

Stabilometric profile of handstand technique in male gymnasts

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Purpose: This study aimed to determine the characteristic features of handstand posture control associated with a high level of ability among male gymnasts. *Methods:* 8 acrobatic gymnasts (4 more and 4 less experienced) participated in the study. They performed a 10-second handstand five times with each hand positioned on one AccuSway (AMTI) force platform and the other hand on the second. Body sway changes were recorded in time series: centre of pressure (COP) and components of the ground reaction force (GRF) (vertical, medial-lateral and anterior-posterior). The COP amplitude and average of GRF components, the index of frequency (by Fast Fourier Transform) for the right and left hand were calculated. *Results:* More experienced gymnasts performing a handstand concentrate mainly on minimizing anterior-posterior body sway with minimum medial-lateral body sway. Less experienced gymnasts' pressure exerted on a surface by the hands is irregular in a medial-lateral direction. More experienced gymnasts control body position in the handstand and show less variation of body sway compared to less experienced gymnasts. More experienced gymnasts revealed lower frequency of body sway in the handstand compared to less experienced gymnasts. *Conclusion:* The stabilometric profile of more experienced gymnasts means the better posture control in handstand. The minimizing of body sway is compensated by exerting more force on a floor surface and the less experienced athletes cannot do that even after several years of training. The gymnasts of both groups, during standing on their hands, put more load on the right hand.

Key words: postural control, acrobatic gymnastics, handstand, males

1. Introduction

Athletes performing sports such as gymnastics, acrobatics and diving need to know how to perform a handstand and maintain handstand balance since it is a basic element of technique. Many of them perform a handstand numerous times during their sports training, trying to improve aspects of their technique. It is theorized [6], [12], [23], [27] that balance control in a handstand is similar to the one maintained in a regular standing position. Asseman et al. [1] did not observe any balance transfer between a standing and handstand position. However, Omorczyk et al. [19] reported that only in the group of senior gymnasts there are links of stability indicators registered in standing

position with the values of indices obtained in the handstand but not in the less experienced juniors.

An inverted vertical position is less stable than a natural upright position due to the shoulder girdle mobility, lower position of head in relation to the surface and different proportions between the upper and lower extremities. From a physiological point of view, equilibrioception is determined by close cooperation between the labyrinth, cerebellum, eyes, and proprioceptive nerve endings [10]. From practical point of view, the quality of a handstand performed either on a surface or a measuring device is important. Quality of balance control refers to an aligned position of body segments and compensation of balance disturbance, so the centre of mass (COM) vertical projection is maintained within the area of support [9], [11],

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Received: December 5th, 2018

Accepted for publication: February 11th, 2019

[27]. Competing amongst each other, athletes are evaluated by professional referees based on quality of their handstand performance. They are also subjected to assessment during a training course conducted by their trainers. Referees evaluate while trainers interpret perceptible compensatory movements and potential body displacement as deviations from the correct handstand technique. For the sake of sports practice and the trainer's experience, it is important to ascertain the direction of changes in the stability index while shaping motor habits when performing this task. Balance control while performing a handstand is mainly based on shifting the centre of pressure (COP) towards the back when the COM shifts to the front, or moving it towards the heels when the COM shifts to the back [23]. Yeadon and Trewartha [27] reported that all gymnasts used a wrist strategy. It means that gymnasts usually control body sway in a handstand by performing movements in the wrist joints and at the same time minimizing movements in different body joints, such as elbows, shoulders, hips, knees and ankles [23]. Although Blenkinsop et al. [3] reported that the cross-correlations of wrist joint torque and COM displacement are not recommended as an appropriate tool for determining feedback time delay in human balance, COM displacement involves a movement in a wrist joint which is associated with the pressure of fingers on a surface. This is the main purpose in gymnastics practice to teach young gymnasts to control changes in limb and torso motion to minimize movement of body segments [14]. Usually this can be achieved after about two years of regular training, but still, the handstand needs to be perfect. Even more, experienced gymnasts revealed a different way to control the body in an inverted position [22]. Kochanowicz et al. [15] reported the lower muscle activity of adult artistic gymnasts in comparison to young gymnasts during handstand, but it did not exhibit any differences in the pattern of electromyographic signal when performing a handstand on the different apparatus (floor, parallel bars and still rings). Busquets et al. [5] reported that the relationship between variability measures and the global performance outcome in gymnasts revealed different functional roles of movement variability (exploratory or restrictive) as a function of changes in experience levels. Bieć and Kuczyński [2] stated that body sway frequency during normal bipedal stance reflects the rate of postural corrections and this is a good indicator of postural strategy development due to maturation and/or training in young soccer players so the sway frequency index could be a good indicator of postural control quality in handstand, too. Troester et al. [25] reported that the body sway veloc-

ity is the most reliable measures of single-leg balance and should be considered for monitoring the changes in postural control. However, the posture control during handstand uses the different shape of the base of support than during single-leg stance, so the body sway frequency seems to be more useful in the handstand. Both of these measures reflect the ability of the central nervous system response to disturbances in balance.

Correct handstand technique requires exerting pressure on the hands in a systematic and synchronic way, even though small asymmetric hand movements are desirable especially when a gymnast performs a handstand on a measuring device or an acrobat on the hands of another acrobat. A non-symmetrical load of lower extremities in a natural standing position is believed to cause negative results [8]. In a handstand, a non-symmetrical load is even more undesirable, although necessary in some exercises. Experience in training indicates that in a handstand on stable floor loads exerted on two hands should be symmetrical which is the most important during handstand on specific gymnastic apparatus. Hrysomallis [12] concluded that balance training may lead to task-specific neural adaptations at the spinal and supraspinal levels. It may suppress spinal reflex excitability, which leads to less destabilizing movements and improved balance ability. Training experience might also improve coordination, strength and range of motion that may enhance balance ability [12].

This study aimed to determine the characteristic features of handstand posture control associated with a level (experience) of ability in male gymnasts. The specific aims were: first – to determine the main factors during a handstand responsible for a high quality of posture control, and second – to establish whether there are differences between the left and right hand activity while performing a handstand and, if so, whether the differences are related to a high level of ability of gymnasts.

2. Materials and methods

The study was based on two groups of male gymnasts with different training experience: group A, being less experienced – 4 gymnasts (22.5 ± 2.5 years old, body mass 67.2 ± 5.99 kg, body height 1.70 ± 0.05 m) – has practised acrobatic gymnastics for 5.5 ± 1.91 years; group B, more experienced – 4 gymnasts (27.0 ± 4.9 years old, body mass 69.0 ± 7.4 kg, body height (1.74 ± 0.05 m) – has practised acrobatic gymnastics for

17.5 ± 6.24 years. The subjects, still active in sport in their own different gymnastic centres in Poland, had no trauma to the arms in the past and at the time of research. The assumption was made that the gymnasts should practise the same technique of the handstand on the floor from the beginning of gymnastic development. All of the subjects were able to perform an aligned handstand on the floor for about 30 s using the wrist strategy [13], [23]. They were recruited to groups based on the length of the training period: group A – at least 3.5 and no more than 9 years; group B – more than 10 years of practising. All subjects declared they were right-handed.

Experimental set-up

The subjects performed a handstand with each hand positioned separately on one AccuSway (AMTI) platform with a sampling frequency of 100 Hz (Fig. 1). After a warm-up and some trial tests, each subject performed five handstand trials with several-minute breaks between trials. Each trial lasted 10 seconds.

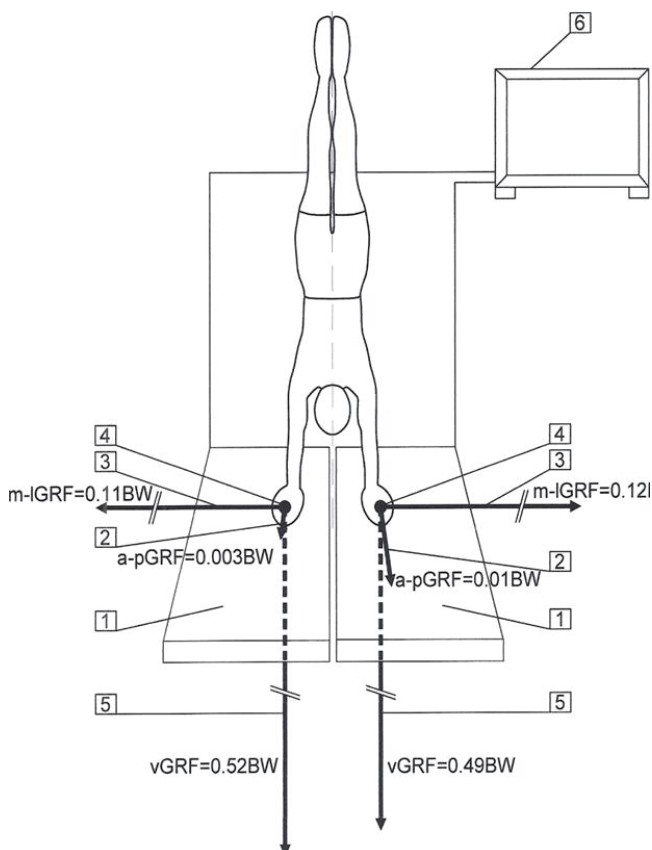


Fig. 1. Scheme of measurement and sample results of one gymnast per body weight (BW), 1 – force platforms: left and right, respectively, 2 – horizontal component of ground reaction force (GRF) in anterior-posterior direction (a-pGRF), 3 – horizontal component of GRF in medial-lateral direction (m-lGRF), 4 – center of pressure (COP), 5 – vertical component of GRF (vGRF), 6 – computer

The researchers adopted such a length of a trial due to the increase of instability over the period of a 15-second handstand [23]. Prior to the tests, the palms print were drawn on the paper glued with adhesive tape on the plate's surface. Each trial was performed with exactly the same hand position. The analysis covered only those trials where a subject maintained balance by using the wrist strategy and not another one (e.g., the hip strategy) that means the main movements were observed in wrist joint [13], [15], [23]. Ethical approval for this research study was obtained from the local research ethics committee (Ethics Committee of the University School of Physical Education) and conformed to the current Declaration of Helsinki guidelines. Each participant has signed an informed consent form before the first trial.

Analyzed parameters

Changes of body sway were recorded in time series: COP in two directions, i.e., medial-lateral (m-l) and anterior-posterior (a-p), vertical component of the ground reaction force (vGRF), and two horizontal components of ground reaction force: in the anterior-posterior direction (a-pGRF) and in the medial-lateral direction (m-lGRF) [21]. The recorded values of GRF components were expressed in relation to body weight (BW). COP time series were used to compute the standard deviation from the mean values of COP shifts. Standard COP shift amplitude in both directions – medial-lateral (COPm-l) and anterior-posterior (COPa-p) – indicated changes in the pressure exerted by the hands on a surface in a handstand. COP amplitude and GRF components computed separately for the right and left hand enabled the researchers to conduct a detailed analysis of hand activity and load in a handstand.

Time series of COP shifts and GRF were also applied to calculate an index of the frequency of COP shifts and GRF components for the right and left hand. Fast Fourier Transformation was applied to determine frequency values of the highest spectral power density of time series COP and GRF – peak frequency (Fig. 2). Analysis of movement frequency of separate segments was applied to evaluate a pattern of coordination control of female gymnasts [18]. Values of peak frequency recorded for a selected gymnast reflected the natural frequency of changes in COP shift and GRF components, and provided information about the efficiency of a system controlling body position in space, and decrease in COP frequency signified an improvement in the quality of balance control [2]. Training experience of the less experienced and more experienced gymnasts was an independent variable.

Statistical analysis

Statistical analysis was carried out using the Statistica 13.1 software package (StatSoft Inc., Tulsa, Oklahoma, USA). First, the homogeneity of variances of both groups was evaluated by the Kruskal–Wallis ANOVA test. Repeated trials (5 repetitions) of handstands were tested by Friedman’s ANOVA to evaluate the interaction between the COP indices and the order of trials. Normal distribution of the results was evaluated using the Shapiro–Wilk’s test, with reference to both groups and left and right upper extremities. Since not all data were normally distributed, the researchers applied the Mann–Whitney *U*-test to evaluate differences between groups A and B. The Wilcoxon test was applied to assess differences observed between the left and right upper extremities. The results were considered significantly different when the probability was less than or equal to 0.05 ($p \leq 0.05$).

3. Results

It was found that body mass ($p = 0.38$), body height ($p = 0.24$) and age ($p = 0.08$) were not significantly different between groups A and B, but the length of experience was ($p = 0.005$). These groups differed significantly only in sports experience. No main effect of COP and GRF results of the repeated trials was observed within each group so the next analysis was based on the 20 (4×5 trials) data in groups A and B. The notions of

COP amplitude in time function, GRF values and frequency of COP shifts, and production of the ground reaction force component were considered in this paper to be characteristics of the stabilometric profile in the inverted vertical position. The use of two force plates enabled the researchers to compare values of stabilometric indices of the left (L) and right (R) hand.

Center of pressure excursion

Comparison of the two groups indicated that COP amplitude in both directions was smaller for both hands in more experienced gymnasts than in less experienced ones (Table 1). The significantly greater value of medial-lateral COP amplitude in the less experienced gymnasts was observed for the right hand. There was no difference between the two hands in the anterior-posterior direction of COP amplitude in this group of athletes. There was no difference in medial-lateral COP amplitude observed in the more experienced gymnasts, but the significantly greater amplitude of COP shifts in the anterior-posterior direction was detected for the right hand (Table 1).

Ground Reaction Force

The m-l and a-p components of the GRF computed for the two groups were statistically significantly different for the left hand, and in the case of more experienced gymnasts revealed a significantly higher value of the two GRF components of the left hand than in the less experienced. For the right hand, the m-lGRF component differs between the groups like the left

Table 1. Results (medians and range 25–75%) of handstand for both groups A (less experienced, $n = 20$) and B (more experienced gymnasts, $n = 20$). Clamps indicate the significant differences between indices of both groups (vertical clamps) and between left and right hand (horizontal clamps)

Groups	Indices	Left hand median	range 25–75%	Right hand median	range 25–75%
A	COPm-l [cm]	0.20	0.17	0.23	0.27
	COPa-p [cm]	1.42	1.26*	1.43*	1.15
	m-lGRF [BW]	0.07	0.06	0.06*	0.14
	a-pGRF [BW]	0.007	0.01***	0.004	0.01
	vGRF [BW]	0.46	0.07	0.49	0.11
B	COPm-l [cm]	0.13	0.46**	0.15	0.34
	COPa-p [cm]	1.02	1.14	1.12	0.86
	m-lGRF [BW]	0.12	0.03**	0.11	0.03
	a-pGRF [BW]	0.01	0.01***	0.003	0.01
	vGRF [BW]	0.49	0.08*	0.52	0.08

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

one, but the a-pGRF does not differ. The vGRF component of the right hand is significantly higher in group B than in group A, but in the case of the left hand we observed only a nonsignificant difference (Table 1). Significantly higher vGRF values of the right hand, compared to the left one, indicated greater load exerted on this hand during handstand in group B than in A. Values of m-lGRF and a-pGRF were significantly lower for the right hand in comparison with the left within both groups (Table 1). However, the GRF vertical component of the right

hand was significantly higher than that for the left one both in the less and the more experienced group. Generally, components of m-lGRF and a-pGRF of both upper extremities were considerably higher in more experienced gymnasts than in less experienced ones.

Frequency domain

The peak frequency of the COP(t) signal in both directions was over 1 Hz for less experienced gymnasts, while in the more experienced group it was

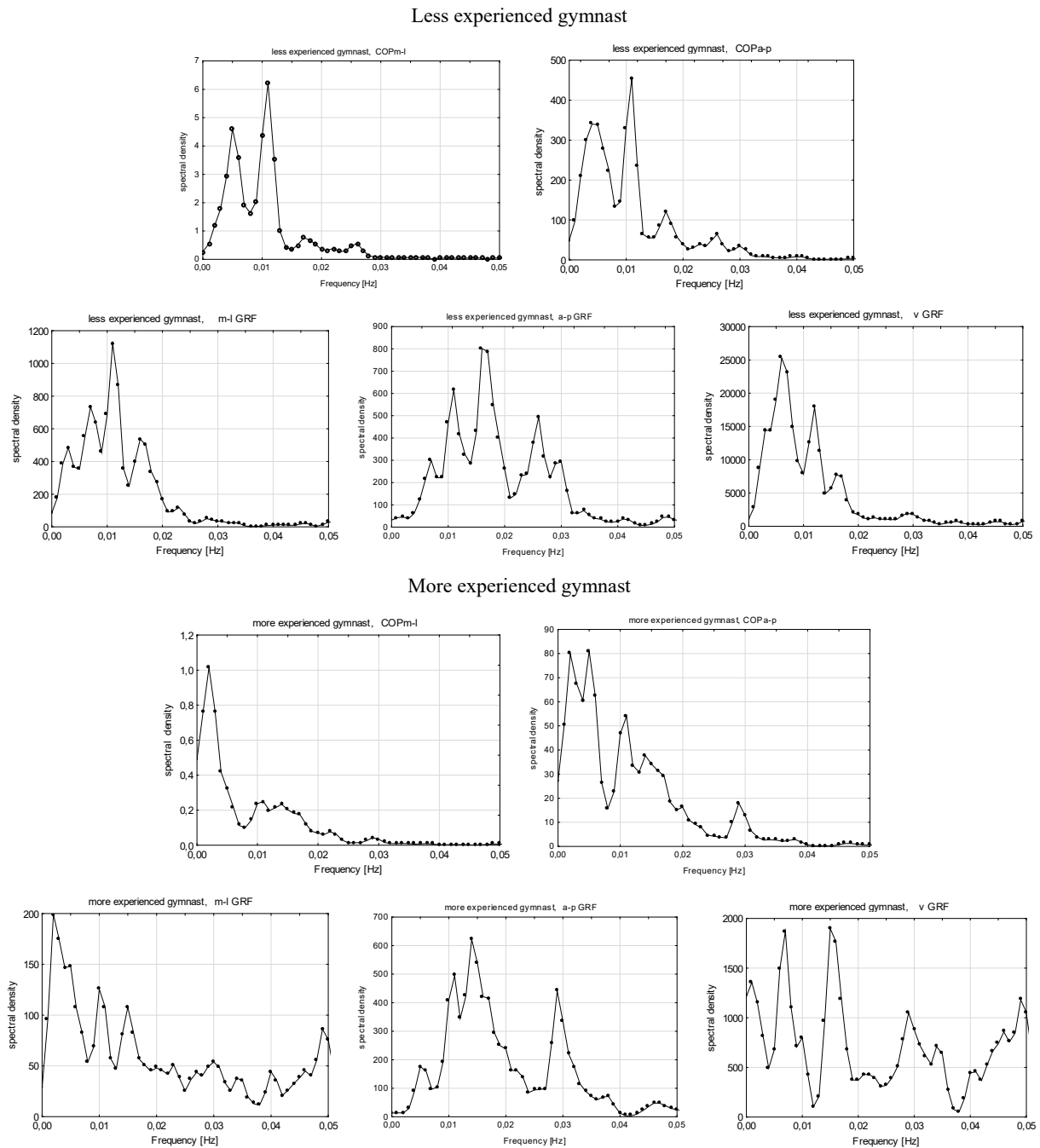


Fig. 2. Frequency analysis of left hand of one representative gymnast in both groups, less and more experienced; 0.01 on the frequency axis represents 1 Hz in reality

Table 2. Frequency of COP and components of ground reaction forces for both groups A (less experienced, $n = 20$) and B (more experienced gymnasts, $n = 20$) and left/right hand. Clamps indicate the significant differences between groups (vertical clamps) and between left and right hand (horizontal clamps)

Groups	Indices	Left hand median	range 25–75%	Right hand median	range 25–75%
A	COPm-l [Hz]	0.70	1.6	0.45	1.4
	COPa-p [Hz]	0.85	1.3	0.85	1.4
	m-lGRF [Hz]	0.55	1.2	0.45	1.6
	a-pGRF [Hz]	1.35	4.0	1.20	4.2
	vGRF [Hz]	0.75	4.3	0.65	4.7
B	COPm-l [Hz]	0.20	1.6	0.20	1.8
	COPa-p [Hz]	0.45	1.8	0.30	1.8
	m-lGRF [Hz]	0.25	2.1	0.25	5.3
	a-pGRF [Hz]	1.40	1.7	1.40	2.5
	vGRF [Hz]	0.90	5.3	0.85	5.5

below 1 Hz (Fig. 2). This relation is presented as the median in Table 2.

Significantly lower values of the COP shift frequency for the right and left hand in the anterior-posterior direction were observed in the group of more experienced gymnasts (Table 2). Also, the frequency of medial-lateral COP shifts was lower for the more experienced than the less experienced gymnasts. It is a statistically significant difference regarding the left hand as well as the m-lGRF. Apart from peak frequency observed in the groups, there were also different harmonic frequencies that were not analyzed in this study.

4. Discussion

A practical point of view indicated some common features in the way the gymnasts with different training experience (ability level) maintained balance. The further thorough analysis of changes in the hands' pressure exerted on a surface and frequency of these changes enabled the researchers to discover that it was training experience which diversified these two groups.

COP analysis

The comparison of these two groups can be presented in general terms as follows: less experienced gymnasts displayed greater amplitude of COP shifts in both directions for both extremities, compared to more experienced gymnasts. Slobonov and Newell [23] con-

cluded that the compensatory movement strategies appeared to be in support of minimizing variability of body segment motion. Ko et al. [14] stated that with the practice of postural control in the normal position on the moving platform, the organization of a compensatory postural coordination mode became more coherent than before practising. It may be reflected in minimizing body sway in the anterior-posterior direction when performing an important handstand in sport. Based on the reports of the Ko et al. [14] and Hrysomallis [12], one can arrive at certain conclusions, namely: smaller amplitude of COP oscillation reflects better control over sways and results in smaller COM displacements in handstands. It is probable that the more experienced gymnasts can better anticipate the direction of body sway and react better by hand pressure to stand steady. In particular, it can be observed in the anterior-posterior COP shifts while performing a handstand [24]. Hrysomallis [12] postulated that balance training promotes a shift in movement control from cortical to subcortical and cerebellar structures that can be reflected by smaller body sway during the specific task for gymnasts. These adaptations, in the author's opinion, help explain the improvement in balance ability in more experienced gymnasts.

In this study, COP amplitude observed in anterior-posterior direction for both hands was much smaller in the more experienced than less experienced group (Table 1). Simultaneously, in more experienced gymnasts COP amplitude of the right hand position in the anterior-posterior COP shift was greater than that of the left hand, while in the less experienced gymnasts pressure exerted by the upper extremities in this di-

rection was similar (Table 1). However, the load of the right hand was considerably greater in both groups, as vGRF was significantly greater for the right hand than for the left one. Genthon and Rougier [8] found that in asymmetric standing COP shifts are greater for the less loaded lower extremity in a normal bipedal stance. These results did not confirm such a relationship in the handstand. Gymnasts from both groups controlled their balance with the more loaded right hand producing higher values of the vGRF than the left one. The pressure exerted by the hands in the m-l and a-p directions differed between the two groups. Less experienced gymnasts control the balance during a handstand by changing the pressure in the medial-lateral direction mainly of the right hand but act symmetrically in the anterior-posterior direction. More experienced gymnasts, on the other hand, control their balance by changing the pressure of the right, more loaded, hand in the anterior-posterior direction and synchronize pressure changeability of the two hands in the medial-lateral direction. It seems that such significant difference between less experienced and more experienced gymnasts results mainly from hands' compensatory movements. More experienced gymnasts performing a handstand concentrate mainly on minimizing anterior-posterior body sway with minimum medial-lateral displacement of the body. It seems that they control body balance in this position better than the gymnasts from group A. Less experienced gymnasts' pressure exerted on a surface by the hands is irregular in a medial-lateral direction. Even though it is similar in the anterior-posterior direction, it still displays greater variability than in the more experienced gymnasts.

GRF analysis

Horizontal components of ground reaction force – a-pGRF and m-lGRF – result from pressure exerted by the athlete's hands on a surface in order to control body sway in a handstand. The whole process is controlled by the central nervous system and performed by the motor system equipped with proprioceptors sensitive to any change in muscle length and tension. These changes control COM and COP displacements. The two horizontal m-l and a-p GRF components were higher in the more experienced gymnasts than in the less experienced (except the a-pGRF of the right hand where the component was almost equal for both groups of gymnasts). These components reflect the hands' activity while performing a handstand. Higher values of a-pGRF and m-lGRF of the more experienced gymnasts confirmed the thesis of better handstand control compared to the less experienced gym-

nasts. It seems logical that decreased body sway needs to be compensated by higher values of the ground reaction force components. It should be emphasized that the vGRF of the right hand was significantly higher than the vGRF of the left hand within both groups. This may indicate its leading role in taking the main load in a handstand independently of the gymnast's experience.

Analysis of the attained results led to the conclusion that the groups did not differ with respect to the asymmetry of GRF components of the right and left hand. Higher values of horizontal GRF (m-lGRF and a-pGRF) components of the left hand observed in both groups and a greater load of the right hand (vGRF) suggest that the right hand supports while the left one steers. However, it might be caused by the right hand domination in all subjects of the study. The other research methods, e.g., EMG, body segments movements analysis could complement the study and/or the left-handed group extension. That is the next task for future.

Frequency analysis

The courses of the time series COPm-l, COPa-p, m-lGRF, a-pGRF and vGRF of balance control in handstands were presented as frequencies. The obtained spectral frequencies of these courses were similar but still significantly different for the less experienced and more experienced gymnasts. Lower COP frequency values (0.2 Hz in the m-l direction, and 0.45 Hz in the a-p direction) were observed in the spectrum characteristic for more experienced gymnasts (Table 2). Higher COP frequency values (0.7 Hz in the m-l direction, and 0.85 Hz in the a-p direction) were observed in the spectrum characteristic for less experienced gymnasts. These results may indicate that the level of balance control depends on the ability level of an athlete. Pillard and Noé [20] stated that lower COP frequencies in a band of 0.2–0.5 Hz reflected the participation of the vestibulo-ocular apparatus aiding balance control, while higher frequencies reflected the participation of the human brain. Frequencies above 2 Hz indicated increased participation of proprioceptive control. According to the statement, the frequency results of COPm-l and COPa-p obtained in our research probably indicated the fact that the more experienced gymnasts use the vestibulo-ocular apparatus to a greater extent to control balance. Less experienced athletes, on the other hand, more often engage centres of balance control of the central nervous system based on kinesthetic feeling. It is worth mentioning that different frequencies in the COP spectrum may be influenced by different muscle tension while doing a handstand. This factor may lead to

changes in the motor system stiffness and, consequently, increase the frequency of COM and COP displacements, which was proven by Winter et al. [26] in a study on bipedal standing. Bonnet et al. [4] presented a balance control model taking into consideration elasticity and suppression in the ankle and hip joints. These authors concluded that increased frequency of body sway in a regular standing position leads to an increase in COP amplitude and results in a risk of balance loss, which means the increase COP amplitude and frequency reflects worse balance control in the given position. Control of balance in a handstand requires limitation of degrees of freedom of the wrists, elbows, shoulders, hips and spine [7]. Reducing the joints' degrees of freedom leads to minimization of body sway in practice, so reducing body sway frequency could increase the ability level of gymnasts' posture control. Hence, these findings suggest that lower frequency power spectrum of COP and GRF may reflect better balance control also in handstands. In practice, it means that people with better balance control sway less and with lower frequency, which cannot be confirmed with the naked eye. Similar results were obtained by Bieć and Kuczyński [2] in their study on postural control in soccer players. They reported that better postural control in soccer players was accompanied by significantly lower values of their sway frequency, compared to non-athletes. This means that better posture control involves the decrease of body sway frequency. However, Kuczyński et al. [16] also found the presence of an additional low-amplitude and high-frequency signal superimposed on the COP during quiet stance in volleyball players, but not in controls. Blenkinsop et al. [3] explained the high frequency of body sway by the hyperextended position of the wrist in handstands. In this position the wrist and finger flexor muscles are stretched close to their limits and increase the amount of force transmitted through the parallel elastic elements of the musculotendinous unit, explaining the increased contribution of passive stiffness during handstands. It should be pointed out that such factors as body position or muscle tension are worked on in the course of prolonged sports training. The results of such training can be visible in a frequency power spectrum of COP and GRF. As Latash [17] reports, the neuromuscular system tries to achieve a given state of minimal muscle activation, and, in his opinion, this basic principle can be called the principle of minimal final action, which may also be viewed as a consequence of the natural trend of physical systems to move to a state with minimal potential energy. Unfortunately, we can not consider the muscle activation

in our study as it needs the EMG research, but it is possible to predict that the muscle force and tension produced by upper limbs in handstand have reflected in COP and GRF frequency spectrum. So the lower frequency of COP shifts and GRF mean the using of minimal potential energy in handstand by the more experienced gymnasts, compared to the less experienced, according to the Kochanowicz et al. [15] results. The latter authors reported that adult gymnast muscles exhibit lower activation in comparison with young gymnasts in a handstand on different gymnastic apparatus, and that it may suggest neuromuscular specialization as a result of a long-term training.

5. Conclusion

The stabilometric profile of handstand technique is different for more and less experienced gymnasts.

More experienced gymnasts, when controlling the body position in handstands, demonstrate a smaller amplitude of body sway with lower frequency, compared to those less experienced. It seems that the stabilometric profile means the better posture control in this position in the more experienced gymnasts. The minimizing of body sway is compensated by exerting more force on a floor surface and the less experienced athletes cannot do that even after several years of training.

Analysis of the ground reaction force components suggests that the right hand functions as the main support, while the left performs balance control movements in both groups, but that can be an effect of the right hand domination in all subjects in this study.

Acknowledgments

This study was supported by the research grant RSA2 022 52 from the Polish Ministry of Science and Higher Education. All experiments comply with the current laws of the country.

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