Acta of Bioengineering and Biomechanics
Vol. 20, No. 2, 2018

Original paper
DOI: 10.5277/ABB-01060-2017-02

Quiet standing postural sway of 10- to 13-year-old, national-level, female acrobatic gymnasts

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Purpose: The aim of the study was to determine whether 10- to 13-year-old, national-level, female acrobatic gymnasts present a different quiet standing postural control (with and without visual cues) than untrained female peers. *Methods*: The mean velocity of the center of pressure (in anterior-posterior and medial-lateral directions) was computed from 60-s long quiet-standing trials on a stationary force plate in fifteen 10- to 13-year-old female acrobatic gymnasts and thirteen sex- and age-matched non-athletes. A two-way repeated measures ANOVA (acrobatic gymnasts *vs*. non-athletes and eyes open *vs.* eyes closed) was used for the anterior-posterior and medial-lateral COP mean velocity. The relation between subjects' body mass and COP mean velocity was tested with the used Spearman's Rank Correlation Coefficient. *Results*: Postural sway (represented by COP mean velocity) was not significantly different between the acrobatic gymnasts and the non-athletes ($p > 0.05$), except for the faster medial-lateral sway in eyes-open conditions in the acrobatic gymnasts ($p < 0.05$). The gymnasts' body mass negatively correlated with their anterior-posterior sway velocity in both visual conditions (eyes open: $r = -0.7$; eyes closed: $r = -0.6$) and with medial-lateral sway velocity during eyes-closed trials ($r = -0.5$; $p < 0.05$). *Conclusions*: Results of the study indicate that in quiet standing postural control 10- to 13-year-old acrobatic gymnasts did not make use of their trained abilities. Heavier gymnasts might have been more stable than lighter ones during quiet standing.

Key words: *gymnastics, school-age females, postural control, postural balance, body mass*

1. Introduction

Postural sway during quiet standing reflects the interplay between destabilizing forces acting on the body and the postural control system action preventing a loss of balance [22]. To quantify postural sway, most studies use force plate posturography which enables describing of the characteristics of the center of foot pressure (COP) trajectory which in quiet standing is closely related to the horizontal sway of the body's center of mass [21]. In the evaluation of quiet standing postural sway the COP mean velocity, among traditional parameters [3], [19], [23] is considered the most reliable. The increased COP mean velocity may indicate a diminished postural balance [7]. During standing on a firm surface it is recommended to include trials with eyes open and closed. Loss of vision decreases postural balance, what is reflected by the increased postural sway [23], however, various human populations may have different ability to use their redundant system to adapt to visual deprivation conditions [28].

Gymnastic disciplines focus on balance training. A gymnastic performance requires a continuous control and correction of body alignment in relation to the environment (postural orientation) [15] and a perfect balancing of the forces acting on the body segments (postural equilibrium) [15]. Researchers have been interested in the mechanisms underlying this excellent balance ability of the gymnasts [1], [6], [8], [12], [26]. An understanding of these mechanisms may be useful

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Received: December 9th, 2017
Accepted for publication: April 9th, 2018

in the process of athletic training for various sport disciplines and in working with patients with balance deficits.

It has been documented that teenage or young adult gymnasts exhibit superior dynamic balance [8], [13] and static unipedal balance, compared to untrained subjects or athletes practicing other disciplines [1], [26]. Studies performed on children have also demonstrated that gymnastic training stimulates the development of their balance ability under challenging conditions [13], [17]. It has been shown that 11-year-old female acrobatic gymnasts have lower COP values while standing on a free seesaw platform, which suggests better dynamic balance than the same age ballet dancers and untrained girls [13]. Another study has also indicated greater dynamic and static balance ability (in a relevé position with hands upward) in three age groups of elite rhythmic gymnasts (9–10, 11–12, and 13–15 years old), compared to the same age groups of non-athletes [17].

It is still unclear whether gymnasts' superior postural control may be also observed during simple quiet standing tasks. Some studies assessing quiet bipedal standing in teenage and adult populations have indicated no differences in the postural sway characteristics between gymnasts and controls or other athletes [1], [12], [26]. However, one study suggested that rhythmic gymnasts used a better strategy to control quiet stance in a medial-lateral direction compared to non-gymnasts, but the opposite phenomenon concerned the anterior-posterior direction [6].

Two studies evaluating quiet standing postural sway in 9- to 11-year-old female gymnasts reported no differences in the magnitude of sway area between the gymnasts and same age untrained subjects [11], [14]. One of the studies indicated no between group differences in regard to this measure [11] and the other study demonstrated a surprising result of greater values of the COP mean velocity in the gymnasts than in their non-athlete counterparts [14]. The aforementioned findings raise a question of why the gymnasts did not demonstrate better postural stability in quiet standing compared to their untrained peers. It also appears that in adolescent gymnasts the COP mean velocity particularly needs further investigation.

To our knowledge quiet standing postural sway has never been examined in a population of female acrobatic gymnasts aged 10 to 13. It is important to determine whether the adaptive mechanisms of the postural control system to the acrobatic gymnastics training can be observed during the unperturbed normal standing. The mechanisms which underlie quiet standing postural control are not fully understood [20] and the postural sway assessment in the population characterised by a superior balance ability may help to expand our knowledge in this area.

Typically, adolescent female gymnasts have a lower body mass compared to their peers [9]. It has been suggested that the body mass may influence quiet standing postural sway in typically developing children [25]. Our literature search has shown that the relationship between the body mass and postural sway of gymnasts has not yet been investigated. Based on the trainers' experience, the impact of body mass on standing stability is known in the acrobatic gymnastics. However, to our best knowledge, it has not been supported by scientific evidence.

The primary aim of this study was to determine whether 10- to 13-year-old, national-level, female acrobatic gymnasts aged 10 to 13 eyars, exhibit different quiet standing postural sway compared to their untrained female peers. We aimed to evaluate subject's quiet standing under two visual conditions: eyes open and closed. Our secondary aim was to investigate the relationship of the subjects' body mass with their postural sway velocity.

2. Materials and methods

This study was conducted with the approval of the Senate Ethics Committee of the Katowice Academy of Physical Education, Poland. Fifteen girls practicing acrobatic gymnastics and thirteen age-matched healthy girls with no experience in practicing sports participated in the study. The age range for the whole group was 10–13 years (subject characteristics are presented in Table 1). The gymnasts were recruited from three acrobatics training centers and the untrained girls were recruited from an elementary school in Upper Silesia. The inclusion criteria for the acrobatic gymnasts were national performance level and practicing for at least 7 hours per week. The inclusion criteria for the untrained girls were no involvement in sports and participation only in the general physical education classes at the elementary school. Exclusion criteria were uncorrectable vision disorders, obesity and any neurological or musculoskeletal abnormalities that could affect balance. Although girl gymnasts are characterized by lower body height and advanced slimness [4], [9], [18], we decided it was not appropriate to intentionally recruit short and underweight girls to represent the healthy untrained group. However, exclusion criteria was obesity, because it may modify quiet standing postural sway [5], [25].

Table 1. Characteristics of 15 young female acrobatic gymnasts and 13 untrained girls*. BMI – Body mass index

	Gymnasts	Untrained
Age [years]	11.3 ± 0.72	10.8 ± 0.72
Height [cm]	134.1 ± 5.36	146.6 ± 6.37
Body mass [kg]	28.1 ± 4.56	38.2 ± 6.20
BMI	15.5 ± 1.46	17.8 ± 2.95
Gymnastics experience (years)	3.5 ± 0.83	0

* Data are shown as means ± standard deviations.

The aim of the study and experimental procedures were explained to all study participants and their legal guardians and written informed consent was obtained from the participants and the guardians, as required by the Helsinki declaration (1964). The acrobatic gymnastics training centers provided the data regarding the girl athletes' duration and frequency of training. The gymnasts have been practicing for, on average 3.5 years and practiced 7–10 hours per week (3–5 times per week for 2–2.5 hours). Based on an administered survey, all school girls had no experience in gymnastics and they participated only in general physical education classes 3 hours per week (4 times per week for 45 minutes).

The girls enrolled in the study reported for testing to the Diagnostic Laboratory at the Department of Human Motor Behavior at the Academy of Physical Education in Katowice. Recording of subject height and body mass preceded posturographic tests. Based on height, body mass and age, individual BMI percentile rankings were calculated and interpreted according to the international BMI cut-off points for children established by the International Obesity Task Force (underweight: <5th, normal weight: 5th–90th, at risk of overweight: 90th–97th, overweight: >97th percentile).

To test postural sway, the girls were instructed to stand barefoot, as still as possible, with feet approximately hip-width apart on a stable force plate (AMTI AccuGait, Watertown, MA, USA). Two 60-second quiet standing trials with arms relaxed by the sides were conducted with the eyes open (looking straight ahead at a wall 3 m away) and with the eyes closed. After each trial, subjects stepped off the platform and rested up to 1 min to avoid any discomfort.

The COP signals transmitted from the force plate were amplified and sampled at the frequency of 100 samples per second. They were filtered with a 4th order low pass Butterworth filter at a 7-Hz cut-off frequency. From the acquired COP traditional parameters, the COP mean velocity was chosen for analysis [3], [19], [23]. This measure is defined as an average speed of COP movement over a time of a trial. In this study the anterior-posterior and medial-lateral components of the COP mean velocity were computed on the basis of the means of two trials for the eyes-open conditions and two trials for the eyes-closed conditions [3], [19].

Statistical analyses were performed on subjects' anthropometric measures and COP mean velocity recorded in the eyes-open and eyes-closed conditions. A Mann–Whitney U test was used to compare the anthropometric measures between the acrobatic gymnasts and the untrained subjects. Because the analysis showed significantly lower body height in the gymnasts than in the untrained girls, the COP velocity was normalized to subject height. Normalizing balance scores relative to body height is recommended when comparing groups with notable stature differences [16]. A two-way repeated measures ANOVA was used for the anterior-posterior and for the medial-lateral COP mean velocity. The inter-group factors were gymnasts and non-gymnasts; the intra-group factors were eyes open and eyes closed. A *post-hoc* Bonferroni test was applied for significant ANOVAs. Confidence intervals were stated at the 95% confidence level. Spearman's Rank Correlation Coefficient was used to test whether the subjects' body mass was correlated with their COP mean velocity. The level of significance was set to $\alpha = 0.05$. The analyses were performed using the Statistica v.10 (StatSoft, Inc., Tulsa, OK, USA).

3. Results

No between-group differences were observed regarding age and BMI ($p > 0.05$), however, acrobatic gymnasts' height and body mass were significantly lower compared to their peers with no experience in gymnastics ($p < 0.0001$; gymnasts' height: 95% confidence interval (CI) 131, 137 cm; non-athletes' height: 95% CI 143, 150 cm, and gymnasts' body mass: 95% CI 26, 31 kg; non-athletes' body mass: 95% CI 34, 42 kg). According to international BMI cut-off points for children, the individual BMI percentile ranking indicated that five acrobatic gymnasts were underweight (<5th percentile) and two untrained girls were at risk of being overweight (90th–97th percentile). The remaining girls demonstrated normal weight (5th–90th percentile).

In regard to COP mean velocity (normalized to body height), an analysis of variance showed a significant group effect only in medial-lateral direction ($F_{1,26}$ = 7.65, p = 0.01). The repeated measures analysis revealed a significant vision effect in both anterior-posterior ($F_{1,26}$ = 101.78) and medial-lateral ($F_{1,26}$ = 39.51) directions ($p < 0.0001$). The group and vision interaction approached significance for the medial-lateral direction ($F_{1,26}$ = 3.83; p = 0.06).

A *post-hoc* comparison showed that under eyes-open conditions, the medial-lateral COP mean velocity was higher in acrobatic gymnasts, compared with untrained (95% CI 4.1, 5.2 mm/s in gymnasts and 2.5, 3.7 mm/s in untrained, p = 0.02; Fig. 1).

An eyes open versus eyes closed conditions comparison showed that the gymnasts' COP mean velocity was increased during standing with eyes-closed both in anterior-posterior ($p < 0.0001$) and medial-lateral (p = 0.02) directions (95% CI 4.0, 5.2 mm/s for the anterior-posterior direction under eyes-open and 4.8, 6.3 mm/s under eyes-closed conditions, and 4.1, 5.2 mm/s for the medial-lateral direction under eyes-open and 4.5, 6.1 mm/s under eyes-closed conditions). Similarly, in the case of the untrained girls, the COP mean velocity was increased under visual deprivation conditions for both directions ($p < 0.0001$; CI 95% 3.0, 4.3 mm/s for anterior-posterior direction under eyes-open and 4.1, 5.7 mm/s under eyes-closed

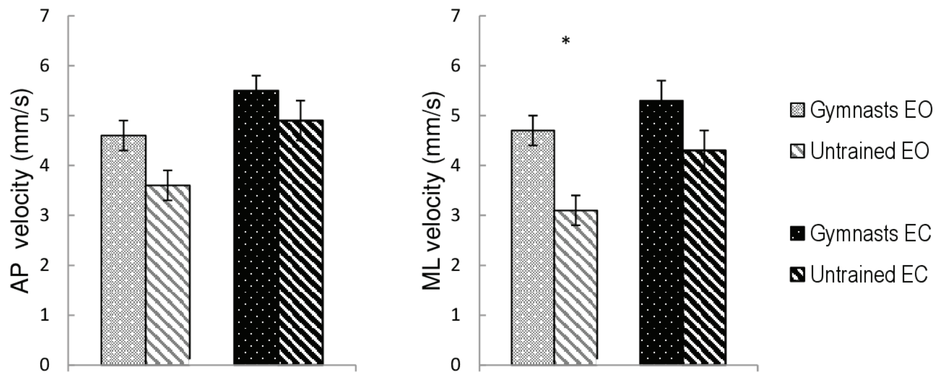

Fig. 1. Center of pressure mean velocity during 60 s of quiet standing with eyes open (EO) or closed (EC) in 15 acrobatic gymnasts and 13 untrained girls. AP – anterior-posterior plane, ML – medial-lateral plane; data shown as means ± standard errors; * Bonferroni *post hoc*: p = 0.02, ANOVA: $F_{1,26}$ = 7.65, p = 0.01

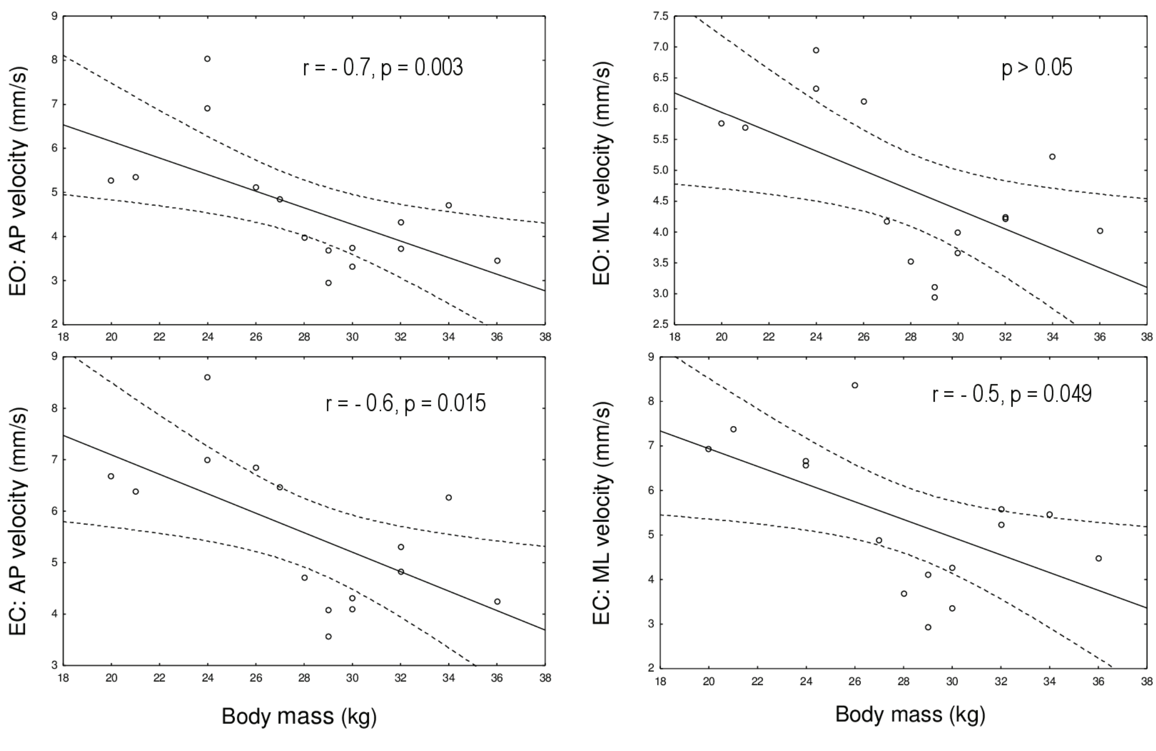

Fig. 2. Spearman's correlation of adolescent female acrobatic gymnasts' body mass with their center of pressure mean velocity during 60s quiet standing trials with eyes open (EO) and closed (EC); AP – anterior-posterior plane, ML – medial-lateral plane

conditions, and 2.5, 3.7 mm/s for medial-lateral direction under eyes-open and 3.5, 5.2 mm/s under eyes-closed conditions).

Spearman's rank correlation coefficient showed that the acrobatic gymnasts' body mass significantly negatively correlated with their anterior-posterior COP mean velocity in eyes-open ($r = -0.704$, $p = 0.003$) and eyes-closed ($r = -0.611$, $p = 0.015$) conditions. A significant negative correlation was also observed between their body mass and the medial-lateral COP mean velocity in the eyes-closed conditions ($r = -0.514$, $p = 0.049$), but not in the eyes-open conditions ($p > 0.05$; Fig. 2). In the untrained group, the body mass did not correlate significantly with the COP mean velocity ($p > 0.05$).

4. Discussion

The aim of this study was to compare quiet standing postural sway mean velocity between national-level, female acrobatic gymnasts aged 10 to 13 years and age-matched female non-athletes. Our study revealed that the group differences in anterior-posterior sway velocity both in eyes-open and eyes-closed conditions and in medial-lateral sway velocity in eyes-closed conditions were not significant. Concomitantly, the gymnasts demonstrated higher medial-lateral sway velocity than the non-athletes during standing with eyes open. The presented study also showed a moderate-to-strong negative correlation between acrobatic gymnasts' body mass and their anterior-posterior sway velocity in both visual conditions and medial-lateral sway velocity in eyes-closed conditions.

Our findings on a similar postural sway velocity in the sagittal plane in both visual conditions and in the frontal plane in eyes-closed conditions in the acrobatic gymnasts and the non-athletes suggest that the gymnasts did not exhibit superior postural stability during the simple quiet standing task. Similarly, studies of quiet bipedal stance by Garcia et al. [11] and Hernández Suárez et al. [14] showed non-significant differences in the magnitude of sway area between rhythmic gymnasts aged 9 to 11 years and age-matched non-gymnasts. Garcia et al. [11] also indicated no between-group differences in the anterior-posterior and medial-lateral COP mean velocity. Adolescent gymnasts demonstrated a superior balance only when under more challenging conditions, i.e., unipedal stance or dynamic balance tasks [13], [17], probably because under those conditions they made a use of their inherited and trained abilities, including increased muscle strength, coordination and body control [17]. Our study and the other two studies concerning quiet standing task [11], [14] suggest that in postural control of a simple bipedal stance the gymnasts did not use their superior abilities.

In our findings interesting is the fact that under normal visual conditions the girl acrobatic gymnasts swayed faster in frontal plane than their untrained peers. Additionally, under those conditions, the gymnasts' medial-lateral COP velocity did not correlate with their body mass. This indicates that the elevated values of the COP measure were independent of body mass and that other factors must have had the impact on the gymnasts' faster sway in frontal plane. Similarly, greater values of COP mean velocity in quiet standing were reported in girls practicing rhythmic gymnastics. However, the study did not present results concerning directional subcomponents of this measure [14].

In our search for the possible cause of the greater medial-lateral sway velocity in the 10- to 13-year-old female acrobatic gymnasts we focused on medial-lateral neuromuscular balance control of quiet standing. As proposed by Winter et al. [27], the dominant control in the frontal plane is maintained by an appropriate muscle tone of hip abductors/adductors in a load/unload mechanism. Faster body sway in frontal plane may indicate greater hip abductor/adductor muscle activity. The question remains of why in the quiet standing the gymnasts swayed faster in the frontal plane. We propose the following possible cause of the observed phenomenon, however it should be considered with caution. Gymnasts are characterized by generalized joint laxity [2], [10] and, theoretically, joint hypermobility may modify postural control because of different tendon reflex pattern [24]. The high absolute range of hip abduction/adduction is typical for the gymnastic disciplines. Therefore, we wondered whether during the simple quiet standing the gymnasts' faster medial-lateral sway could have been related to their greater hip abductor/adductor muscle activity due to the increased hip joint abduction/adduction mobility. Our suggestion is that future studies should focus on investigating possible relationship between gymnasts' joint mobility and their bipedal and unipedal static and dynamic postural balance.

In the part of our study examining quiet standing with eyes closed, the phenomenon of the faster postural sway in the gymnasts was not observed, however, the results for the group and vision interaction approached significance for the frontal plane. It is possible that under visual deprivation conditions the gymnasts' superior body control decreased the effect of the increased joint mobility.

Regarding anthropometric characteristics, our study demonstrates that the 10- to 13-year-old girls practicing acrobatic gymnastics (national level) were shorter and lighter than their healthy untrained peers. Moreover, five of fifteen gymnasts were underweight. Other studies similarly indicated lower body height and advanced slimness in girl gymnasts [4], [9], [18]. In our study we attempted to determine whether girls' body mass could have had the impact on their postural sway velocity. The findings suggest a moderate to strong negative correlation between acrobatic gymnasts' body mass and their postural sway velocity. More specifically, they indicate that the gymnasts with higher body mass swayed with the lower velocity in the sagittal plane, than those who were lighter, despite visual conditions. The heavier gymnasts also swayed with a lower speed in the frontal plane under visual deprivation conditions. This suggests that the heavier acrobatic gymnasts may be more stable than lighter ones during quiet standing. Our findings could be explained by the fact that in acrobatic gymnastics the heaviest and the strongest gymnasts, beside their acrobatic skills, also train static standing balance while supporting and securing their lighter team-mates. This skill is not practiced by the lightest gymnasts. The interpretation appears to be in agreement with our results obtained for the untrained girls suggesting no dependence of postural sway on body mass. It is also in accordance with the conclusion drawn from the review study on balance ability in different athletes, based on which the author suggested that the ability to maintain balance might be specific to the trained task and not a general trait [16].

Concluding, in quiet standing postural control acrobatic gymnasts did not make a use of their trained abilities. Our study also indicates that heavier gymnasts might have been more stable than lighter ones during quiet standing. Balance ability of the acrobatic gymnasts aged 10 to 13 years appears to be specific to their trained tasks. Because of the small sample size of the present study, the results and conclusions should be considered with caution.

Acknowledgements

We thank the Academy of Physical Education in Katowice for funding the editorial assistance.

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