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Static Balance in Female Artistic Gymnasts and Non-Training Girls

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Abstract: Sports activities can constitute a factor in improving postural control. The aim of this study is to compare static balance in the tandem stance between female artistic gymnasts and non-training girls. This was performed with and without visual control, as well as in a position with open eyes, on a 1.25 m high platform. Two groups of thirty girls participated in the study. The first group consisted of gymnasts (mean age 9.50 ± 1.20 years, body height 133.50 ± 11.40 cm, and body mass 28.90 ± 6.90 kg), while the second group comprised non-training girls (mean age 9.80 ± 1.20 years, body height 142.60 ± 10.90 cm, and body mass 37.40 ± 9.70 kg). Balance measurements were taken using the CQ Stab 2P two-plate stability platform. In the measurements conducted with the subjects' eyes closed, the gymnasts obtained a lower value for displacement regarding the maximal centre of pressure (COP) in the anterior–posterior direction and a higher frequency of COP displacement ($p < 0.05$). In the trial performed on a platform, a greater COP displacement frequency was found among the non-training girls ($p < 0.001$). Differences in the values of the variables characterising the static balance of gymnasts and non-training girls were revealed only in conditions of increasing difficulty concerning the motor task (increasing the height of the position and/or without eye control).

Keywords: balance; artistic gymnastics; tandem stance; girls

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1. Introduction

In both everyday life and in most sports activities, people employ an internal mechanism that allows them to maintain a stable standing position. Regulatory processes are based on information from the visual, vestibular, and somatosensory systems, which are processed by the central nervous system and then transferred to the effector organs [1–3]. The great potential for improving the motor effects of this mechanism has been proven in recently published studies on the subject. The stimulation of the processes responsible for maintaining balance occurs in people of different ages and with various dysfunctions of the musculoskeletal system [4–9]. High efficiency of the balance system is particularly important in the case of athletes undertaking various sports disciplines. This may be considered a significant factor in obtaining higher levels in sports championships [10,11].

In artistic gymnastics, the ability to maintain balance should be considered both within the context of potentially achieving satisfactory sports results and as a key element of athletes' safety during exercises. The effects of the adaptation processes taking place in the balance system are especially visible in tasks that are unnatural for humans, such as performing a handstand [12–14].

The prospect of comparing the ability to maintain balance between gymnasts and people who do not train in this discipline requires the use of easily adjustable body positioning settings, of which the most common are postures in both the bipedal quiet and unipedal stance positions. In the unipedal stance, gymnasts obtained more favourable results than their non-training peers and competitors of other sports [15–17]. On the other hand, in the case of a natural, free postural position, conclusions regarding the natural quiet stance are not so clear [15,18–20].

The results of our research allow us to indicate that training in gymnastics may have a positive effect on coping with stimuli disturbing postural control. Vuillerme et al. [21] formulated a conclusion stating that, compared to competitors of other disciplines, gymnasts, after shutting off visual control in the unipedal stance, better utilised the remaining sensory modalities to compensate for the lack of vision. Kochanowicz et al. [22] confirmed the positive effects of gymnastics training on the stability in the bipedal stance without the visual system. On the other hand, Asseman et al. [15] did not report such results, neither in the unipedal position nor in bipedal stance with closed eyes. The divergent conclusions of these studies encourage further analysis of this issue.

Another significant factor influencing the processes related to maintaining stability is the height at which the body is located. In research carried out among adults, it was indicated that psychological, physiological, and postural responses may be a reply to a perceived state of danger related to height [23,24]. The influence of height on postural reactions in children training in artistic gymnastics was a topic discussed in our earlier work [25]. We found that the length of the statokinesiogram path in the natural and tandem stance positions was greater in the tests carried out at the height of 1.25 m than on the ground.

The postural stability of children is assessed in various positions, including the tandem stance [26]; however, few authors are focused on research among artistic gymnasts. Aleksić-Veljković et al. [27] emphasized that in this discipline, the tandem stance is a particularly important position during exercises performed on a balance beam. In this position, the athletes start and finish various gymnastic elements. Losing balance results in the athlete falling from the beam, which, in the event of a sports competition, significantly reduces the point value obtained for the performed routine. Thus, the risk of injury is increased [28]. The result is adversely affected by even a slight "disturbance", and to an extent that can be observed by the judges. According to the standards developed by the International Gymnastics Federation [29], the height of the beam's top surface during a competition must be 1.25 m above the floor. These facts clearly indicate that such a height should not constitute a factor disturbing the processes responsible for maintaining balance.

The above considerations prompted the authors to undertake research aimed at comparing static balance in the tandem stance between female artistic gymnasts and non-training girls in conditions of visual control and without it, as well in a position with open eyes and at a height of 1.25 m.

2. Materials and Methods

2.1. Participants

The study comprised 2 groups of 30 girls, aged 8 to 12. The characteristics of the subjects are presented in Table 1.

Table 1. Characteristics of the female artistic gymnasts (n = 30) and non-training girls (n = 30).

	G [$\bar{x} \pm$ SD]	N [$\bar{x} \pm$ SD]	Z	p
Age [years]	9.50 ± 1.20	9.80 ± 1.20	−0.98	0.326
Body height [cm]	133.50 ± 11.40	142.60 ± 10.90	−3.29	0.001 *
Body mass [kg]	28.90 ± 6.90	37.40 ± 9.70	−3.54	<0.001 *
Training experience [years]	4.47 ± 1.01	0		-

$\bar{x}$—arithmetic mean; SD—standard deviation; Z—value of the Mann–Whitney U test; p—probability value. * $p < 0.05$.

In the present study, the first group (G) included female artistic gymnasts from the "Korona" Sports Club in Krakow. The selection of this group for the study was deliberate, and the criteria were: at least 3 years training experience, systematic participation in gymnastics training (5 training sessions a week, 2–3 h each), no complaints resulting from injuries to the musculoskeletal system, and written consent of parents/legal guardians and coach.

The second group (N) consisted of healthy girls attending various Krakow primary schools. We decided to limit the number of randomly chosen schools to 10. Then, the parents of the students aged 8–12 were informed in writing about the intention to carry out research. From among those who expressed their willingness to participate in these measurements and those who met the inclusion criteria, 30 girls were selected at random. The selection criteria for this group were: no participation in professional sports training, involvement in physical education classes, no complaints resulting from injuries to the musculoskeletal system, and written consent of parents or legal guardians.

The studied groups of girls did not differ in terms of age. On the other hand, the gymnasts were significantly shorter and lighter (Table 1).

Before taking measurements, all the girls were acquainted with the course and methodological assumptions of the study. The participants were informed of the possibility to withdraw from the study at any stage and without any consequences. All procedures were carried out in full compliance with the Declaration of Helsinki. The study was approved by the Bioethics Committee at the University of Rzeszow, Poland (Approval Ref. No. 0/12/2019).

2.2. Examination Protocol

Biomechanical testing of balance was performed using a CQ-Stab 2P two-platform posturograph (manufactured by CQ Electronik System, Czernica, Poland). Measurements were carried out in tandem stance and in 3 study conditions: EO_L—standing with open eyes on platforms placed on the floor (low); EC_L—standing with closed eyes on platforms placed on the floor (low); EO_H—standing with open eyes on platforms situated on another platform (high), which made it possible to obtain a height of 1.25 m between the upper surface of the platforms and the floor.

The order of these measurements was random (the number of possible combinations equalling 6). During each test, the stabilographic platforms maintained the same position—one in front of the other. The duration of each recording was 30 s.

Before initiating measurements, the girls were instructed on how to perform the tests. Then, they performed a general warm-up, which lasted about 5 min and was conducted by an artistic gymnastics coach. After climbing onto the stabilographic platform, the examined person stood upright, and each time, the same dominant lower limb was in front, with the arms freely dangling and the eyes (in the measurements with open eyes: EO_L and EO_H) directed towards the fixation point located 2 m in front of the subject at eye level. The interval between measurements was 1 min (during this time, depending on the type of the next measurement, the stabilographic platforms were placed on the floor or a landing).

During the measurements carried out at a high level, the examined girls were belayed by 1 person from the research team (who was also a qualified artistic gymnastics coach). After the child stood on the stabilographic platform situated on the landing, the belayer stood behind the examined person. Thus, the belayer was not in her field of view. There were 20 cm high gymnastic mattresses placed around the platform. These were employed to provide additional support for the subject and resembled the placement mattresses around the gymnastic balance beam during training and sports competitions (standards regulated by the International Gymnastics Federation [29]). To obtain the appropriate height of the dynamographic platforms, the Alspaw Light SPL stage platform (dimensions: 1 m $\times$ 0.5 m) was used; notably, this platform's height was adjustable. Before the measurements were taken, the platform was levelled.

The examined girls wore sports attire (T-shirt and shorts) and were barefoot.

2.3. Evaluated Indices of Balance

Based on the recorded movement regarding the centre of pressure (COP), the following balance indices were analysed:

- SP [mm]—(total) statokinesiogram path length on both axes;
- SPAP [mm]—statokinesiogram path length on the anterior–posterior plane;
- SPML [mm]—statokinesiogram path length on the medial–lateral plane;
- MaxAP [mm]—maximal displacement of COP from the 0 point along the anterior–posterior plane;
- MaxML [mm]—maximal displacement of COP from the 0 point along the medial–lateral plane;
- SA [mm^2]—displacement area delimited by the COP point;
- MF [Hz]—mean frequency of COP displacement.

In Figures 1–3, COP statokinesiogram paths are demonstrated regarding each of the 3 recorded measurements (EO_L, EC_L, EO_H) for one of the tested female athletes.

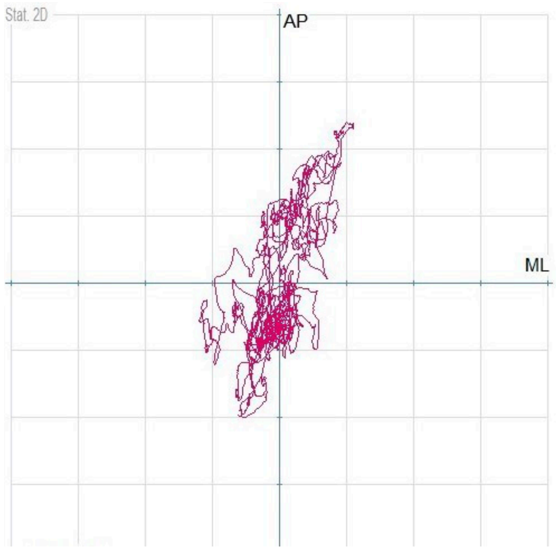

Figure 1. Diagram showing path length sample for COP during EO_L test.

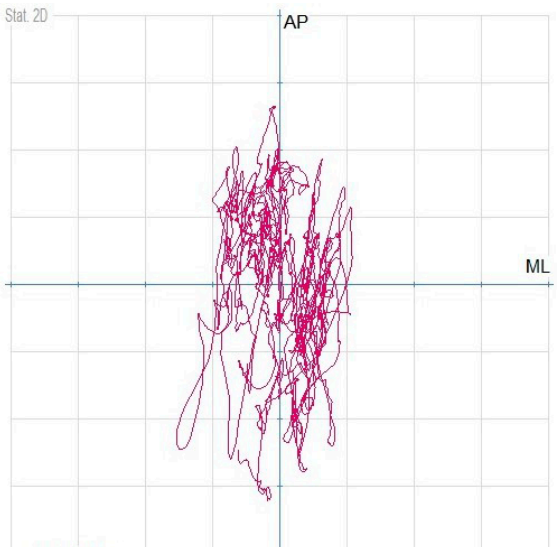

Figure 2. Diagram showing path length sample for COP during EC_L test.

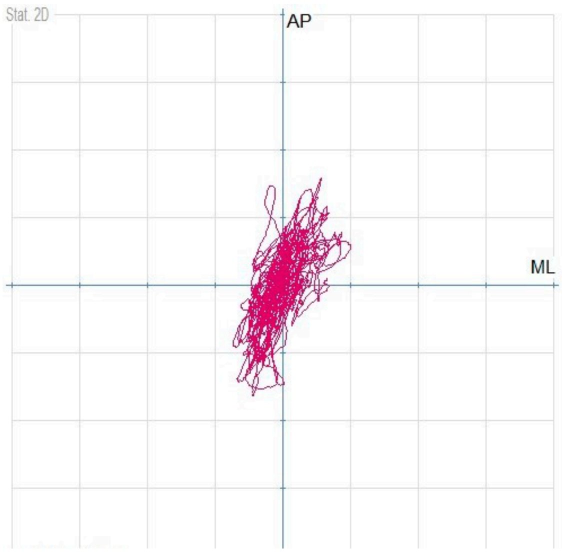

Figure 3. Diagram showing path length sample for COP during EO_H test.

2.4. Statistical Analysis

Statistical analysis was performed using the IBM SPSS Statistics 26 (Armonk, NY, USA) statistical package. First, the assumption for normality of distribution concerning the results was verified via the Shapiro–Wilk test. The obtained results of the test did not allow for the indication that the distribution of the studied variables was close to normal; therefore, a decision was made to use the non-parametric Mann–Whitney U test, which was implemented to compare the results obtained for girls from both study groups.

As the distribution of the studied variables differed from the norm, the values of 25th, 50th (Me—median), and the 75th percentile were applied to describe the collected quantitative data. The threshold for statistical significance was adopted at the level of $p < 0.05$.

3. Results

In Table 2, descriptive statistics are presented together with the results of the Mann–Whitney U test, relating to the data obtained for the tandem stance test performed in a low position with open eyes (EO_L). In this case, no statistically significant differences were noted between the studied groups of girls ($p > 0.05$).

Table 2. Comparison of balance indicator values in tandem stance position with open eyes low (EO_L) between gymnasts and non-training girls.

Balance Indicator	Group	Percentile			Z	*p*
		25	50 (Me)	75		
SP-EO_L [mm]	N	546.25	704.00	826.50	−0.45	0.652
	G	624.75	716.00	813.25		
SPAP-EO_L [mm]	N	428.00	515.50	675.25	−0.11	0.912
	G	448.00	516.50	629.25		
SPML-EO_L [mm]	N	239.50	357.50	460.50	−0.87	0.387
	G	294.25	348.50	449.75		
MaxAP-EO_L [mm]	N	8.20	12.45	19.73	−0.63	0.530
	G	8.23	11.40	17.25		

Table 2. *Cont.*

Balance Indicator	Group	Percentile 25	Percentile 50 (Me)	Percentile 75	Z	p
MaxML-EO$_L$ [mm]	N	7.65	14.35	18.90	−0.24	0.807
	G	9.05	13.10	18.73		
SA-EO$_L$ [mm^2]	N	532.25	1313.50	1989.00	−0.03	0.976
	G	670.25	983.50	1737.25		
MF-EO$_L$ [Hz]	N	0.61	0.71	0.90	−0.07	0.947
	G	0.63	0.73	0.93		

Z—value of the Mann–Whitney U test; *p*—probability value.

The results obtained for the measurements performed in the tandem stance with closed eyes (EC$_L$) are presented in Table 3. These indicate that the gymnasts obtained significantly lower values in terms of maximal anterior–posterior COP displacement (MaxAP-EC$_L$). The difference between the median values (Me) obtained for the non-training girls and the female gymnasts was 8.45 mm ($p < 0.05$). The mean frequency of the COP displacement (MF-EC$_L$) also differentiated the groups and was higher in the female athletes by 0.15 Hz ($p < 0.05$).

Table 3. Comparison of balance indicator values in tandem stance position with closed eyes and low (EC$_L$) between gymnasts and non-training girls.

Balance Indicator	Group	Percentile 25	Percentile 50 (Me)	Percentile 75	Z	p
SP-EC$_L$ [mm]	N	792.50	1167.00	1956.00	−0.70	0.487
	G	898.25	975.00	1356.50		
SPAP-EC$_L$ [mm]	N	596.00	733.50	1511.75	−1.18	0.240
	G	568.75	708.50	844.50		
SPML-EC$_L$ [mm]	N	376.75	666.50	1074.25	−0.21	0.836
	G	444.25	641.00	827.75		
MaxAP-EC$_L$ [mm]	N	16.23	24.70	52.33	−2.00	0.045 *
	G	11.45	16.25	31.65		
MaxML-EC$_L$ [mm]	N	12.83	23.90	43.63	−0.53	0.595
	G	14.03	23.20	29.08		
SA-EC$_L$ [mm^2]	N	1397.25	3255.00	11543.75	−1.51	0.132
	G	1523.25	2050.50	4228.25		
MF-EC$_L$ [Hz]	N	0.59	0.69	0.81	−2.34	0.019 *
	G	0.66	0.84	0.90		

Z—value of the Mann–Whitney U-test; *p*—probability value. * $p < 0.05$.

The results of the measurements taken on the platform (EO$_H$) are presented in Table 4. They indicate that the gymnasts and girls who did not practice the sport significantly differed in relation to the mean frequency of the COP displacement (MF-EO$_H$). The non-training girls obtained higher values, and the difference between mean values was 0.20 Hz ($p < 0.001$). At the level of statistical tendency ($0.05 < p < 0.10$), the gymnasts obtained a 4.60 mm higher value for maximal COP displacement in the lateral–medial direction (MaxML-EO$_H$) than the non-training girls. For the remaining indices, no significant differences were noted between the studied groups ($p > 0.05$).

Table 4. Comparison of balance indicator values in tandem stance position with opened eyes and high (EO_H) between gymnasts and non-training girls.

Balance Indicator	Group	Percentile			Z	p
		25	50 (Me)	75		
$SP\text{-}EO_H$ [mm]	N	558.00	725.50	999.25	−1.04	0.297
	G	677.75	799.00	876.25		
$SPAP\text{-}EO_H$ [mm]	N	425.25	490.50	611.75	−1.01	0.311
	G	457.25	556.00	671.75		
$SPML\text{-}EO_H$ [mm]	N	267.25	330.50	555.75	−0.99	0.322
	G	355.00	398.00	518.25		
$MaxAP\text{-}EO_H$ [mm]	N	7.08	13.35	18.05	−0.64	0.520
	G	9.00	13.65	16.90		
$MaxML\text{-}EO_H$ [mm]	N	6.38	10.35	17.98	−1.83	0.068
	G	9.08	14.95	21.10		
$SA\text{-}EO_H$ [mm^2]	N	521.00	1062.50	1898.75	−1.64	0.101
	G	821.50	1319.00	1853.50		
$MF\text{-}EO_H$ [Hz]	N	0.86	0.94	1.02	−3.40	<0.001 *
	G	0.62	0.74	0.85		

Z—value of the Mann–Whitney U test; *p*—probability value. * $p < 0.05$.

4. Discussion

The comparison of the indices characterising static balance between the female artistic gymnasts and non-training girls showed that with regard to the measurements taken in the tandem stance with open eyes and in a low position (EO_L), both groups obtained similar results. To the authors' knowledge, there are not many studies in the literature concerning measurements of postural stability among female artistic gymnasts while considering the tandem stance position. The few studies include that of Aleksić-Veljković et al. [27], comprising two groups of gymnasts: younger (aged 9.0 ± 1.1 years) and older (aged 12.1 ± 0.6 years). The authors did not find statistically significant inter-group differences in the values of the balance indices obtained in the two-legged positions, namely, double-leg and tandem stance; instead, the differences concerned the values of balance indicators obtained in the one-leg stance position. Due to the comprehensive impact of gymnastics training on human physical fitness [30,31], as a result of the given study, the levels of the balance indicators in the female athletes were expected to be better than their non-training peers. It was assumed that various movement tasks carried out in the course of sports training significantly differentiated both groups of young girls, especially since the tandem stance position is sometimes repeated during exercises on a balance beam. The conclusion based on this measurement (EO_L) is in line with the view of some authors who studied the bipedal quiet stance [21,32,33], stating that differences between the balance level of gymnasts and comparative groups do not appear in such positions. However, they may occur in younger groups, as observed by Garcia et al. among 5–7-year-old gymnasts and non-training girls [19].

The results of the measurements in the tandem stance without visual control and performed on platforms located on the floor (EC_L) showed that the girls training in artistic gymnastics obtained a significantly lower value for maximal COP displacement in the anterior–posterior direction ($MaxAP\text{-}EC_L$) compared to their peers who did not engage in any sports. The lower value of this index in the female gymnasts was associated with a significantly higher mean frequency of COP displacement ($MF\text{-}EC_L$). The obtained differences between the groups seem to confirm that artistic gymnastics training may promote the better use of information from the prediction and vestibular systems by athletes in the process of stability control in the tandem stance. Nonetheless, this does not translate into significantly lower values for the total length of the statokinesiogram path (SP-EC_L) or the statokinesiogram path measured in both directions (SPAP-EC_L and SPML-EC_L). It should be borne in mind that in the balance measurements, not only the exclusion of visual control but also the type of stance determine differences between groups.

Vuillerme et al. [21] showed that with the increasing difficulty of the task, the role of visual information for maintaining stability also experiences an increase. When examining adult gymnasts and athletes performing other disciplines, these researchers found that in the bipedal task, the performance of both groups was not altered by the suppression of vision. In the unipedal tasks, closing one's eyes increased postural displacement, but lower (more favourable) values were noted in gymnasts.

The results of the measurements performed at a height of 1.25 m, during which the examined girls had open eyes (EO_H), significantly differed between the groups, but only in terms of mean frequency regarding COP displacement (MF-EO_H). A greater value of this variable was noted in the non-training girls. In this group, at the level of statistical tendency, a lower value of maximal COP displacement in the medial–lateral direction (MaxML-EO_H) was observed. Despite the fact that in the case of other balance indices, no statistically significant differences were noted, it can be stated that their mean values (Me) were lower in girls not practicing sports. Similarly, in the balance measurements performed on a platform among adult participants, the frequency of corrective reactions also increased, while there was a simultaneous decrease in the amplitude of COP displacement [34–37]. Undoubtedly, further research is required regarding explanations as to which variables may influence the results of balance measurements carried out at height. The observations noted to date allow us to suggest that they should also be found in psychological aspects. In non-training girls, the higher frequency of COP displacement and lower values of other balance indicators could be associated with the feeling of greater anxiety resulting from performing a new task in unusual conditions (elevation) and, thus, with reduced self-efficacy. Such an emotional state may contribute to impaired concentration, which leads to deterioration in the efficiency of performing motor tasks [38–40]. In future studies, it is suggested to consider these aspects in order to broaden knowledge on this subject.

5. Conclusions

The comparison of static balance in the tandem stance between female artistic gymnasts and non-training girls did not prove that the process was separate in conditions with limited disruptive stimuli, namely, with visual control and at a low height (natural for humans) (EO_L). Differences in the values of the variables characterising body balance were revealed between the groups, but only in the conditions of increasing motor task difficulty (elevating the height of the position and/or ceasing visual control). In the test performed with closed eyes (EC_L), lower values of maximal COP deflection in the anterior–posterior direction and a higher frequency of displacement of this point were recorded in the girls training in artistic gymnastics. On the other hand, during the measurements of balance with maintained visual control carried out on a platform (EO_H) and in non-training girls, a higher frequency of COP displacement and lower values of indices characterising the described motor task were found.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and has been approved by the Bioethics Committee of the University of Rzeszow, Poland (Approval Ref. No. 10/12/2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets that were generated for this study are available upon request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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