EFFECTS OF SYSTEMATIC GYMNASTIC TRAINING ON POSTURAL CONTROL IN YOUNG AND ADULT MEN

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Abstract

The aim of the study was to investigate the influence of gymnastics expertise of children and adolescents and young adults on the postural control with and without the use of visual information and during dynamic postural task. The study comprised a total of 105 males, including 48 athletes practicing gymnastics and 57 non-gymnasts. Both groups were divided into three age categories: 8-10, 12-14 and 18-24 years old. Participants' postural control was measured on force platform in bipedal static (eyes open/close) and dynamic with visual feedback condition. ANOVA test (group vs age) with repeated measurements (visual control) was used to distinguish effect of gymnastic training in three age groups. Results show that in analysis of the center of pressure surface area, all gymnast had significantly better (p=0.013) static postural control in regardless visual control (group effect), although, there were no differences in each individual age groups (group vs age; p=0.556). Furthermore, the youngest groups had significantly higher values than two other groups, indicating worse performance. Dynamic task with visual feedback showed that the youngest non-gymnasts needed much more time to complete the task in compare to all other groups of gymnasts or non-gymnasts. The results showed that gymnastic training has influence in postural control of young and adults, but unspecific static and visual feedback condition does not fully reflect adult gymnast's capabilities. However, systematic participation in gymnastics training during the early-school period could increase the ability to coordinate and regulate body posture.

***Keywords:** balance, visual feedback, sensory reintegration, proprioception, training adaptation.*

INTRODUCTION

Maintaining upright body posture is extremely difficult from a biomechanical point of view due to the small surface of support and a complicated system of kinetic chains with multiple degrees of freedom (Bairstow & Laszlo, 1981; Dallas, Dallas, Theodo, & Papouliakos, 2016; Tsopani et al., 2014). When performing daily activities such as locomotion (walking on flat, uneven surfaces, stairs etc.), physical labour in a standing position and many other, a person uses them to a small extent. By far a greater wealth of activities related to maintaining body balance is observed in sport. Efficient postural control results from complex physiological mechanisms, including, among others, the functions of the organ of sight (Cody & Nelson, 1978), proprioception (Fujisawa et al., 2005), the central and the peripheral nervous system (Kavounoudias, Gilhodes, Roll, & Roll, 1999), the vestibular organ (Iatridou, Mandalidis, Chronopoulos, Vagenas, & Athanasopoulos, 2014). Through sensory organization , a person efficiently maintains body balance while walking or running and performs many complex movements (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; Winter, 1995).

Carrick, Oggero, Pagnacco, Brock, and Arikan (2007), Freeman and Broderick (1996), Taniewski, Zaporożanow, Kochanowicz, and Kruczkowski (2001) emphasize that the development of the postural control is influenced by practical activity and gaining different experiences since the earliest years. At the age of 3–4 an assessment of the overall position of the body and its individual parts is already partly stabilised. At the age of 5–6 a child develops an ability to evaluate the correct body posture, develops a habit of dynamic balance, expands the range of differentiation of particular body positions and conditions for taking them. In some 9-year-old gymnasts coordination skills in maintaining upright body posture, in terms of a unspecific static posturographic assessment, are not significantly different from adults (Kochanowicz, 2010).

Artistic gymnastics is one of the sports, where most gymnasts start their trainings at an early age of 6-7 years (Garcia, Barela, Viana, & Barela, 2011; Kochanowicz, Boraczyńska, & Boraczyński, 2009), thus their natural postural control development is influenced by gymnastic training. Gymnasts have to operate their bodies in space and on various apparatuses, (balance beam, pommel horse, still rings, dismounts, floor acrobatics etc.) where body changes rapidly the position of centre of gravity. Therefore, through intensive training they are able to perform many exercise that require a great sense of balance (Croix, Chollet, & Thouvarecq, 2010).

Many studies have been conducted to investigate the influence of gymnastic expertise on the postural control in various conditions. Garcia et al. (2011) observed that 5–7-years-old gymnasts had better postural control in static conditions with visual information in comparison to control peers, but older 9–11-year-old gymnasts and non-gymnasts did not differ in their performance with eyes opened or closed. Although, Mellos et al (2014) showed better performance of 9-10-years old gymnasts in comparision to untrained controls in flamingo balance test. F. B. Asseman, Caron, and Cremieux (2008) showed that adult gymnasts in comparison with other non-gymnast athletes demonstrated better performance only in a unipedal posture regardless of visual condition. In contrast, Vuillerme, Danion, et al. (2001) observed no difference between adult gymnasts and other athletes in postural control during a bipedal or unipedal posture. Although they noticed the influence of vision on the performance, where gymnasts demonstrated better results, especially in more difficult postures (unipedal and unipedal on the foam surface). Moreover, Asseman, Caron, and Cremieux (2004) in another study showed that there was no transfer of postural ability from the handstand or a unipedal posture to an unspecific bipedal posture. The mentioned studies suggest that postural control in static conditions might not be altered by gymnastic expertise after its establishing at the age of 8-9 and other more specific tests should be performed for gymnasts.

On the other hand, gymnasts' abilities of adjusting to various postural perturbations presents different results. Gymnasts demonstrated better performance in reweighting proprioceptive information (Vuillerme, Teasdale, & Nougier, 2001), lower attentional demand for regulating postural sway (Teasdale & Simoneau, 2001) and a shorter sensory-motor delay (Gautier, Thouvarecq, & Larue, 2008) as well as specific modifications of postural regulation (Gautier, Thouvarecq, & Vuillerme, 2008; Marin, Bardy, & Bootsma, 1999). Some studies (Dallas et al. 2016, Chen et al. 2016) used comprehensive methods of sensory organization test to evaluate the integrity of three systems (visual, vestibular, and somatosensory) in gymnasts. Chen et al. (2016) showed that 15-years old gymnasts had similar sensory organisation ability in comparison to untrained peers, although their performance was better when the visual information was unreliable. As appears from the above, that the most of the studies were performed on adult gymnasts and their untrained counterparts or other non-gymnast athletes. There is also lack of concurrence about the impact of gymnastic expertise on the visual component in postural control. Therefore, the aim of the study was to investigate the influence of gymnastics expertise of children, adolescents and young adults on the postural control with and without the use of visual information in particular their ability to visually control the center of pressure.

METHODS

The study involved a total of 105 male subjects, including 48 athletes practicing gymnastics (G) and 57 non-gymnasts (NG). Both groups were divided into three age categories. The first category consisted of children aged 8–10 years (G1, n = 21; NG1, n = 21), the second one comprised 12-14-year-old boys (G2, n = 15; NG2, n = 20), and the third one included 18–25-year-old men (G3, n = 12; NG3, n = 16). All the studied gymnasts started their training at the age of 6–7 years. The youngest gymnasts' group trained for about 22 hours a week and the middle and the oldest group trained from 24 to 26 hours a week. They were distinguished by very high sports achievements at the national and the international level. The non-training group declared no participation in sport and they were matched with gymnasts considering body mass and height. The participants were characterized by appropriate health status during the previous three months (they had not taken any pharmacological substances). The level of the subjects' basic morphological characteristics is presented in Table 1. There were no significant differences between participants in particular age groups, considering the height and the body mass. However, difference between each age group could be observed. The study was conducted with an approval of the Bioethics Committee at the Regional Medical Chamber in Gdańsk with approval number of KG -12/15. All participants as well as children's legal guardians gave informed consent to this study.

Table 1
Mean values and standard deviations of morphological characteristic of gymnasts (G) and non-gymnasts (NG) aged 8-10 years, 12-14 years, 18-25 years

		Non-gymnasts	Gymnasts	p
Height (cm)	8 – 10 years	135.6 ± 6.1	132.1 ± 6.9	0.153
	12 – 14 years	158.3 ± 8.6	154.9 ± 9.8	0.314
	18 – 25 years	175.2 ± 6.1	172.5 ± 4.0	0.193
Body mass (kg)	8 – 10 years	32.4 ± 6.4	30.1 ± 3.8	0.177
	12 – 14 years	45.8 ± 8.6	42.6 ± 7.6	0.283
	18 – 25 years	75.5 ± 14.2	72.0 ± 5.1	0.414
BMI	8 – 10 years	17.9 ± 3.0	16.7 ± 1.2	0.121
	12 – 14 years	17.9 ± 1.8	18.6 ± 1.2	0.208
	18 – 25 years	24.9 ± 4.7	24.1 ± 0.9	0.560

The study of postural control was conducted in the morning in a quiet indoor laboratory on an AccuGait force platform recording the displacement of center of pressure (COP) using the AMTI software. Measurement of static postural control in the upright position on both legs with eyes open (EO) and closed (EC) took place for 30s with a frequency sampling of 100 Hz. During all measurements, participants' feet were placed parallel and at pelvis width. Children put their hands alongside the hips and they were instructed to stay still during all measurements.

After the static measurements, the dynamic postural control with visual feedback evaluation was performed. The subject's position was the same as in the static balance trial. The time of recording the visual feedback body balance test with the 100 Hz sampling rate depended on the efficiency of the performed trial. The shorter the trial realization time, the better the performance. The trial consisted in achieving targets displayed on a 20-inch monitor screen positioned at a distance of one meter in front of the participant and at his line of sight. Each target was positioned at the line of 85% base of support (BOS). Circle-shaped targets in size of 10% BOS appeared on the monitor screen in consecutively designated locations: T0 (central) T1 (front), T0 (central), T2 (right-side), T0 (central), T3 (back), T0 (central), T4 (left-side) and T0 (central) (see Fig 1.). The target was considered achieved if the projection of the subject's COP remained within the circle for 1 seconds. Targets were displayed in exact same order for each participant and when the subject's COP reached indicated target it was highlighted.

Once the target has been achieved, another one appeared. The total number of targets to be achieved in the trial was eight. In study analysis numeric values only from the central (mean of four T0 targets) were taken into consideration. Subjects started test always from the central position, after maintaining 5 seconds at starting target in size of 10% BOS. During this task participants were instructed to reach with a cursor (visualization of their COP) the displayed target as soon and as precisely they could and to maintain at it until the next target appeared. Reliability of measuring device was previously investigated and included research involving both gymnasts (Croix et al., 2010; Harringe, Halvorsen, Renström, & Werner, 2008) and non-trained participants (Geldhof et al., 2006; Stemplewski, Maciaszek, Osiński, & Szeklicki, 2011) and demonstrated from good to excellent reliability.

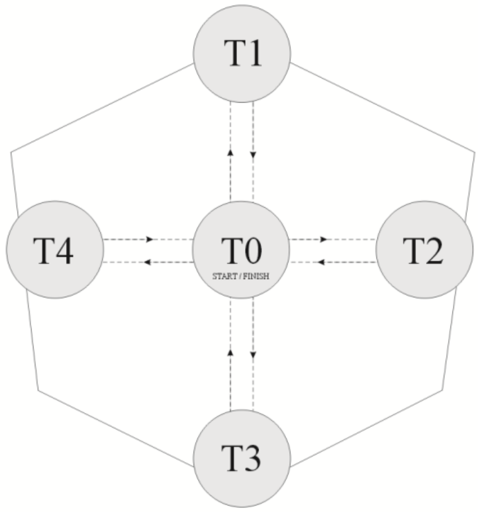

Figure 1. Designated locations: T0 (central) T1 (front), T0 (central), T2 (right-side), T0 (central), T3 (back), T0 (central), T4 (left-side) and T0 (central).

It should be stressed that a day before the study of postural control the subjects took a session acquainting them with the procedure, which consisted in three-time repetition of the trials after their clear explanation. All body balance trials were carried out three times with one-minute intervals. The best result, which in terms of postural control was the lowest value, was taken into consideration for further analysis. The level of static postural control in the upright standing position on both legs with open and closed eyes was defined by the COP surface area of the 95th percentile ellipse (surface area [mm²]). Moreover, to determine the level of dynamic postural control with visual feedback, the sum of times to achieve a target divided by the use of the target (Avg Achievement Time Index [s]) was taken into consideration.

To specify the differences in the measured posturographic indices between the non-training and the gymnastic groups in each age category, in terms of both visual control and without it, three-way ANOVA (*group vs age*) with repeated measurements (*visual control*) was used. The *group* effect determined whether the individual was a gymnast or not, which represented an impact of gymnastic training, and the *age* effect considered belonging to one of the three age categories, which implies the role of somatic development. The impact of *visual control* on static postural control was defined by the repeated measurements factor in form of performance with eyes opened and eyes closed. In a study of differences in the ability to control the center of pressure in conditions of visual feedback, two-way ANOVA was used (*group vs age*). Statistically significant main effects and their interactions were subjected to the Post Hoc-Tukey test. In addition, effect size of each factor was calculated using the Eta-squared (η^2) statistics.

The statistical significance was considered at $p < 0.05$. Shapiro-Wilk and Levene tests were performed to check the normal distribution and homogeneity of variance, respectively.

RESULTS

All statistical results of the main effects as well as interaction between them in ANOVA test can be found in Table 2.

Analysis of the mean values of the surface area in the non-training group (3.19 ± 2.59 cm^2) and among gymnasts (2.31 ± 2.20 cm^2), showed significant effects of the *group* factor ($p < 0.05$). The *age* effect also turned out to be significant ($p < 0.001$). The obtained values show that with age there is a marked trend to narrow the field of COP sways in all subjects. However, it should be noted that the difference in the mean value of surface area was significant only between subjects aged 8–10 years (4.36 ± 2.75 cm^2) and two other groups: aged 12–14 years (2.12 ± 1.62 cm^2) and aged 18-24 years (1.07 ± 0.65 cm^2). The results of the static postural control among the oldest subjects were on the verge of significance in comparison to the younger age category. The interaction between *age* and *group* effect showed to be insignificant ($p > 0.05$) and the main effect of *visual control* was significant ($p < 0.0001$) in the form of lower surface area in EO (2.02 ± 1.73 cm^2) in comparison to EC (3.47 ± 3.14 cm^2) condition. An interaction between *visual control* and *age* was also significant ($p < 0.05$) where differences between performance in EO and EC were significant only in the age group of 8–10 (EO: 3.23 ± 2.0 cm^2 vs EC: 5.50 ± 3.54 cm^2) and 12–14 (EO: 0.80 ± 0.41 cm^2 vs EC: 1.35 ± 0.90 cm$^{2)}$. An Interaction between *group* and *visual control* ($p > 0.05$) as well as the interaction between the *group*, *age* and *visual control* effect of static postural control defined by the surface area showed to be insignificant ($p > 0.05$). However, it needs to be stressed that in all age categories gymnasts achieved better results than non-gymnasts in postural control with both eyes open and eyes closed (see Fig. 2).

In the analysis of dynamic balance task with visual feedback, differences between groups were reported in the Avg Achievement Time Index. For this variable, the effect of the *group* factor turned out to be significant at $p < 0.05$, where results of non-gymnasts and gymnasts were 8.66 ± 8.14 and 5.73 ± 3.74 s, respectively. The analysis of the *age* effect also showed a significant result ($p < 0.001$), where the significant differences were observed between the 8–10-year-olds (10.49 ± 7.91 s) and 12-14-year-olds (5.36 ± 4.56 s) and 18–25-year-olds (5.16 ± 4.88 s). Interaction between the *group* and the *age* factors (see Fig. 3) showed to be significant ($p < 0.05$). It should be emphasised that the differences in gymnasts and non-gymnasts in each age category was significant only in reference to the youngest non-training boys.

Table 2
Analysis of the static and dynamic postural control with visual feedback. Two groups vs three ages vs two visual conditions ANOVA of repeated measures and two groups vs three ages conditions ANOVA.

Variable	Effect	F	df	p	Effect size (η2)	Post-Hoc	p
COP surface area [mm]	Gr vs Age vs Vc	0.53	2, 99	0.529	0.01		
	Gr vs Age	0.58	2, 99	0.556	0.01		
	Gr vs Vc	3.34	1, 99	0.077	0.03		
	Age vs Vc	7.87	2, 99	0.001	0.13	G1,G2,NG1,NG2: EO < EC	< 0.01
	Age	30.45	1, 99	0.000	0.38	G1,NG1 > G2,G3,NG2,NG3	< 0.01
	Gr	6.34	1, 99	0.013	0.06	G < NG	0.028
	Vc	49.45	1, 99	0.000	0.33	EO < EC	0.001
Average Achievement Time Index [s]	Gr vs Age	3.38	2, 97	0.038	0.07	NG1 > NG2,NG3,G1,G2,G3,	< 0.01
	Gr	6.97	1, 97	0.009	0.07	G < NG	0.012
	Age	10.79	2, 97	0.000	0.18	G1,NG1 < G2,G3,NG2,NG3	< 0.01

Legend: COP – center of pressure; Gr – group; Vc – visual control, NG – non-gymnasts, G – gymnasts, (NG/G)1 – 8-10 years old, (NG/G)2 – 12-14 years old, (NG/G)3 – 18-24 years old, EC – eyes closed, EO – eyes opened, ns – not significant

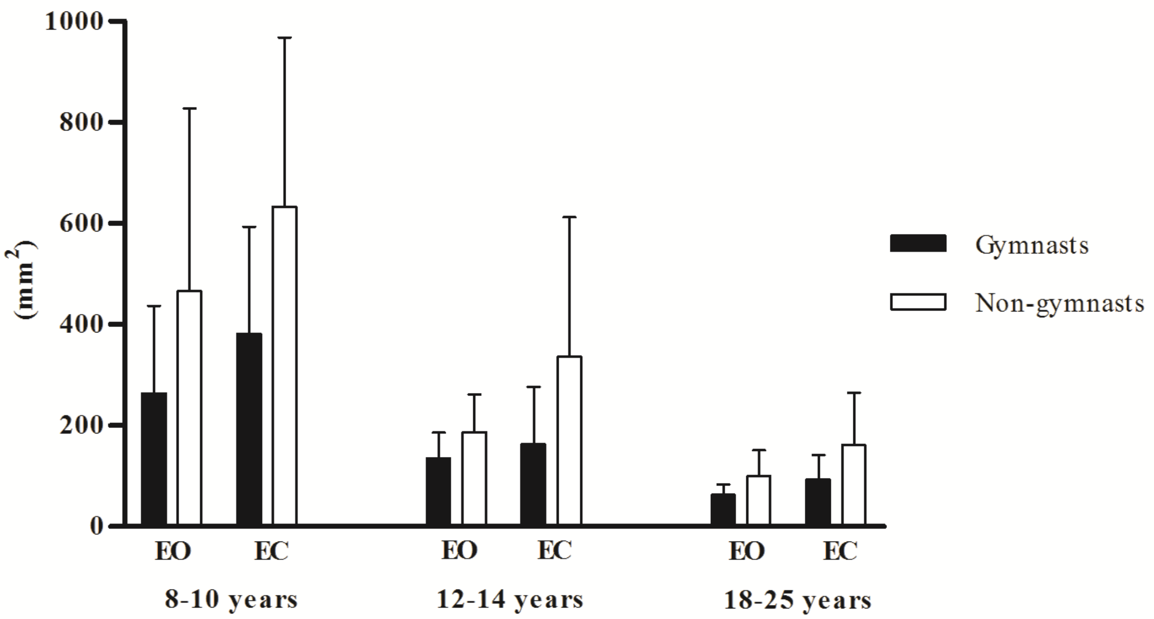

Figure 2. Postural control with both eyes open (EO) and eyes closed (EC).

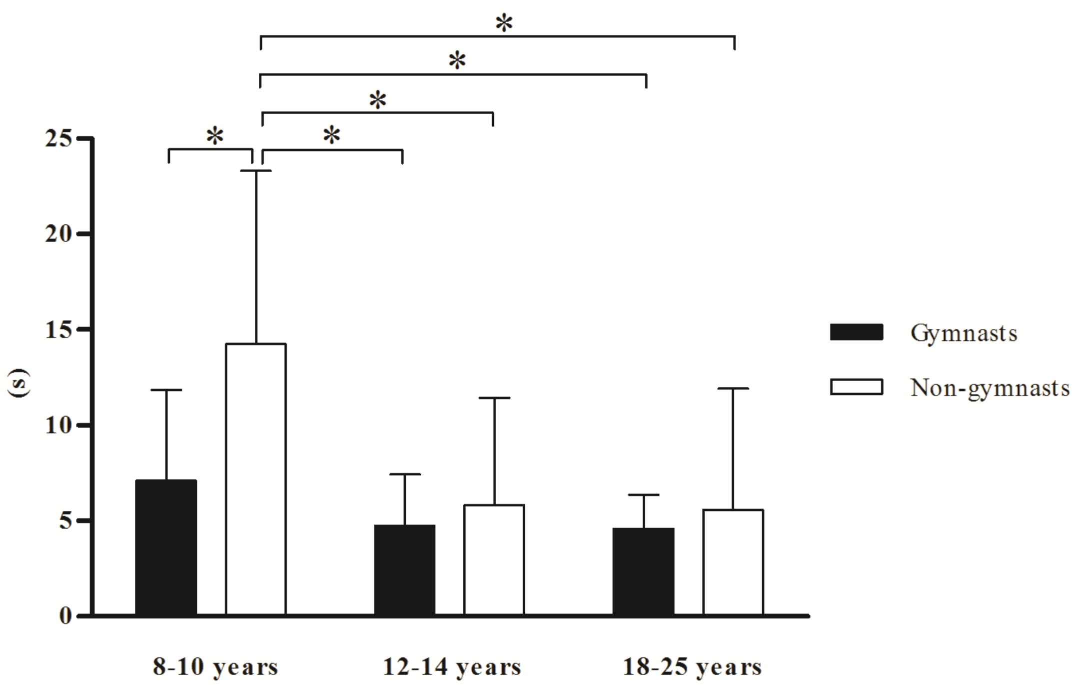

Figure 3. Interaction between the *group* and the *age* factors.

DISCUSSION

Analysis of research results allows to extend the existing knowledge of the development of the postural control in gymnasts and non-training persons. They point to a great differentiation of all measured indices in eyes open, eyes closed, and visual feedback trials. In the study, non-gymnasts and those training artistic gymnastics, regardless of their age and sports level, were characterized by the coefficient of variation at the level of 15-60%. These results allow making a statement about a highly individualized nature of the body balance function during the ontogenetic development between 8–25 years of age.

A similar study of influence of gymnastic training on the static balance control was performed by Garcia et al. (2011), although they investigated female gymnasts and girls at the age of 5–11, while our study consisted of male gymnasts and controls at the age from 8 to 25 years. They found that the youngest group of non-gymnasts (5–7 years old) had significantly worse performance of static bipedal posture in comparison to older peers (9–11 years old) and gymnasts of both ages. The older groups of gymnasts and non-gymnasts did not differ, which was also noticed in study of Hernández Suárez, Guimaraes Ribeiro, Hernández Rodríguez, Rodríguez Ruiz, and García Manso (2013). In our study the difference between youngest male gymnasts and non-athletes (8–10 years old) did not reached significance, although it was close to it. Moreover, both gymnasts' and controls' performance was significantly worse in comparison to gymnasts and adolescents at age of 12–14 years and adults.

The influence of the *vision* factor on static postural control was significant in our youngest (8–10 years old) groups of gymnasts and non-gymnasts. Their static balance performance was better in eyes open condition. In compare, studies on younger female groups showed that at the age of 5–7 years only gymnasts were able to effectively use their visual control to improve performance of static quiet stance (Garcia et al., 2011) . This same study showed that both gymnasts and non-gymnasts aged 9–11 years were not influenced by a lack of vision and their performance was similar both with eyes opened and closed. However, our study could not confirm that in the middle group (12–14 years old), a lack of vision did not have an impact only on the performance of gymnasts. Although, it should be noted that our study consisted of male gymnasts and controls while the one mentioned above investigated females. However, it has been shown that boys exhibit a lag in terms of developing postural control (Roepke, Smith, Ronnekleiv, & Kelly, 2012; Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006). Especially up to the age of 12, girls show better postural control than boys (Roepke et al., 2012).

Moreover, static postural control of 12–14-year-old gymnasts was similar to both groups of adults regardless of vision conditions. The same lack of impact of vision on the level of static balance performance within adult gymnasts and other non-gymnast athletes were previously reported (Asseman et al., 2004; Vuillerme, Teasdale, et al., 2001).

Such results suggest that adults develop their static balance abilities to the extent where a lack of vision is compensated by the other senses and such development can be facilitated through gymnastic training. The results of the present analysis confirm observations of other authors engaged in research with a use of the posturographic method that static postural control in conditions of relative peace among the youth and adults gymnasts does not fully reflect their balance capabilities (Asseman et al., 2004; Hernández Suárez et al., 2013; Vuillerme, Teasdale, et al., 2001).

According to Davlin-Pater (2010), level of dynamic postural control development could be evaluated, among others, by biofeedback posturographic tests. Such test was proposed in our study in contrast to unspecific static bipedal condition. Results in dynamic postural control with visual feedback were comparable to those in static conditions with eyes opened, thus the impact of gymnastic training was only visible for children at the age from 8 to 10 years. It also may indicate that during the early-school period systematic participation in gymnastics training which includes exercises based on joint position and force sense can increases the ability to coordinate and regulate body posture. Considering dynamic postural control, Vuillerme, Teasdale, et al. (2001) showed that adult gymnasts demonstrated better performance in reweighting proprioceptive information in comparison to other athletes. Moreover, Taniewski et al. (2001) investigated impact of stimulating vestibular organ by rotation of the body in the longitudinal axis among gymnasts and non-athletes. It has been shown that after a stimulation gymnasts who were characterized by better results of the COP surface area prior to the excitation of the vestibular organ also had better results after its stimulation, as well as that difference between gymnasts and non-athletes were increasing with age of participants. Other studies showed that after perturbation of the body in the sagittal plane, highly qualified gymnasts stood out with much quicker recovering balance than non-training subjects. Moreover, in gymnasts during stabilizing the body posture the most distinct movements were recorded in the knee joints, while non-gymnasts used their hips for this purpose, showing the training influence on strategy of maintaining body balance (Gautier, Thouvarecq, & Larue, 2008). Gautier, Thouvarecq, and Chollet (2007) and Viullerme and Nouguier (2004), point to the need to monitor changes in postural control that occur in athletes under the influence of specific exercises, systematically applied in training. Our study showed that both unspecific static as well as dynamic postural control with visual feedback are affected by gymnastic training, mainly in early years of human development. The limitation of the study is that the static and dynamic tasks used in the research did not fully represent adult gymnasts' capabilities of postural control. This was due to the fact that the tests included in the study were chosen so that they could be performed by both professional gymnasts and untrained children. However, more complex or more specific postural tasks could be useful in investigating and showing adult gymnasts' postural control potential.

CONCLUSIONS

Results may suggest that both static postural control in unspecific bipedal conditions and dynamic postural control in visual feedback conditions, after developing them, are at a similar level despite gymnastic training, although training can accelerate the development of such abilities in children and early adolescents. While the unspecific static bipedal and dynamic with visual feedback tests do not reflect the capabilities of postural control in adult gymnasts, other more sport-specific tests should be incorporated for them.

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