Acta of Bioengineering and Biomechanics
Vol. 15, No. 3, 2013

Original paper
DOI: 10.5277/abb130304

The effect of short- and long-term vibration training on postural stability in men

MAGDALENA PIECHA[1]*, PIOTR KRÓL[1], GRZEGORZ JURAS[2], GRZEGORZ SOBOTA[2], ANNA POLAK[1], BOGDAN BACIK[2]

[1] Department of Physiotherapy Basics, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland.
[2] Department of Human Motor Behavior, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland.

The study aimed to establish the short- and long-term effects of vibration on postural stability in young men. A single set of exercises and a 4-week vibration training were assessed for their impact on the center of foot pressure (COP) sway. The sample consisted of 49 male subjects randomly allocated to seven comparative groups, six of which exercised on a vibration platform whose parameters were set individually for the groups. Group VII was the control group. The stabilographic signal was recorded before the test commenced, after a single application of vibration, before the last set of exercises of the 4-week vibration training, immediately afterwards, as well as one week and one month after the training ended. The subjects were exposed to vibration 3 times a week for 4 weeks. Both a single application of vibration and the 4-week vibration training had an effect on all parameter values, but most changes were statistically insignificant. Group III was the only one where the COP sway in the anterior-posterior direction significantly increased after a single exposure to vibration and significantly decreased in both anterior-posterior and medio-lateral planes one week after vibration training compared with the pre-test recordings.

Key words: *mechanical oscillations, postural sway, whole body vibration*

1. Introduction

In vibration training, a person standing on a vibration platform producing whole-body oscillation is asked to maintain a certain posture or do dynamic exercises. The body's reaction to vibration is reflexive, following from the excitement of alpha motoneurons by the stimulation of neuromuscular spindles. The physiological reaction of the neuromuscular system to mechanical vibration, resembling the stretch reflex, is increased tension of the stimulated muscles [1].

Although researchers have been interested in the effect of mechanical vibration on different human systems and tissues for some time now, the knowledge about vibration effects on postural stability is still unsatisfactory and the available studies present conflicting results. Researchers apply different vibration parameters (frequency and amplitude) and vibration training procedures. Vibration amplitudes may vary from 1 to 10 mm. For instance, while Polonova and Hlavacka [2] applied 40–100 Hz vibration, in the Talis and Solopova study [3] frequencies ranged between 60 and 70 Hz, and Gomez et al. [4] chose 85 Hz. Randomized control studies examining the effects of different frequencies and amplitudes on postural stability have not been found.

The existing studies on postural body balance disturbed by vibration use either of the two devices: a vibration platform indirectly producing whole-body vibration [5], [6] and oscillating heads applied directly to the belly or a muscle or a tendon [2]. According to the known results of research, the effects of vibration are determined by the period of training [6], [7]. A short-term application of vibration to single groups

* Corresponding author: Magdalena Piecha, Department of Physiotherapy Basics, The Jerzy Kukuczka Academy of Physical Education, ul. Mikołowska 72a, 40-065 Katowice, Poland. Tel: +48 694979640, fax: +48 (32) 251 10 97, e-mail: magdapiecha@wp.pl
Received: January 28th, 2013
Accepted for publication: April 14th, 2013

of muscles increases sway [7]. The range and direction of the COP sway (Center-of-foot Pressure) depend on what frequency of vibration has been applied and where the stimulated muscles are [2]. In the available studies multiple application of whole-body vibration training has either improved human ability to maintain postural balance [8], [9] or has not changed it significantly [6], [10].

These somewhat confusing results and the variety of vibration training methods provided grounds for conducting a more in-depth study on the influence of mechanical vibration on postural stability. The experiment presented in this article aimed to assess the effect of short- and long-term vibration training utilizing different vibration parameters (frequencies and amplitudes) on the AP and ML postural stability in young men.

2. Materials and methods

2.1. Subjects

All methods, the plan and scope of the experiment, the allocation of subjects to groups and other procedures necessary to carry out the experiment were analysed, approved and accepted for use by the Institutional Review Board of the Academy of Physical Education in Katowice.

Forty nine subjects were purposefully selected for the experiment taking into account their age (23.6 years on average) and sex (males). The mean body mass of a subject was 78.7 kg ± 7.9 and the mean height was 180.78 cm ± 5.6 cm. Professional athletes were excluded from the experiment. Some other non-eligibility criteria were episodes of disequilibrium, acute inflammations and infections, epilepsy, cardiovascular diseases, the acute phase of osteoarthritis. The subjects were randomly allocated to seven comparative groups, each consisting of seven persons. Subjects in groups I–VI participated in a 4-week training on a vibration platform, with the frequency and amplitude of vibration being set individually for each group, i.e., 2 mm/20 Hz for group I, 2 mm/40 Hz for group II, 2 mm/60 Hz for group III, 4 mm/20 Hz for group IV, 4 mm/40 Hz for group V, and 4 mm/60 Hz for group VI. The experiment used all combinations of two extreme frequencies (20, 60 Hz) and medium frequency (40 Hz) with the two available amplitudes (2 and 4 mm). Vibration below 20 Hz is not used in vibration training studies, because mechanical resonance it induces in the human body has an adverse effect on the internal organs [11].

Group VII was the control group. The control group was formed in order to find out if 4-week vibration training has an effect on the COP signal.

2.2. Procedures

Vibration training

The 4-week vibration training was carried out on a Fitvibe 600 vibration platform made by Gymna Uniphy N.V. During the experiment, groups I–VI did 5 one-minute exercises separated by 1-minute breaks 3 times a week (Monday, Wednesday, and Friday). The exercise and rest times were adopted following the procedures used by other researchers [12], [13]. Each subject from groups I–VI was asked to stand static on the vibration platform with the knee and hip joints flexed at 90 degrees, the upper extremities stretched horizontally forwards. The participants from control group VII performed the same static exercises as those in other groups, but without the concurrent application of vibration. In this exercise position muscle torques acting on the ankle joints, knee joints and hip joints are strongly engaged.

The published studies point to significantly increased bioelectrical activity of the lower extremity muscles of subjects standing with the knee joints bent at 90° [13]. The position is also safer for subjects, because the knee flexion reduces the amount of vibration reaching their heads. Also the wobbling mass in the upper body (muscles, soft tissues, internal organs and fluids in the body) is able to reduce the total internal load on the rigid mass of the upper body (skeleton) during the whole body vibration [14].

Stabilographic measurement

Stabilographic measurements were performed with the Kistler dynamometric platform. The measurement station consisted of a piezoelectric dynamometric platform (type 9281C) with a charge amplifier (type 9865B) and a computer. The parameter values were recorded by the BioWare™ software (type 2812A1-20). The sampling frequency was 100 Hz (25 Hz low-pass filter) [15]. The platform filtering frequency of the output signal was set at 25 Hz, which was adopted from the Zatsiorsky and Duarte's procedures [16]. All seven groups of subjects were evaluated for postural stability in accordance with the standard measurement method for subjects standing in a natural position. At the first recording of the posturographic signal, each measurement was repeated five times. Prior to the 30-second stabilographic measurements, the subjects were asked to stand with eyes closed which was to prevent interference by external signals and disable an important sensory source of compensatory information. During each trial the stabilographic signal was recorded for the AP and ML planes. The effect of short-term and long-term vibration on a human subject was established by means of stabilographic tests performed different times. To assess the effects of short-term vibration, the postural stability of subjects standing on the dynamometric platform was measured in groups I–VI immediately before training, immediately after the first set of exercises (which consisted of 5 one-minute exercises separated by 1-minute breaks) and immediately after the last session of the 4-week training. The direct influence of vibrations was taken into account. The effect of a long-term vibration means the changes registered over a longer period of time without direct influence of vibrations. To establish the effects of long-term vibration stabilographic measurements were made before the last session of the 4-week training, as well as one week and one month after it ended.

The postural stability of subjects in the control group was measured in the same manner, but without the concurrent application of vibration. Sway ranges were calculated for the AP and ML planes.

2.3. Statistical analysis

The data obtained from the measurements were processed using the predominant methods of statistical analysis. The Shapiro–Wilk and Lilliefors tests were used to check the data for normal distribution, while variance homogeneity was investigated with the Levene's test. Because some parameters failed to meet the assumption about the normal distribution of variables and variance homogeneity, the Wilcoxon matched pairs test was employed to assess how significant the differences between the means of particular variables in the groups were. The influence of vibration frequencies and amplitudes on the means of particular variables was verified with one-way ANOVA for repeated measures. Then all combinations of the pairs of the means were compared with a post-hoc Tukey's test. The intergroup statistical analysis used the relative values of the variables, which were calculated as a ratio of the difference between the initial and final value of a variable to its initial value,

$$\text{relative value of variable} = \frac{(\text{initial value} - \text{final value})}{\text{initial value}}.$$

The level of statistical significance assumed for all analyses was $p < 0.05$.

3. Results

The effect of short-term vibration on a human subject was established by means of stabilographic tests performed before the training commenced, immediately after the first set of exercises and after the last training session. Tables 1 and 2 show the ranges of sway in the AP and ML planes recorded for short-term vibration training. While all measured parameters were found to change, only increases in the AP sway measured in group III directly after a single training session and in group V immediately after the last session of the 4-week training were statistically significantly compared with the initial measurements ($p < 0.05$).

Table 1. Sway ranges in the AP plane (mean ± standard deviation) (mm) after short-term training

Group	Before training	Immediately after a single training session	Immediately after the last session of the 4-week training
Group I	22.7 ± 7.14	24.5 ± 8.38	29 ± 10.7
Group II	20.6 ± 4.48	20.1 ± 3.06	23.2 ± 6.71
Group III	23.4 ± 6.83	21.8 ± 5.22	18.4 ± 3.66
Group IV	22.1 ± 4.68	18.1 ± 5.36	18.3 ± 6.75
Group V	18.4 ± 6.39	20.1 ± 5.71	16.8 ± 3.24
Group VI	20.1 ± 4.6	19 ± 6.39	23.8 ± 10.3
Group VII	24.7 ± 8.18	24.2 ± 6.75	25.8 ± 8.19

Wilcoxon matched pairs test

Table 2. Sway ranges in the ML plane (mean ± standard deviation) (mm) after short-term training

Group	Before training	Immediately after a single training session	Immediately after the last session of the 4-week training
Group I	18.5 ± 6.59	16.9 ± 4.53	20.1 ± 5.55
Group II	13.3 ± 4.21	13.9 ± 3.26	14.3 ± 5.69
Group III	15 ± 3.56	**18* ± 3.83**	13.8 ± 3.14
Group IV	14.2 ± 3.59	14.6 ± 3.96	13.9 ± 5.23
Group V	13.1 ± 4.05	13.6 ± 4.38	**16.4* ± 4.51**
Group VI	15.3 ± 3.58	14.9 ± 3.38	16.1 ± 3.91
Group VII	11.2 ± 3.29	11.4 ± 3.71	12.6 ± 4.55

* Statistically significantly different compared with the initial measurement ($p < 0.05$).

Wilcoxon matched pairs test

Table 3. Sway ranges in the AP plane (mean ± standard deviation) (mm) after long-term training

Group	Before training	Before last training session	One week after training	One month after training
Group I	22.7 ± 7.14	24.5 ± 10.07	22.3 ± 10.07	24.3 ± 8.51
Group II	20.6 ± 4.48	23.5 ± 5.49	24.4 ± 4.11	28.3 ± 7.47
Group III	23.4 ± 6.83	22.5 ± 4.41	**17.8* ± 2.76**	23.7 ± 7.33
Group IV	22.1 ± 4.68	21.5 ± 8.99	18.3 ± 2.6	19.5 ± 3.9
Group V	18.4 ± 6.39	19.5 ± 6.73	18.3 ± 5.71	19.3 ± 8.49
Group VI	20.1 ± 4.6	21.7 ± 3.54	20.5 ± 3.9	21.3 ± 5.38
Group VII	24.7 ± 8.18	25.8 ± 8.19	25.6 ± 9.76	23.3 ± 6.68

* Statistically significantly different compared with the initial measurement ($p < 0.05$).
Wilcoxon matched pairs test

Table 4. Sway ranges in the ML plane values (mean ± standard deviation) (mm) after long-term training

Group	Before training	Before last training session	One week after training	One month after training
Group I	18.5 ±6.59	16.4 ± 4.31	15.9 ±5.32	16.6 ±5.91
Group II	13.3 ± 4.21	14 ± 4.73	16.1 ± 6.49	15.1 ± 5.45
Group III	15 ± 3.56	12.8 ± 2.55	**13.1* ± 3.58**	14 ± 5.21
Group IV	14.2 ± 3.59	15.6 ± 4.32	13.8 ± 5.43	13.9 ± 2.72
Group V	13.1 ± 4.05	15.1 ± 6.38	15 ± 5.97	12.8 ± 3.56
Group VI	15.2 ± 3.58	16.8 ± 3.02	15.5 ± 4.67	15.9 ± 1.96
Group VII	11.2 ± 3.29	12.6 ± 4.55	13.9 ± 5.64	14 ± 5.55

* Statistically significantly different compared with the initial measurement ($p < 0.05$).
Wilcoxon matched pairs test

To establish the effects of long-term vibration stabilographic measurements were made before the 4-week vibration training commenced, immediately before its last session, as well as one week and one month after it ended. Tables 3 and 4 show sway ranges recorded in the ML and AP directions for long-term vibration training. The Wilcoxon test revealed that one week after the 4-week vibration training ended sway ranges in group III decreased statistically significantly in both planes compared with their initial values ($p < 0.05$).

The results of intergroup ANOVA did not show the frequencies and amplitudes used in the study to have a significant effect on the range of COP sway ($p > 0.05$).

4. Discussion

Postural control is a very complex process involving the precise cooperation of many elements. Its effectiveness is greatly determined by the processing of information which comes from four sensory entrances (the labyrinth, the sight organ, proprioceptors and tactile receptors) and enables people to move safely in the immediate environment [17]. Many studies on human postural balance disturbed by external stimuli [2], [4], [18] or during the gait [19], [20] have been conducted so far.

If sensory receptors receive incorrect information, then postural stability may be affected [10]. In this experiment proprioceptors were disturbed by mechanical vibration of different amplitudes (2, 4 mm) and frequencies (20, 40, 60 Hz). Brumagne et al. [21] have demonstrated that vibration impairs proprioception in healthy humans. Following the application of mechanical vibration (70 Hz, 5 mm) the subjects in their study could not adjust the lumbosacral section of the spine to its previous position.

In this experiment sway ranges changed in all test groups, but most changes were statistically insignificant ($p > 0.05$). The statistical insignificance of the differences between sway ranges in most groups exposed to vibration (I–VI) may be attributed to compensatory adjustments in postural control. Healthy humans use compensatory information from the complementary sensory systems (visual, vestibular and proprioceptive) for postural control [22]. The re-ranking of the receptor information as a result of disturbed postural stability has been discussed by many authors [22]–[24]. Too much sensory information or malfunctioning of any of the receptors causes that the nervous system reduces the receptor's role in body posture control and switches to signals from receptors offering more reliable and noise-free information. When the lower leg muscles are exposed to vibration and fatigue [24] and the support structure is unstable [23], then most postural information comes from the labyrinth [23]. The hierarchy of receptors depends, inter alia, on the motor task requirements [24] and receptor efficiency [18]. The literature has not provided yet a precise ranking of sensory entrances based on their importance for postural control.

The changes in the range of COP sway in group III was found interesting. A single vibration procedure significantly increased the range of AP sway in that group ($p < 0.05$) vis-à-vis its initial value (Table 2). As already mentioned, mechanical vibration disturbs proprioceptive information [21] that is also used for postural balance control. A very tentative conclusion can be that compared with the other combinations of parameters in the experiment a single application of vibration of 60 Hz and amplitude of 2 mm affects postural balance most strongly.

Another interesting finding was that the range of sway in group III was significantly decreased in both directions one week after the training ended compared with the initial value ($p < 0.05$). Fransson et al. have found that cyclical exposure to vibration frequently induces adaptive changes in the COP signal [25]. The range of postural sway could change in group III because of the frequency and amplitude of mechanical vibration (60 Hz/2 mm) repeatedly disturbing subjects' postural balance during the 4 weeks of the experiment.

Long-term vibration was not found to change significantly the range of sway in most of the groups investigated. Similarly, the Torvinen et al. [5] and Verschueren et al. [6] studies have not detected major changes in subjects' postural balance after repeated application of whole-body vibration. Torvinen et al. [5] studied the effects of 4-month vibration training where 56 subjects exercised on a vibration platform 3–5 times a week for not longer than 4 minutes. Vibration amplitude was 2 mm and frequencies ranged within 25–40 Hz. Significant training-related changes in subjects' postural stability were not found. Verschueren et al. [6] asked 25 post-menopausal females to participate in a 6-month vibration training (35–40 Hz) conducted 3 times a week, finding no significant changes in the AP and ML sway in subjects standing in a natural position with eyes open or closed.

An important factor affecting the stability of the postural balance system is age. All subjects in this study were aged 21–24 years. In this period of ontogenetic development the nervous system controlling postural stability is characterised by a relative balance between excitation and inhibition processes. The nervous systems of healthy individuals in this age group swiftly process information and the motor systems are very efficient. Dolny and Reyes [26] have concluded that whole-body vibration may not be sufficient to induce adaptive changes in the neuromuscular system of young healthy individuals. According to these authors, the young age of the subjects may explain why short- and long-term application of vibration has not significantly differentiated most of the study groups with respect to the range of sway.

Age differences were also described in the research on postural balance control ability [27]. Blaszczyk et al. [28] have reported that nervous centres responsible for postural adjustments degenerate with age, consequently raising the sensitivity threshold of the sensory systems and decreasing nerve conduction velocity. Postural control becomes less effective, one manifestation of which is increased sway. Perhaps repeated application of vibration disturbing body balance is worth considering as an alternative therapy for preventing elderly people or patients with postural balance control from falling.

Most studies reviewed under this experiment assessed geriatric postural stability based on functional tests evaluating dynamic balance [8], [9], [29]. A popular tool is the Tinetti test, where the motor tasks are intended to estimate the gait and balance of elderly individuals.

In the Runge et al. study [29], 34 subjects aged 61–85 years participated in a 6-month vibration training. Each subject was exposed to a 6-minute whole-body vibration 3 times a week (the frequency was 27 Hz and the amplitude ranged within 7–14 mm). The measurements showed that dynamic balance in the "rising from a chair" test improved by 18%. Iwamotow et al. [8] have demonstrated that a 3-month vibration training (once a week, 4 minutes, 20 Hz) combined with having the subject stand on one leg for one minute every day and do ten semi-knee bends improves static balance performance in the standing-on-one-leg test by 6.8%. Kawanabe at al. [9] also applied vibration training (4 minutes once a week for 2 months, 12–20 Hz) to find similarly improved time of standing on one leg. A probable reason why elderly people perform better in functional tests is that vibration training increases maximal strength, explosive strength and mechanical power of the lower extremities [8], [9]. It is possible that repeated exposure to disturbing stimuli allows subjects to develop an ability to appropriately react to vibration [30].

In subjects standing in a natural position the ML sway is greater than the AP sway [17], because the human body behaves then as a monolithic, inverted pendulum with the rotation axis located in the ankle joints. The results obtained for all groups in this study also confirm this observation (Tables 1–4). Kuczyński [31] likens control of the upright position to stabilization ensured by springs and absorbers representing the viscoelastic properties of the system. The AP stability is achieved because the body is supported on both legs and the mobility of the lower extremity joints is significantly limited in this direction [17]. A smaller range of sideways sway in the ML direction depends, inter alia, on an appropriately large support area defined by the size of subject's feet and the spacing between them. In the reports reviewed for this study spacing ranged from 15 cm [7], [18] to 5 cm [24]. In most studies, though, this information is not available [3], [10], [32]. In this experiment, the subjects were asked to "stand in a natural position with feet at shoulders' width apart and not to move" before posturographic measurements were made. The absence of statistically significant changes in the AP plane seems to suggest that their feet were spread wide enough during the measurements.

Capicikova et al. [7] has brought attention to the effect of vibration time on the range of COP sway. In their study, vibration of 60 Hz and amplitude of 1 mm was applied to the soleus muscles of 17 subjects in three separate trials lasting 10 seconds, 20 seconds and 30 seconds, respectively. The posturographic measurements did not show a correlation between the velocity of backward sway and the time of vibration, but duration-related differences in the range of sway were statistically significant. The backward sway increased with extending vibration time (the sway values for particular times were 15 mm (10 seconds), 23 mm (20 seconds), and 26 mm (30 seconds)). The sway stopped increasing after the COP reached the plateau phase. In this experiment vibration application time was 1 minute, as in the studies of other authors [12], [13]. There are opinions that vibration applied continuously for longer than 1 minute causes muscle fatigue [33] that is known to increase postural instability in the ML and AP directions [34]. As shown by the results of this experiment, five 1-minute static exercises did not induce muscle fatigue in any group but group III.

While being aware that more research into the effects of various types of vibration training on postural stability is necessary, the authors of this study present a conclusion that 4-week vibration training with frequencies of 20, 40 and 60 Hz and amplitudes of 2 mm and 4 mm, excluding the 60 Hz and 2 mm combination, does not significantly change the ML or AP sway in young males. For positive adaptive changes to be induced in the postural stability system of a human 4-week vibration training with parameters of 60 Hz and 2 mm should be applied.

References

[1] EKLUND G., HAGBARTH K., *Normal variability of tonic vibration reflex in man*, Exp. Neurol., 1966, Vol. 16, 80–92.

[2] POLONYOVA A., HLAVACKA F., *Human postural responses to different frequency vibrations of lower leg muscle*, Physiol. Res., 2001, Vol. 50, 405–410.

[3] TALIS V., SOLOPOVA A., *Vibration-induced postural reaction continues after the contact with additional back support*, Motor Control, 2000, Vol. 4, 407–419.

[4] GOMEZ S., PATEL M., MAGNUSSON M., JOHANSSON L., EINARSSON E., FRANSSON P., *Differences between body movement adaptation to calf and neck muscle vibratory proprioceptive stimulation*, Gait Posture, 2009, Vol. 30(1), 93–99.

[5] TORVINEN S., KANNUS P., SIEVANEN H., JARVINEN TERO A., PASANEM M., KONTULAINEN S., *Effect of four-month vertical whole body vibration on performance and balance*, Med. Sci. Sports Exerc., 2002, Vol. 34(9), 1523–1528.

[6] VERSCHUEREN S., ROELANTS M., DELECLUSE C., SWINNEN S., VANDERSCHUEREN D., BOONEN S., *Effect of 6-month whole body vibration training on hip density, muscle strength and postural control*, J. Bone Miner. Res., 2004, Vol. 19, 352–359.

[7] CAPICIKOVA N., ROCCHI L., HLAVACKA F., CHIARI L., CAPPELLO A., *Human postural response to lower leg muscle vibration of different duration*, Physiol. Res., 2006, Vol. 55, 129–134.

[8] IWAMOTOW J., TAKEDA T., SATO Y., UZAWA M., *Effect of whole-body vibration exercise on lumbar bone mineral density, bone turnover and chronic back pain in post-menopausal osteoporotic women treated with alendronate*, Aging Clin. Exp. Res., 2005, Vol. 17(2), 157–163.

[9] KAWANABE K., KAWASHIMA A., SASHIMOTO I., TAKEDA T., SATO Y., IWAMOTO J., *Effect of whole-body vibration exercise and muscle strengthening, balance, and walking exercise on walking ability in the eldery*, Keio. J. Med., 2007, Vol. 56(1), 28–33.

[10] THOMPSON C., BELANGER M., FUNG J., *Effects of bilateral Achilles tendon vibration on postural orientation and balance during standing*, Clin. Neurophysiol., 2007, Vol. 118(11), 2456–2467.

[11] JORDAN J., NORRIS S., SMITH D., HERZOG W., *Vibration training: an overview of the area, training consequences, and future considerations*, J. Strength Con. Res., 2005, Vol. 19(20), 459–466.

[12] CARDINALE M., LIM J., *Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies*, J. Strength Cond. Res., 2003, Vol. 17(3), 621–624.

[13] KROL P., PIECHA M., SLOMKA K., SOBOTA G., POLAK A., JURAS G., *The effect of whole-body vibration frequency and amplitude on the myoelectric activity of vastus medialis and vastus lateralis*, J. Sport Sci. Med., 2011, Vol. 10, 169–174.

[14] YUE Z., MESTER J., *A model analysis of internal loads, energetic, and effects of wobbling mass during whole-body vibration*, J. Biomech., 2002, Vol. 35(5), 639–647.

[15] SOBERA M., SIEDLECKA B., *Repeatability of frequency of corrective foot pressure during balance control in children aged between 2 and 7*, Acta Bioeng. Biomech., 2010, Vol. 12(2), 73–77.

[16] ZATSIORSKY V., DUARTE M., *Instant equilibrium point and its migration in standing tasks: rambling and trembling components of the stabilogram*, Motor Control, 1999, Vol. 3(1), 28–38.

[17] WINTER D., PATLA A., PRINCE F., ISHAC M., GIELO-PERCZAK K., *Stiffness control of balance in quiet standing*, J. Neurophysiol., 1998, Vol. 80, 1211–1221.

[18] ADAMCOVA N., HLAVACKA F., *Modification of human postural responses to soleus muscle vibration by rotation of visual scene*, Gait Posture, 2007, Vol. 25, 99–105.

[19] STASZKIEWICZ R., RUCHLEWICZ T., FORCZEK W., LASKA J., *The impact of changes in gait speed and step frequency on the extent of the center of mass displacements*, Acta Bioeng. Biomech., 2010, Vol. 12(3), 13–20.

[20] ZIELIŃSKA T., TROJNACKI M., *Postural stability in symmetrical gaits*, Acta Bioeng. Biomech., 2009, Vol. 11(2), 57–64.

[21] BRUMAGNE S., CORDO P., LYSENS R., VERSCHUEREN S., SWINNEN S., *The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain*, Spine, 2000, Vol. 25(8), 989–994.

[22] PATEL M., GOMEZ S., LUSH D., FRANSSON P., *Adaptation and vision change the relationship between muscle activity of the lower limbs and body movement during human balance perturbations*, Clin. Neurophysiol., 2009, Vol. 120(3), 601–609.

[23] HATZITAKI V., PAVLOU M., BRONSTEIN A., *The integration of multiple proprioceptive information: effect of ankle tendon vibration on postural responses to platform tilt*, Exp. Brain Res., 2004, Vol. 154(3), 345–354.

[24] VUILLERME N., DANION F., FORESTIER N., NOUGIER V., *Postural sway under muscle vibration and muscle fatigue in humans*, Neurosci. Lett., 2002, Vol. 333(2), 131–135.

[25] FRANSSON P., JOHANSSON R., HAFSTRÖM A., MAGNUSSON M., *Methods for evaluation of postural control adaptation*, Gait Posture, 2000, Vol. 12(1), 14–24.

[26] DOLNY D., REYES G., *Whole body vibration exercise: training and benefits*, Curr. Sports Med. Rep., 2008, Vol. 7(3), 152–157.

[27] ŁAPSZO J., GIOVANIS V., PRUSIK K., PRUSIK K., *Balance control contributors – the relationships between leg strength and balance control ability in seniors*, Acta Bioeng. Biomech., 2012, Vol. 14(3), 3–8.

[28] BLASZYK J., BACIK B., JURAS G., *Clinical assessment of postural stability*, J. Mech. Med. Biol., 2003, Vol. 3(2), 135–144.

[29] RUNGE M., REHFELD G., RESNICEK E., *Balance training and exercise in geriatric patients*, J. Musculoskeletal. Neuronal. Interact., 2000, Vol. 1, 54–58.

[30] VALKIVIC P., KRAFCZYK S., BÖTZEL K., *Postural reactions to soleus muscle vibration in Parkinson's disease: scaling deteriorates as disease progresses*, Neurosci. Lett., 2006, Vol. 401(1–2), 92–96.

[31] KUCZYŃSKI M., *Visco-Elastic Control of Posture*, Hum. Mov. Sci., 2001, Vol. 2(4), 33–38.

[32] SLIJPER H., LATASH M., *The effects of muscle vibration on anticipatory postural adjustments*, Brain Research, 2004, Vol. 1015, 57–72.

[33] COCHRANE D.J., *Vibration exercise: the potential benefits*, Int. J. Sports Med., 2011, Vol. 32, 75–99.

[34] SALAVATI M., MOGHADAM M., EBRAHIMI I., ARAB A., *Changes in postural stability with fatigue of lower extremity frontal and sagittal plane movers*, Gait Posture, 2007, Vol. 26, 214–218.