Introduction

For most of their life people remain in an upright position. The vertical posture is the basis of bipedal locomotion and many other movements. While standing, humans can perform a variety of life activities. In everyday life and in sport versatile assessment of the vertical posture is absolutely necessary. Postural stability has been a subject of research in such sports as gymnastics, judo, rifle shooting or skiing [1–4]. Few researchers have focused on the question of postural sway in team games players, especially in volleyball, which has particular requirements to combine postural stability with control of the ball and the overall assessment of the situation in the field.

Volleyball is highly challenging to players as they must hit or pass the ball while being in highly dynamic and often unstable postures [5]. A technical element, which is particularly important, is the player’s ability to adopt and maintain the so-called volleyball posture. It should ensure, at least instantaneously, appropriate body balance and allow body movements in all directions [6]. In all volleyball actions during which the player has contact with the floor, maintaining postural stability is crucial. Such actions include receiving a serve, defense, standing serve, setting and digging. The high effectiveness of these actions is determined by the player’s ability to control his or her postural sway. High robustness to any disturbances of body balance is necessary as actions with the ball without postural stability are far less accurate. This is because the central nervous system aims first at restoring the body vertical [7].

The analysis of the world championship matches shows that success in present-day volleyball is largely determined by efficient individual actions. Thus, apart from perfecting the players’ general and specific fitness, technical preparation, team and individual tactics,
mental training, stimulation and experience, also some other factors should be sought. One of them could be the players’ exceptional postural control skills which were identified in the Polish male team prior to the 2006 world championships [8]. We believe that if a similar postural performance is presented by the average second league athletes, this can provide evidence that postural control skills are an important training goal. Further, this would also demonstrate that studying the international level players, who are often beyond the reach of researchers, could be effectively substituted by the research on athletes of national ranking.

The purpose of this study was to compare postural control in quiet stance in second-league male volleyball players with the age-matched physically active male students. We hypothesized that the athletes would display better postural performance due to implementation of different and more effective postural strategies than the control group.

**Material and methods**

The subjects included 23 volleyball players (22.9 ± 4.7 years of age, body height 193.0 ± 5.4 cm, body weight 87.6 ± 6.4 kg) from sports clubs from the second league; and 24 physically active non-training students of the Opole University of Technology (22.9 ± 1.3 years of age; body height 180.9 ± 6.4 cm; body weight 77.9 ± 10.0 kg). All subjects were in good health and expressed their written consent to participate in the study which was approved by the local Ethics Committee.

During the test the subjects stood quietly for 20 s on a force plate with their eyes open; the center of pressure (COP) was recorded in the anterior-posterior (AP) and medial-lateral (ML) planes with the sampling rate of 20 Hz. From the recorded signals the COP variability and range were calculated. Further, using the second order autoregressive model [9] the frequency of the difference between the COP and the center of mass signals as well as the respective values of postural stiffness were computed.

The results from both groups were compared with Student’s t-test for independent samples at \( p < 0.05 \).

**Results**

Table 1. compares mean values (± SD) of computed parameters in both groups of subjects. The COP variability and range were 22–27% higher in the control group, with the exception of insignificant differences in variability in the ML plane. These results indicate superior postural stability in volleyball players. The COP mean velocity was 48% higher in the AP plane and 22% in the ML plane in the volleyball players than in the students. This points to an increased activity of the nervous system in postural control among the athletes. Postural frequency and stiffness were higher in the players than in the control group only in the AP plane, with the difference between the frequencies very close (\( p < 0.07 \)) to the assumed level of statistical significance.

**Discussion**

Postural performance can be assessed using amplitude characteristics (variability and range), and lower values of these parameters are thought to account for better postural performance and stability. The amplitude characteristics are also good indices of coordination abilities of the equilibrium system [4]. Thus the volleyball players in this study exhibited superior postural stability and better motor coordination than their non-training peers. These results confirmed our hypothesis pointing to possible relationships between the inter-group differences and the specificity of volleyball training.

Comparison between the changes in the COP mean velocity may raise some doubts as the inter-group dif-

| Table 1. COP parameters in quiet stance in the control and study groups (students and volleyball players) |
| --- |
| Anterior-posterior plane | Medial-lateral plane |
| **Variability (mm)** | Students | Volleyball players | Students | Volleyball players |
| **Range (mm)** | 4.6 ± 1.7 | 3.7 ± 0.8* | 3.2 ± 1.0 | 2.9 ± 0.6 |
| **Mean velocity (mm/s)** | 22.8 ± 6.7 | 179 ± 3.8*** | 18.2 ± 4.8 | 14.4 ± 4.1*** |
| **Frequency (Hz)** | 6.7 ± 2.0 | 9.9 ± 2.7**** | 5.9 ± 1.5 | 7.2 ± 1.9*** |
| **Stiffness (Nm/rad)** | 0.57 ± 0.12 | 0.65 ± 0.15 | 0.65 ± 0.14 | 0.63 ± 0.16 |
| **Stiffness (Nm/rad)** | 1255 ± 516 | 1803 ± 793** | 1465 ± 495 | 1789 ± 786 |

* \( p < 0.05 \), ** \( p < 0.01 \), *** \( p < 0.0001 \)
ferences in signal variability are usually accompanied by similar differences in mean velocity. The results of the present study revealed an opposite trend: the group of athletes had lower COP variability and significantly higher COP mean velocity than the control group. Theoretically, a higher COP mean velocity could have been due to an increase in one or more of the three COP parameters: amplitude, useful frequency of the COP signal, and noise frequency. Our results suggest that a combination of the first two parameters could not have led to the observed velocity increase. Thus only the appearance of a low-amplitude noise with high frequency would explain the higher COP mean velocity in athletes as opposed to the subjects from the control group. However, since noise is usually associated with deteriorated information, and control engineers always try to eliminate it in order to improve the effectiveness of their devices, the above explanation seems at the first glance as being against common sense.

It appears that one plausible interpretation of these results in terms of positive impact of noise may be based on the concept of stochastic resonance [10, 11]. Stochastic resonance is probably the only known example of using noise to enhance the detection of weak information-carrying signals e.g. sensorimotor signals in biological systems [12, 13]. Priplata et al. [14] showed that artificial generation of a subsensory (90% of perceptual threshold) noise in the form of slight pressure on the sole of a standing subject led to a reduction in postural sway due to faster and/or more accurate detection of this sway from the vertical. It seems feasible that highly trained athletes, whose performance in competition may critically depend on their postural stability, have learnt to make use of this modality. A similar inverse relationship between the changes in the COP mean velocity has been found in the world class volleyball players [8], however the latter group presented even lower frequency of the correction signal and larger improvement in postural stability thus providing a more compelling evidence for the presence of the useful noise in their COP signals than in this study. This can indicate that the second league players were still in the developmental phase of adjusting their postural strategies and that these strategies may play crucial role during the competition.

Our results raise a question regarding the odds that stochastic resonance is the actual reason for the observed discrepancies between the volleyball players and controls [15]. Had it been the only data providing this evidence, we would have to be extremely cautious in making neuromotor inferences. However, three other projects that are currently carried out by our team have also yielded similar results. These studies concerned 2006 volleyball world champions in comparison with the control group; subjects standing 1.5 m above the ground versus subjects standing on the floor; and subjects in light touch stance versus subjects in quiet stance. In all the cases a lower COP variability, which indicated better postural stability, was associated with a higher COP mean velocity. It is then highly probable that the central nervous system uses a mechanism similar to stochastic resonance in hazardous situations or situations requiring higher accuracy of action or resistance to perturbations.

Another problem concerns the scope of further research and its practical applications. Two important questions arise: What specific elements of volleyball training and competition can activate the mechanism of stochastic resonance? How to measure and discriminate between stochastic resonance and ordinary noise which can often occur during tests? The answer to the first one would make it possible to improve therapy of patients susceptible to falls by enhancing the existing rehabilitation procedures with specific sport exercises. It should be emphasized that the discussed regulatory mechanism of postural control in the volleyball players can be possibly found among other athletes representing different sports. The second question is more challenging. The existing computational methods are unable to effectively discriminate between the sources of slight noise in the signal, though the viscoelastic modeling provides certain means [16, 17] to cope with this problem, as we have shown here by analyzing the interplay between the COP mean velocity vs. COP variability and postural frequency. Some new possibilities can be offered by chaotic measures and fractal dimension of the COP signal [18] as well as by time-to-boundary measures of postural control [19]. It seems, however, that studying postural mechanisms in professional sport must lead to new methods of mathematical modeling and distinct experiments based on the specificity of individual sports.

References
1. Era P., Konttinen N., Mehto P., Saarelas P., Lyytinen H., Postural stability and skilled performance – a study on top level and naive rifle shooters. J Biomech, 1996, 29, 301–306.
2. Vuillerme N., Nougier V., Attentional demand for regulating postural sway: the effect of expertise in gymnastics. Brain Res Bull, 2004, 63(2), 161–165.
DOI: 10.1016/j.brainresbull.2004.02.006.
3. Perrin P., Deviterne D., Hugel F., Perrot C., Judo, better than dance, develops sensorimotor adaptabilities involved in balance control. Gait Posture, 2002, 15(2), 187–194. DOI: 10.1016/S0966-6362(01)00149-7.

4. Noe F., Paillard T., Is postural control affected by expertise in alpine skiing? Br J Sports Med, 2005, 39, 835–837. DOI: 10.1136/bjsm.2005.018127.

5. Papageorgiou A., Spitzley W., Volleyball: A Handbook for Coaches and Players. Meyer & Meyer Sport, 2002.

6. Uzarowicz J., Volleyball. What is on? [in Polish]. AWF, Kraków 2001.

7. Naglak Z., Teaching and learning multisubject ball games. Part I: Teaching the player at a preliminary level [in Polish]. AWF, Wrocław 2005.

8. Kuczyński M., Rektor Z., Borzucka D., Postural control in world championship level male volleyball players. Br J Sports Med (submitted).

9. Kuczyński M., The second order autoregressive model in the evaluation of postural stability. Gait Posture, 1999, 9, 50–56.

10. Cordo P., Inglis J.T., Verschueren S., Collins J.J., Merfeld D.M., Rosenblum S. et al., Noise in human muscle spindles. Nature, 1996, 383, 769–770. DOI: 10.1038/383769a0.

11. Fallon J.B., Carr R.W., Morgan D.L., Stochastic resonance in muscle receptors. J Neurophysiol, 2004, 91, 2429–2436. DOI: 10.1152/jn.00928.2003.

12. Wiesenfeld K., Moss F., Stochastic resonance and the benefits of noise: from ice ages to crayfish and SQUIDs. Nature, 1995, 373, 33–36. DOI: 10.1038/373303a0.

13. Collins J.J., Imhoff T.T., Grigg P., Noise-enhanced tactile sensation. Nature, 1996, 383, 770. DOI: 10.1038/383770a0.

14. Priplata A.A., Patritti B.L., Niemi J.B., Hughes R., Gravelle D.C., Lipsitz L.A. et al., Noise-enhanced balance control in patients with diabetes and patients with stroke. Ann Neurol, 2006, 59(1), 4–12. DOI: 10.1002/ana.20670.

15. Moss F., Ward L.M., Sannita W.G., Stochastic resonance and sensory information processing: a tutorial and review of applications. Clinical Neurophysiology, 2004, 115(2), 267–281. DOI: 10.1016/j.clinph.2003.09.014.

16. Kuczyński M., Visco-elastic control of posture. Hum Mov, 2001, 2(4), 33–38.

17. Kuczyński M., Dean E., Jones A., The viscoelastic model of standing balance control: preliminary norms and clinical implications. Hum Mov, 2002, 1(5), 5–13.

18. Kuczyński M., Sobera M., Serafin R., Postural control in the elderly: Relations between traditional, chaotic, and viscoelastic measures of postural stability. Polish Journal of Environmental Studies, 2007, 16 (5C, part I), 306–310.

19. Hertel J., Olimsted-Kramer L.C., Deficits in time-to-boundary measures of postural control with chronic ankle instability. Gait Posture, 2007, 25(1), 33–39. DOI: 10.1016/j.gaitpost.2005.12.009.

Paper received by the Editors: June 3, 2008.
Paper accepted for publication: June 23, 2008.

Address for correspondence
Michał Kuczyński
Katedra Fizjoterapii w Dysfunkcjach Narządu Ruchu Akademia Wychowania Fizycznego
al. I.J. Paderewskiego 35
51-617 Wrocław, Poland

e-mail: michkucz@awf.wroc.pl