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Static balance and dynamic balance related to rotational movement in ballet dance students

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Abstract

The aim of this study was to assess static and dynamic balance related to rotational movements en pointe and en demi pointe in ballet dance students. The study group consisted of 13 people – students of one of the ballet schools in Poland: 9 dancers from the junior class (14 years old) and 4 dancers form the senior class (18 years old). For the purpose of statistical analysis, the group was divided into 4 subgroups. Each person took part in a static balance test which included a 30s trial with eyes opened and 30s trial with eyes closed. The examination of dynamic balance related to rotational movements was also performed to compare movements en pointe vs. movements en demi pointe. Analyses were performed using the Kistler 9286BA platforms, which are the module of BTS Smart DX 7000. Data processing was performed with the use of BTS Sway and Statistica 10. Accepted level of significance was α = 0.05.

Increase in the following center of pressure parameters was observed in the examination with eyes closed: maximal radius, longitudinal range, equivalent area and velocity. Participants from the senior class did not show these differences. There were no differences found between movements en demi pointe in comparison with movements en pointe. Static balance deteriorated with eyes closed in the entire examined group. Participants from the senior class showed more stable parameters of static balance. There were no differences in dynamic balance when the base of support was decreased.

Key words: Dancing, Postural Balance, Rotation, Biomechanical Phenomena, Objective Movement Analysis

1. Introduction

Ballet is not only the aesthetic but also physical demanding activity. Dance may be considered as a high-intensity intermittent exercise because of highly complex, multidirectional movement requirements (Annino *et al.*, 2007). In a literature review on static and dynamic balance in ballet dancers, the authors underlined the importance of balance, together with training and postural oscillation, for the performance of movement in classical ballet (Costa *et al*., 2013).

Static and dynamic balance can be evaluated directly by measuring displacement of the center of mass or indirectly by analyzing the center of pressure (COP), which represents the point through which the ground reaction forces are considered to act. In ballet, the control over the COP has been related to the control of the contact of the feet with the ground, which influences the static and dynamic balance and the impression of the dancer's body by the audience. Weight shifting and balance are essential components of ballet technique training.

While evaluating different joint oscillations in posture and balance analysis some authors used an assessment of multi-joint coordination (Tanabe *et al.*,2014; Thulier and Moufti, 2004). Balance and shifts are usually measured with a force-platform (Pedersen *et al*., 2006). Such platforms have also been widely used to analyze postural control through the measurements of fluctuations of the COP in anteroposterior and mediolateral directions (Rigoldi *et al.*, 2013). Measurements and characteristics of postural sway provide the information about the neuromuscular control system (Cimolin *et al*., 2011; Galli *et al*., 2011).

Standing on the toe of one leg is important in ballet training because is used when dancers perform a pirouette. In this pose, the legs are strictly separated into the supporting leg (which is in contact with the ground) and the gesture leg (Pedersen *et al*., 2006). However, the aesthetics of dance are intimately dependent on precise control of both the limbs and trunk (Russel, 2013). According to Bernstein (1967), learning movement skills is a process in which the neural control system achieves movement coordination of the body and limbs by mastering redundant degrees of freedom. Those redundant degrees of freedom can occur in the beginning of motor learning (Hodges *et al*., 2005). Controlling dancer's own position in *relevé* is beneficial in learning all pirouettes in ballet training (Tanabe *et al.*,2014). This is demanding, since the dancers have a decreased support polygon, yet their movement should be smooth and aesthetically pleasing. Professional ballet dancers are expected to balance on a base of support as small as 30 mm in diameter in case of *en pointe* technique (Golomer *et al*., 2009a). Dancing *en pointe* decreases the support polygon and can lead to numerous injuries in young dancers, who have not had enough proper training (Russel *et al*., 2010). While performing this technique, it is important that the center of gravity and the support polygon are vertically aligned. Postural control will be lost when the center of gravity moves beyond the limits of stability. The *en pointe* technique requires an extreme amount of plantar flexion that includes motion among the bones of the feet (Russel *et al*., 2011). It is important to have proper foot strength, sufficient ankle range of motion, along with stability and control while rising to the toes and then lowering. The level of ballet training, expressed by the number of days and hours per week the student attends ballet classes, seems to be an important factor to achieve that. It is also known that dance shoes play an important role in stability and control during movement (Walter *et al*., 2011). Pointe shoes in ballet support the foot providing stiffness and compromise of the mid-foot ligaments. Their ability to dissipate force through the sole is better than that of soft ballet shoes. However, some evidence suggests that soft shoes used in *demi pointe* technique are helpful in reducing leg, ankle, and foot injuries in adolescent dancers (Pearson and Whitaker, 2012).

The aim of this study was to evaluate static and dynamic balance related to rotational movement *en pointe* and *en demi pointe* in ballet dance students. Research hypotheses, based on the current knowledge (Imura *et al*., 2008; Perrin *et al*., 2002), assumed that dancers static balance can be deteriorated with eye closure and dynamic balance during rotational movement can worsen when the base of support was decreased. That has an implication in terms of training programs modifications such as introducing proprioceptive and individual balance training, to avoid the risk of injury related to worse balance parameters. The present study adds to the current knowledge by showing the analysis of dynamic balance parameters not in case of one specific rotational ballet movement but during few movements which differ in the way of performing. Moreover, rotational movements performed by particular study group were chosen according to the dancers age and level of experience.

2. Methods

Investigators followed the Ethical Guidelines of Ethics Committee of Medical University of Lodz, Poland. Approval number obtained for human investigation was RNN/172/13/KE from 18th June, 2013. Dancers and their parents gave their informed consent for participation in the research study. The study group consisted of 13 people – students of one of the ballet schools in Poland. All participants started their education related to ballet dance at the age of 6. Mean number of hours per week spent on practicing dance by participants was 25 ± 4 hours per week.

For the purposes of statistical analysis the group was divided into 4 subgroups:

- Group A – Female Senior and Junior dancer Group (FSJG) – 11 female ballet dancers (3 from the senior class and 8 from the junior class)
- Group B – Female Senior group (FSG) – 3 female ballet dancers from the senior class
- Group C – Male and Female Junior and Senior dancer Group (JSG) – 13 ballet dancers (11 females and 2 males – from the junior and senior classes)
- Group D – Male and female senior dancer group (SG) – 4 ballet dancers (3 females an 1 male – from the senior class)

Group B (FSG) was separated from the group A (FSJG) to emphasize the analysis of dynamic balance parameters related to more complicated rotational movements associated to higher level of experience. Group D (SG) was separated from group C (JSG) to check if higher level of experience has an influence on static balance parameters and if seniors static balance results could disturb the results of whole examined study group.
Mean age expressed in years with standard deviation (SD) in particular group is presented in

Figure 1.

Figure 1. Analysis of mean age for each group.

Analysis of Body Mass Index (BMI), defined as the ratio of an individual's weight to height squared (kg/m^2), was performed according to age and sex of participants (Nihiser *et al*., 2007). Junior male and female dancers as well as senior male dancer were classified as youth with normal weight with BMI at or above the 5th percentile and below the 85th percentile. Only senior female dancers were classified as underweight youth with BMI below the 5th percentile.
Each person took part in a static balance examination. Female groups A (FSJG) and B (FSG) were evaluated with dynamic balance examination to compare movements *en pointe* vs. movements *en demi pointe*. Male dancers could not take part in this comparison because they do not perform movements *en pointe*.
Static and dynamic balance examinations were performed with the Kistler 9286BA platforms, which are the module of BTS Smart DX 7000 optoelectronic system for objective movement and balance analysis.
Static examination consisted of a 30s trial with eyes opened and a 30s trial with eyes closed. One trial was carried out for each experimental condition. The position of the feet was imposed in order to define a common postural condition. The participant was asked to maintain an upright standing position for 30s with arms at the sides and feet positioned over sketches representing the foot with an angle of 30° with respect to the 806 anteroposterior direction. Firstly, the participant was asked to maintain an upright standing position with eyes opened, looking at red square of 5 cm, which was positioned vertically in the dancer's direct line of sight. In the second trial, the participant was instructed to keep eyes closed.
Dynamic balance examination consisted of movements related to whole body rotation. In group A (FSJG), participants were firstly asked to perform pirouettes on a single, dominant leg. Pirouettes were consistent with principles of classical ballet created by Waganowa (1956). The following turns were examined: *pirouette* from the 4th position *en dehor*, *pirouette* from the 4th position *en dedans.* Pirouettes *en dedans*, are inside movements in which the body turns in the way that the working leg moves forward or ahead of the supporting leg. *En dehor* pirouettes are outside movements in which the body turns in the direction of the working leg.
Participants in group A (FSJG) were, moreover, asked to perform a whole body turn *sutenou en tournant* in which the dancer must first execute a *demi plié* while extending the leading leg and then stepping up on a tight leg and begin the turn. Simultaneously, the dancer brings the other leg up to a raised position and completes a 360° turn. Group A (FSJG) members were also asked to perform *glissade en tournant*, which is a traveling step starting in fifth position with *demi plié*. The

front foot moves out to a point, both legs briefly straighten, and weight is shifted onto the pointed foot. The other foot moves in to meet the first. Movements performed on both legs, whole body rotation *sutenou en tournant* and *glissade en tournant*, were started from the dominant leg.
Group B (FSG) was asked to perform additionally: *pirouette* from the 5th to 5th position, *grand pirouette in arabesque* and *grand pirouette in attitude*. Pirouettes were performed on the dominant leg according to principles of classical ballet created by Waganowa (1956). *Grand pirouettes* are large turns with the gesture leg out to the side.
Some movements and positions are presented in Figure 2.

Figure 2. Movements and positions according to Waganowa (1956):
A: differences between movements en dehors and en dedans
B: the 4th position of feet
C: the 5th position of feet

Each movement was performed on the special ballet floor to avoid the risk of injury. We analyzed one repetition from each dancer's best trial as judged by the dancer and dance teacher, who was present during the examination. All participants were tested after the first ballet class of the day.
The outputs of the force platform allow to compute the COP parameters in the anteroposterior direction (longitudinal parameters) and the mediolateral direction (transverse parameters). The following parameters were considered for the analysis of static and dynamic examination:
- parameters for COP trajectory length: trace length (mm), transversal COP displacement (mm), longitudinal COP displacement (mm) – describe postural sway related to COP displacement
- parameters for range of COP displacement: radius (mm), maximal radius (mm), minimal radius (mm), transversal range (mm), longitudinal range (mm) – show the effectiveness of the postural system in keeping the center of gravity closer to the barycenter

- COP velocity (mm/s) was obtained by dividing the trace length by the test period time (Vahtrik *et al*., 2014) – higher values can indicate greater energetic loss to the dancer
- equivalent area (mm^2) also described as ellipse area or elliptical area expresses the area related to COP trajectory (Vahtrik *et al*., 2014).

Data processing was performed with the use of BTS Sway and Statistica 10. For statistical analysis, elements of summary statistics were used. The Shapiro – Wilk Test of normality was applied. In case of normal distribution, parametric dependent samples t – test was chosen. For other parameters non – parametric Wilcoxon signed – rank test was applied. Correlations between static and dynamic balance variables were assesed with the use of Pearson product – moment correlation coefficient (r) (Stanisz, 2006). The accepted level of significance was $\alpha = 0.05$.

3. Results

In group A (FSJG) statistically significant differences related to the comparison of the static examination with eyes opened vs. eyes closed in parametric dependent samples t – test were observed for longitudinal range (p=0.0278) and velocity (p=0.0342). Moreover, in non – parametric Wilcoxon signed – rank test – significant differences were found for maximal radius (p=0.0164) and equivalent area (p=0.0328). The comparison of the static examination with eyes opened vs. eyes closed revealed no statistically significant differences in group B (FSG) in the parametric dependent samples t – test. In contrast, according to parametric dependent samples t – test, significant differences were found for trace length (p=0.0346) and velocity (p=0.0118) in group C (JSG). Significant results were observed in non – parametric Wilcoxon signed-rank test for maximal radius (p=0.0058), transversal range (p=0.0231), longitudinal range (p=0.0046) and equivalent area (p=0.0107). Statistically significant differences in parametric dependent samples t – test (p=0.0314) could be found in group D (SG) only for the equivalent area. Tables 1 and 2 show summary statistics of static examination results with significant differences between trials with eyes opened vs. eyes closed. 809

Table 1. Summary statistics of static examination results in groups A (FSJG) and B (FSG). Note: a Significant differences between results of static examinations with eyes opened vs. eyes closed in group A. Static examination results	Eyes opened Group A (n=11)			Eyes closed Group A (n=11)			Eyes opened Group B (n=3)			Eyes closed Group B (n=3)		
Parameter:	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD
Transversal displacement (mm):	38.5	±	21.6	33.3	±	19.7	48.4	±	20.6	45.0	±	13.6
Longitudinal displacement (mm):	-66.4	±	31.0	-66.0	±	36.8	-68.8	±	30.3	-66.4	±	33.8
Radius (mm):	5.7	±	2.0	6.3	±	2.2	5.6	±	3.1	6.5	±	2.3
Maximal radius (mm):	16.8	±	5.7	27.7	±	25.4 a	20.6	±	5.2	24.5	±	8.9
Minimal radius (mm):	0.4	±	0.3	0.4	±	0.2	0.4	±	0.4	0.4	±	0.2
Transversal range (mm):	17.5	±	3.8	32.1	±	34.5	15.5	±	5.0	29.9	±	19.5
Longitudinal range (mm):	26.2	±	8.5	33.1	±	13.9 a	28.8	±	9.7	31.9	±	7.1
Trace length (mm):	451.3	±	118.2	560.7	±	227.8	368.8	±	96.0	438.6	±	144.9
Equivalent area (mm2):	813.6	±	372.2	1772.2	±	2467.4 a	693.4	±	544.3	1063.7	±	762.6
Velocity (mm/s):	16.2	±	3.9	19.3	±	6.2 a	13.7	±	1.6	16.2	±	3.1

Table 2. Summary statistics of static examination results in groups C (JSG) and D (SG).

Note: a Significant differences between results of static examinations with eyes opened vs. eyes closed in group C; b Significant differences between results of static examinations with eyes opened vs. eyes closed in group D. Static examination results	Eyes opened Group C (n=13)			Eyes closed Group C (n=13)			Eyes opened Group D (n=4)			Eyes closed Group D (n=4)		
Parameter:	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD
Transversal displacement (mm):	37.3	±	20.2	31.3	±	19.1	42.0	±	21.1	36.2	±	20.7
Longitudinal displacement (mm):	-68.0	±	29.0	-64.4	±	34.7	-68.2	±	24.8	-68.4	±	27.9
Radius (mm):	5.5	±	1.9	6.4	±	2.2	5.4	±	2.6	6.2	±	2.0
Maximal radius (mm):	15.9	±	5.6	26.6	±	23.3 a	18.2	±	6.4	23.3	±	7.6
Minimal radius (mm):	0.4	±	0.3	0.4	±	0.3	0.4	±	0.3	0.3	±	0.1
Transversal range (mm):	17.1	±	3.7	30.5	±	31.7 a	15.2	±	4.2	27.2	±	16.8
Longitudinal range (mm):	25.2	±	8.2	33.0	±	12.7 a	26.2	±	9.6	31.8	±	5.8
Trace length (mm):	426.5	±	127.3	536.7	±	216.1 a	330.9	±	109.1	431.2	±	119.2
Equivalent area (mm^2):	751.5	±	374.4	1647.2	±	2276.1 a	596.7	±	484.6	964.7	±	653.5 b
Velocity (mm/s):	15.8	±	4.0	19.2	±	5.6 a	12.8	±	2.3	16.8	±	2.8

In dynamic balance examination only female groups A (FSJG) and B (FSG) were evaluated. Male dancers could not take part in this comparison due to the character of movement, therefore groups C (JSG) and D (SG) are not presented in this part of statistic evaluation. While comparing movements *en pointe* vs. movements *en demi pointe* in dynamic balance examination, statistically significant differences were only observed in group A (FSJG) – for longitudinal COP displacement (p=0.0056) in pirouette from the 4th position *en dedans,* and in group B (FSG) – for velocity (p=0.0385) in pirouette from the 5th to 5th position. Both differences were found in the parametric dependent samples t – test. Displacement decreased for movement *en pointe* in group A (FSJG) (mean displacement: 31.7 ± 49.6mm *en demi pointe*, -21.0 ± 77.6mm *en pointe*), whereas velocity increased for movement *en pointe* in group B (FSG) (mean velocity: 201.8 ± 6.3mm *en demi pointe*, 206.0 ± 5.8mm *en pointe)*. Tables 3 and 4 show summary statistics of dynamic balance examination results with significant differences between trials *en pointe* vs. *en demi pointe*.

Table 3. Summary statistics of dynamic examination results in group A (FSJG).

Note: a Significant differences between results of dynamic examination *en pointe* vs. *en demi pointe* in group A. Dynamic examination results	*pirouette* from the 4th position *en dehor*		*pirouette* from the 4th position *en dedans*		*sutenou en tournant*		*glissade en tournant*	
en pointe	*en demi pointe*	*en pointe*	*en demi pointe*	*en pointe*	*en demi pointe*	*en pointe*	*en demi pointe*	
Parameter:	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD
Transversal displacement (mm):	28.0 ±34.7	19.7 ±67.9	19.8 ±50.3	21.9 ±40.3	11.7 ±43.8	19.6 ±47.0	-28.8 ±58.0	-35.2 ±62.1
Longitudinal displacement (mm):	-23.0 ±68.5	-26.0 ±81.5	-21.0 ±77.6	31.7 ±49.6 a	-26.0 ±81.9	-14.7 ±76.9	-47.0 ±103.5	-11.2 ±59.0
Radius (mm):	86.8 ±46.2	65.5 ±32.7	102.6 ±46.3	100.9 ±47.1	83.1 ±28.5	75.4 ±15.7	85.3 ±31.3	73.3 ±25.9
Maximal radius (mm):	190.3 ±85.8	181.6 ±97.6	200.5 ±77.0	217.0 ±76.0	183.4 ±36.5	171.9 ±31.2	207.0 ±76.9	184.1 ±66.1
Minimal radius (mm):	20.9 ±30.8	13.4 ±8.8	34.2 ±35.2	21.0 ±16.0	21.1 ±18.3	15.9 ±9.6	17.1 ±9.0	15.9 ±11.4
Transversal range (mm):	195.0 ±66.9	184.2 ±52.3	209.3 ±63.9	190.2 ±44.3	210.5 ±61.0	174.9 ±32.1	194.7 ±46.6	205.6 ±43.4
Longitudinal range (mm):	248.1 ±169.5	231.1 ±158.6	271.9 ±151.8	336.4 ±150.8	275.1 ±93.2	286.6 ±53.7	284.9 ±130.5	254.7 ±101.6
Trace length (mm):	1509.3 ±1064.7	1431.6 ±963.3	1504.9 ±1050.9	1709.9 ±937.9	1543.7 ±567.2	1468.6 ±506.1	1283.4 ±561.2	1131.4 ±503.9
Equivalent area (mm2):	35397.5 ±43536.8	28401.6 ±25411.2	42132.4 ±45276.2	49227.5 ±48055.2	36396.4 ±20593.3	34038.9 ±14116.2	27232.0 ±17687.9	20665.5 ±6854.7
Velocity (mm/s):	234.8 ±110.2	212.0 ±79.6	224.6 ±78.9	231.1 ±48.6	250.5 ±67.4	239.1 ±63.3	277.7 ±51.5	232.0 ±73.2

Table 4. Summary statistics of dynamic examination results in group B (FSG).

Note: a Significant differences between results of dynamic examination *en pointe* vs. *en demi pointe* in group B. Dynamic examination results	*pirouette* from the 5th to 5th position		*grand pirouette in arabesque*		*grand pirouette in attitude*	
	en pointe	*en demi pointe*	*en pointe*	*en demi pointe*	*en pointe*	*en demi pointe*
Parameter:	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD
Transversal displacement (mm):	58.0 ±20.4	40.2 ±3.7	-9.9 ±61.4	-11.0 ±58.6	-1.2 ±58.6	0.2 ±56.6
Longitudinal displacement (mm):	-74.5 ±44.8	-110.3 ±16.4	19.0 ±33.6	32.1 ±29.9	89.0 ±79.5	95.4 ±78.1
Radius (mm):	53.6 ±7.9	42.2 ±4.6	47.3 ±6.5	46.3 ±8.7	82.5 ±36.1	83.9 ±38.4
Maximal radius (mm):	128.9 ±14.1	116.4 ±4.9	106.3 ±18.9	105.2 ±19.7	117.5 ±54.8	118.9 ±57.9
Minimal radius (mm):	7.6 ±3.2	-0.5 ±4.1	3.7 ±0.7	4.8 ±1.8	33.8 ±35.5	9.8 ±5.2
Transversal range (mm):	188.3 ±28.3	168.1 ±6.6	140.9 ±74.2	139.9 ±74.5	167.6 ±127.7	169.0 ±131.1
Longitudinal range (mm):	191.1 ±90.3	135.8 ±9.6	135.0 ±25.5	134.0 ±25.5	207.9 ±96.5	209.4 ±97.3
Trace length (mm):	1288.9 ±488.5	1006.5 ±19.2	1235.2 ±16.9	1234.2 ±16.3	1326.9 ±114.3	1328.3 ±117.3
Equivalent area (mm2):	17895.7 ±3078.1	16458.3 ±965.0	14161.2 ±1276.3	14160.1 ±1278.5	43582.1 ±24481.6	33583.6 ±12472.7
Velocity (mm/s):	206.0 ±5.8	201.8 ±6.3 a	208.4 ±5.8	208.4 ±8.1	225.4 ±54.5	190.1 ±7.5

There were only few statistically significant correlations between static and dynamic variables in group A (FSJG). Coefficient indicating strong positive correlation ($0.5 \leq r < 0.7$) was observed: for radius (r=0.6) between static examination with eyes opened and *sutenou en tournant en demi pointe* and for velocity (r=0.6) between static examination with eyes opened and *sutenou en tournant en pointe.* Strong negative correlation appeared: for radius (r=-0.6) between static examination with eyes opened and *pirouette* from the 4th position *en dehor en demi pointe,* for radius (r=-0.6) between static examination with eyes closed and *pirouette* from the 4th position *en dehor en demi pointe,* for maximal radius (r=-0.6) between static examination with eyes opened and *pirouette* from the 4th position *en dedans en demi pointe* and for longitudinal displacement (r=-0.6) between static examination with eyes closed and *glissade en tournant en demi pointe.* Very strong positive correlation ($0.7 \leq r < 0.9$) was found in group A: for trace length (r=0.8) between static examination with eyes opened and *sutenou en tournant en demi pointe* and for minimal radius (r=0.7) between static examination with eyes closed and *glissade en tournant en pointe.* Very strong negative correlation appeared: for longitudinal range (r=-0.7) between static examination with eyes opened and *pirouette* from the 4th position *en dehor en demi pointe*, for longitudinal range (r=-0.7) between static examination with eyes opened and *pirouette* from the 4th position *en dedans en demi pointe* and for trace length (r=-0.7) between static examination with eyes opened and *glissade en tournant en demi pointe.* Almost perfect positive correlation ($0.9 \leq r < 1$) was observed for velocity (r=0.9) between static examination with eyes opened and *sutenou en tournant en demi pointe.*

4. Discussion

Ballet dancers exhibit a better postural control as a result of their ballet training (Rein *et al.*, 2011). Dancers pursue higher level of skill-specific motor training, so they are able to compensate for vestibular and fatiguing perturbations (Hopper *et al*., 2014). They present less variable ankle–hip coordination, which can contribute to increased coordination stability, neuromuscular control, and to their ability to perform complex balance tasks (Kiefer *et al*., 2011). Dance training enhances sensorimotor control functions underlying static and dynamic equilibrium. It is said that dancers have a lower power of body oscillations and are less dependent on vision for postural control with increased accuracy of their proprioceptive inputs (Tanabe *et al*., 2014). Such observations were not fully confirmed in the presented study. In the whole examined group (group C – JSG), and in the group which consisted only of female dancers (group A – FSJG), the following parameters increased in static examination with eyes closed in comparison to the examination with eyes opened: maximal radius, longitudinal range, equivalent area, and velocity. This shows that the static balance of dancers deteriorates with closing their eyes. Negative impact on balance related to the lack of visual control and unstable surface was confirmed by Schmit *et al*. (2005) in most dependent measures in the anteroposterior and mediolateral sway axes. Deterioration of static balance with eye closure was also observed by Celletti *et al.* (2011) in a 15-year-old girl who practiced classic dance until her teens. She was similar in age to the dancers from the junior class who participated in the research; however, she suffered from joint hypermobility syndrome (JHS) and also presented with severe joint instability and consequently balance impairment. Celletti's results suggest that there is a need of an additional evaluation of joint mobility in dancers in order to exclude JHS and to determine the influence of prolonged ballet training on joint mobility and a dancer's stability.

In our study, the participants from the senior class (group B – FSG and group D – SG) did not present many differences related to the parameters of static balance, which can be considered a beneficial result of ballet training. A similar conclusion was drawn by Bruyneel *et al*. (2010), who examined two groups of dancers, i.e. a younger group (8 and 16 years old) and an adult group (17 and 30 years old). In both groups, ground reaction forces related to mediolateral and anteroposterior components were evaluated.

In comparison to the adults, young dancers were characterized by an instability combined with an increase in the number of oscillations and a decrease in variability of mediolateral sway. Moreover, the younger group was less efficient in controlling their balance. The results indicated that it could be related to the number of hours of practicing dance, which were different in both groups. Ballet training improved balance, awareness of movement, and the body's orientation in relation to the surrounding surfaces (Schmit *et al*., 2005).

A whole body turn is an especially complex movement because it involves stabilizing and mobilizing components of the equilibrium. Dancers should maintain vertical posture and equilibrium until the end of the turn. Proper equilibrium during each rotation phase can be kept by developing shoulder–hip coordination related to reduction of the shoulder–hip angle. It is also linked with the stability of the working lower limb (Golomer *et al*., 2009b). Imura *et al*. (2008) examined a group of dancers performing the *fouette turn* on the force plate in soft ballet shoes. The authors considered that the magnitudes of the moment of ground reaction forces, which could help to assess the maintenance of the COP, might have changed if dancers would turn the *fouette* wearing hard ballet shoes. This observation was not confirmed in the presented study. This study showed that there was practically no difference between movements *en demi pointe* in comparison with movements *en pointe,* although the base of support was smaller for movements *en pointe*. Thullier *et al*. (2004) compared dancers with gymnasts that had no dance training, who might have excelled in the ability to stabilize postures in their exploitation of the redundancy in the number of degrees of freedom of the body. Although both the dancers and gymnasts were equally stable, dancers were more successful in reproducing the orientation and shape of the movement. The errors in those parameters of movement could indicate some imperfections in the internal representation of the movement pattern or in the transformation of the representation into motor control signals to perform the complex movement. Taking into consideration results obtained by Thullier and the results of the presented study, it can be observed that due to ballet training, an individual can increase the ability of the nervous system to integrate multiple degrees of freedom to improve body balance while producing complex movement. That could be the reason why the smaller base of support did not affect the balance related to movements *en demi pointe* in comparison with movements *en pointe*.

According to Perrin *et al*. (2002), ballet improves orthostatic balance control when eyes are opened. They reported that the foot had an important impact on balance because it controlled external information, i.e. position in relation to the ground and internal constraints related to the sense of position. In Perrin's study, dancers with closed eyes displayed poor static balance control. This was explained as being the result of training in classical ballet and developing specific modalities of balance rather than static posture control. Visual input is not used in dancers' practice to solve the task, but to take landmarks for perceiving the surroundings. High-speed body rotations are regular while head position changes occur in fits and starts, with short periods of fixation at each turn. Gaze fixation allows dancers to avoid post rotatory nystagmus. Kilby *et al*. (2012) claimed that ballet dancers had better balance in more demanding tasks, which were related to the specific ballet movements. Those results are similar to observations made in the present study. Dancers presented no differences in dynamic balance control in movements related to ballet dance with rotation *en pointe* in comparison to *en demi pointe*. However, there was a deterioration in static balance control with eyes closed, which was observed in the whole examined group. On the other hand, this deterioration was not found in the participants from the senior class, which can confirm the theory that prolonged specific ballet training could contribute to balance control.

Analysis of dependencies between static and dynamic balance variables did not revealed many statistically significant correlations in respect to many analyzed parameters. Similar observations can be found in literature (Muehlbauer *et al.,* 2013; Sell, 2012). Few correlations observed in group A (FSJG) referred to parameters for range and trajectory length of COP displacement, mainly between static examination with eyes opened and movement *en demi pointe*.

Tanabe *et al*. (2014) suggested that COP analysis should be extended to the investigation related to inter-joint coordination, which means evaluation of joint's oscillations and its relationships to other joints. This approach could elucidate the postural control process from a mechanical perspective. Regarding the present study, it is planned to continue the analysis of the kinematic data obtained by optoelectronic system to complement the results. It is also planned to perform a follow-up study of the same dancers to check if the higher level of ballet training would be related to the improvement of static balance and balance during rotational movement.

We acknowledge limitations to our study: 1) it was carried out in laboratory settings and did not replicate all the aspects of a real-life dance; 2) the small number of participants. Nevertheless, data obtained from this sample can be useful for further analyses. Nevertheless, this study also had some strengths: 1) the senior and junior group of dancers had ballet training in the same school, and therefore had the same program of training in respect to the level of skills; 2) all analysis of movements were objectively conducted with the use of high accuracy optoelectronic system.

5. Conclusions

In conclusion, static balance deteriorated with eye closure in the whole examined group. Participants from the senior class presented more stable parameters of static balance. There were no differences shown in dynamic balance when the base of support was decreased.

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