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The level of body balance in standing position and handstand in seniors athletes practicing artistic gymnastics

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Purpose: The aim of the study was to compare the values of selected stability indices registered in the trials in standing with eyes open and without visual control, and in handstand in athletes practicing artistic gymnastics at the highest level of advancement. *Methods:* The study included 20 athletes practicing artistic gymnastics. The research tool was posturograph CQ-Stab 2P. The results obtained in individual trials were compared using Friedman repeated measures analysis of variance by ranks and then subjected to Dunn post-hoc test with Bonferroni adjustment. *Results:* Statistically significant differences in the values of stability indices recorded in individual samples were found. Exceptions are the results obtained in the trials with eyes open and without visual control with regard to the size of the surface area delineated by the COP ($p = 0.173$) and the frequency of corrective reactions ($p = 0.464$), as well as the length of the statokinesiogram path in the mediolateral direction ($p = 0.342$), mean velocity of COP movement in the mediolateral direction ($p = 0.246$), maximal amplitude of the COP in the mediolateral direction ($p = 0.342$) and number of COP displacements in the mediolateral direction ($p = 0.246$). *Conclusions:* In seniors, disabling visual control during free standing as well as adopting a handstand position result in deterioration of the stability indices, which is a resultant of the COP displacement in both directions as well as in the anteroposterior direction. Lack of differences in the values of stability indices in the mediolateral direction suggest that in a free standing position, seniors practicing artistic gymnastics control the movement of the center of foot pressure in the mediolateral direction and eye control is not important for the stability of the body in the frontal plane.

Key words: *standing position, handstand, stabilometry*

1. Introduction

The ability to maintain balance is an important component of coordination affecting the quality of movements in technical and aesthetic disciplines, to which artistic gymnastics belongs. It enables the gymnasts to reduce the risk of sports injury and failures during sports competitions which require performing difficult and dangerous motor tasks repeatedly. Loss of balance or even slight body "imbalance" during static and dynamic exercises affects decisions of the judges' committees on the reduction of the score, and thus the final evaluation of the competitor [5].

Scientific studies clearly indicate that properly programmed training can be effective for postural and neuromuscular control improvements [28]. Krištofič et al. [16] observed that even a low volume specific balance program performed in addition to regular training sessions may lead to postural stability enhancement. Review of the available scientific literature enables to conclude that in standing position, which is natural for a man, gymnasts obtain similar or significantly better postural control indices in relation to non-exercisers and athletes representing other disciplines. Garcia et al. [8] observed significantly better postural stability indices in 5-to-7-year-old gymnasts with visual control than in their non-exercising peers. In the same studies, both with the eyes open and without visual control, no significant differences were found in the group of older athletes (group of 9–11-year-olds). Kochanowicz et al. [15] divided the gym-

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nasts and non-exercising group into three age groups: 8–10, 12–14 and 18–24 years old. More favorable indices of postural control, both with visual control and without it, were noted in the participants of gymnastics training, with the biggest differences concerning the youngest age category. Gautier et al. [9], on the basis of the analysis of results obtained in the group of adult gymnasts compared to the representatives of other sports such as handball, sprinting, and football, recognized that gymnasts were able to react rapidly after destabilization to decrease their center of pressure and the angular movements. Moreover, they used their knees to stabilize posture, whereas the non-gymnasts used their hips. However, Bressel et al. [4] showed no statistically significant differences in the static and dynamic balance between adult female gymnasts and soccer players. Mellos et al. [20] noted significantly better results of the "flamingo balance test" in children aged 9–12 years training gymnastics, compared to non-training peers. Asseman et al. [2], on the basis of a comparison of the stability in two positions: bipedal and unipedal in adult female gymnasts and athletes practicing other sports disciplines, stated that expertise in gymnastics seemed to improve postural performances only in situations for which their practise is related to, i.e., unipedal with eyes open.

In artistic gymnastics, most of the elements performed by competitors consist of positions and movements unnatural for a man, and their mastering requires specialized sports training. Hence, the process of sensorimotor adaptation carried out during such training should ensure the development of movement patterns allowing control of body balance during exercise. It is equally important to train the ability to recover full stability in standing position immediately after dynamic exercises. This situation occurs in the landing phase of jumps from different instruments, acrobatic jumps, or jumping across the vaulting table. In this phase, the gymnast must absorb the impact forces of the dismount without losing balance or moving their feet during the landing [11]. It can, therefore, be concluded that the appropriate level of postural control in standing for a gymnast is a basis to learn and perform unnatural movements specific to that sport.

One of the most important gymnastic elements in the career of every gymnast is handstand [12], [24], [25], [30], which is the starting position, the end position or one of the phases of the movement structure in the case of many gymnastic elements [7], [29]. The way (strategy) of balancing when standing on hands seems to be well described in the literature. The body configuration for the handstand requires specific postural control from four joints: wrists, elbows, shoulders, and hips [1], [9], with the dominant role in control strategy attributed to the "wrist strategy" [3], [13], [27]. In handstand, the center of pressure displacements range in the sagittale plane is crucially higher than in the frontal plane [22], [23]. Gautier et al. [10] assessed the balance in handstand with visual inspection and with eyes closed in adult gymnasts. As a result of the research they concluded that the gymnasts held a significantly more stable handstand with vision than without vision.

Gautier et al. [9] and Kochanowicz et al. [14] observed lower values of COP sway in handstand of more experienced gymnasts, compared to competitors with shorter training experience. On this basis, it can be concluded that the values of stability indices in handstand are determined by the level and sporting experience of the competitor.

The aim of the study was to compare the values of selected stability indices registered in the trials in a standing with eyes open and without visual control, and in handstand in athletes practicing artistic gymnastics at the highest level of advancement.

2. Materials and methods

The study included 20 seniors athletes practicing artistic gymnastics in Polish gymnastic clubs (average age: $\bar{x}$ = 21.10 ± 3.8 years). The average training period of the tested athletes was $\bar{x}$ = 15.25 ± 3.60 years. The obtained data show that the average body weight of the studied athletes was $\bar{x}$ = 68.71 ± 6.08 kg and the average body height was $\bar{x}$ = 173.80 ± 5.73 cm.

Selection of the research groups was purposive. The inclusion criteria were: competitive artistic gymnastics for at least 10 years, no complaints resulting from injuries to the musculoskeletal system, the ability to keep handstand for 30 seconds [1], dominating right hand and leg (determined on the basis of Waterloo Handedness and Footedness Questionaire – Revised) [21], written informed consent to participate in the study.

The study was approved by the Bioethics Committee at the Regional Medical Chamber in Krakow, Poland (Approval Ref. No. 42/KBL/OIL/2017).

The tests were carried out the day before the start of the athletes in multi-discipline gymnastic event, as part of the Polish Championships in Sports Gymnastics (Warsaw, Poland, May 2017). The championships were held in accordance with the rules of the International Gymnastic Federation [5]. In order to exclude the impact of sports training fatigue on the results, the tests were conducted before the training, on a day off from starts. They were preceded by a 15-minute warm-up, after which each of the gymnasts performed two trials of handstand on the mattress.

In order to preserve the integrity of the research process, all the tests were carried out in the morning, using the same measuring instruments, operated by the authors. The measurements were carried out in the gym, in conditions which ensure the isolation of acoustic stimuli that could interfere with postural reflexes during the study. Athletes were wearing gymnastic costumes without shoes. All procedures were carried out in full compliance with the Declaration of Helsinki. All participants received detailed information concerning the aim and method used in the study.

The research tool was two-platform posturograph (manufactured by *CQ Electronic System*). The test consisted of three 30-second trials. The first attempt was the measurement of the body stability in a relaxed standing position. The platforms were levelled, their surfaces aligned in a single plane. After entering the platform, the subject stood still trying to keep his eyes on the fixation point which was placed 1 meter away. The stance width of the lower limbs and the feet angle were natural, unforced. Subsequently, the second test was conducted, while the subject had his eyes closed (i.e., had no visual control over the positioning of his body). The third trial was carried out in handstand. Before measuring the body stability in this position, the plates of the platform were placed at a distance allowing the subject to have free hand spacing. The subjects performed handstand with rebound of one leg and swing of the other leg. Stability measurement was recorded when the lower limbs were joined in a vertical position. During the test, the examiner stood next to the examined person for the sake of protection.

The motion signal, as generated by the point of application of the resultant pressure force exerted by the feet directly onto the platform plates, duly registered in the computer memory, was then used to calculate the values of the stability indicators. The names of the displacement directions of the center of foot/hand pressure (COP) were referred to the Cartesian coordinate system, as made up by the pairs of perpendicular axes. The X axis was the axis of the abscissae, and the Y axis – of the ordinate, wheras the point O (coordinates 0.0), i.e., the origin of the system of coordinates was the so-called "geometric center of gravity of the COP trajectory".

The following indicators of stability were analyzed:

- SA – sway area delimited by the COP point (i.e., the surface area of an irregularly shaped polygon, demarcated by a boundary line connecting up the extreme points of the statokinesiogram) [mm^2];
- SP – statokinesiogram path length [mm];
- SPAP – statokinesiogram path length on the Y axis (i.e., the trajectory followed by the COP in the anteroposterior direction (AP) during a 30-second measurement) [mm];
- SPML – statokinesiogram path length on the X axis (i.e., the trajectory followed by the COP in the mediolateral direction (ML) during a 30-second measurement) [mm];
- MV – mean velocity of COP movement [mm/s];
- MVAP – mean velocity of COP movement on the Y axis (anteroposterior direction) [mm/s];
- MVML – mean velocity of COP movement on the X axis (mediolateral direction) [mm/s];
- MaxAP – range of anteroposterior stability: maximal displacement of the COP from the origin on the Y axis (i.e., maximal amplitude of the COP in the anteroposterior direction) [mm];
- MaxML – range of mediolateral stability: maximal displacement of the COP from the origin on the X axis (i.e., maximal amplitude of the COP in the mediolateral direction) [mm];
- MF – mean frequency of COP displacement (i.e., the ratio of the total statokinesiogram's path length [on both axes] to the circumference of the circle the radius of which is equal to the average COP displacement, calculated per 1 second) [Hz];
- LWAP – number of COP displacements along the Y axis (i.e., number of COP displacements in the anteroposterior direction, within the range: over 0.2 mm – below – 0.2 mm, relative to the center of the coordinate system);
- LWML – number of COP displacements along the X axis (i.e., number of COP displacements in the mediolateral direction, within the range: over 0.2 mm – below – 0.2 mm, relative to the center of the coordinate system).

Examples of the path length for the COP are comprised in Figs. 1–3.

The consistency of the values with the normal distribution was verified by means of the Shapiro–Wilk test. The results obtained in individual trials were compared using Friedman repeated measures analysis of variance by ranks and then subjected to Dunn post-hoc test with Bonferroni adjustment. Results were considered statistically significant if the probability level of the test was lower than the predetermined level α = 0.05. The IBM SPSS Statistics application (version 24) was used to process the test results.

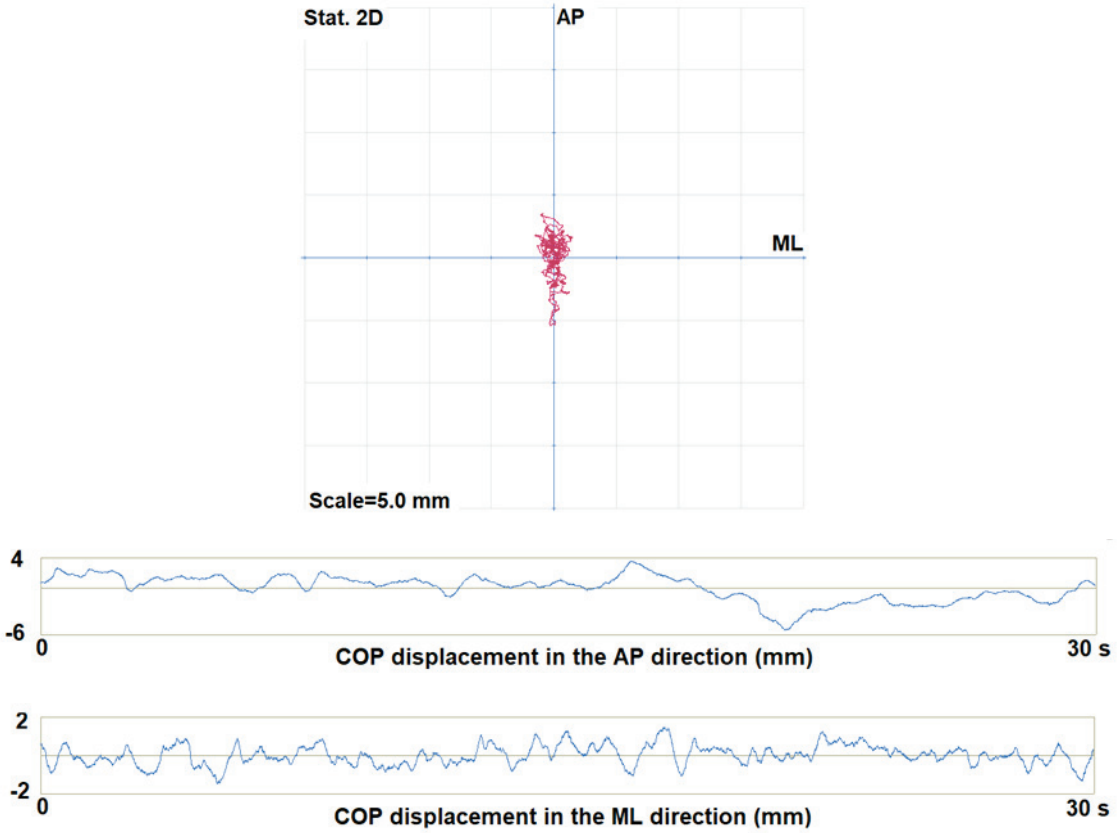

Fig. 1. Diagram showing the sample of the path length for the COP during the test in standing position with eyes open

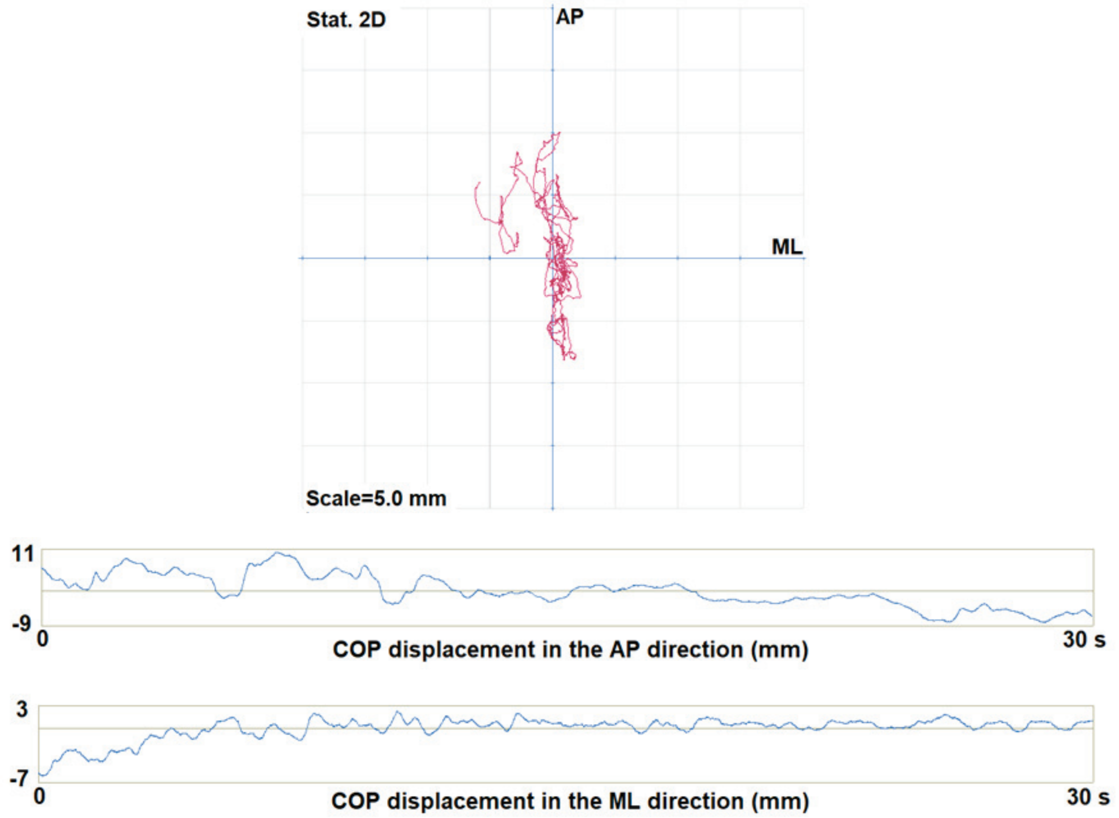

Fig. 2. Diagram showing the sample oh the path length for the COP during the test in standing position with eyes closed

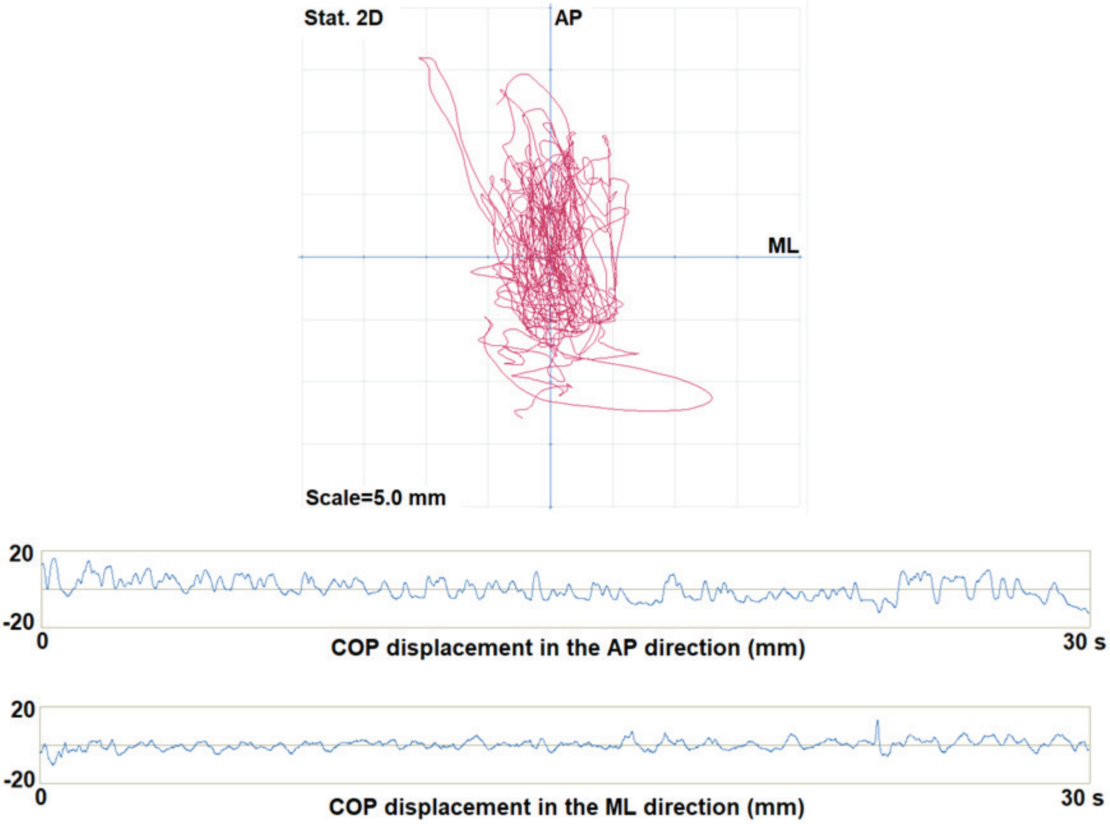

Fig. 3. Diagram showing the sample oh the path length for the COP during the handstand

3. Results

The data presented in Table 1 indicate a statistically significant variation in the values of stability indices recorded in individual samples. A more detailed analysis with the post-hoc test revealed that the exceptions were the results obtained in the trials with eyes open and without visual control with regard to the size of the surface area delineated by the COP ($p = 0.173$) and the frequency of corrective reactions ($p = 0.464$), as well as the length of the statokinesiogram path.

In the mediolateral direction ($p = 0.342$), mean velocity of COP movement in the mediolateral direction ($p = 0.246$), maximal amplitude of the COP in the mediolateral direction ($p = 0.342$) and number of COP displacements in the mediolateral direction ($p = 0.246$).

4. Discussion

Own research showed statistically significant differences in the values of such indices as: statokinesiogram path length, statokinesiogram path length in the anteroposterior direction, mean velocity of COP movement, mean velocity of COP movement in the anteroposterior direction, number of COP displacements in the anteroposterior direction – recorded during the trials in standing with open and closed eyes. These results indicate the important role of eye control in the process of maintaining stability under static equilibrium conditions. It can be assumed that this is the effect of the need to use information from the visual receptors during the performance of physical tasks in gymnastic training, in order to better orientate in space, especially when performing complex evolutions and elements containing the flight phase. Visual inspection helps to perform the correct landing, which ends with adoption of a stable posture on both lower limbs. Lee et al. [17] reached similar conclusions analyzing the results of research on the postural stability of trampolinists performing forward somersaults. According to the authors, vision improves precision of control. In turn, Davlin et al. [6] based on the analysis of stability indices in female gymnasts, concluded that gymnasts were more stable at landing under conditions that allowed vision during either the entire somersault or the last half of the sumersault. In the Luis and Tremblay [18] study participated

Table 1. Comparison of the values of stability indices obtained in standing position with eyes open, standing position with eyes closed and handstand

Indicator	Standing position with eyes open (EO)		Standing position with eyes closed (EC)		Handstand (hand)		X^2	p	W
	x ± SD	Me	x ± SD	Me	x ± SD	Me			
SA [mm^2]	149.95 ± 118.87	111.50	229.40 ± 165.64	186.00	2261.55 ± 1159.18	2390.50	33.60	<0.001*	0.84
Post-hoc	SA-EO *vs*. SA-EC (p = 0.173); SA-EO *vs*. SA-hand (p < 0.001*); SA-EC *vs*. SA-hand (p < 0.001*)								
SP [mm]	219.80 ± 43.71	198.00	319.70 ± 115.19	289.00	1518.20 ± 352.85	1472.00	38.10	<0.001*	0.95
Post-hoc	SP-EO *vs*. SP-EC (p = 0.013*); SP-EO *vs*. SP-hand (p < 0.001*); SP-EC *vs*. SP-hand (p = 0.003*)								
SPAP [mm]	138.15 ± 37.38	124.00	241.45 ± 114.74	190.00	1270.55 ± 353.09	1211.00	40.00	<0.001*	>0.99
Post-hoc	SPAP-EO *vs*. SPAP-EC (p = 0.005*); SPAP-EO *vs*. SPAP-hand (p < 0.001*); SPAP-EC *vs*. SPAP-hand (p = 0.005*)								
SPML [mm]	140.95 ± 23.02	135.00	157.65 ± 29.25	156.00	586.20 ± 154.61	560.50	32.50	<0.001*	0.81
Post-hoc	SPML-EO *vs*. SPML-EC (p = 0.342); SPML-EO *vs*. SPML-hand (p < 0.001*); SPML-EC *vs*. SPML-hand (p < 0.001*)								
MV [mm/s]	7.33 ± 1.46	6.60	10.65 ± 3.84	9.60	50.61 ± 11.76	49.05	38.10	<0.001*	0.95
Post-hoc	MV-EO *vs*. MV-EC (p = 0.013*); MV-EO *vs*. MV-hand (p < 0.001*); MV-EC *vs*. MV-hand (p = 0.003*)								
MVAP [mm/s]	4.61 ± 1.25	4.10	8.05 ± 3.83	6.30	42.36 ± 11.77	40.35	40.00	<0.001	>0.99
Post-hoc	MVAP-EO *vs*. MVAP-EC (p = 0.005*); MVAP-EO *vs*. MVAP-hand (p < 0.001*); MVAP-EC *vs*. MVAP-hand (p = 0.005*)								
MVML [mm/s]	4.70 ± 0.77	4.50	5.26 ± 0.97	5.20	19.55 ± 5.16	18.70	33.44	<0.001	0.84
Post-hoc	MVML-EO *vs*. MVML-EC (p = 0.246); MVML-EO *vs*. MVML-hand (p < 0.001*); MVML-EC *vs*. MVML-hand (p < 0.001*)								
MaxAP [mm]	5.51 ± 2.96	4.30	9.72 ± 6.84	7.70	23.29 ± 6.09	22.35	30.70	<0.001	0.77
Post-hoc	MaxAP-EO *vs*. MaxAP-EC (p = 0.034*); MaxAP-EO *vs*. MaxAP-hand (p < 0.001*); MaxAP-EC *vs*. MaxAP-hand (p = 0.008*)								
MaxML [mm]	2.89 ± 1.38	2.3	3.42 ± 1.19	3.50	10.32 ± 5.00	9.25	26.80	<0.001	0.67
Post-hoc	MaxML-EO *vs*. MaxML-EC (p = 0.342); MaxML-EO *vs*. MaxML-hand (p < 0.001*); MaxML-EC *vs*. MaxML-hand (p = 0.002*)								
MF [Hz]	0.69 ± 0.26	0.72	0.76 ± 0.27	0.78	1.22 ± 0.25	1.20	23.70	<0.001*	0.59
Post-hoc	MF-EO *vs*. MF-EC (p = 0.464); MF-EO *vs*. MF-hand (p < 0.001*); MF-EC *vs*. MF-hand (p < 0.003*)								
LWAP	12.55 ± 6.00	11,50	23.85 ± 10.33	24.00	63.70 ± 18.47	65.50	36.40	<0.001*	0.91
Post-hoc	LWAP-EO *vs*. LWAP-EC (p = 0.034*); LWAP-EO *vs*. LWAP-hand (p < 0.001*); LWAP-EC *vs*. LWAP-hand (p = 0.002*)								
LWML	22.00 ± 11.95	20.50	26.75 ± 10.99	25.00	76.70 ± 18.26	75.50	33.44	<0.001	0.84
Post-hoc	LWML-EO *vs*. LWML-EC (p = 0.246); LWML-EO *vs*. LWML-hand (p < 0.001*); LWML-EC *vs*. LWML-hand (p < 0.001*)								

Abbreviations: SA – sway area delimited by the COP point; SP – statokinesiogram path length; SPAP – statokinesiogram path length in the anteroposterior direction; SPML – statokinesiogram path length in the mediolateral direction; MV – mean velocity of COP movement; MVAP – mean velocity of COP movement in the anteroposterior direction; MVML – mean velocity of COP movement in the mediolateral direction; MaxAP – maximal displacement of the COP from the origin in the anteroposterior direction; MaxML – maximal displacement of the COP from the origin in the mediolateral direction; MF – mean frequency of COP displacement; LWAP – number of COP displacements in the anteroposterior direction; LWML – number of COP displacements in the mediolateral direction; $\bar{x}$ – arithmetic mean; SD – standard deviation; Me – Median; X^2 – value of the Friedman's test statistic; p – probability value; W – Kendall's tau.

*α = 0.05.

the experienced female acrobats performed back tucksomersaults under four experimental conditions: full-vision, vision at angular head velocity below 350 deg/s, vision at angular head velocity above 350 deg/s, and no-vision. The authors stated that presence of visual feedback during all phases of an aerial skill is beneficial for landing stability. Asseman et al. [2], Garcia et al. [8], Kochanowicz et al. [15] and Krištofič et al. [16] arrived at similar conclusions. The results of our research and reports of other authors indicate that visual information improves the balance reactions, which certainly translates into athletic performance and the safety of exercise performed by athletes practicing gymnastics. Geiblinger and Dowden [11] carried out research aimed at investigated landing techniques and strategies used by elite male gymnasts in opinion of gymnastics experts. The authors pointed out that on landings from backward somersaults or front somersaults with a half twist, the gymnast should spot the ground. On forward landings the gymnast senses where he is and spots the wall or whatever is in front and above. All somersaults must be spotted and sensed.

Greater COP displacement in the anteroposterior direction in seniors practicing artistic gymnastics observed in own studies may be dictated by the specificity of training. It can be assumed that in a multi-year process of sports training within this discipline the "ankle strategy" is developed in the mechanism of maintaining the balance in a standing position. This is facilitated by repeated repetitions of exercises ending with landing. Marinšek [19] clearly emphasized that in properly performed landing, in the landing phase, the toes touch the ground first and heels come later. Before getting the correct end position, in addition to the activation of the ankles, there is also flexion and extension in the knee and hip joints.

It is also worth emphasizing that proper performance of the jump requires complete elimination of lateral body movements. This is possible due to proper cocontraction. In the forward position, the foot COP displacements in the frontal plane are controlled by a load–load down mechanism regulated by the hip adductors and abductors [26]. Therefore, the lack of differences in the values of body stability indices in the mediolateral direction can be explained by the good performance of these muscle groups and the high level of deep sensation, which is the effect of training. Likewise, in the handstand, we observed smaller ranges of hand COP displacements in the mediolateral direction. This leads to the claim that balancing in this position takes place mainly in the anteroposterior direction. The obtained results confirm the observations of other authors [13], [22], [23], [27].

Our research also allowed to observe that the balance indices obtained in standing with the eyes open and without visual control achieved better results in relation to the results recorded in the handstand. The biggest discrepancies concerned the surface area delineated by the COP. The values of this index obtained in the handstand were more than 20 times higher compared to the results obtained in the standing with open eyes and almost 14 times higher in relation to the results recorded in the trial without visual control. Sobera et al. [23] observed higher COP displacement amplitude in the sagittal and frontal plane values in athletes practicing artistic gymnastics and rhytmic artistic gymnastics in the position of standing on the hands in comparison to another unnatural position for the human – side balance stance with one leg lifted up to head. It seems that these are important proofs confirming the great difficulty of developing "full" stability in handstand, that is, the one that allows balancing the body in a manner invisible to observers. This is especially important during sporting competition, because the body or its segments being disturbed is considered a technical error [5].

The results of our research show that in the case of athletes practicing artistic gymnastics, disabling the visual control during free standing, as well as adopting the handstand position causes deterioration of the stability indices that result in the COP displacement in both directions. This indicates the need to include exercises that would allow to limit visual control while engaging somatosensory systems in the training process.

The obtained results are a contribution to further scientific research in order to more accurately review the observed trends. We are convinced that every report regarding the issues undertaken at this paper is a valuable addition to scarce publications on the subject.

It would be beneficial to verify our results based on studies of athletes practicing gymnastics at various levels of advancement. More detailed analysis would allow for the appropriate selection of the type of exercise and training loads to optimize the training process.

5. Conclusions

In practicing artistic gymnastics disabling visual control during free standing, as well as adopting a handstand position, results in deterioration of the stability indices which is a resultant of the COP displacement in both directions, as well as in the anteroposterior direction.

Lack of differences in the values of stability indices in the mediolateral direction suggest that in a free standing position, seniors practicing artistic gymnastics control the movement of the center of foot pressure in the mediolateral direction and eye control is not important for the stability of the body in the frontal plane.

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