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Balance in handstand and postural stability in standing position in athletes practicing gymnastics

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Purpose: The aim of this study was to compare and analyse of relationships between stability indices registered in two positions: standing and handstand in athletes practicing gymnastics at various levels of advancement. *Methods*: The study included 46 athletes practicing gymnastics. The research tool was posturograph CQ-Stab 2P. *Results*: In both standing position and handstand in the seniors there were statistically significantly lower values of such indicators as: sway area delimited by the center of pressure ($p = 0.004$, $p = 0.014$), mean amplitude of COP ($p = 0.021$, $p = 0.017$), mean displacement of the center of feet/hands pressure in medio-lateral direction ($p = 0.011$, $p = 0.003$) and maximal displacement of the center of feet/hands pressure in mediolateral direction ($p = 0.036$, $p = 0.036$). In the standing position, seniors also had statistically significantly lower values of the statokinesiogram path length, both total ($p = 0.000$) as well as in anteroposterior ($p = 0.001$) and mediolateral ($p = 0.002$) directions. In the seniors group there were statistically significant correlations between variables obtained in standing position and handstand. *Conclusions*: The level of sport advancement significantly differentiates the stability of a body in standing position and handstand. The seniors practicing gymnastics, compared to juniors, are characterized by a better ability to control the position of the body in both positions. The lack of relationships between stability indices registered in standing and handstand in juniors suggests that the analysis of the values of stability indices obtained in a standing position does not provide the possibility of predicting the ability to maintain balance in the handstand during the recruitment of candidates for gymnastics.

Key words: *balance, handstand, free standing position, gymnastics*

1. Introduction

Among numerous components affecting the sport level of gymnastics athletes, the ability to maintain body balance is often mentioned and assessed [2], [14], [17], [18]. This ability not only affects the quality of the presented gymnastic elements, but is also an important factor improving the safety of the athlete during performed movement. The capacity for learning postural control, depends primarily on the integrated function of the nervous, vestibular and proprioceptive systems [21], [22]. During gymnastic exercises, the athletes are subjected to factors that may interfere with sensory system functions. These include exercises with rotations in various planes, high speed of the body or its individual segments, reduced support plane or instability of the device (in the case of exercises on wheels). The group of such elements include handstand, which plays a significant role in the sporting career of every gymnast [12], [26], [31]. It is position which can be both the starting and the end position of many gymnastic exercises (e.g., swing forward with straight arms to handstand on rings, basket to handstand on parallel bars) or is one of the components of the entire motor structure (e.g., forward or backward handspring) [4], [7], [30]. Therefore, it is important to train this position, giving the opportunity to perform it in an error-free, and thus, stable manner.

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There are reports in the literature about balance in handstand in female athletes and athletes practicing gymnastics at various levels of advancement [12]. Balancing (balance strategy) in handstand [8], [13], [19], [25] and the influence of the level of maintaining balance on athletic performance [15] was studied. Gautier et al. [9] assessed the effect of peripheral vision and the central visual anchoring on maintaining the handstand position performed on two horizontal bars. Croix et al. [5] studied expert and non-expert gymnasts performing a handstand on a force platform in 4 conditions: open or closed eyes on a firm or foam support. Vinken and Heinen [28] assessed the applicability of elastic tapes to improve postural control in handstand in gymnastics. Hedbávný et al. [11] investigated relationships between strength abilities and quality of handstand. Kochanowicz et al. [16] compared the muscle activity between handstands performed on three apparatus (floor, rings and parallel bars) between young and well-trained adult gymnasts.

The effectiveness of the handstand teaching process in beginners is not easy to predict. The experts studying motor learning movements unanimously agree that in order learn handstand more quickly, increase stability (smaller displacement of COP), a variety of methods and exercises should be used. Investigating this issue, Croix et al. [6] noticed in women training gymnastics, that light finger touch applied to the thigh facilitates the maintenance in handstand. Rohleder and Vogt [23], based on the study of students, compared the impact of two different types of feedback (tactile-verbal feedback vs. visual-comparative feedback) on the enhancement of handstand. They also studied time and quality of handstand in young female and male gymnasts after applying additional static exercises accompanied by dynamic adjustments regarding pelvis rotation and scapula protraction and elevation [24].

Handstand is an unnatural position for a human and, therefore, requires a proper sensorimotor adaptation. The detailed analysis of body stability indices recorded in athletes at various levels of sporting advancement may allow the process of this adaptation to be tracked. At the same time, it is puzzling whether people with better integration of systems responsible for postural control in a natural position for human beings are also characterized by better stability in the inverted position. Obtaining unambiguous data could affect the recruitment of candidates for professional gymnastics as well as the planning of sports training. The study by Asseman et al. [1] provides some information on this aspect. The authors investigated the relationship between maintaining the balance in three positions: bipedal, uni-bipedal and handstand, using two stability indices for this purpose: surface and mean velocity of the center of pressure (COP) motions. For the surface ranks analysis no significant correlation was observed between: handstand and bipedal, handstand and unibipedal. For the mean velocity ranks analysis no significant correlation was observed between handstand and bipedal. However, a significant correlation was observed between handstand and unibipedal conditions. The authors found that postural ability of elite gymnasts in the handstand is not transferable to upright standing postures.

Presented facts became a direct reason for undertaking the subject of the paper, the aim of which was reduced to comparison and analysis of relationships between stability indices registered in two positions: standing and handstand in athletes practicing gymnastics at various levels of advancement. Conducted research aimed to answer whether the values of body stability indices in standing and handstand differentiate junior and seniors athletes practicing gymnastics, and whether there are relationships between stability indices in standing position and handstand in junior and seniors athletes practicing gymnastics.

2. Materials and methods

46 athletes practicing gymnastics in Polish gymnastic clubs participated in the study, including 23 juniors (average age: $\bar{x}$ = 15.9 ± 0.8 years) and 23 seniors (average age: $\bar{x}$ = 22.7 ± 4.6 years). The tests were carried out the day before the athletes entered 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 [3]. Selection of the research groups was purposive. The inclusion criteria were: performing gymnastics competitively, 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 [20], written informed consent to participate in the study.

In Table 1 the basic somatic parameters of the tested juniors and seniors are presented. These data indicate statistically significant intergroup differences in terms of body weight (p = 0.001), body height (p = 0.050) and body mass index (p = 0.003). Juniors were characterized by significantly lower values of these somatic features.

Table 1. Somatic features of the tested athletes

Feature	Juniors (n = 23)	Seniors (n = 23)	Student's t-test	
	$\bar{x}$ ± SD	$\bar{x}$ ± SD	t	p
Body mass [kg]	59.9 ± 8.9	67.9 ± 6.0	–3.49	0.001*
Body height [cm]	168.6 ± 7.6	172.8 ± 5.9	–2.02	0.050*
BMI	21.0 ± 2.1	22.7 ± 1.5	–3.20	0.003*

Abbreviations: BMI – body mass index; $\bar{x}$ – arithmetic mean, SD – standard deviation, t – value of the Student's t-test, p – probability value, * $p \leq 0.05$.

The average training period of the juniors participating in the tests was $\bar{x}$ =10.30 ± 0,80 years and in the case of seniors it was $\bar{x}$ =16.70 ± 3.60 years.

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

The research tool was two-platform posturograph (*CQ Electronic System*). The test consisted of two 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 in a distance of 1 meter. The stance width of the lower limbs and the feet angle were natural, unforced (Fig. 1).

Fig. 1. Conditions of measurement of stabilityin a free standing position. Source: own study. The authors obtained the participant's consent to publish the image

The second trial was carried out in handstand. Before measuring of 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 (Fig. 2). During the test, the examiner stood next to the examined person for the sake of protection.

Fig. 2. Conditions of measurement of stability in a handstand position. Source: own study. The authors obtained the participant's consent to publish the image

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 methodology used in the study.

The following indicators of stability were analyzed:

SP – statokinesiogram path length [mm],

SPAP – statokinesiogram path length in anteroposterior direction [mm],

SPML – statokinesiogram path length in mediolateral direction [mm],

MA – mean COP displacement [mm],

MAAP – mean COP displacement in anteroposterior direction [mm],

MAML – mean COP displacement in mediolateral direction [mm],

MaxAP – maximal displacement of the COP in anteroposterior direction: anteroposterior stability range [mm];

MaxML – maximal displacement of the COP in mediolateral direction: mediolateral stability range [mm];

SA – sway area delimited by the COP point [mm^2];

MF – mean frequency of COP displacements [Hz].

The consistency of the values with the normal distribution was verified by means of the Shapiro–Wilk test. In order to evaluate intergroups differences in average values of the somatic features and analyzed stability indices we used the Student's *t*-test for independent samples. In order to evaluate the correlations between the the stability indicators registered in standing position and handstand, Pearson's correlation was applied. Multiple regression analysis was used to predict the independent variables (stability indicators in standing position) based on dependent variables (stability indicators in handstand). In the first stage of analyzes, forward stepwise regression was applied, which consists of a gradual (stepwise) addition only of those variables that have the most significant impact on the dependent variable to the list of explanatory variables included in the model. In turn, statistically insignificant independent variables were eliminated from base models using backward step regression. This way, variables which in the given step had the least significant impact on the dependent variable were also removed from the models. Such a procedure allowed to build models in which all variables were statistically significant, and, thus, each prediction variable had a statistically significant effect on the dependent variable. The level of significance was set at the value of 0.05. The Stat Soft STATISTICA application (version 13.1) was used to process the test results.

3. Results

Data collected in Table 2 show that in both standing position and handstand in the seniors there were statistically significantly lower values of such indicators as: mean amplitude of COP displacement (stand-

Table 2. Comparison of the values of stability indices obtained in juniors and seniors participating in the tests in standing position and handstand

Indicator	Standing position				Handstand			
	Juniors (n = 23)	Seniors (n = 23)	Student's *t*-test		Juniors (n = 23)	Seniors (n = 23)	Student's *t*-test	
	$\bar{x}$ ± SD	$\bar{x}$ ± SD	*t*	*p*	$\bar{x}$ ± SD	$\bar{x}$ ± SD	*t*	*p*
SP	258.0 ± 49.6	212.7 ± 29.6	3.76	0.000*	1714.6 ± 548.0	1435.5 ± 388.9	1.99	0.053
SPAP	163.0 ± 39.0	129.6 ± 23.3	3.52	0.001*	1435.5 ± 524.9	1199.8 ± 362.5	1.77	0.083
SPML	164.5 ± 28.2	140.8 ± 21.6	3.20	0.002*	644.1 ± 222.5	562.9 ± 149.8	1.45	0.154
MA	2.6 ± 1.5	1.7 ± 0.9	2.40	0.021*	8.5 ± 2.9	6.6 ± 2.1	2.48	0.017*
MAAP	2.0 ± 1.2	1.4 ± 0.9	1.99	0.053	7.3 ± 2.4	6.0 ± 2.0	1.95	0.057
MAML	1.2 ± 0.9	0.7 ± 0.3	2.66	0.011*	3.1 ± 1.6	1.9 ± 0.8	3.12	0.003*
MaxAP	7.5 ± 5.9	4.9 ± 2.3	1.97	0.055	26.5 ± 7.9	23.7 ± 7.8	1.24	0.220
MaxML	4.1 ± 2.4	2.9 ± 1.3	2.17	0.036*	15.5 ± 12.1	9.6 ± 4.8	2.17	0.036*
SA	222.7 ± 156.7	117.0 ± 61.1	3.01	0.004*	3994.9 ± 2612.9	2480.8 ± 1117.0	2.55	0.014*
MF	0.6 ± 0.2	0.8 ± 0.3	–1.70	0.097	1.1 ± 0.3	1.2 ± 0,.3	–0.84	0.406

Abbreviations: SP – statokinesiogram path length, SPAP – statokinesiogram path length in anteroposterior direction, SPML – statokinesiogram path length in mediolateral direction, MA – mean COP displacement, MAAP – mean COP displacement in anteroposterior direction, MAML – mean COP displacement in mediolateral direction, MaxAP – maximal displacement of the COP in anteroposterior direction, MaxML – maximal displacement of the COP in mediolateral direction, SA – sway area delimited by the COP point, MF – mean frequency of COP displacements, $\bar{x}$ – arithmetic mean, SD – standard deviation, *t* – value of the Student's t-test statistic, *p* – probability value; * $p \leq 0.05$.

Table 3. Relationships between stability indices registered in juniors in standing position and handstand

Hands / Feet		SP	SPAP	SPML	MA	MAAP	MAML	MaxAP	MaxML	SA	MF
SP	*r*	–0.16	–0.19	–0.01	–0.01	0.04	–0.10	–0.12	–0.18	–0.10	–0.29
	p	0.471	0.380	0.980	0.980	0.856	0.639	0.600	0.405	0.657	0.181
SPAP	*r*	–0.10	–0.13	0.02	0.09	0.13	–0.04	–0.08	–0.16	–0.04	–0.35
	p	0.645	0.540	0.924	0.698	0.556	0.847	0.723	0.462	0.868	0.101
SPML	*r*	–0.21	–0.24	–0.04	–0.13	–0.09	–0.17	–0.15	–0.19	–0.17	–0.17
	p	0.335	0.268	0.857	0.564	0.699	0.436	0.503	0.392	0.449	0.449
MA	*r*	–0.20	–0.21	–0.06	–0.04	–0.01	–0.09	–0.20	–0.24	–0.14	–0.23
	p	0.361	0.343	0.793	0.861	0.974	0.677	0.370	0.274	0.524	0.301
MAAP	*r*	–0.17	–0.19	–0.02	0.00	0.02	–0.02	–0.23	–0.19	–0.09	–0.24
	p	0.429	0.377	0.940	0.997	0.942	0.925	0.301	0.385	0.669	0.279
MAML	*r*	–0.23	–0.20	–0.16	–0.15	–0.09	–0.25	–0.12	–0.28	–0.23	–0.13
	p	0.295	0.354	0.463	0.508	0.697	0.250	0.593	0.192	0.294	0.544
MaxAP	*r*	–0.27	–0.24	–0.23	–0.01	0.04	–0.11	–0.14	–0.20	–0.19	–0.37
	p	0.216	0.276	0.296	0.956	0.865	0.607	0.516	0.361	0.389	0.083
MaxML	*r*	–0.34	–0.31	–0.23	–0.11	–0.05	–0.22	–0.17	–0.31	–0.27	–0.28
	p	0.109	0.143	0.297	0.605	0.829	0.313	0.443	0.149	0.219	0.200
SA	*r*	–0.23	–0.22	–0.12	–0.10	–0.06	–0.15	–0.22	–0.26	–0.19	–0.22
	p	0.302	0.310	0.599	0.659	0.783	0.491	0.316	0.238	0.374	0.323
MF	*r*	0.28	0.31	0.02	0.03	0.04	–0.01	0.31	0.33	0.12	0.25
	p	0.194	0.148	0.929	0.894	0.850	0.954	0.151	0.128	0.570	0.255

Abbreviations: Feet – indices registered in standing position, Hands – indices registered in handstand, SP – statokinesiogram path length, SPAP – statokinesiogram path length in anteroposterior direction, SPML – statokinesiogram path length in mediolateral direction, MA – mean COP displacement; MAAP – mean COP displacement in anteroposterior direction, MAML – mean COP displacement in mediolateral direction, MaxAP – maximal displacement of the COP in anteroposterior direction, MaxML – maximal displacement of the COP in mediolateral direction, SA – sway area delimited by the COP point, MF – mean frequency of COP displacements, *r* – the Pearson's correlation coefficient, *p* – probability value.

Table 4. Relationships between stability indices registered in seniors in standing position and handstand

Hands / Feet		SP	SPAP	SPML	MA	MAAP	MAML	MaxAP	MaxML	SA	MF
SP	*r*	0.21	0.18	0.25	0.20	0.18	0.10	0.09	0.32	0.21	–0.02
	p	0.329	0.422	0.249	0.367	0.401	0.639	0.676	0.140	0.336	0.919
SPAP	*r*	0.34	0.33	0.20	0.40	0.43*	–0,02	0.26	0.20	0.28	–0.16
	p	0.115	0.123	0.349	0.058	0.040	0.940	0.230	0.350	0.188	0.464
SPML	*r*	0.01	–0.05	0.21	–0.09	–0.14	0.20	–0.12	0.33	0.06	0.13
	p	0.966	0.828	0.330	0.699	0.520	0.363	0.596	0.128	0.787	0.539
MA	*r*	–0,11	–0.11	–0.04	–0.03	0.01	–0.30	–0.12	–0.24	–0.11	–0.10
	p	0,615	0.612	0.867	0.889	0.948	0.163	0.589	0.272	0.611	0.660
MAAP	*r*	–0.08	–0.07	–0.04	–0.02	0.04	–0.33	–0.11	–0.30	–0.10	–0.08
	p	0.725	0.742	0.844	0.939	0.865	0.128	0.627	0.165	0.649	0.728
MAML	*r*	–0.28	–0.29	–0.12	–0.21	–0.23	–0.04	–0.17	0.10	–0.23	–0.06
	p	0.196	0.179	0.573	0.335	0.283	0.865	0.445	0.658	0.284	0.791
MaxAP	*r*	–0.11	–0.08	–0.19	–0.14	–0.08	–0.42*	–0.33	–0.36	–0.27	0.01
	p	0.612	0.727	0.389	0.533	0.719	0.046	0.123	0.089	0.208	0.954
MaxML	*r*	–0.31	–0.33	–0.13	–0.25	–0.27	–0.08	–0.18	0.09	–0.27	–0.09
	p	0.147	0.123	0.552	0.246	0.219	0.705	0.412	0.668	0.216	0.669
SA	*r*	–0.11	–0.11	–0.01	–0.04	0.00	–0.26	–0.13	–0.17	–0.11	–0.08
	p	0.631	0.606	0.952	0.872	0.994	0.225	0.558	0.448	0.615	0.723
MF	*r*	0.23	0.21	0.16	0.29	0.24	0.45*	0.38	0.39	0.35	–0.13
	p	0.299	0.338	0.478	0.178	0.265	0.033	0.071	0.064	0.101	0.549

Abbreviations: Feet – indices registered in standing position, Hands – indices registered in handstand, SP – statokinesiogram path length, SPAP – statokinesiogram path length in anteroposterior direction, SPML – statokinesiogram path length in mediolateral direction, MA – mean COP displacement, MAAP – mean COP displacement in anteroposterior direction, MAML – mean COP displacement in mediolateral direction, MaxAP – maximal displacement of the COP in anteroposterior direction, MaxML – maximal displacement of the COP in mediolateral direction, SA – sway area delimited by the COP point, MF – mean frequency of COP displacements, *r* – the Pearson's correlation coefficient, *p* – probability value; * $p \leq 0.05$.

ing position: $p = 0.021$; handstand: $p = 0.017$), mean displacement of the center of feet/hands pressure in mediolateral direction (standing position: $p = 0.011$; handstand: $p = 0.003$), maximal displacement of the center of feet/hands pressure in mediolateral direction (standing position: $p = 0.036$; handstand: $p = 0.036$) and sway area delimited by the COP (standing position: $p = 0.004$; handstand: $p = 0.014$). In standing position seniors also had statistically significantly lower values of the statokinesiogram path length, both total (p = 0,000) as well as in anteroposterior ($p = 0.001$) and mediolateral ($p = 0.002$) directions.

Data collected in Table 3 indicate the lack of statistically significant relationships between the stability indices registered in juniors in standing position and handstand.

In turn, statistically significant relationships were found in seniors. Particularly noteworthy is the correlation of statokinesiogram path length (which is the projection of the center of feet pressure in the anteroposterior direction) with mean displacement of the center of hands pressure in the same direction ($r = 0.43$; $p = 0.040$). In addition, the frequency of feet corrective reactions showed a positive connection with the mean displacements of the center of hands pressure in mediolateral direction: $r = 0.45$; $p = 0.033$ (Table 4).

There was also a negative relationship between the maximal displacement of the center of feet pressure in the anteroposterior direction and the mean displacement of the center of hands pressure in the mediolateral direction. However, both the relation of these two variables as well as the orientation of the correlation is a manifestation of various "activities" of COP, which under the feet moved in the AP direction, and under the hands in the ML direction. Therefore, they can be considered as accidental, not justified in the mechanisms of postural control (Table 4).

Analyzes with multiple regression have shown that the results of stability tests in juniors in handstand or in standing position did not enable to obtain statistically significant models. In contrast, statistically significant regression models were obtained in the group of seniors. Table 5 presents structural parameters of statistically significant models, developed based on the results obtained in the group of seniors. These data indicate that the variation of the statokinesiogram path length in the anteroposterior direction, registered in a handstand in 16% was accounted for the variation of the statokinesiogram path length in the anteroposterior direction registered in a standing position and the size of the area encircled by center of foot pressure ($R^2 = 0.16$). The slope of the regression line indicates that if the value of the $SPAP_{(Feet)}$ variable increases by a unit, the value of the explained variable (dependent) will increase by 8.77 mm. In turn, if the value of the $SA_{(Feet)}$ variable increases by a unit, then the value of the explained variable will decrease by 2.51 mm (Table 5).

Variables: statokinesiogram path length in anteroposterior direction registered in standing position, statokinesiogram path length registered in standing position and maximal displacement of the center of foot pressure in anteroposterior direction accounted for together of 32% of the variance of the dependent variable termed: mean of center of hands pressure displacement in anteroposterior direction ($R^2 = 0.32$). The slope of the regression line indicates that if the value of the $SPAP_{(Feet)}$ variable increases by a unit, that the explained variable $MAAP_{(Hands)}$ value would

Table 5. Statistically significant multiple regression models in seniors

Predictor variable	Dependent variable	Value of the regression model	R^2	R	b	t	p
$SPAP_{(Feet)}$	$SPAP_{(Hands)}$	$F(2.20) = 3.52$; $p = 0.049$*	0.16	0.48	8.77	2.41	0.026*
$SA_{(Feet)}$					–2.51	–2.11	0.047*
$SPAP_{(Feet)}$	$MAAP_{(Hands)}$	$F(3.19) = 4.43$; $p = 0.016$*	0.32	0.64	0.10	3.40	0.003*
$SP_{(Feet)}$					–0.05	–2.17	0.043*
$MaxAP_{(Feet)}$					–0.31	–2.15	0.045*
$MaxAP_{(Feet)}$	$MaxAP_{(Hands)}$	$F(2.19) = 4.01$; $p = 0.035$*	0.29	0.62	1.90	2.84	0.010*
$SPAP_{(Feet)}$					0.21	2.89	0.009*

Abbreviations: Feet – indices registered in standing position, Hands – indices registered in handstand, SPAP – statokinesiogram path length in anteroposterior direction, SA – sway area delimited by the COP point, SP – statokinesiogram path length, MaxAP – maximal displacement of the COP in anteroposterior direction, MAAP – mean COP displacement in anteroposterior direction, F – the Fisher–Snedecor test, R^2 – coefficient of determination, R – coefficient of multiple correlation, b – the slope of the regression line, t – value of the Student's t-test statistic, p – probability value; * $p \leq 0.05$.

increase by 0.10 mm, assuming that the remaining variables would not change. In turn, if the value of the $SP_{(Feet)}$ variable increases by a unit, then the value of the explained variable $MAAP_{(Hands)}$ would decrease by *b* 0.05 mm. If the value of the predictor variable: $MaxAP_{(Feet)}$ increases by a unit, the value of the dependent variable will decrease by 0.31 mm (Table 5).

Variables: maximal displacement of the center of foot pressure in anteroposterior direction and statokinesiogram path length in anteroposterior direction registered in standing position was the predictive variable for the maximal displacement of the center of hand pressure in anteroposterior direction, accounting for 29% of the variance of the dependent variable ($R^2 = 0.29$). The slope of the regression line indicates that if the value of the $MaxAP_{(Feet)}$ variable increases by a unit, the value of the dependent variable: $MaxAP_{(Hands)}$ will increase by 1.90 mm, while the value of the $SPAP_{(Feet)}$ variable increases by a unit, the value of the dependent variable $MaxAP_{(Hands)}$ value will increase by 0.21 mm (Table 5).

4. Discussion

Our research indicated that in gymnastics the level of athletes advancement significantly differentiates the stability of the body in standing position and handstand. In both positions seniors were characterized by better values of the following indicators sway area delimited by the center of feet/hands pressure, mean amplitude of COP displacement, mean displacement of the center of feet/hands pressure in ML direction and medio-lateral stability range. In addition, in the standing position the seniors were much better at controlling the center of feet pressure sway both in AP and ML direction. Better results in athletes with longer training experience confirm the observations of other authors about the significant impact of professional gymnastic training on body stability in natural and unnatural positions for humans [5], [10], [12], [15].

It is worth noting that in the handstand position in both groups the total statokinesiogram path length, which is the resultant movement of the center of hands pressure relative to the X and Y axes, was more than six times longer than the path covered by center of feet pressure in the standing position. In turn, the sway area delimited by the center of hands pressure in the handstand in the case of juniors was over 17 times larger, and in the case of seniors – more than 21 times bigger than the sway area delimited by the center of feet pressure in the standing position. These disparities seem to explain the lack of relationships between the analogous stability indices, obtained in a standing position and handstand. Moreover, they indicate that maintaining a stable handstand position is such a difficult and unusual task for a man that minimization of the sways of individual body segments in this position requires appropriate training, including exercises in an inverted position. It can be assumed that higher values of the center of hands pressure displacement in the handstand are conditioned, as described by Winter [27], by much lower number and sensitivity of the receptors located in the distal joints of the upper limb, compared to their number in the talocrural joint, which are characterized by the smallest threshold of excitation, and, thus, the greatest sensitivity. Due to the small number of papers concerning this subject, it is difficult to confront the obtained data with the results of other authors. One of few papers is written by Sobera et al. [25], who examined athletes practicing artistic gymnastics and rhythmic gymnastics, and observed in the handstand greater values of COP displacement amplitude in the sagittal and frontal plane, compared to the position of side balance stance with one leg lifted up to head, despite the fact that the duration of the handstand was 10 seconds, and one leg standing one was twice as long.

In the present study, statistically significant relationships were found between some stability indices in standing and handstand in seniors. There were noticeable links between the indices of the center of feet and hands pressure displacements in the same direction. Both the path of the center of feet pressure and the mean displacement of the center of hands pressure were oriented in the antero-posterior direction. In turn, the increase in the mean frequency of COP displacement in the free standing position was accompanied by an increase in the amplitude of the displacement of the center of hands pressure in the medio-lateral direction. A more accurate analysis of the results conducted with the use of multiple regression showed statistically significant relationships between the stability indicators obtained in standing position and handstand. The dependencies between the stability indicators of the single name, in other words analogous are worth emphasizing. This confirms that wrist strategy can be considered as equivalent to ankle strategy in standing [3], [29]. It seems, however, that such results are obtainable only for athletes with longer training experience, characterized by better stability indicators.

It is worth noting that in both groups the values of the COP displacement in the anteroposterior direction in the handstand were greater than in the latero-medial direction, which is consistent with the results of other authors [8], [12], [29].

Our research among juniors did not show statistically significant relationships between results related to stability indicators in standing position and handstand. Also, analyzes performed with multiple regression method showed that in juniors it is impossible obtain statistically significant models based on the results of stability tests in the handstand or in standing position. This suggests that at this sporting level, stability of the inverted position is significantly influenced by other variables, which were not evaluated in these studies. Among juniors, the higher values of COP displacement in handstand, as well as the lack of connections between the analyzed balance indicators result probably from larger angular displacements in joints other than the radiocarpal joint. Gautier et al. [9] emphasized that body configuration for the handstand requires specific postural control from four joints: wrists, elbows, shoulders, and hips. Kerwin and Trewartha [13] found that wrist torque had the most dominant role in accounting for mass center variance, followed by shoulder torque and hip torque. The high experts mainly controlled their handstand with wrist-shoulder coupling. Gautier et al. [8] showed that the low experts led their coordination with their hips with high angular amplitudes. The authors concluded that a possible explanation is that the hips are the only joint that is common in both daily posture and handstand control. In connection with the above, it can be stated that in the process of adaptation to maintain a stable position in the handstand, reduction in angular displacements in the hip, shoulder and elbow joints occurs along with the involvement of the radiocarpal joints and the activation of the muscles of the fingers corresponding to the talar joint and toes increases in the relaxed stance. Blenkinsop et al. [3], when studying adult female and male gymnasts, noticed that both perturbed and unperturbed balance, the prevalent control strategies were an ankle strategy in standing and a wrist strategy in handstand.

The lack of statistically significant relationships between the results obtained in both trials in juniors may be caused by to insufficient strength preparation of the muscles responsible for body stability in the inverted position. Hedbávný et al. [11], [12] stressed that handstand position requires an extraordinary muscle activity of upper extremities, which substitute for the antigravitational task of lower extremities. Although the muscle activity of upper extremities is more precise, they succumb to fatigue. The lower level of strength in juniors may be also indicated by greater range of COP displacement than in the case of seniors in both analyzed positions.

The results of our research indicate that for athletes with longer training experience standing in an inverted position seems to be a more "natural" position compared to less experienced ones. Improving this position by repetitions enables for adaptation of somatosensory systems and development of appropriate patterns (e.g., setting the fingers of the hands, radiocarpal joints) and strategies for maintaining the balance analogously to a relaxed stance. In addition, as the fitness level increases, handstand is less affected by other factors influencing the quality of this position and stability. The obtained results are a contribution to further scientific research in order to more accurately review the observed trends. In order to achieve this goal, research on postural stability and its variability due to sports training should be continued. We are convinced that every report regarding the issues undertaken in this paper is a valuable addition to scarce publications on the subject. It would be beneficial to verify our results based on longitudinal studies, as it would enable the appropriate selection of the type of exercise and training loads to optimize the training process.

5. Conclusions

The level of sport advancement significantly differentiates the stability of the body in standing position and handstand. Seniors practicing gymnastics in a relaxed standing position, have better control over the displacement of the center of feet pressure than it is in the juniors. Moreover, in both positions they are characterized by better values of such indicators as: sway area delimited by the center of feet/hands pressure, mean amplitude of COP displacements, mean displacement of the center of feet/hands pressure in medio-lateral direction and medio-lateral stability range.

Only in the group of seniors there are links of stability indicators registered in standing position with the values of indices obtained in the handstand. The lack of relationships in juniors suggests that the analysis of free-standing stability indices does not provide the possibility of predicting the ability to maintain balance in the handstand and, therefore, cannot be the only criterion when recruiting gymnastics candidates and monitoring the progress of the beginning athletes practicing this discipline.

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