THE EFFECT OF INTERVENTION BALANCE PROGRAM ON POSTURAL STABILITY

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Abstract

The study is focused on evaluation of the effect of intervention balance program on postural stability (PS) among university students of "Specialization of gymnastic sports". The experimental group (n = 18) performed a specific balance program in addition to their regular training sessions and the control group (n = 15) underwent their normal sport regimen. The multi-sensory FOOTSCAN platform was used for the posturographic examination. We evaluated the parameters Centre of Pressure (COP) *in the tests: narrow standing position with (NS-VC) and without (NS-WC) visual control, flamingo stance on the preferred leg (FPL) and non-preferred leg (FNL). The results revealed a significant effect of time on changes in PS in bipedal tests regardless of group and visual control ($F_{1,62} = 4.65$, $p = 0.03$, $\eta^2_p = 0.07$). Visual control had a significant effect on PS in both groups ($F_{1,62} = 12.55$, $p = 0.001$, $\eta^2_p = 0.17$). The intervention program had a significant effect on PS in one leg standing position (FPL: $COP_{pre\text{-}test} = 1006.01 \pm 396.17$ mm, $COP_{post\text{-}test} = 875.78 \pm 284.24$ mm, $t_{17} = 2.34$, $p<0.05$; FNL: $COP_{pre\text{-}test} = 1102.44 \pm 323.82$ mm, $COP_{post\text{-}test} = 987.89 \pm 357.63$ mm, $t_{17} = 2.20$, $p<0.05$) and test NS-WC ($COP_{pre\text{-}test} = 145.67 \pm 34.91$ mm, $COP_{post\text{-}test} = 128.89 \pm 36.03$ mm, $t_{17} = 3.26$, $p<0.05$). In the control group, we found a significant improvement only for FNL test ($p<0.05$). The results of study showed that even a low volume specific balance program performed in addition to regular training sessions may also lead to postural stability enhancement.*

Keywords: *postural stability; gymnastics; balance program; visual control; balance assessment.*

INTRODUCTION

Stability is an ability of the system to stabilize under stimuli to the equilibrium state. Because two-thirds of our body mass is located in two-thirds of body height above the ground we are an inherently unstable system unless a control system is continuously acting. The ability to maintain a balanced position depends on the size of support surface, the center of gravity, height of the central body and its projections on the base of support (Winter, 1995). The level of postural stability refers to the ability of individuals to minimize fluctuations of the center of gravity in other words, the ability to maintain the upright stance and adequately respond to changes in external and internal forces. Vařeka and Vařeková (2009) define three main components of the system upright stance, namely sensory, control and executive component. The sensory component is represented by proprioception and exteroception, vision and vestibular system. The control function is provided by the CNS – brain and the spinal cord. Finally, the executive component is represented by the movement system. In a broader context, postural stability can be expressed as the level of balance ability, which belongs to basic coordination functions. Nashner (1997) defines balance as the process of maintaining the position of the body's center of gravity vertically over the base of support relying on rapid, continuous feedback from visual, vestibular and somatosensory structures and then executing smooth and coordinated neuromuscular actions.

From a physiological point of view, balancing consists of a number of phases. The first phase is a detection of a specific situation via sensory systems. When maintaining an upright position, a man uses a combination of information from vestibular apparatus, visual and proprioceptive information (Fransson, Kristinsdottir & Hafström, 2004; Vuillerme, Pinsault & Vaillant, 2005). Proprioception is based on a function of mechanoreceptors in skin, muscles and connective tissue and provides information about relative configuration and position of body segments, thus proprioception is essential for coordinated functioning of muscles (Shumway-Cook & Woollacott, 2007). Visual information conveys the spatial coordinates which are necessary for spatial orientation. When the visual control is limited, the correcting movements for maintaining the given position are of greater extent (Vuillerme, Teasdale & Nougier, 2001). The vestibular apparatus is a sensory organ that mediates perception of balance, respectively perception of the position and movements of the head. Strešková (2003) in her study confirmed that physical exercises have a positive effect on the function of vestibular apparatus; moreover, its functions are affected by the position of the head (frontbow, rearbow, handstand). For sporting purposes Hirtz (1997) defines seven coordination abilities: differentiation ability, orientation ability, balance ability, reaction ability, ability to connect movements and ability to transform and adapt movements. Coordination abilities, and thus also balance ability, are genetically determined but with a suitably chosen external stimulus of a sufficient intensity they can be extensively influenced (Hirtz, 2002). The level of coordination is significantly affected by the balance ability, i.e. ability to stabilize and maintain the human body in a balanced position. Experts have shown that there are relationships between the proper functioning of the balance and other coordination motor skills (Bressel, Yonker, Kras & Heath, 2007). Balance ability can be perceived as a prerequisite for an athlete's performance which is particularly determined by movement control processes which make him or her eligible for sport performance at the certain level (Blume, 1981). Several studies have independently demonstrated that strength training improve balance, or that interrelationships between individual physical abilities can be found, respectively (Binda, Culham & Brouwer, 2003; McCurdy & Langford, 2006). The maintenance of balance is a complex physiological process involving the interactions of numerous body sub-systems regarding the difficulty of the task and the environment (Kaščček & Supej, 2014). The ability to balance the body plays an important role in the shaping and improving specialized motor habit, as it is the basis for the mastery of complex technical elements necessary to achieve significant sporting results (Poliszczuk, Broda & Poliszczuk, 2012). It is an important attribute in learning sports skills, and shows differences depending on the characteristics of sports branches (Sirmen et al., 2008; McGuine, Greene, Best & Leverson, 2000). According to Strešková (2003) a sensitive period for development of balance is younger school age between 8 and 12 years. Children achieve adult level already at the age of 13. Studies which focused on the comparison of athletes and non-athletes showed that athletes improve balance significantly more than non-athletes due to their training stimuli over time (Balter, Stikroos, Akkermans & Kingma, 2004; Bressel et al., 2007).

In gymnastic sports, such as artistic and rhythmic gymnastics, the level of balance abilities is one of limiting factors due to movement content and the way of evaluation of the sport performance. Simultaneously, gymnastic activities represent specific stimuli which influence the level of individual's balance abilities. It has been proved that many factors as different physiological and anthropometric factors might influence the gymnast's performance (Cagnoa et al., 2009). Gymnastics requires a great diversity of movements: transition from dynamic and static elements and vice versa, frequent changes of the body position in space (Bučar Pajek, Čuk, Kovač & Jakše, 2010). This represents high demands on coordination, i.e. balance ability, respectively. Tsigilis and Theodosiou (2008) in their study present that the significant difference between gymnasts and non-athletes of the presented study can be explained as the result of repetitive training experiences that influence motor responses. Similarly, other studies showed that gymnasts achieved better results in balance tests than untrained adolescents and that fitness and coordination training could enhance the level of postural stability (Vuillerme & Nougier, 2004; Poliszczuk & Broda, 2010; Ramsay & Riddoch, 2001). Application of balance exercises also has impact in a health-preventive field. Hrysomallis (2007) state that a high level of balance ability decreases sport injury risk and that this relationship was confirmed by a number of studies. Balance requires achieving the most mechanically efficient position of the body, reducing the abnormal wearing of joint surfaces and reducing stress on the ligaments holding the joints of the spine together, becoming a useful skill for the daily life (Mellos, Dallas, Kirialanis, Fiorilli & Di Cagno, 2014). Balance training could prevent low back pain and lessens fatigue because muscles are being used more efficiently, allowing the body to use less energy (Harringe, Nordgren, Arvidsson & Werner, 2007). The aim of presented study is to evaluate whether a low volume balance program performed in addition to regular gymnastic training sessions may lead to postural stability enhancement of gymnasts.

METHODS

The research involved 33 participants, male and female students of the Faculty of Physical Education and Sport, Charles University in Prague (gymnastic specialization), who participated in artistic or rhythmic gymnastics training in their clubs in addition to studying at the time of project implementation. The condition for participation in the project was good current state of health without contraindications that would affect the results of measurements. Participants were randomly divided into two groups; the members of the experimental group performed a specific balance program in addition to their regular club training sessions for 14 weeks (once a week for 30 min) and the members of the control group underwent their normal study and sport regimen. The movement base of gymnastic sports, such as artistic or rhythmic gymnastics, is very similar, with high demands on firming of posture and balancing abilities. The postural stability of the gymnasts (both females and males) is influenced by training and we assume that it can be also affected by a specific intervention program. Division into groups was carried out with no respect to differences in number of men and women, performing artistic or rhythmic gymnastics or individual's level of performance. The experimental group: n = 18; 13 women; 5 men; average age 21.50±1.17 years; average body height 170± 6.57 cm; average body weight 64.60±7.86 kg. The control group: n = 15; 8 women; 7 men; average age 22.50±1.69 years; average body height 171±8.50 cm; average body weight 65.70±8.90 kg. The period between the first and second measurement was 14 weeks in both groups.

The research was approved by the Ethical Committee of the Faculty of Physical Education and Sports at Charles University in Prague. Measurements were carried out in accordance with the ethical standards of Declaration of Helsinki and ethical standards in sport and exercise science research (Harriss & Atkinson, 2011).

COP (Centre of Pressure) measured from a force platform is generally considered the gold standard measure of balance, i.e. postural stability, respectively (Clark et al., 2010). Winter (1995) defines COP as the point location of the vertical ground reaction force vector. It represents a weighted average of all the pressures over the surface of the area in contact with the ground. In addition to a bipedal stance, a one leg stance, which is a part of natural locomotion of a man, is used as a diagnostic means in a series of motor tests for assessing postural stability (Fetz, 1987).

The multi-sensory FOOTSCAN platform (RS scan; Belgium; 0.50 m × 0.40 m; approximately 4100 sensors; sensitivity from 0.10 of N/cm^{-2}; sampling frequency 500Hz) was used for the posturographic examination. Pressure on individual sensors was measured, and the center of pressure (COP) was calculated on the contact area. Resulting force reacting to the ground is calculated from pressure and contact area under both feet by the equation (1):

$F = p \times S$ (1)

where F is reacting force [N], p is pressure [Pa], S is area [m^2] and this force is called Centre of Force (COF). Testing of postural stability was composed of 4 standardized tests (Kapteyn et al., 1983):

- *T1 (NS-VC) - wide stance with visual control lasting for 30s,*
- *T2 (NS-WC) - wide stance without visual control lasting for 30s,*
- *T3 (FPL) - flamingo stance on the preferred leg lasting for 60s,*
- *T4 (FNL) - flamingo stance on the non-preferred leg lasting for 60s.*

A laterality test was carried out before the measurement using a question which leg is preferred (e.g. when kicking a ball) and which one is non-preferred. Stability was measured before and after experimental period in the above-mentioned order of the tests. During the measurements participants stood at a distance of 3 meters from a wall on which a visual point (a black circle with a diameter of 3 cm) was located at the level of the participant's eyes. The standard standing position with a wide base was measured according to standard practice (Kapteyn et al., 1983) and transparent sheeting for the tracing foot position was used during the examination. We recorded the entire course of total travelled way (TTW) of COP. Measurements were carried out in a laboratory under conditions which minimized the influence of interfering elements. At the same time, it was ensured that the participants did not perform physically demanding activities before the measurement.

Intervention balance program

The experimental group underwent a specific balance program (14 sessions, 1× a week for 30 minutes approximately) during the semester (in addition to their own training sessions):

- ballet exercises (rhythmical slow movements of the unloaded leg in one leg stance according to the demonstrator – 5 min),
- balancing in medicine ball stance with symmetrical arm movements according to instructions (5 min),
- walking on a low balance beam with a book on the head (5×),
- rope skipping on a low balance beam (5 series/30s),
- balancing on inflatable balance boards in bipedal and unipedal stances – throwing and catching a ball in this labile position (5 min),
- balancing on a balance board plate put on a metal cylinder (5 series/30s).

The normality of the distributions was assessed using the Shapiro-Wilks test. Descriptive statistics were calculated for both measurements. Two-way mixed-design ANOVA with two between subject effects

(Group [experimental vs. control] and visual control [with and without vision control]) and one within subject effect (intervention) was used for evaluating differences in TTW between the factors. Moreover we did two-way mixed-design ANOVA analysis for with two levels of between subject factor Group (experimental vs. control), two levels of between factor for Laterality (preferred vs. non-preferred leg) and with two levels of within subject factor Intervention (1st and 2nd measurement). Paired differences between the pre- and post-intervention were evaluated using Student's t-test for dependent samples. In case of violation of data distribution we used nonparametric Wilcoxon's test for paired samples. In case of violation of data distribution we used nonparametric MannWhitney U test for unpaired samples. The probability of a type I error was set at $\alpha=0.05$ in all statistical analyses. The effect size was evaluated using the PartialEta Squared coefficient (η^2_p) Statistical analyses were performed using IBM® SPSS® v21 (Statistical Package for Social Science, Inc., Chicago, IL, USA).

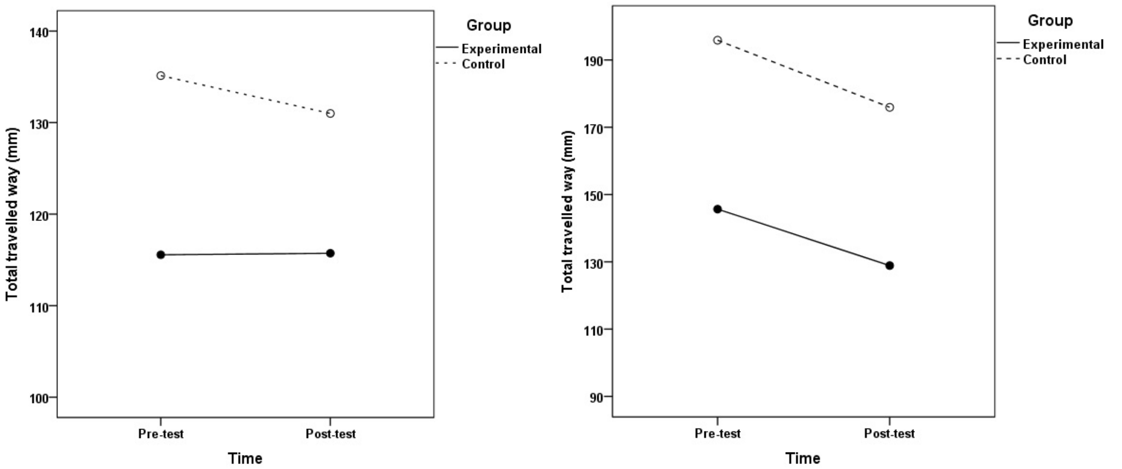
RESULTS

Mixed design ANOVA showed a significant effect of time on changes in postural stability in the bipedal tests regardless of group and visual control ($F_{1,62} = 4.65$, $p = 0.03$, $\eta^2_p = 0.07$). Between-subject effect in the monitored groups (experimental vs. control group) was significant in the bipedal stance ($F_{1,62} = 9.87$, $p = 0.003$, $\eta^2_p = 0.14$). Also visual control significantly influenced the level of participants' postural stability ($F_{1,62} = 12.55$, $p = 0.001$, $\eta^2_p = 0.17$) (Figure 1 A,B). The interaction effect between the main factors TIME×GROUP and TIME×VISUAL CONTROL was not significant ($p>0.05$). In T1 test (NS-VC), no significant difference was found between the level of postural stability measured in input and output measurements in any of the tested groups (experimental or control). In T2 test (NS-WC), we found a significant improvement in the level of postural stability in the experimental group ($p<0.01$), while the change in the control group was not significant (Table 1).

Table 1
The level and comparison of postural stability in the selected tests and monitored groups

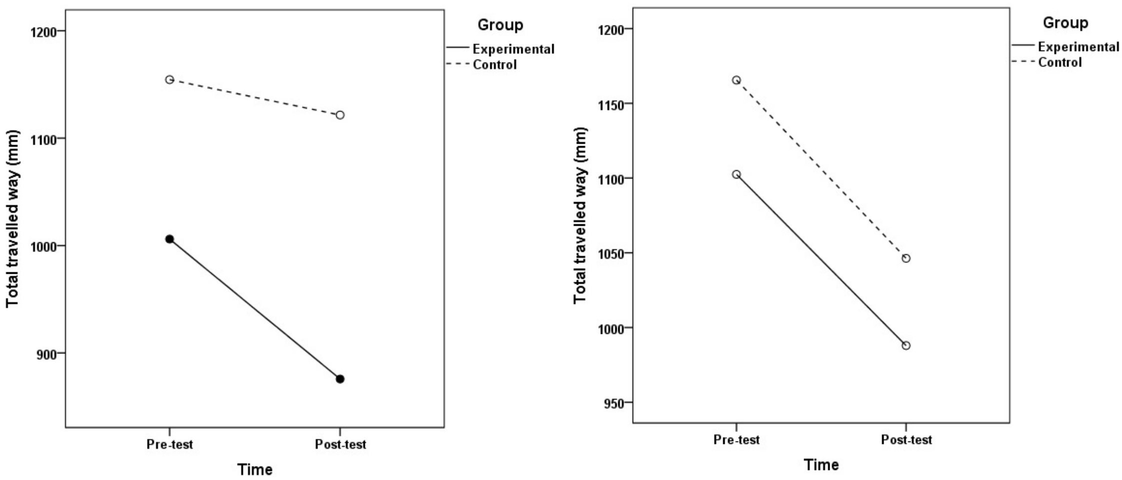
Group	Test	Pre		Post		t	Sig
		$\bar{x}$	SD	$\bar{x}$	SD		
EG	NS-VC [mm]	115.56	34.91	115.72	28.90	0.04	0.97
	NS-WC [mm]	145.67	46.81	128.89	36.03	3.27	0.01
	FPL [mm]	1006.01	396.17	875.78	284.24	2.34	0.03
	FNL [mm]	1102.44	323.82	987.89	357.63	2.20	0.04
CG	NS-VC [mm]	135.13	38.09	131.00	42.14	0.42	0.68
	NS-WC [mm]	195.86	79.36	175.93	54.58	1.23	0.24
	FPL [mm]	1154.47	390.77	1121.53	396.06	0.46	0.66
	FNL [mm]	1165.53	264.22	1046.27	190.96	2.29	0.04

Legend: EG – experimental group, CG – control group, NS-VC – narrow standing with visual control, NS-WC – narrow standing without visual control, FPL– flamingo test on preferred leg, FNL – flamingo test on non-preferred leg, SD – standard deviation



A B

Figure 1. A - changes in body postural stability in the bipedal test with visual control, B - changes in body postural stability in the bipedal test without visual control.



A B

Figure 2. A - changes in postural stability in the flamingo test on the preferred leg, B - changes in postural stability in the flamingo test on the non-preferred leg.

When testing postural stability in one leg stance (flamingo stance) we discovered a significant effect of time on its level ($F_{1,62} = 2.64$, $p = 0.001$, $\eta^2_p = 0.16$) (Figure 2A,2B). In this type of stance we did not find any significant difference in the level of postural stability between the monitored groups ($F_{1,62} = 2.64$, $p = 0.11$, $\eta^2_p = 0.04$) and in the standing leg ($F_{1,62} = 0.21$, $p = 0.65$, $\eta^2_p = 0.003$). The interaction effect between the main factors TIME×GROUP and TIME×LATERALITY was not significant ($p>0.05$). We found a significant improvement in both tests (FPL, FNL) after intervention in the experimental group (Table 1). In the control group, an insignificant change was found when standing on the preferred leg and a significant change when standing on the non-preferred leg (Table 1).

DISCUSSION

The results of our study showed significant improvements of postural stability in the experimental group in three tests (NS-WC, FPL, FNL) out of four, while in the control group improvement was only found in one test (Table 1). In the bipedal test with visual control, we did not find any improvement of postural stability performance in any of the groups. In test without visual information after comparing absolute values, we found improvement in both groups (Table 1); however, only in the experimental group the difference was significant and effect size was medium. In the flamingo test on the non-preferred leg, a significant improvement ($p<0.05$) was found in both groups (control group by 10.23 % and experimental group by 10.39 %); in flamingo test on the preferred leg a significant improvement only appeared in the experimental group (by 12.94 %). These results correspond with the results of the study by Mellos et al. (2014), who reported a year-on-year improvement in flamingo test on the preferred leg by 17.32 % in young gymnasts (11-12 years old). The non-preferred leg was not tested. However, among non-sporting youths of the same age the improvement was only minimal. Kochanowicz, A., Kochanowicz, K., Niespodziński, Mieszkowski and Sawicki (2017) in their study comparised the groups of gymnasts and non-gymnasts from the point of view influence of gymnastics expertise of children on the postural control with and without the use of visual information in three age categories of males (8-10, 12-14 and 18-24 years). Results show that in analysis of the center of pressure surface area, all gymnast had significantly better ($p=0.01$) static postural control in regardless visual control (group effect), although, there were no differences in each individual age groups (group vs age; $p=0.55$) and that gymnastic training has positive influence in postural control of young and adults. Hernández Suárez, Guimaraes Ribeiro, Hernández Rodríguez, Rodríguez Ruiz, and García Manso (2013) in their study analyzed the effect of early systematic gymnastic training on postural performance and control by comparing young rhythmic gymnastics (9 years) with non-athletes of the same age. Results both investigated groups were similar as regards their anthropometric data and did not prove improvement compared with non-athletes. Authors report that improvement of performance due to learning is specific to the task and not directly transferred or generalized for example to more usual upright stance in young females. This corresponds with the findings of a recent study Kümmel, Kramer, Giboin and Gruber (2016) in which they report, that in healthy populations balance training can improve the performance in trained tasks, but may have only minor or no effects on non-trained tasks. Consequently coaches should identify exactly those tasks that need improvement, and use these tasks in the training program and as a part of the test battery that evaluates the efficacy of the training program.

Presented study is, unlike the previous studies , focused on verifying the effect of specific balancing training performed in addition regular gymnastic training sessions , which itself has a stimulating effect on postural stability. Bryant, Trew, Bruce, Kuisma and Smith (2005) in their studies reported that there are no gender differences after normalizing (the subject's height) the balance performance in elders or adults. Unlike this study Dallas, G. and Dallas, K. (2016) present findings that elite female gymnasts exhibit better postural stability scores compared to elite males. The authors agree that gender differences of postural stability can be affected by many different circumstances and further research is needed. Priority of this study is to evaluate whether a low volume balance program can influence postural stability of gymnasts, regardless of gender differences.The intervention balance program was performed by the experimental group for 14 weeks, with a frequency of 1× a week. Each session lasted for approximately 30 minutes, which is not a great stimulus. Both groups also performed regular gymnastic training during this period and postural stability performance in both groups improved between pre-test and post-test assessment. A greater improvement seen in the experimental group points to the fact that such a low volume specific balance program performed in addition to regular training activities may also lead to postural stability enhancement. The fact that the improvement of postural stability was also in the control group (3×small and 1× medium effect size) can be explained as the effect of normal gymnastic training, which was the same as before the experiment, without specific balance exercises. Based on the findings from literary sources (Arazi, Faraji & Mehrtash, 2013; Strešková, 2003), it is supposed that there would be a greater efficiency of similar programs among youths or among male and female gymnasts at lower performance levels. However, it is necessary to confirm these results through further studies. Postural stability, or balance ability, respectively, must be perceived as a dynamic parameter, the value of which is affected by variability of endogenous and exogenous factors throughout the changes over time. The factors are of both physical and psychological nature. The level of concentration and other individual mental functions can significantly affect parameters of postural stability (Zech et al., 2010). Another factor influencing the level of balance ability is fatigue, both acute and cumulative. In an organism under fatigue, chemical-physical changes appear that negatively affect functional systems (Gauchard, Gangloff, Vouriot, Mallié & Perrin, 2002). The fact that regular balance exercises can enhance postural stability has been confirmed by several studies (Granacher, Gollhofer & Strass, 2006; Myer, Ford, Brent & Hewett, 2006) but not with such specific and low-frequency intervention (1x a week) for 14 weeks. Our results confirm that even low-frequency balance training can improve postural control in physical education students with gymnastic specialization. The results may be partly influenced by the different input level of postural stability the control and experimental group, but this is due to a randomized selection of respondents. Also studies focused on the comparison of postural stability between gymnasts and non-athletes or between gymnasts and other athletes are in favor of gymnasts (Mellos et al., 2014; Vuillerme & Nougier, 2004) and thus support the thesis of the necessity of including gymnastic activities in school programs. Bressel et al. (2007) compared the level of static and dynamic balance in female basketball players, soccer players and gymnasts. Gymnasts and soccer players did not differ in terms of static and dynamic balance. In contrast, basketball players displayed inferior static balance compared with gymnasts and inferior dynamic balance compared with soccer players. The authors suggest that gymnasts must learn to keep their balance when performing leaping and tumbling maneuvers, as well as in static poses, barefoot on surfaces that vary in stiffness, or to balance in handstand that require specific balance ability by gymnasts. According to Hrysomallis (2011), based on the available data from cross-sectional studies, gymnasts tended to have the best balance ability, followed by soccer players, swimmers, and then basketball players.

Tests used in our study were only focused on the assessment of static balance; further research could extend this field by assessing the level of dynamic stability. Static balance is the ability to maintain a base of support with minimal movement. Dynamic balance may be considered as the ability to perform a task while maintaining or regaining a stable position or the ability to maintain or regain balance on an „unstable surface" with minimal extraneous motion (Paillard & Noe, 2006). One of reasons of low correlation between static and dynamic balance are, according to Cromwell and Newton (2004), mechanical and physiological differences applied in the process of maintaining static and dynamic balance. It would also be appropriate to focus in the further studies on assessment of asymmetries in postural stability that could be a sign of preferring one of the limbs (footnesses), for instance in jumping exercises (Gryc et al., 2013). To increase the objectivity of postural stability determination Błaszczyk (2016) recommend expanding the COP characteristics about three novel output measures: the sway directional index, the sway ratio, and the sway vector.

CONCLUSION

Physical fitness depends on innate predispositions and environmental factors, such as primarily training. With the development of the human body, over time the level of balance ability changes and the training factor becomes increasingly important. The results of our study showed that balance training with a frequency of 30 min per week lasting for 14 weeks can be a worthwhile adjunct to the usual training of athletes and results in improving body postural stability. However, more research is required to confirm this effect on elite athletes. In elite male and female gymnasts, a relatively high level of postural stability can be assumed as a result of adaptation to specific training stimuli. Gymnastic training up to the stage of elite training is a long-term process which is affected by many factors, including training methods and approaches. Inclusion of specific balance programs in addition to the usual training of individual disciplines is, particularly in youth categories, a worthwhile extension to physical training. Our findings indicate a significant effect of balance intervention program on unipedal postural stability as well as bipedal postural stability without visual control. The results may be beneficial for researchers, clinical and sports science staff in gymnastics and other sports because the balance program is a part of performance preparation as well as injury prevention in a many sports. Results may be also a useful set of reference values for comparison with subjects of particular groups.

REFERENCES

Arazi, H., Faraji, H., & Mehrtash, M. (2013). Anthropometric and physiological profile of Iranian junior elite gymnasts. *Facta universitatis-series: Physical Education and Sport, 11*(1), 35-41.

Balter, S.G.T., Stikroos, R.J., Akkermans, E., & Kingma, H. (2004). Habituation to galvanic vestibular stimulation for analysis of postural control abilities in gymnasts. *Neuroscience Letters, 366*, 71-75.

Binda, S., Culham, E., & Brouwer, B. (2003). Balance, muscle strength, and fear of falling in older adults. *Experimental Aging Research*, *29*, 205-219.

Błaszczyk, J. W. (2016). The use of sway vector for the assessment of postural instability. *Gait & Posture, 44*(2), 1-6.

Blume, D. (1981). Charakteristik der koordinations Fahigkeiten und Möglichkeiten Iber Entwicklung im Trainingsprozes. *Zeitschrift*, *3*, 17–41.

Bressel, E., Yonker J.C., Kras, J., & Heath, E. (2007). Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *Journal of Athletic Training, 42*(1), 42–46.

Bryant, E.C., Trew, M.E., Bruce, A.M., Kuisma, R.M., & Smith, A.W. (2005). Gender differences in balance performance at the time of retirement. *Clinical Biomechanics, 20*, 330-335.

Bučar Pajek, M., Čuk, I., Kovač, M., & Jakše, B. (2010). Implementation of the Gymnastics Curriculum In: The Third Cycle of Basic School In Slovenia. *Science of Gymnastics Journal, 2*(3), 15-17.

Cagnoa, A.D., Baldari, C., Battaglia, C., Monteiro, M.D, Pappalardo, A., Piazza, M., & Guidetti, L. (2009). Factors influencing performance of competitive and amateur rhythmic gymnastics-Gender differences. *Journal of Science and Medicine in Sport*, *12*, 411-416.

Clark, R.A., Bryant, A.L., Pau Y,. McCrory, P., Bennell, K., & Hunt, M. (2010). Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. *Gait & Posture*, *31*(3), 307-310.

Cohen, J. (1992). Statistics a power primer. *Psychological Bulletin, 112*(1), 115-59.

Cromwell, R. L., & Newton, R. A. (2004). Relationship between balance and gait stability in healthy older adults. *Journal of Aging and Physical Activity*, *12*, 90–100.

Dallas, G., Dallas, K. (2016). Effects of ankle joint injuries on balance in male and female gymnasts. *Science of Gymnastics Journal*, *8*(2), 149-156.

Fetz, F. (1987). *Senzomotorisches Gleichgewicht.* Wien: Osterreichischer Bundesverlag. 243 p.

Fransson, P.A., Kristinsdottir, E.K., & Hafström, A. (2004). Balance control and adaptation during vibratory perturbations in middle-aged and elderly humans. *European Journal of Applied Physiology*, *91*, 595-603.

Gauchard, G.C., Gangloff, P., Vouriot, A., Mallié, J.P., & Perrin, P.H.P. (2002). Effects of exercise-induced fatigue with and without hydration on static postural control in adult human subjects. , *International Journal of Neuroscience*, *112*, 1191–1206.

Granacher, U., Gollhofer, A., & Strass, D. (2006). Training induced adaptations in characteristics of postural reflexes in elderly men. *Gait & Posture*, *24*(4), 459-466.

Gryc, T., Zahálka, F., Malý, T., Malá, L., Vaidová, E., & Teplan, J. (2013). Morphological and Postural Asymmetry of Lower Limbs in Elite Female Soccer Players. *Medicine and Science in Sports and Exercise, 45*(5), 168-168.

Harringe, M.L., Nordgren, J.S., Arvidsson, I., & Werner, S. (2007). Low back pain in young female gymnasts and the effect of specific segmental muscle control exercises of the lumbar spine: a prospective controlled intervention study. *Knee Surgery Sports Traumatology Arthroscopy, 5*, 1264-1271.

Harriss, D. J., & Atkinson, G. (2011). Update - Ethical Standards in Sport and Exercise Science Research. *International Journal of Sports Medicine, 32*(11), 819-821.

Hernández Suárez, M., Guimaraes Ribeiro, D.E., Hernández Rodriguez, E., Rodríguez Ruíz, D., García Manso, J. (2013). The effect of early systematic gymnastics training on postural control. *British Journal of Sports Medicine, 47*(10), 31-39.

Hirtz, P. (1997). Koordinationstraining. In: Schnabel, G., Harre, D. & Borde, A. (Hrsg.): Trainingswissenschaft. Leistung. Training. Wettkampf. Berlin, 114-122.

Hirtz, P. (2002). Acht Thesen zu den koordinativen Fähigkeiten zwischen Tradition und Perspektive. *Leipzitger sportwissenschaftliche Beiträge, 43*(2), 107-115.

Hrysomallis, C. (2007). Relationship between balance ability, training and sports injury risk. *Sports Medicine, 7*(6), 547-556.

Hrysomallis, C. (2011). Balance Ability and Athletic Performance. *Sports Medicine*, *41*(3), 221-232.

Kapteyn, T.S., Bles, W., Njiokiktjien, Ch.J., Kodde, L., Massen, C.H., & Mol, J.M.F. (1983). Standardization in platform stabilometry being a part of posturography. *Agressologie*, *24*(7)*,* 321–326.

Kaščeк, A., & Supej, M. (2014). Comparative restoration of balance after disturbing the vestibular aparatus with passive whole-body station: case study. *Science of Gymnastics Journal, 6*(1), 55 – 66.

Kochanowicz, A., Kochanowicz, K., Niespodziński, B., Mieszkowski, J., Sawicki, P. (2017). Effects of systematic gymnastic training on postural control in young and adult men. *Science of Gymnastics Journal, 9*(1), 5-15.

Kümmel, J., Kramer, A., Giboin, L. S., & Gruber, M. (2016). Specificity of Balance Training in Healthy Individuals: A Systematic Review and Meta-Analysis. *Sports Medicine*, *46*(9), 1261-71.

McCurdy, K., & Langford, G. (2006). The relationship between maximum unilateral squat strength and balance in young adult men and women. *Journal of Sports Science and Medicine*, *5*, 282-288.

McGuine, T., Greene, J., Best, T., & Leverson, G. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine, 10*, 239-244.

Mellos, V., Dallas, G., Kirialanis, P., Fiorilli, G., & Di Cagno, A. (2014). Comparison between physical conditioning status and improvement in artistic gymnasts and non-athletes peers. *Science of Gymnastics Journal, 6*(1), 33 – 43.

Myer, G.D., Ford, K.R., Brent, J.L., & Hewett, T.E. (2006). The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. *The Journal of Strength & Conditioning Research*, *20*(2), 345-353.

Nashner, L.M. (1997). Practical biomechanics and physiology of balance. In: G.P. Jacobson, C.W. Newman, & J.M. Kartush, (Eds.). *Handbook of balance function testing* (p. 261-279). San Diego: Singular Publishing Group.

Paillard, T., & Noe, F. (2006). Effect of expertise and visual contribution on postural control in soccer. *Scandinavian Journal of Medicine and Science in Sports, 16* (5), 345-348.

Poliszczuk, T., & Broda, D. (2010). Somatic constitution and the ability to maintain dynamic body equilibrium in girls practicing rhythmic gymnastics. *Pediatric Endocrinology Diabetesand Metabolism, 16*(2), 94-99.

Poliszczuk, T., Broda, D., & Poliszczuk, D. (2012). Changes in Somatic Parameters and Dynamic Balance in Female Rhythmic Gymnasts Over a Space of Two Years. *Polish Journal of Sport and Tourism*, *19*(4), 240–245.

Ramsay, J.R., & Riddoch, M.J. (2001). Position-matching in the upper limb: Professional ballet dancers perform with outstanding accuracy. *Clinical Rehabilitation*, *15,* 324-330.

Shumway-Cook, A., & Woollacott, M. (2007). Motor Control 3. vyd. Baltimore, Maryland. In *Theory and Practical Applications* (pp. 3-20). Baltimore, Maryland: Lippincott Williams &Wilkins.

Sirmen, B., Atilgan, O., Uzun, S., Ramazanoglu, N., Atil, Z., & Danismen, E. (2008). The Comparıson of Statıc Balance and Postural Sway of Waterpolo Players, Karate, Athletes and Sedentary people. *50th ICHPER-SD Anniversary World Congress Japan.*

Strešková, E. (2003). *Koordinačné schopnosti v športovej príprave mládeže.* Bratislava: NIŠ.

Tsigilis, N., & Theodosiou, A. (2008). The influence of multiple administration of a psychomotor test on performance and learning. *Journal of Strength and Conditioning Research, 22*, 1964-1968.

Vařeka, I., & Vařeková, R. (2009). *Kineziologie nohy*. Olomouc: Vydavatelství UP.

Vuillerme, N., Teasdale, N., & Nougier, V. (2001). The effect of expertise in gymnastics on proprioceptive sensory integration in human subjects. *Neuroscience Letters*, *311*, 73-76.

Vuillerme, N., & Nougier, V. (2004). Attentional demands for regulating postural sway: the effect of expertise in gymnastics. *Brain Research Bull*etin, *63*,161–165.

Vuillerme, N., Pinsault, N., & Vaillant, J. (2005). Postural control during quietstanding following cervical muscularfatigue: Effects of changes in sensoryinputs. *Neuroscience Letters*, *387,* 135-139.

Winter, D.A. (1995). Human balance and posture control during standing and walking. *Gait & Posture, 3*(4), 193-214.

Zech, A., Hubsubscher, M., Vogt, L., Banzer, W., Hansel, F., & Pfeifer, K. (2010). Balance Training for Neuromuscular Control and Performance Enhancement: A Systematic Review. *Journal of Athletic Training*, *4*, 392-403.

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