Acta of Bioengineering and Biomechanics
Vol. 20, No. 3, 2018

Original paper
DOI: 10.5277/ABB-01178-2018-02

Acute effects of core stability exercises on balance control

RAFAŁ SZAFRANIEC[1]*, JAGODA BARAŃSKA[2], MICHAŁ KUCZYŃSKI[3]

[1] Faculty of Sports Science, University School of Physical Education in Wrocław, Wrocław, Poland.
[2] Faculty of Physiotherapy, University School of Physical Education in Wrocław, Wrocław, Poland.
[3] Department of Biomechanics, Opole University of Technology, Opole, Poland.

Purpose: The aim of this study was to investigate whether a single bout of core stability exercises improves body balance immediately after the bout of exercise and during a retention test. *Methods:* The study involved 16 women (age 22–25 years, body weight 60.5 ± 5.2 kg, height 166 ± 5.4 cm). Postural stability was assessed in the mediolateral (ML) and anteroposterior (AP) planes separately on a force plate (Kistler 9286 AA) during quiet standing on a soft support surface with the eyes closed. Subjects were measured 4 times: just before (T_0), 1 minutes after ($T_{1\ \mathrm{m}}$), 30 minutes after ($T_{30\ \mathrm{m}}$), and 24 hours after the workout ($T_{24\ \mathrm{h}}$). Postural balance was evaluated by five parameters based on the center of pressure (COP) signal: variability (VAR), mean velocity (VEL), sample entropy (ENT), frequency (FRE), and fractal dimension (FRA). *Results*: We observed a decrease in VAR and VEL in the ML plane at $T_{30\ \mathrm{m}}$ and $T_{24\ \mathrm{h}}$, compared to T_0. The COP entropy significantly increased in the ML plane at $T_{24\ \mathrm{h}}$, compared to T_0. *Conclusions:* A single bout of core stability exercises improved the control of the mediolateral body balance. This effect was evident within 30 minutes after exercise, and remained for at least 24 hours. In addition, 24 hours after exercise we observed an increased automaticity in the strategy to maintain a stable upright stance.

Key words: *postural stability, motor learning, posturography, balance training, trunk muscles, sway entropy*

1. Introduction

Postural control is an integral component of motor skill and a prerequisite for dexterous coordination [19]. Adequate balance in the upright stance is essential for practicing daily activities, enhancing performance, and preventing injuries in sports. Postural stability integrates two mechanisms that determine the processes of balance control, including (1) the ability to maintain balance, and (2) the efficiency in responding to destabilizing forces. Both the maintenance and recovery of balance is possible due to the coordinated work of postural muscles, including the muscles forming the core, in which the center of gravity of the body's anatomical position is located [4], [18]. The core can be described as a muscular cylinder, with the abdominals in the front, the paraspinal and gluteal muscles in the back, the diaphragm forming the roof, and the pelvic floor and hip girdle muscles forming the floor [1].

The core is important in providing local strength and balance, and is central to almost all kinetic chains of daily activities. Kibler et al. [18] defined core stability as the ability to control the position and motion of the trunk over the pelvis and legs, which allows optimal production, transfer, and control of force and motion to the terminal segment in integrated kinetic chain activities. Core stability exercises refer to exercises that activate specific motor patterns of the trunk muscles by challenging spinal stability and trunk postural control [17]. An interesting question is whether the stimulation of trunk muscles results in any acute effects on the ability to maintain balance.

Therefore, the aim of this study was to investigate whether a single bout of core stability exercises improves body balance immediately after the bout of exercise and during a retention test.

* Corresponding author: Rafał Szafraniec, Faculty of Sports Science, University School of Physical Education in Wrocław, al. I.J. Paderewskiego 35, 50-537 Wrocław, Poland. Phone: +48713473146, e-mail: rafal.szafraniec@awf.wroc.pl

Received: August 1st, 2018
Accepted for publication: October 12th, 2018

2. Materials and methods

Participants

The study involved 16 women who were students at the University School of Physical Education in Wrocław (Poland), who were between the ages of 22–25 years and had an average body weight of 60.5 kg (±5.2) and a height of 166 cm (±5.4). Inclusion criteria for subjects included a lack of the following: (1) experience in sports, (2) regular high-intensity physical activity, (3) experience in performing core stability exercises, and (4) musculoskeletal and nervous system disorders. The study was approved by the local ethics committee and all subjects provided written informed consent to participate in the study.

Procedure

Postural stability was assessed in four 20-second trials of quiet standing on a soft support surface (a thick foam pad placed on a Kistler force plate) with the eyes closed. The subjects were asked to stand barefoot while moving as little as possible, with their feet together and their hands at their sides. A practice run was allowed prior to the test to ensure that the subjects felt comfortable in the laboratory area. Each recording started 10 seconds after the subject was ready for testing to eliminate possible transients in the COP data. The sampling frequency was 100 Hz.

Subjects were measured 4 times: just before (T_0), 1 minute after ($T_{1\,m}$), 30 min after ($T_{30\,m}$), and 24 hours after the workout ($T_{24\,h}$).

Data analysis

The recorded COP time-series were used to evaluate postural performance and strategies. Specifically, postural performance was assessed by means of sway variability (VAR) and mean velocity (VEL), with lower values of the two latter indices indicating better performance. Postural strategies were evaluated based on sway fractal dimension (FRA) and sample entropy (ENT) which measure COP complexity and irregularity, respectively. Low complexity of the COP may indicate better postural stability, while high values of this parameter are interpreted as increased adaptability of the postural control system to the changing environmental demands [5]. Regarding the COP entropy, its larger values are characteristic for a more irregular sway which is indicative for a less attention demanding, more automatic or efficient postural control [24]. On the other hand, a less irregular sway (i.e., with lower entropy) demonstrates larger conscious involvement in maintaining balance, which implies a lower level of automaticity [8]. Additionally, the COP mean frequency (FRE) was computed. Frequency may provide information on the relative contribution of the three sensory inputs used in postural control [16].

More technically, sample entropy quantifies conditional probability that a short epoch of data of length [m] is repeated during the time series within a specific tolerance [r]. The optimal values of these input parameters were computed based on the relative error [20] for all subjects and both planes that resulted in $m = 3$ and $r = 0.02$. The fractal dimension of sway was calculated using custom-written software in Matlab (Higuchi's algorithm).

The data were tested for normal distribution and homogeneity of variances. After log-transformation of the non-normally distributed data, all dependent variables were subjected to 2 planes (AP and ML) × 4 times (BASELINE, 1 min, 30 min, and 24 hours) ANOVA (Statistica 12.5, StatSoft, USA). Selected pairwise comparisons were explored using follow-up analyses (Tukey's test). The level of significance was set at $p < 0.05$.

Exercise program

Prior to exercise, subjects were instructed how to obtain a neutral position of the lumbo-pelvic-hip complex (LPHC), which is necessary in core stability training. The workout time was 40 min. There is no single exercise that stimulates all muscles of the core, and in order to improve core stability, a combination of exercises is recommended [7].

Those exercises were:

1. Crook lying, feet on the floor: abdominal hollowing for 10 s – 20 repetitions (reps).
2. Crook lying, feet on the floor: abdominal hollowing while bringing the knee to the chest, holding the position for 3 s, and then lowering the leg down to the ground – 10 reps on each leg.
3. Crook lying, feet on the floor: lifting the pelvis off the ground while supporting on feet and shoulders (bridge); holding position for 10 s – 10 reps.
4. Crook lying, feet on the floor: lifting both legs so that they form a right angle in the hips and knees; hands placed on the thighs; pressing the hands on the thighs and vice versa; holding position for 10 s – 10 reps.
5. Sit with knees in flexion and feet on the floor: twist the trunk with both hands touching the floor (seated twist) – 10 reps on each side.
6. Sit with knees in flexion and feet on the floor, hands behind the torso resting on the floor: the knees approach the chest with simultaneous flexion of the elbows, followed by extension of the

knee joints and a return to the starting position – 10 reps.

7. Prone position, upper limbs lie on the floor in front of the head: abdominal hollowing for 10 seconds – 10 reps.
8. Prone position, upper limbs lie on the floor in front of the head: simultaneous lifting of the right arm and shoulder, the left lower limb, and the head; holding position for 5 s – 10 reps on each side.
9. Quadruped position: abdominal hollowing for 10 s – 10 reps.
10. Quadruped position: lifting the right arm so that it is in the extension of the trunk, then adduction of the upper limb to the moment when it is perpendicular to the body; return to the starting position – 10 reps on each side.
11. Quadruped position: lifting the right arm and the left lower limb so that they are in the extension of the trunk; holding position for 3 s – 10 reps on each side.
12. Forearm "plank" on knees; holding position for 10 s – 10 reps.
13. Side forearm "plank" on knees; holding position for 10 s – 5 reps on each side.
14. Forearm "plank" with straight legs; holding position for 10 s – 10 reps.
15. Forearm "plank" with straight legs, then raising hips so body forms an inverted V and back to the starting position – 15 reps.

Applied exercises intensively stimulated abdominal muscles (transversus abdominis, obliques, and rectus abdominis), erector spinae, quadratus lumborum, and gluteal muscles, which are the main stabilizers of the spine and are responsible for controlling pelvis and trunk positioning [22].

3. Results

COP variability (VAR)

There was a main effect of time ($F(3,45) = 5.01$, $p < 0.01$), which reflected a gradual decrease in COP variability. Post-hoc analysis demonstrated that this effect took place in the ML plane only showing decreased variability at $T_{30\text{ m}}$ ($p = 0.04$) and at $T_{24\text{ h}}$ ($p < 0.01$), compared to T_0. There was also a main effect of plane ($F(1,15) = 60.15$, $p < 0.01$), with higher variability in the AP plane (Fig. 1).

COP mean velocity (VEL)

There was a main effect of time ($F(3,45) = 3.89$, $p = 0.02$), which indicated decreased COP mean velocity after the workout. Post-hoc analysis demonstrated that this effect took place in the ML plane only, showing decreased variability at $T_{30\text{ m}}$ ($p = 0.02$) and at $T_{24\text{ h}}$ ($p = 0.03$), compared to T_0. There was also a main effect of plane ($F(1,15) = 129.33$, $p < 0.01$), showing higher velocity in the AP plane (Fig. 2).

COP fractal dimension (FRA)

Core stability exercises did not cause any changes in the COP fractality over time. Also, there were no differences in the latter postural sway measures between the AP and ML planes (Fig. 3).

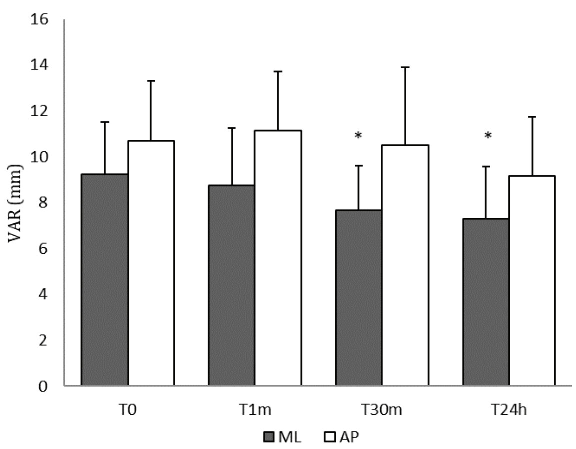

Fig. 1. Mean values of the COP variability (VAR) in both planes: ML – mediolateral plane, AP – anteroposterior plane; vertical bars indicate the standard deviation; * significant differences between T_0 and both $T_{30\text{ m}}$ ($p = 0.04$), and $T_{24\text{ h}}$ ($p < 0.01$)

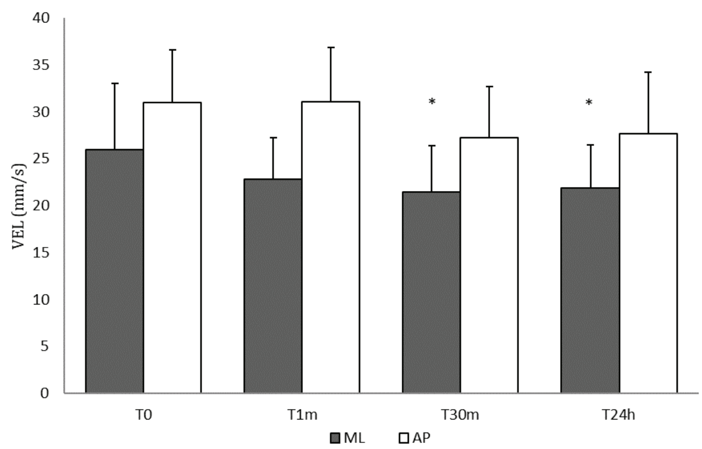

Fig. 2. Mean values of the COP mean velocity (VEL) in both planes: ML – mediolateral plane, AP – anteroposterior plane; vertical bars indicate the standard deviation; * significant differences between T_0 and both $T_{30\text{ m}}$ ($p = 0.02$), and $T_{24\text{ h}}$ ($p = 0.03$)

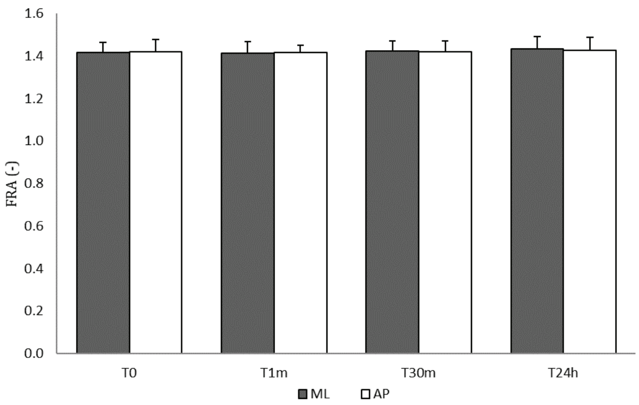

Fig. 3. Mean values of the COP fractal dimension (FRA) in both planes: ML – mediolateral plane, AP – anteroposterior plane; vertical bars indicate the standard deviation

COP sample entropy (ENT)

There was a main effect of time ($F(3,45) = 8.73$, $p < 0.01$), which revealed an increase in sway entropy. The follow-up analysis established that this increase took place on the second day only (at $T_{24\ h}$) in the ML plane (Fig. 4). In contrast to the postural performance measures, i.e., sway variability and velocity, the COP entropy did not show any changes at $T_{30\ m}$, which implied some time lag between the improved performance and the development of postural strategies.

There was a main effect of plane ($F(1,15) = 21.16$, $p < 0.01$), showing higher sway entropy in the AP plane (Fig. 4).

COP frequency (FRE)

There was a main effect of time ($F(3,45) = 3.38$, $p = 0.03$), which indicated increased COP frequency collapsed over planes. However, post-hoc analysis did not demonstrate significant differences in the ML and AP plane, separately. There were no differences in the latter postural sway measures between the AP and ML planes (Fig. 5).

4. Discussion

The purpose of this paper was to analyze the acute effects of a single bout of core stability exercises on the ability to maintain a stable upright stance. Three findings seem of particular interest. First, a single bout of core stability exercises affected postural performance as indicated by reduced sway amplitude and velocity. These changes may be interpreted as more precise balance control and less strenuous effort to maintain upright posture, respectively, and thus suggest apparent improvement in postural control. Second, the improvement in postural control after exercise was further corroborated by the increased COP entropy, which has been shown to mark an increased automaticity and less attentional involvement in postural tasks. Interestingly, the gain in sway entropy came to light only during the last test, being preceded by the decrease in sway amplitude and velocity that took place in the T_{30} test. Third, all advantageous changes in postural control due to core stability exercises were found in the ML plane.

Consequently, the decline in VEL and VAR may be the result of increased tone of muscles responsible for core stability. Lower values of the two latter postural performance measures lasting up to 24 hours after the applied procedure may justify the usefulness of core stability exercises in sport training, especially in disciplines in which the balance of the body is crucial (shooting, archery, figure skating, judo, gymnastics, and many others) and in the rehabilitation of individuals with impaired balance. To prevent loss of

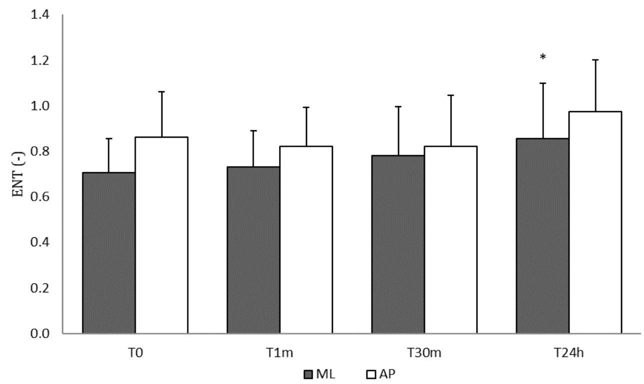

Fig. 4. Mean values of the COP sample entropy (ENT) in both planes: ML – mediolateral plane, AP – anteroposterior plane; vertical bars indicate the standard deviation; * significant difference between $T_{24\ h}$ and T_0 ($p < 0.01$)

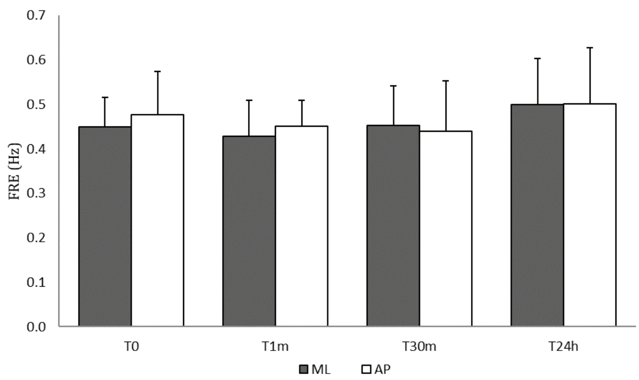

Fig. 5. Mean values of the COP frequency (FRE) in both planes: ML – mediolateral plane, AP – anteroposterior plane; vertical bars indicate the standard deviation

balance and potential falls, postural adjustments are needed to move the center of gravity back over the base of support. These adjustments in body posture require core activation to stabilize the lumbar spine [4]. Core stability is a kind of foundation for movements. In the case of an undisturbed recruitment of the deep muscles of the trunk, they are activated at the moment before the planned locomotion activity, creating the appropriate conditions in the form of a stable body posture [10], although Allison et al. [2] pointed out that the transverse abdominal muscle, like other trunk muscles, acts asymmetrically during single-arm flexion and is clearly directionally specific. Brown [6] suggested that the optimum stability of the trunk is achieved by the musculature, providing dynamic constraints, and the passive stiffness of intervertebral joints, spine ligaments, and fascia. Kaji et al. [15] demonstrated that immediately after short bouts of core stability exercises, the COP excursion area and velocity during quiet standing were reduced. It has also been shown that immediately after core exercise bouts, performance on the Star Excursion Balance Test was improved [12]. A likely explanation is that these exercises can improve core proprioceptive ability, which may lead to improvements in balance control. Some investigations have shown that 6 to 12 weeks of core stabilization training improves balance performance in young, healthy populations [13]. Resistance training, besides its effect on enhancing muscular strength, also increases the coordination of synergistic and antagonistic muscle activation, thereby improving stability [4]. The neural adaptations occurring in the early phase of a resistance training program lead to an improved coordination of the stabilizing muscles.

The selection of a more automatic and less deliberate control concurs with research comparing the effects of augmented versus reduced sensory input on postural control. For example, standing on a hard support surface has been shown to increase sway frequency and entropy, compared to standing on a compliant support surface [25]. Similarly, subjects have higher values of sway frequency and entropy before whole-body cryotherapy than just after, when cooling temporarily deteriorates the function of several sensors contributing to balance [9]. Athletes in some sports have also been shown to have larger sway entropy than sedentary subjects [14]. One more example is the increased sway complexity after application of sub-sensory foot sole vibrations [26]. All of these examples provide support for the notion that the improvement of sensory input should be considered a primary reason for developing increased complexity of standing postural sway dynamics. For instance, increases in COP complexity after participation in Tai Chi were associated with improved plantar sensation and physical function [21].

Based on the results of the present study, we propose that the enhanced combined proprioceptive information regarding the reciprocal position of the trunk and legs as a sensory modality benefited most from core stability training and contributed to finer balance performance. This is in line with Anderson et al. [3], who suggested that improved core stability allowed participants to move from a hip to an ankle postural control strategy, through improved coordination of muscles involved in balance. This change in strategies clearly indicates that a postural task that required a hip strategy prior to exercise, became less challenging after exercise, as it was executed by a simpler and more economical ankle strategy. Thus, the improved trunk stability likely facilitated more skilled motor control at the ankles, which, in turn, improved the overall body stability.

Finally, an important finding in this study was the time course of the two events. The improved performance was observed at $T_{30\ \mathrm{m}}$ and apparently preceded changes in postural strategies that were apparent at $\mathrm{T}_{24\mathrm{h}}$. The true value of this delay, which may be significantly shorter than 24 hours, remains unknown. Still, the completion of a higher level of postural performance seems to be necessarily antecedent to the discernible change in postural strategies. In other words, the strategy remains unchanged until motor abilities improve to an acceptable level. This sequence of events closely resembles a similar situation reported by Giemza et al. [9], except for the direction of changes in performance. Whole-body cryotherapy adversely affected postural performance immediately after the therapy, while no changes in postural complexity occurred. It was not until at least 80 s later that sway entropy and frequency decreased as if in response to some decrease in performance that required changing strategies, i.e., switching to more conscious and attention-demanding control.

The latter finding may have important consequences for the research design and interpretation. In previous work it has always been implicitly assumed that changes in performance and strategies take place simultaneously. Our data indicate that such assumption may be false and lead to obvious mistakes in making related inferences. The results of this study and those of Giemza et al. [9] tell us that even if changes in sway entropy and/or frequency in response to some experimental factors did not occur, there would still be a chance to detect these changes after a reasonable amount of time.

Changes in postural control, due to the performance of core stability exercises, were limited to the ML plane, with no effects on balance in the AP plane. This may be explained by the fact that in the ML plane the gluteus medius muscles were primarily responsible for maintaining balance [11], and the muscles of the hip girdle were heavily involved during the conducted exercises. No effect being observed in the AP plane may be due to the fact that sagittal balance is controlled at the ankle joints [11], and the triceps surae and tibialis anterior muscles were not particularly involved in the exercises. The observed improvement in the ML balance control may be particularly interesting in terms of implementation, because the loss of postural control, as a result of progressive involutional changes in the aging process, is characterized by the intensity of the body instability in the frontal plane [23]. Therefore, it seems reasonable to emphasize the forms of exercise stimulating the balance control mechanisms, implemented by the abductor and adductor muscles of the hip joint.

5. Conclusions

A single bout of core stability exercises improved the control of body balance. This effect was evident at 30 minutes after exercise, and remained for at least 24 hours. Improvement of postural stability was related to the frontal plane, which can be explained by the fact that the balance control in this plane corresponded to the hip girdle muscles, which were significantly involved in the exercise. In addition, 24 hours after exercise we observed an increased automaticity in the strategy to maintain a stable upright stance.

References

[1] AKUTHOTA V., FERREIRO A., MOORE T., FREDERICSON M., *Core stability exercise principles*, Curr. Sports Med. Rep., 2008, 7(1), 39–44.

[2] ALLISON G.T., MORRIS S.L., LAY B., *Feedforward responses of transversus abdominis are directionally specific and act asymmetrically: implications for core stability theories*, J. Orthop. Sports Phys. Ther., 2008, 38(5), 228–237.

[3] ANDERSON G.S., DELUIGI F., BELLI G., TENTONI C., GAETZ M.B., *Training for improved neuro-muscular control of balance in middle aged females*, J. Bodyw. Mov. Ther., 2016, 20(1), 10–18.

[4] ANDERSON K., BEHM D.G., *The impact of instability resistance training on balance and stability*, Sports Med., 2005, 35(1), 43–53.

[5] BIEĆ E., ZIMA J., WÓJTOWICZ D., WOJCIECHOWSKA-MASZKOWSKA B., KRĘCISZ K., KUCZYŃSKI M., *Postural stability in young adults with Down syndrome in challenging conditions*, PLoS ONE, 2014, 9(4), DOI: 10.1371/journal.pone.0094247.

[6] BROWN T.D., *Getting to the core of the matter*, Strength Cond. J., 2006, 28(2), 50–53.

[7] CHOLEWICKI J., VANVLIET J.J., *Relative contribution of trunk muscles to the stability of the lumbar spine during isometric exertions*, Clin. Biomech., 2002, 17(2), 99–105.

[8] DONKER S.F., ROERDINK M., GREVEN A.J., BEEK P.J., *Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control*, Exp. Brain Res., 2007, 181(1), 1–11.

[9] GIEMZA C., CZECH P., PALUSZAK A., BIEĆ E., BORZUCKA D., KUCZYŃSKI M., *Acute effects of cryotherapy on postural control*, Neurosci. Lett., 2013, 536, 6–9.

[10] HIBBS A.E., THOMPSON K.G., FRENCH D., WRIGLEY A., SPEARS I., *Optimizing performance by improving core stability and core strength*, Sports Med., 2008, 38(12), 995–1008.

[11] HORAK F.B., *Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls?*, Age Ageing, 2006, 35(Suppl 2), ii7-ii11.

[12] IMAI A., KANEOKA K., OKUBO Y., SHIRAKI H., *Comparison of the immediate effect of different types of trunk exercise on the star excursion balance test in male adolescent soccer players*, Int. J. Sports Phys. Ther., 2014, 9(4), 428–435.

[13] IMAI A., KANEOKA K., OKUBO Y., SHIRAKI H., *Effects of two types of trunk exercises on balance and athletic performance in youth soccer players*, Int. J. Sports Phys. Ther., 2014, 9(1), 47–57.

[14] ISABLEU B., HLAVACKOVA P., DIOT B., VUILLERME N., *Regularity of Center of Pressure Trajectories in Expert Gymnasts during Bipedal Closed-Eyes Quiet Standing*, Front Hum. Neurosci., 2017, 11, DOI: 10.3389/fnhum.2017.00317.

[15] KAJI A., SASAGAWA S., KUBO T., KANEHISA H., *Transient effect of core stability exercises on postural sway during quiet standing*, J. Strength Cond. Res., 2010, 24(2), 382–388.

[16] KANEKAR N., LEE Y.J., ARUIN A.S., *Frequency analysis approach to study balance control in individuals with multiple sclerosis*, J. Neurosci. Methods, 2014, 222, 91–96.

[17] KAVCIC N., GRENIER S., MCGILL SM., *Quantifying tissue loads and spine stability while performing commonly prescribed low back stabilization exercises*, Spine, 2004, 29(20), 2319–2329.

[18] KIBLER W.B., PRESS J., SCIASCIA A., *The role of core stability in athletic function*, Sports Med, 2006, 36(3), 189–198.

[19] KUCZYŃSKI M., SZYMAŃSKA M., BIEĆ E., *Dual-task effect on postural control in high-level competitive dancers*, J. Sports Sci., 2011, 29(5), 539–545.

[20] LAKE D.E., RICHMAN J.S., GRIFFIN M.P., MOORMAN J.R., *Sample entropy analysis of neonatal heart rate variability*, Am. J. Physiol. Regul. Integr. Comp. Physiol., 2002, 283(3), R789–R797.

[21] MANOR B., LIPSITZ L.A., WAYNE P.M., PENG C-K., LI L., *Complexity-based measures inform tai chi's impact on standing postural control in older adults with peripheral neuropathy*, BMC Complement Altern. Med., 2013, 13, DOI: 10.1186/1472-6882-13-87.

[22] MCGILL S.M., *Low back stability: from formal description to issues for performance and rehabilitation*, Exerc. Sport Sci. Rev., 2001, 29(1), 26–31.

[23] PUSZCZAŁOWSKA-LIZIS E., BUJAS P., OMORCZYK J., *Postural stability in women in the eighth and ninth decades of life*, Acta Bioeng. Biomech., 2016, 18(3), 115–121.

[24] ROERDINK M., HLAVACKOVA P., VUILLERME N., *Center-of--pressure regularity as a marker for attentional investment in postural control: a comparison between sitting and standing postures*, Hum. Mov. Sci., 2011, 30(2), 203–212.

[25] STRANG A.J., HAWORTH J., HIERONYMUS M., WALSH M., SMART L.J., *Structural changes in postural sway lend insight into effects of balance training, vision, and support surface on postural control in a healthy population*, Eur. J. Appl. Physiol., 2011, 111(7), 1485–1495.

[26] ZHOU J., LIPSITZ L., HABTEMARIAM D., MANOR B., *Subsensory vibratory noise augments the physiologic complexity of postural control in older adults*, J. Neuroeng. Rehabil., 2016, 13(1), DOI: 10.1186/s12984-016-0152-7.