Acta of Bioengineering and Biomechanics
Vol. 17, No. 3, 2015
Original paper
DOI: 10.5277/ABB-00150-2014-03

The influence of sounds on posture control

BOŻENA SIEDLECKA, MAŁGORZATA SOBERA*,
ALEKSANDRA SIKORA, IZABELA DRZEWOWSKA

University School of Physical Education, Faculty of Physical Education, Wrocław, Poland.

Purpose: It is still not clear which parameters of sound are the most significant for body reactions and whether the way of sound reception plays a role in body control. The purpose of this study was to determine the influence of frequency, spectrum and loudness of sounds on posture control in healthy women and men. Methods: The study subjects were 29 young adults who were submitted to a 60-second standing test in the bipedal stance on the force platform (AMTI). During the tests, 3 sinusoidal sounds with various timing and 2 musical sounds (guitar and piano) of the frequency 225 Hz, 1000 Hz and 4000 Hz were applied through headphones. The centre of pressure (COP) amplitude was registered. The sway area and COP mean velocity were computed. Results: It was found that high frequency sounds contributed to a significant decrease of sway area values. No significant influence of low frequency sounds on posture control was observed. The influence of the sound spectrum (timbre) on posture control is limited; only the crescendo spectrum improves the body stability in the bipedal stance and not the music spectrum as guitar and piano. The loudness of sound, although extremely high, is not the cause of postural control changing in relation to lower loudness. No effect of gender was found in terms of body stability under different sound conditions. Conclusion. Based on the results, it can be argued that, in general, in a bipedal stance in terms of stability high sound frequency improves posture control, whereas sound spectrum and intensity show a limited impact.

Key words: *sounds, posture control, COP, healthy adults, stability improvement*

1. Introduction

The influence of noise on health and quality of life was reported by Lercher [15] and Job [13]. A positive effect of music manifested as improved step synchronization during walking in persons with health deficiencies was reported [25], [5]. Petersen et al. [4] examined the influence of sound information on body posture control induced by body movements performed, and a significant reduction of body sway was observed. It was also reported that a particular kind of noise (stochastic resonance) can improve postural control by stimulating and provoking muscular reactions [10], [20]. There are already data reporting the influence of selected musical fragments on the cardiovascular system [3].

The basis of motor performance is to control postural stability under different internal and external conditions. Posture control is manifested by body sway connected with visual, proprioceptive (kinaesthetic), vestibular and auditory stimuli [18], [28]. Because the phonoreceptors and the vestibular organ are situated anatomically close to each other, sound vibrations can influence posture control [16]. The auditory organ, which is morphologically and functionally mutually connected with the vestibular system, receives sound stimuli in the form of a wave of air density disturbances which affects the vestibular system as well and in general postural control [28], [16], [2]. The influence of sounds on posture control in a standing position in humans has already been addressed [23], [11], [7]. Mainenti et al. [16] concluded that "no statistic difference was

* Corresponding author: Małgorzata Sobera, University School of Physical Education, Faculty of Physical Education, al. J.I. Paderewskiego 35, 51-612 Wrocław, Poland. Tel: +48 713473372, e-mail: malgorzata.sobera@awf.wroc.pl
Received: August 4th, 2014
Accepted for publication: November 5th, 2014

found when conditions with and without sound stimulation were compared at the same visual condition with any type of sound". However, Sakellari and Soames (1996) [24] and Raper and Soames [23] found increased body sway in conditions with auditory stimuli, which means the deterioration of body stabilization [14]. But they investigated posture control under sound stimulation by loudspeakers.

A sound sensation which depends on different parameters such as loudness (intensity), frequency and spectrum is transmitted via the vestibulocochlear nerve. Sakellari and Soames [24] reported that certain bands of sound frequency appeared to influence the regulation of body sway in an antero-posterior direction, while increasing loudness tended to increase the body sway in a medio-lateral direction. The authors observed a difference in posture control reaction depending of the sound parameters. Palm et al. [18] reported that "distracting auditory signals do not appear to significantly influence postural control in healthy subjects". Furthermore, a sudden sound provokes destabilization of the upright body posture, which results in greater increase in postural sway [16]. On the other hand, a mobilization effect of sounds on postural control has been reported [11], [7], [24], [27]. The influence of sound on posture control related to quality of the acoustic environment has been a subject of interest. White noise signals and applause have been employed as well [7], [27], [21]. It was found in that study that posture control significantly improved according to different levels of loudness of the sounds in a bipedal stance. Such a stimulus is a specific sound because it is impossible to determine its physical parameters exactly. Music, on the other hand, is a collection of many ordered harmonic sounds with an amplitude spectrum (it is called timbre of sound) and differs basically from white noise [17], so it seems to be more rational to apply such sound stimuli to determine the effect on posture control.

The important role of the auditory system on postural control is not sufficiently explained. The results of the influence of sound on postural control often include all sound parameters together. It seems to be interesting which sound parameter affects body sway and may improve body stability. The positive effect of the different parameters of sounds on posture control can be considered as a basis for applying sounds with different parameters in healing therapies. Therefore it is important to determine which sound parameters exert the greatest impact on postural control.

The aim of this study was to determine the influence of frequency, spectrum (timbre) and loudness of sounds on posture control in healthy adults.

2. Materials and methods

2.1. Research material

In the present study, 29 persons (17 female and 12 male) took part. They were chosen from among the students of the University School of Physical Education in Wrocław, aged 20 to 26, with body mass from 41.7 to 93.3 kg and height from 1.47 to 1.97 m. The participants were selected on the basis of the following criteria: an interview concerning threats to hearing and balance organs, laryngological examination results, and the pure spectrum audiometry threshold. The study included only subject with no ear or vestibular disease even in the past. After the audiometric tests some of them were excluded by a laryngologist because of a hearing defect. The number 29 does not include the subjects who had hearing defects. The study subjects were informed about the procedure and agreed to take part. The study was approved by the Ethics Committee of the University School of Physical Education in Wrocław.

2.2. Audiometric examinations

Audiometric hearing examinations were performed in appropriate conditions required for the Siemens 260 audiometer. Tonal threshold curves of air conduction were determined in the frequency range of 225–8000 Hz, while for bone conduction the values were between 225 and 4000 Hz. The threshold of uncomfortable loudness level in the range of loudness (intensity) of sound and sound frequency at 225–8000 Hz was determined [12]. Audiometric hearing examination results determining hearing thresholds for each of the participants showed correct values. The determined thresholds of uncomfortable loudness level for each of the participants were taken into account in extreme trials by increasing loudness in the range from 80 to 120 dB.

2.3. Experimental set-up

The experimental set-up included a stereo to play sounds of high definition (Yamaha) with stereo headphones of high quality, a notebook and an AccuSway force platform (AMTI).

2.4. Research procedure

Before each experimental trial, the body mass and height of the persons were measured. Each participant performed 19 consecutive trials of one-minute bipedal standing on the force platform. The only verbal instruction given to each participant was to keep the body in a normal standing position, avoiding movements of the body segments. Feet were placed parallel at the width of the hips, and arms hung along the body. The subjects looked straight ahead at a defined point in space situated at a distance of 3 m at sight level. The amplitudes of the centre of feet pressure (COP) in two directions, medial-lateral and anterior-posterior, were registered in the function of time. The sampling rate was 100 Hz. The stability indices – sway area and average velocity of COP in all directions – were calculated from the COP time series. The sway area was automatically determined in the software in such a way that 5% of the extreme COP amplitudes were cut off (Fig. 1). Stability indices were calculated by the Bioanalysis software, which is compatible with the force platform.

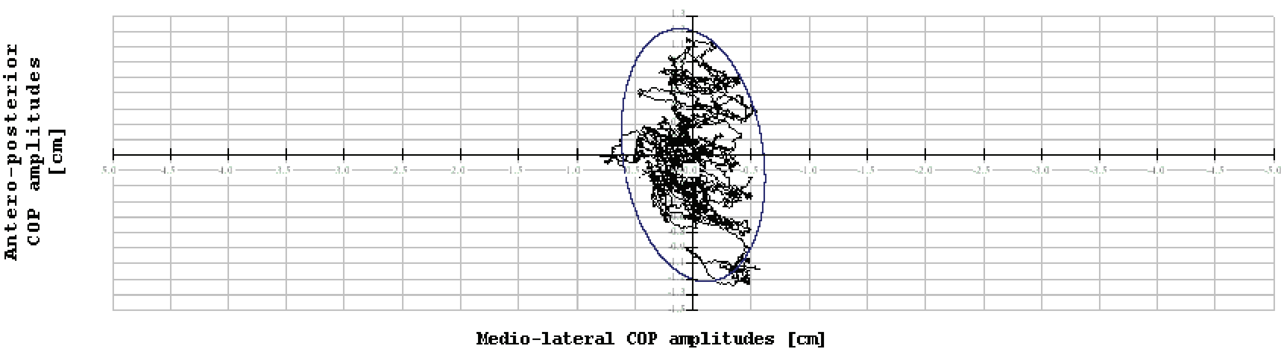

Fig. 1. An example of COP ellipse area delimitation

The sound was applied through high quality headphones. Sounds of high loudness (intensity) (80 dB – constant for all trials apart from the last extreme trial), different frequencies, i.e., 225 Hz, 1000 Hz, and 4000 Hz, and different sound spectra were applied in the trials. Three simple sinusoidal sounds with a different time course and two musical sounds (from guitar and piano) were used. An extreme trial was also carried out with the characteristic of white noise with diverse frequency and loudness (80–120 dB), taking into account thresholds of uncomfortable hearing individual for each participant. They determined their own threshold of sound loudness until they could not accept a higher one with respect to the sound frequency as above. The threshold was noted in the database. Sounds were administered randomly. After each trial the participant remained seated for two minutes in order to avoid any influence of fatigue. Each consecutive test was identified with a number as follows:

trial 0 – without sound

trials 1, 2, 3 – with sinusoidal sound, 225, 1000, 4000 Hz;

trials 4, 5, 6 – with sinusoidal sound, 225,1000, 4000 Hz vibrato (pulsating sound);

trials 7, 8, 9 – with sinusoidal sound, 225,1000, 4000 Hz crescendo (sound of increasing loudness);

trials 10, 11, 12 – with tonal sound, 225, 1000, 4000 Hz guitar;

trials 13, 14, 15 – with tonal sound, 225, 1000, 4000 Hz piano;

trials 16, 17, 18 – white noise ≈ 225, 1000, 4000 Hz > 80–120 dB.

The applied sounds were played from a CD (each kind of sound was a sound track; the pattern of sounds/pauses was the same for every subject) on which they were recorded at fixed time intervals: 0–9 s silence, 10–24 s sound, 25–29 s silence, 30–36 s sound, 37–39 s silence, 40–41 s sound, 42–49 s silence, 50–51 s sound, 52–54 s silence, 55–56 s sound, 57–60 s silence. The duration of sounds and pauses was confirmed by a professional sound researcher from the University School of Technology in Wrocław. The duration of sounds and pauses was chosen in such a way as not to allow the subject to predict when a sound would appear. Prolonged sounds were applied at the beginning of the trial because of less likelihood of "fatigue" of the nervous system under the influence of sound, and the sound duration was shortened at the end of the trial period for the same reason. In the study, we tried to avoid the habituation phenomenon (adaptation to a repeated stimulus).

The last 3 trials with extreme loudness were avoided in the analysis of the effect of sound frequency and timbre on the indices of postural control. The trials with 225 and 1000 Hz were chosen for the analysis of the sound timbre and the COP indices, as the sound frequency is close to the threshold of normal hearing (http://blog.khron.net/2007/08/20/ludzki_sluch_czestotliwosc_dynamika/). The effect of sound loudness on the COP indices were analysed with the frequency factors. The human ear is not equally sensitive to all frequencies. Sounds with a high frequency are heard as "louder" than medium or low frequency sounds [24]. It means that the sound loudness should be considered with reference to the sound frequency in this paper. All trials with the same frequency and loudness of 80 dB were put together and compared to the extreme loudness sounds with respect to frequency.

2.5. Statistical methods

Normality of the distribution was checked with the Shapiro–Wilk test, taking into account the sort of tests. Analysis of variance (a factorial ANOVA module) was applied in order to determine the influence of the effect of sounds on the value of stability indices with respect to the gender of the subjects. One factor was the parameter of sound (frequency, timbre or loudness) and the second one was the gender of subjects. The post-hoc Tukey HSD test was applied in order to assess the significance of the differences between each trial with sound and the trial without sound. All statistical analyses were performed using STATISTICA 10.0 software. The significance threshold in all tests was set at the level $p < 0.05$.

3. Results

3.1. Sound frequency

No significant interaction was found between gender and sound frequency on sway area; $F(3, 456) = 1.34$, $p = 0.26$ (Fig. 2). There was not a significant effect of gender and sound frequency and the sway area but there was a significant effect of the frequency factor in general; $F(3, 456) = 16.84$, $p = 0.0000$. The greatest decrease of the sway area was observed in the trials with sound frequency 4000 Hz in relation to no sound ($p = 0.03$) and low frequency sound trials ($p = 0.0001$). No significant effect between the low frequency sounds and the trials without sound in the sway area values was documented.

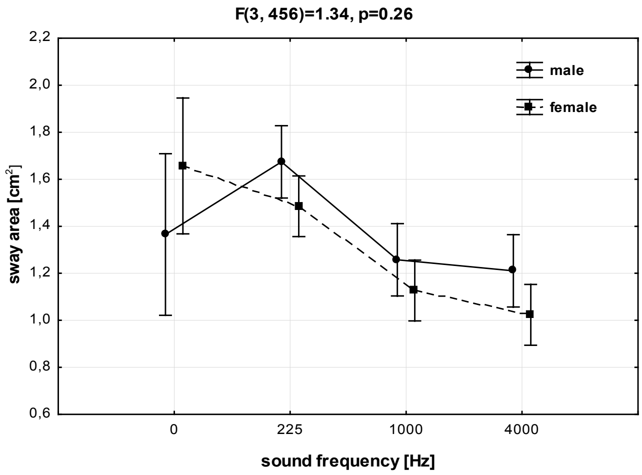

Fig. 2. The sway area and frequency of sound in each trial (except the extreme trials). Error bars indicate 95% confidence intervals

No significant interaction was found between gender and sound frequency on COP velocity; $F(3, 456) = 0.044$, $p = 0.98$. No effect of the frequency factor was found; $F(3, 456) = 1.07$, $p = 0.36$.

3.2. Timbre of sound

No significant interaction was found between gender and sound timbre on sway area; $F(5, 307) = 0.78$, $p = 0.56$ (Fig. 3). A significant effect of sound timbre and sway area was reported without the gender factor; $F(5, 307) = 2.51$, $p = 0.03$. Post-hoc tests showed that only the difference between sway area between the vibrato and crescendo trial was statistically significant ($p = 0.05$). The value of sway area in the crescendo trial was lowest compared to the other trials with different timbres of sound. The crescendo, guitar and piano sounds almost did not differ with respect to the no sound trial.

There were no significant interactions between the sound timbre, gender and the COP velocity; $F(5, 307) = 0.07$, $p = 0.99$. The effect of sound spectrum (timbre) and COP velocity showed only a non-significant decrease in trials with crescendo, guitar and piano sound in reference to the no sound and sinusoidal sound trials; $F(5, 452) = 2.18$, $p = 0.06$.

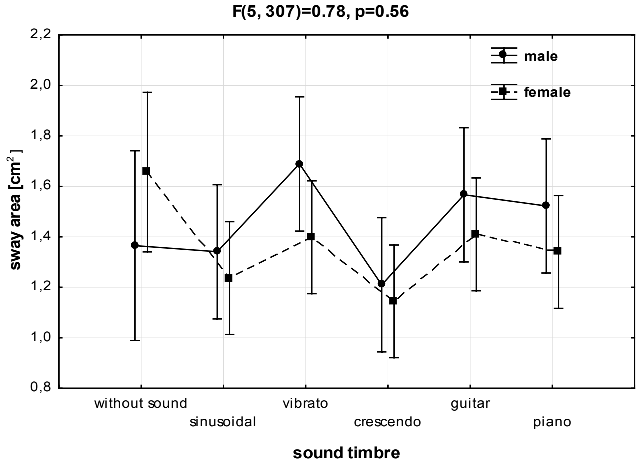

Fig. 3. The sway area and sound timbre in trials with sound frequency 225 and 1000 Hz (explanation in the text). Error bars indicate 95% confidence intervals

3.3. Loudness

No significant interaction was found between gender and sound loudness with the frequency factor on sway area; $F(2, 537) = 0.012$, $p = 0.98$. No significant interaction was found between sway area and loudness with respect to the sound frequency factor, either; $F(2, 544) = 0.62$, $p = 0.54$ (Fig. 4). There were significant differences in the sway area between the no sound and low frequency sound trials and the highest frequency trials (4000 Hz), where sway area significantly decreased in the case of extreme loudness ($p < 0.05$).

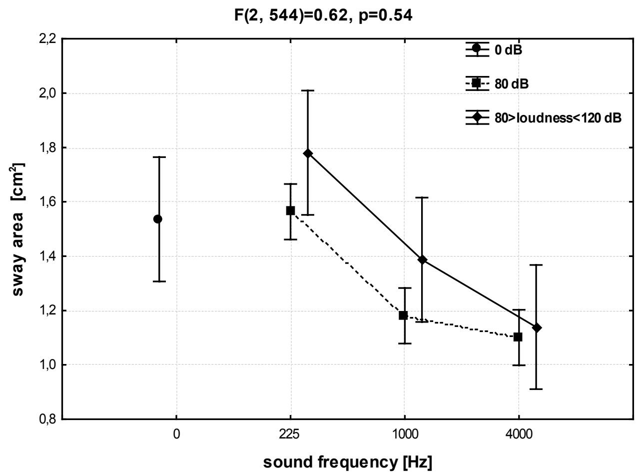

Fig. 4. The interactions of sway area and sound loudness in relation to the sound frequency. Error bars indicate 95% confidence intervals

No significant interaction was found between gender and sound loudness with respect to sound frequency; also no effect of this stability index and sound loudness without the gender factor was noted; $F(2, 545) = 1.27$, $p = 0.28$.

4. Discussion

The correlation coefficients between the dependent measures revealed a high, positive and significant correlation (from 0.44 to 0.86) between the COP range and variability in both directions with the total sway area in each trial, which is why the results for only the latter index were presented. The correlation coefficient between the value of average COP velocity and the sway area revealed very weak and not significant correlation (from 0.27 to –0.24), so the COP velocity was considered as well to find interactions between the latter and the parameters of sound with respect to the gender of subjects.

4.1. Gender and the sound influence on postural control

No significant interactions were found between the factor of sex, the sound parameters and the value of the sway area and COP velocity. Polechoński and Błaszczyk [21] reported differences between the male and female sensitivity of the postural stability system and different parameters of sound but only under closed eyes conditions. The present study confirms the results of those authors; only the eyes open condition was used in this research, so there were no significant interactions between the sound parameters and stability indices with the gender factor. Therefore, all the next analyses of the influence of sounds on posture control should be carried out for the entire group with no gender division in the case of healthy adults.

4.2. The influence of sound frequency on postural control

Based on the results of this study it can be argued that sounds with certain physical parameters are not neutral for posture control in the standing bipedal position. We observed no effect of low frequency sounds on posture control, in contrast to the documented effect for high frequency sounds. In trials with high (1000 Hz) and very high (4000 Hz) frequency a significant decrease of the sway area was observed. This result supports the view that body sway in the erect bipedal posture is dependent on sound frequency (Fig. 2) and the high frequency sounds cause improvement of body balance.

A significant positive correlation between the frequency of sounds and antero-posterior sway was reported by Sakellari and Soames [24]. The authors observed no effect of sound on postural sway in the range 100 to 1480 Hz, but sound in the frequency range 2320 to 3700 Hz was related to considerable antero-posterior sway. The differences of the results in this study may be caused by the different intensity of sounds. Sakellari and Soames [24] applied loudness at the level of 70 and 90 phones (it means that 1000 Hz sounds were applied with the loudness of 70 and 90 dB), and in this study we used 80 dB sounds in all trials with 225 and 1000 Hz. Furthermore, in their study, sound frequency appeared to influence the regulation of antero-posterior sway. COP oscillation in both the antero-posterior and medio-lateral direction are included in sway area so the changes of COP oscillation just in one direction could not be significant under the sound condition but it is possible that they could be significant if sway area were analysed. But the most important thing was that they conclude that in the appropriate frequency range sound stimuli can affect posture control. The results of this study confirm that the higher sound frequency (1 and 4 kHz) affected the postural sway, which is reflected by the decrease of the COP sway area on the support surface. It is important to consider that the observed decrease in body stability indices can be interpreted as increased stability of posture control [4], [29]. Thus, the decrease of the sway area under the high frequency sounds conditions (1 kHz, 4 kHz) can be understood as posture control improvement. To date there is no direct answer as to which of the sound physical parameters can be considered the most important in producing normal hearing sensations. In general, it is believed to be sound frequency. Following the results of Everest and Pohlmann [8], the sound parameter which affects posture control could be high frequency, which is documented in the present study. The observed reactions may be of a similar background to the one which was referred to as immovable, freezing or stiffening when viewing emotion-eliciting images which led to a decrease of body sway [1], [9], [26]. In this study in trials with low sound frequencies no special reactions were observed, as other authors confirmed [24].

4.3. Sound timbre and posture control

Sound spectrum (timbre) is a basic sensory feature of auditory stimuli strongly connected with frequency. That is why the influence of this parameter on postural control is rather difficult to assess. Following the results of this study (see Fig. 3), an impact was observed only in the crescendo trials, where the sway area significantly decreased in relation to the no sound trials or the other timbre trials. This observation suggests that the documented significant increased stability in posture control is related to sounds in the crescendo spectrum (timbre) but not in the other spectrum of sounds. A small increase of the sway area in the trials with vibrato sounds in relation to the no sound trials was documented. It could be the cause of the significant difference between the trials with crescendo and vibrato, as the difference between the no sound and crescendo trials was not significant. However, the vibrato sounds can make the posture control slightly worse because the phonoreceptors and the vestibular organ are situated anatomically close to each other and sound vibrations can influence posture control.

This result appears particularly interesting when compared to the results reported in the area of music therapy. Varying dynamics of musical parts of the crescendo significantly stimulated the autonomic system, resulting in contraction of blood vessels then consequently increased blood pressure and heart rate [3]. The results reported in this study revealed that the timbre of sound influences posture control only in a limited way to increase body stability.

4.4. Sound loudness and postural control

In this study, trials with extreme loudness (intensity) in the range 80 dB to 120 dB, during which white noise with the frequency close to 225 Hz, 1 kHz and 4 kHz was produced, influenced participants' posture control comparatively to trials with the intensity of 80 dB (all trials from 1 to 15). It means the extreme loudness sounds modify postural control as well as the quieter sounds for the same conditions of the sound frequency. At the level of the highest frequency extreme sounds the improvement of body stability was observed as well as in the quieter trials with reference to low frequency and no sound conditions. These results are in line with the data where the noise intensity was manipulated. The observed changes of the stability indices did not show any significant associations with loudness at the levels of 60 dB, 80 dB or 100 dB [21]. So far it can be argued that sound loudness is a parameter applied in standards of a healthy acoustic environment (intensity up to 120 dB) with no significant influence on posture control in young healthy adults. Meanwhile, it was reported that sound loudness at the level of 90 dB influences posture control documented as a medio-lateral COP amplitudes increase [24]. The results of this paper do not necessarily represent contradictory results to Sakellari and Soames [24]. Body sway in one direction usually causes limited sway in the other [6], so the sway area (ellipse) can change the shape or slope but also may become generally smaller under the extreme loudness condition. On the basis of this study we can state improvement of posture control (better body stability) as the sway area was significantly reduced under the extreme loudness trials with very high frequency sounds compared to the low frequency trials. The same regularities were found under the lower loudness conditions. That means there is no specific reaction in posture control when a person resides in the extreme loudness condition compared to quieter loudness. The results of this study indicate once again the main effect of sound frequency on postural control.

5. Conclusion

Based on the results of the present study concerning the influence of sounds on posture control, it was found that the most important physical parameter of auditory stimuli is sound frequency. The improvement of posture control was observed only when a high frequency sound stimulus was produced. The low frequency does not cause any changes in body stability in relation to the normal stance without sound stimuli. The influence on posture control of the sound spectrum (timbre) is limited; only the crescendo spectrum improves the body stability in a bipedal stance and not the music spectrum as guitar and piano. The loudness of sound, although extremely high, is not the cause of postural control changing in relation to lower loudness. No effect of gender was found in terms of body stability under different sound conditions. It would be possible to gain more precise data for the posture control reactions to the sound loudness if we applied a few different levels of loudness in the study, as loudness is a sound parameter to which most people are very sensitive.

These results can be useful in sound therapy to mobilize the posture control system in ergonomics or sport.

Acknowledgements

The authors gratefully acknowledge our friend, who wants to remain anonymous, for comments which were very helpful in improvement of the manuscript. This research was supported by a grant of the University School of Physical Education in Wrocław.

References

[1] AZEVEDO T.M., VOLCHAN E., IMBIRIBA L.A., RODRIGUES E.C., OLIVEIRA J.M., OLIVEIRA L.F., LUTTERBACH L.G., VARGAS C.D., *A freezing-like posture to pictures of mutilation*, Psychophysiology, 2005, Vol. 42, 255–260.

[2] BACSI A.M., COLEBATCH J.G., *Evidence for reflex and perceptual vestibular contributions to postural control*, Exp. Brain Res., 2005, Vol. 160, 22–28.

[3] BERNARDI L., PORTA C., CASUCCI G., BALSAMO R., BERNARDI N.F., FOGARI R., SLEIGHT P., *Dynamic interactions between musical, cardiovascular, and cerebral rhythms in humans*, Circulation, 2009, Vol. 119(25), 3171–3180.

[4] BIEĆ E., KUCZYŃSKI M., *Postural control in 13-year-old soccer players*, Eur. J. Appl. Physiol., 2010, Vol. 110, 703-708.

[5] BUCHMAN C.A., JOY J., HODGES A., TELISCHI F., BALKANY T., *Vestibular effects of cochlear implantation*, Laryngoscope, 2004, Vol. 114, Suppl. 1–22.

[6] DERLICH M., KRĘCISZ K., KUCZYŃSKI M., *Attention demand and postural control in children with hearing deficit*, Research in Developmental Disabilities, 2011, Vol. 32, 1808–1813.

[7] DOZZA M., HORAK F.B., CHIARI L., *Audio-biofeedback improves balance in patients with bilateral vestibular loss*, Arch. Phys. Med. Rehabil., 2005, Vol. 86(7), 1401–1403.

[8] EVEREST F.A., POHLMANN K.C., *Podręcznik akustyki, Master Handbook of Acoustics*, publisher Sonia Draga, Katowice 2009, Poland, ISBN 978-83-7508-168-8.

[9] FACCHINETTI L.D., IMBIRIBA L.A., AZEVEDO T.M., VARGAS C.D., VOLCHAN E., *Postural modulation induced by pictures depicting prosocial or dangerous contexts*, Neuroscience Letters, 2006, Vol. 410, 52–56.

[10] GAMMAITONI L., HANGGI P., JUNG P., MARCHESONI F., *Stochastic resonance*, Reviews of Modern Physics, 1998, Vol. 70(1), 223–287.

[11] HEGEMAN J., HONEGGER F., KUPPER M., ALLUM J.H., *The balance control of bilateral peripheral vestibular loss subjects and its improvement with auditory prosthetic feedback*, J. Vestib. Res., 2005, Vol. 15(2), 109–117.

[12] JANCZEWSKI G., *Otolaryngologia Praktyczna*. tom I. *Practical Otolaryngology*, Via Medica, Gdańsk 2007, Poland, ISBN-8360072660.

[13] JOB R.F.S., *The influence of subjective reactions to noise on health effects of the noise*, Environ. International, 1996, Vol. 22(1), 93–104.

[14] KUCZYŃSKI M., *The second order autoregressive model in the evaluation of postural stability*, Gait & Posture, 1999, Vol. 9, 50–56.

[15] LERCHER P., *Environmental noise and health: an integrated research perspective*, Environ. International, 1996, Vol. 22(1), 117–129.

[16] MAINENTI M.R.M., DE OLIVEIRA L.F., DE MELO T., DE LIMA M.A., NADAL J., *Stabilometric signal analysis in tests with sound stimuli*, Exp. Brain Res., 2007, Vol. 181, 229–236.

[17] MOORE B.C.J., *Wprowadzenie do psychologii słyszenia. Introduction to the psychology of healing*, PWN, Warszawa-Poznań, 1999, Poland, ISBN 83-01-12-766-X.

[18] PALM H.G., STROBEL J., ACHATZ G., LUEBKEN F., FRIMERT B., *The role and interaction of visual and auditory afferents in postural stability*, Gait & Posture, 2009, Vol. 30(3), 328–333.

[19] PETERSEN H., MAGNUSSON M., JOHANSSON R., FRANSSON P., *Auditory feedback regulation of perturbed stance in stroke patients*, Scand. J. Rehabil. Med., 1996, Vol. 28(4), 217–223.

[20] PETRACCHI D., GEBESHUBER I.C., DE FELICE L.J., HOLDEN A.V., *Stochastic resonance in biological systems*, Chaos, Solitons & Fractals, 2000, Vol. 11, 1819–1822.

[21] POLECHOŃSKI J., BŁASZCZYK J.W., *The effect of acoustic noise on postural sway in male and female subjects*, J. Hum. Kinet., 2006, Vol. 15, 37–51.

[22] PRIPLATA A., NIEMI J., SALEN M., HARRY J., LIPSITZ L.A., COLLINS J., *Noise-enhanced human balance control*, Physical Review Letters, 2002, Vol. 89(23), 81–101.

[23] RAPER S.A., SOAMES R.W., *The influence of stationary auditory fields on postural sway behaviour in man*, Eur. J. Appl. Physiol. Occup. Physiol., 1991, Vol. 63, 363–367.

[24] SAKELLARI V., SOAMES R.W., *Auditory and visual interactions in postural stabilization*, Ergonomics, 1996, Vol. 39(4), 634–648.

[25] SCHAUER M., STEINGRUBER W., MAURITZ K.H., *Effect of music on gait symmetry of stroke patients on treadmill*, Biomed. Tech. (Berl.), 1996, Vol. 41(10), 291–296.

[26] STINS J.F., BEEK P.J., *Effects of affective picture viewing on postural control*, BMC Neuroscience, 2007, Vol. 8, 83–90.

[27] TANAKA T., KOJIMA S., TAKEDA H., INO S., IFUKUBE T., *The influence of moving auditory stimuli on standing balance in healthy young adults and the elderly*, Ergonomics, 2001, Vol. 44(15), 1403–1412.

[28] TREW M., EVERETT T., *Human Movement*, Elsevier Churchill Livingstone, London 2005, ISBN 0-443-07446-1.

[29] TRUSZCZYŃSKA A., RĄPAŁA K., GMITRZYKOWSKA E., TRZASKOMA Z., DRZAŁ-GRABIEC J., *Postural stability disorders in patients with osteoarthritis of the hip*, Acta Bioeng. Biomech., 2014, Vol. 16(1), 45–50.