basis for further analysis regarding this problem in terms of age, training experience and the number of training sessions per week.

Conclusions

Based on the conducted research, the obtained results, the hypothesis that kinaesthetic stimulation affects the distribution of foot force on the ground among children practicing and not practicing dance in a different way, it has been confirmed that there are numerous statistically significant differences between the results obtained for children dancing and not attending dance classes. Accordingly, the following conclusions may be drawn:

- The obtained results indicate that in the studied groups, prior to kinaesthetic stimulation, there were statistically significant differences in the average distribution of forces on the metatarsal bones and left foot tarsus, as well as the toes and metatarsus of the right foot. However, after kinaesthetic stimulation, the difference only occurred in the average distribution of forces on the toe bones of the right foot.
- As a result of the conducted research, it can be stated that attending dance classes improves balance in the occurrence of kinaesthetic stimulation.
- In order to expand and compare the obtained results, further analysis and repetition of tests are needed for other age groups with different training experience, as well as groups with different numbers of training units during the week.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethics Committee

References:

[1] Urych I: *Motoryczność człowieka*. Roczniki Naukowe WSWFiT w Białystoku. 2014;10(10):79-82.

[2] Grabowski H: *Teoria fizycznej edukacji*. Kraków: Wydawnictwa Szkolne i Pedagogiczne; 1999.

[3] Malina RM: *Physical activity and health of youth.* Ovidius University Annals, Series Physical Education & Sport/Science, Movement & Health. 2010;10(2): 271-277.

[4] Migasiewicz J: *Wybrane przejawy sprawności motorycznej dziewcząt i chłopców w wieku 7-18 lat na tle ich rozwoju morfologicznego*. Wrocław: Wydawnictwo Akademii Wychowania Fizycznego; 2006.

[5] Kruczkowski D, Jaszczur-Nowicki J: *Zdolność zachowania równowagi ciała w różnych aspektach biologicznej i sportowej determinacji*. Olsztyn: Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego; 2015.

[6] Leszczak J, Drzał-Grabiec J, Rykała J, Podgórska-Bednarz J, Rachwał M: *Charakterystyka wybranych parametrów antropometrycznych kończyn dolnych w warunkach odciążenia i obciążenia masą własną u dzieci w wieku szkolnym*. Medical Review. 2014; 1:55-61.

[7] Łagan S, Stopka J: *Ocena parametrów stóp u dzieci trenujących szermierkę metodą podoskopii komputerowej - analiza indywidualnych przypadków*. Aktualne Problemy Biomechaniki. 2017; 14:37-44.

[8] Miszewska A, Miszewski WJ, Głowacka-Mrotek I, Simińska J, Hagner W: *Postawa dziecka w wieku przedszkolnym i wczesnoszkolnym*. Medycyna rodzinna. 2018:21(1A):54-58. doi: 10.25121/MR.2018.21.1A.54.

[9] Grabiec-Drzał J: *Wpływ masy ciała na wysklepienie łuku podłużnego stóp*. Probl Hig Epidemiol. 2012;93(2):315-318.

[10] Pilewska W, Matczak P, Slováková M: *The influence of dancing on the level of selected coordination properties for male and female sports ballroom dancers*. W: Baisová K., Kružliak M., Zvolen, redaktor. Telesna wchova a šport v živote cloveka, Zvolen 2017. 8-23.

[11] Paszko- Patej G, Terlikowski R, Kułak W, Sienkiewicz D, Okurowska-Zawada B: *Czynniki wpływające na proces kształtowania równowagi dziecka oraz możliwości jej obiektywnej oceny.* Neurologia Dziecięca. 2011; 41:121-127.

[12] Sobera M: *Charakterystyka procesu utrzymania równowagi ciała u dzieci w wieku 2–7 lat*. Wrocław: AWF; 2010. (Studia i monografie; nr 97).

[13] Ocetkiewicz T, Skalska A, Grodzicki T: *Badanie równowagi przy użyciu platformy Balansowej – ocena powtarzalności metody*. Gerontol Pol. 2006; 14:144–148.

[14] Mrozkowiak M, Sokołowski M, Kaiser A: *The effect of physical exercise on selected sports on habitual posture*. Journal of Education, Health and Sport. 2016;6(10):131-157. doi: 10.5281/zenodo.160499.

[15] Hopper DM, Grisbrook TL, Newnham PJ, Edwards DJ: *The effects of vestibular stimulation and fatigue on postural control in classical ballet dancers.* Journal of Dance Medicine and Science. 2014; 18:67–73. doi: 10.12678/1089-313X.18.2.67

[16] Kiefer AW, Riley MA, Shockley K, Sitton CA, Hewett TE, Cummins-Sebree S, et al.: *Multi-segmental postural coordination in professional ballet dancers.* Gait and Posture. 2011; 34:76–80. doi: 10.1016/j.gaitpost.2011.03.016

[17] Tanabe H, Fujii K, Kouzaki M: *Inter- and intra-lower limb joint coordination of nonexpert classical ballet dancers during tiptoe standing*. Human Movement Science. 2014; 34:41–56. doi: 10.1016/j.humov.2013.12.003

[18] Golomer E, Toussaint Y, Bouillette A, Keller J: *Spontaneous whole body rotations and classical dance expertise: How shoulder–hip coordination influences supporting leg displacements.* Journal of Electromyography and Kinesiology. 2009; 19(2):314–321. doi: 10.1016/j.jelekin.2007.08.004.

[19] Schmit JM, Regis DI, Riley MA: *Dynamic patterns of postural sway in ballet dancers and track athletes.* Experimental Brain Research. 2005; 163:370–378.

[20] Ibuki A, Mani H, Takeda K, Hasegawa N, Yamamoto K, Maejima H, et al.: *Characteristic relationship between the centre of pressure and the centre of mass during quiet standing in female ballet dancers.* International Physical Medicine & Rehabilitation Journal. 2017;1(2):34-36. doi: 10.15406/ipmrj.2017.01.00009.

[21] Michalska J, Kamieniarz A, Fredyk A, Bacik B, Juras G, Słomka KJ: *Effect of expertise in ballet dance on static and functional balance*. Gait Posture. 2018; 64:68–74. doi: 10.1016/j.gaitpost.2018.05.034

[22] Piątek E, Barczyk K, Demczuk-Włodarczyk E, Hawrylak A: *Assessment of morphological architecture of feet in young Disco-Dance dancers.* Physiotherapy. 2015; 23:24-32. doi: 10.1515/physio-2015-0023.

[23] Zabrocka A, Sawczyn S: *Efektywność kształtowania koordynacyjnych zdolności motorycznych u tancerzy tańca sportowego na początkowym etapie szkolenia*. Rocznik Naukowy AWFiS w Gdańsku. 2010; XX:48-55.

[24] Bruyneel AV, Mesure S, Paré JC, Bertrand M: *Organization of postural equilibrium in several planes in ballet dancers.* Neuroscience Letters. 2010; 485:228–232. doi: 10.1016/j.neulet.2010.09.017.

[25] Fronczek–Wojciechowska M, Padula G, Kowalska J, Galli M, Livatino S, Kopacz K: *Static balance and dynamic balance related to rotational movement in ballet dance students*. International Journal of Performance Analysis in Sport. 2016;16(3):801-816. doi: 10.1080/24748668.2016.11868929.

Author for correspondence:

Joanna Magdalena Bukowska
E-mail: joanna.bukowska@uwm.edu.pl
ORCID: 0000-0003-0729-7292

Jarosław Jaszczur –Nowicki ORCID: 0000-0001-5256-1406
Dariusz Kruczkowski ORCID: 0000-0002-2582-5661