CLINICAL APPLICATIONS OF POSTUROGRAPHY: FROM RESEARCH TO PRACTICE

KLINICKÉ VYUŽITIE POSTUROGRAFIE: OD VÝSKUMU K PRAXI

Erika ZEMKOVÁ, Dušan HAMAR, Thomas KEINBACHER, Gerold EBENBICHLER

Prof. Mgr. Erika Zemková, Ph.D.[1],
Prof. MUDr. Dušan Hamar, Ph.D.[1],
Thomas Kienbacher, MD.[2], *Assoc.*
Prof. Gerold Ebenbichler, MD.[3]

[1] *Department of Sports Kinanthropology, Faculty of Physical Education and Sports, Comenius University in Bratislava, Nábr. arm. gen. L. Svobodu 9, 814 69 Bratislava, Slovakia*

[2] *Karl-Landsteiner Institute of Outpatient Rehabilitation Research, Porschestraße 29, A-1230 Vienna, Austria*

[3] *Department of Physical Medicine & Rehabilitation, Medical University of Vienna & Vienna General Hospital, Währinger Gürtel 18-20, A-1090 Vienna, Austria*

Abstrakt

Táto prehľadová štúdia poukazuje na možnosti využitia posturografie v klinickej medicíne. Doposiaľ sa v praxi na posudzovanie stability postoja využíval najmä Rombergov test či tandemový Rombergov test. Tieto testy však môžu byť zaťažené určitou chybou merania a nemusia byť dostatočne citlivé na odhalenie zmien parametrov rovnováhy počas cvičebných programov. Objektívnu možnosť diagnostiky predstavujú stabilografické systémy. V našich podmienkach používame systém FiTRO Sway Check, ktorý umožňuje monitorovanie pohybu ťažiska tela v horizontálnej rovine na základe analýzy distribúcie vertikálnej sily registrovanej pomocou dynamometrickej platne s tromi tenzometrickými snímačmi sily frekvenciou 100 Hz. Na posudzovanie stability postoja sa v praxi najviac využíva statická posturografia. Aj keď je citlivosť takéhoto merania na prijateľnej úrovni umožňujúcej hodnotenie stability postoja na väčších skupinách, nedosahuje úroveň potrebnú na individuálne posudzovanie v praxi. Skúsenosti ukazujú, že dynamická posturografia umožňuje citlivejšie diferencovať jedincov s rôznou úrovňou rovnováhových schopností. Inou možnosťou je test, pri ktorom dochádza k narušeniu rovnováhy neočakávaným uvoľnením závažia, ktoré testovaná osoba drží v predpažení. K zvýšeniu náročnosti podmienok na udržanie rovnováhy možno použiť penovú podložku alebo platňu na pružinách spolu s vylúčením zrakovej kontroly. Novinkou v diagnostike rovnováhových schopností sú performačné testy stability postoja založené na vizuálnej spätnoväzbovej kontrole polohy ťažiska tela a regulácii jeho pohybu v požadovanom smere. Tieto testy našli svoje uplatnenie pri posudzovaní aktuálneho stavu rovnováhových schopností jedincov rôzneho veku a výkonnosti, schopnosti udržania rovnováhy a rýchlosti jej obnovy po narušení v športovo-špecifických podmienkach, vplyvu rôznych foriem telesného zaťaženia na stabilitu postoja, ako aj adaptačných zmien pri systematickom cvičebnom programe zameranom na jej zlepšenie. Na druhej strane, nevyužité sú zatiaľ možnosti ich uplatnenia v klinickej medicíne a rehabilitácii. Na opodstatnenosť posudzovania stability postoja v prípade určitých ochorení či poranení pritom poukazujú mnohé zahraničné štúdie. V tejto práci preto upriamime pozornosť predovšetkým na metódy posudzovania stability postoja v našich podmienkach.

Kľúčové slová: testy statickej a dynamickej rovnováhy, performačné testy stability postoja, test rovnováhy pri náhlom narušení stability postoja

Introduction

Romberg's test is commonly used as a part of the neurological examination. However, it is considered to be a rather qualitative assessment of postural stability because only greater sway may be observed (Jansen et al., 1982). Diagnostic systems based on force platform represent more objective alternative. These are able to assess various aspects of postural control system. The displacement of the center of pressure (CoP) is used as a measure of stabilizing postural reactions in quiet standing, as well as in expected or unexpected perturbations.

Traditionally used static balance, however, in most cases is not sensitive enough to reveal balance problems in an early phase of disease. This lack of sensitivity is a consequence of multiple sensory inputs (visual, vestibular, and proprioceptive) involved in postural control. Such a system can compensate for a smaller impairment of balance in such a way that under static conditions no deficits in postural stability may be apparent. Under dynamic conditions, the control mechanisms are taxed to a substantially greater extent so that individual differences can be revealed. These are characterized by a stance on a foam cushion, by external perturbations from a platform either shifting in antero-posterior (A-P) and medio-lateral (M-L) direction or tilting toes up and down, and by applying them directly to the body, for example by pushing/pulling the trunk, shoulders or pelvis.

Experience indeed indicates that standing on an unstable foam surface or a spring-supported platform while testing balance function is more efficient for discriminating within-group and between-group differences as compared to static balance tests (Zemková, Hamar, 2015; Zemková et al., 2015a). These conditions are also more effective in revealing slight changes in sensorimotor functions following exercise programs (Zemková, 2010). In addition, the testing of balance under unstable conditions, coupled with or without visual references, is able to reveal changes in the postural control system throughout the lifespan (Zemková et al., 2010). This may be due to the fact that reduced reliability of proprioceptive information, either by standing on a sway-referenced surface (Redfern et al., 2001) or on a compliant foam surface (Teasdale et al., 1993), increases attention demand associated with maintaining balance. In particular, vision is of greater significance when demands on the postural task increase (Buchanan, Horak, 1999; Mergner et al., 2005). According to Taube et al. (2008) there is a significant interaction between the visual and the support surface conditions indicating that the H-reflex is more strongly affected by changes in visual feedback while standing on an unstable surface.

Contrary to this, visual feedback control of the center of mass (CoM) position may compensate for reduced proprioceptive information while standing on a foam surface (Zemková et al., 2010). However, providing visual feedback in more demanding and functional balance tasks (i.e., the stance on a spring-supported platform) enhances discrimination of sway variables in A-P and M-L directions during a visually-guided CoM tracking task (Zemková et al., 2010). In comparison with static balance tests, task-oriented balance tests showed comparable reliability but better potential for the differentiation between groups with different level of balance capabilities (Hamar, Zemková, 2009).

Dynamic posturography also represents a more sensitive and hence a more appropriate alternative for the assessment of balance than systems which monitor the CoP in static conditions (Zemková et al., 2005a; Zemková et al., 2005b). Platform perturbations on some systems are unpredictable and are determined by the subject's positioning and sway movement. Other systems have a more predictable sinusoidal waveform, which remains constant regardless of subject positioning. Another example is the system that has a centrally pivoted platform with a tilt sensor. The stability of the platform is controlled by pressure in a pneumatic cushion under the platform and the tilt sensor monitors the deviation from the reference position. Some systems utilize a multiaxial platform similar to that of a BAPS board or wobble board that allows approximately 20° of deflection in any direction. Novel systems are equipped with the trunk sensor applied to the subject's trunk which is capable of detecting trunk oscillations in A-P and M-L directions in erect as well as seated positions.

For instance, one of the most used, the NeuroCom´s EquiTest, is equipped with a moving visual surround allowing the assessment of different sensory modalities. During the assessment, inaccurate information is delivered to the patient′s eyes, feet and joints through sway referencing of the visual surround and/or the support surface. The Sensory Organization Test (SOT) consists of six conditions designed to evaluate the effects of vision, proprioception, and vestibular input during standing. Several studies have reported moderate to good reliability of the SOT in young and older subjects (e.g., Ford-Smith et al., 1995). Some of the studies showed test-retest reliability of the SOT equilibrium scores using the estimated G coefficient in the range of 0.51 for the SOT condition 4 and 0.64 for the SOT condition 5 (Dickin, Clark, 2007) to 0.67 for the composite SOT score (Wrisley et al., 2007) in healthy young adults. However, Wrisley et al. (2007) found significant changes in the composite and equilibrium scores for the SOT conditions 4, 5 and 6 over 5 repetitions when testing young people, suggesting that a learning effect was present. A significant learning effect for the SOT conditions was also observed in patients with chronic low back pain (Leitner et al., 2009). Likewise, significant learning effects seem to limit the use of the SOT as an outcome monitor in early of lung transplantation rehabilitation. The Motor Control Test does not seem to provide additional information to the planning of lung transplantation rehabilitation programs. The Limits of Stability Test provides an excellent level of reliability and an acceptable level of detection of expected changes in postural stability as a result of planned rehabilitation intervention (Ebenbichler et al., 2015; Ebenbichler et al., 2016). However, this system used in clinical examination is rather expensive and not available for smaller physiotherapy or rehabilitation centres. In addition, the practice has shown that it is more useful to utilize computerized portable systems that are more applicable to routine testing as opposed to laboratory conditions (Zemková, 2013a; Zemková et al., 2015b).

Instrumented tests such as trunk repositioning and load release tasks (Reeves et al., 2006; Silfies et al., 2007) which are a quick-to-administer, could serve as a possible alternative to overcome these limitations. The trunk repositioning tasks require a subject to actively or passively return to a neutral spine position following a predefined displacement. Load release tasks require the subject to perform an isometric trunk contraction at a predefined intensity against an external load, which is subsequently released, and the displacement of the trunk is quantified. The voluntary surface electromyography can be recorded from the core musculature to examine the on–off activation of muscles following release. These tests are mainly used to evaluate functional impairments among elderly people and those with concurrent neck or low back pain (Michaelson et al., 2003; Jørgensen et al., 2011; Karayannis et al., 2013; Sturnieks et al., 2013).

Though most of these tests were applied to athletes (Zemková, 2011; Zemková, 2012; Zemková, 2014a; Zemková, Hamar, 2014; Zemková et al., 2015c), some of them were also used in children and youth (Kováčiková et al., 2011; Štefániková, Zemková, 2013a; Štefániková, Zemková, 2013b; Zemková, 2013b; Štefániková, Zemková, 2014), physically active and sedentary adults of different ages (Štefániková et al., 2011; Zemková et al., 2013; Zemková et al., 2016a), overweight and obese individuals (Zemková et al., 2016b), Parkinson patients (Valkovič et al., 2012) and in those after lower limb injury (Zemková, Vlašič, 2009; Vlašič, Zemková, 2011; Zemková et al., 2011). This study is aimed at presentation of methods used for assessment of body balance in our conditions and their possible applications in clinical medicine, physiotherapy, and rehabilitation.

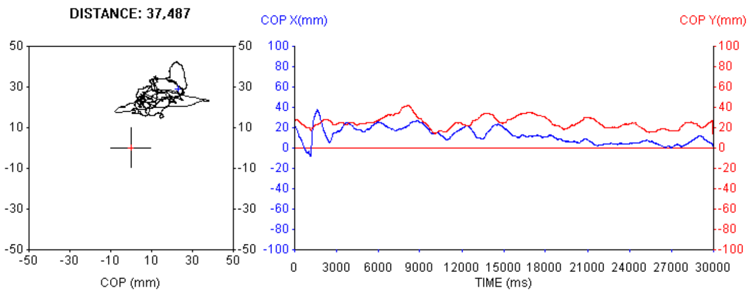
Static balance tests

Subjects stand barefoot on a force platform with their arms relaxed comfortably at their sides (Figure 1). They are instructed to stand in an upright posture with their feet abducted 10° and their heels separated mediolaterally by a distance of 6 cm. A series of two trials are conducted in random order under different conditions: bipedal stance on a force platform with eyes open and eyes closed, respectively; bipedal stance on an foam surface placed on the force platform with eyes open and eyes closed, respectively; and one-legged stance on the force platform with eyes open. Each test consists of two 30-second trials while better result is taken for the evaluation.

Basic parameters of postural sway (mean CoP position in the X- and Y-axis, mean CoP velocity, mean CoP acceleration, mean trace length of the CoP, mean distance from the middle of the CoP, mean squared distance from the middle of the CoP, and area of trace of the CoP) are registered by using a system FiTRO Sway Check (FiTRONiC, SVK) (Figure 2). The force platform data are sampled at a frequency of 100 Hz. As an alternative, an unstable spring-supported platform can be used.

Analyses of repeated measurements identified that the most reliable parameter was mean CoP velocity with the test-retest correlation coefficient of 0.819 and the measurement error of 10.4% (Zemková, Hamar, 1998). The mean of the best two out of five 30-second trials recorded for evaluation were considered as a reliable measure of postural stability ($r = 0.987$). There were no significant day-to-day changes in measures of postural stability which signify stability of measurement.

Figure 1 Tests of static balance using the FiTRO Sway Check system



Interval	X-mean (mm)	X-SD (mm)	Y-mean (mm)	Y-SD (mm)	Length X (mm)	Length Y (mm)	DX/DY	Length (mm)	Speed-mean (mm/s)
0 - 5	-10.9	1.2	38.9	8.3	29.8	188.5	0.2	209.1	41.8
5 - 10	-13.3	0.8	35.4	1.4	18.1	31.8	0.6	45.0	9.0
10 - 15	-13.8	0.9	37.7	1.7	18.6	31.8	0.6	45.7	9.1
15 - 20	-14.2	0.6	33.8	2.5	16.7	45.5	0.4	55.9	11.2
20 - 25	-15.9	0.6	35.4	4.7	14.3	53.4	0.3	63.7	12.7
25 - 30	-16.4	0.6	34.7	2.1	14.1	59.0	0.2	68.8	13.8

Figure 2 An example of results

Although mean CoP velocity and mean distance of the points on the stabilographic curve from its center are reliable to assess postural stability in a group of subjects, these are not sensitive enough for individual assessment. As the movement of the CoM is characterized as a random process, partly based on Chaos Theory, it is possible to use the mathematical model, so-called diffusion analysis, for its evaluation.

The stabilogram-diffusion analysis (SDA) assumes that the CoP during quiet stance can be modeled as a system of coupled, correlated random walks (Collins, De Luca, 1993). This analysis revealed that over short time intervals during quiet stance, the CoP tends to drift away from a relative equilibrium point, while over long time intervals, the CoP tends to return to a relative equilibrium point. This finding was interpreted as an indication that the postural control system utilizes open-loop control mechanisms over short-term intervals, and closed-loop control over long-term intervals to maintain upright stance. An open-loop control system is one which operates without sensory feedback, and in the case of the human postural control system it may correspond to descending commands which set the steady-state activity levels of the postural muscles. Closed-loop control systems, on the other hand, operate with sensory feedback, and in the case of the human postural control system they correspond to the visual, vestibular and somatosensory systems. This enables us to relate the measures quantifying the stochastic behavior of the CoP profile to the neuromuscular mechanisms underlying the maintenance of upright posture (Collins, De Luca, 1993; Collins, De Luca, 1995; Collins et al., 1995).

According to the authors, the SDA is capable of detecting several changes related to the postural control system. For instance, the method can differentiate postural stability between young and elderly subjects (Collins, De Luca, 1995), or between healthy elderly subjects and those with idiopathic Parkinson´s disease (Mitchell et al., 1995). SDA also more sensitively revealed fine details in response to the training consisting of squats performed on an unstable surface in an altered-G environment as compared to CoP statistics (Oddsson et al., 2006; Zemková et al., 2006; Oddsson et al., 2007; Zemková et al., 2007).

Despite its promising clinical applicability in terms of physiological interpretations of the results, the SDA has been subject to some controversy in the literature (e.g., Delignières et al., 2003). The main drawbacks include fair to good reliability, the inconsistent methodology employed in different studies, the time-consuming testing procedure (at least ten 30 seconds trials with eyes open and eyes closed), as well as the problematic neuromuscular interpretation of the SDA (Peterka, 2000). The idea that there is some critical point in time that distinguishes open-loop and closed-loop processes in postural control is questionable (Carlton, 1992). Also the findings of Newell et al. (1997) suggest that it is premature to consider the trajectory of the CoP as a two-process, open-loop and closed-loop random walk model. Therefore, alternative methods of investigating the dynamic nature of the CoP profile have been investigated with aim to be implemented into practice.

Test of dynamic balance

Subjects stand on a force plate connected to a computer with a special program that generates its movement in the horizontal plane (Figure 3). They are not informed regarding the direction and timing of perturbations. A signal from the computer triggers a random motion of the platform, thus the subject receives no cues as to when the perturbation would occur. The platform motion produces a sudden change in the external forces acting on the subject, leading to a displacement of the subject's CoP. The perturbation causes only a postural sway response, i.e. the subject do not need to take a step to maintain balance. The protocol, based on the investigation of varied determinants of platform translation, such as the direction (forward, backward, left-lateral, and right-lateral), displacement (1 cm, 2 cm, 4 cm, 6 cm, 8 cm, 10 cm, 12 cm, and 14 cm), and velocity (5 cm/s, 10 cm/s, 15 cm/s, and 20 cm/s) and their influence on postural sway responses, has recently been described in detail (Zemková et al., 2015d).

Parameters of balance are recorded 5-s before, during, and 5-s following the sudden motion of the platform, using the FiTRO Dynamic Posturography system (FiTRONiC, SVK). Ground reaction forces are recorded at a sampling frequency of 100 Hz. The force plate is placed over a moving device that produces side-to-side movements at a predefined velocity and amplitude. Besides parameters mentioned above, after perturbations (e.g., in antero-posterior direction) following parameters are registered: peak anterior displacement of the subject´s CoP, peak posterior displacement of the subject´s CoP, total anterior to posterior displacement of the subject´s CoP, time to peak anterior displacement of the subject´s CoP, time to peak posterior displacement of the subject´s CoP, time from peak anterior to peak posterior displacement of the subject´s CoP. Concurrently with measurement of dynamic balance, trunk movement representing roughly the CoM movement can also be monitored using the FiTRO Dyne Premium (FiTRONiC, SVK) (Zemková et al., 2016c).

Figure 3 Tests of dynamic balance using the FiTRO Dynamic Posturography system

Task-oriented balance tests

Subjects can perform a visually-guided CoM tracking task (Figure 4) or a visually-guided CoM target-matching task (Figure 5). In the first test, subjects are provided with feedback on the CoM displacement on a computer screen while standing on a force platform. Their task is to trace, by shifting their CoM, a curve flowing either in horizontal direction (regulation of CoM movement in Y-axis) or vertical direction (regulation of CoM movement in X-axis). The deviation of an instant CoP position from the curve is recorded at 100 Hz by means of the FiTRO Sway Check system (FiTRONiC, SVK). In the second test, subjects have to hit the target randomly appearing in one of the corners of the screen by a horizontal CoM shift in the appropriate direction while standing on a spring-supported platform equipped with a computer-based system used for feedback monitoring of the CoM movement. The system registers the time, distance, and velocity of the CoP trajectory between the appearance of the stimulus and its being hit by a horizontal CoM shift.

The analysis of repeated measurements showed test-retest correlation coefficients and measurement errors of 0.81 and 8.8% for a visually-guided CoM target-matching task and 0.83 and 7.0% for a visually-guided CoM tracking task (Zemková, Hamar, 2010).

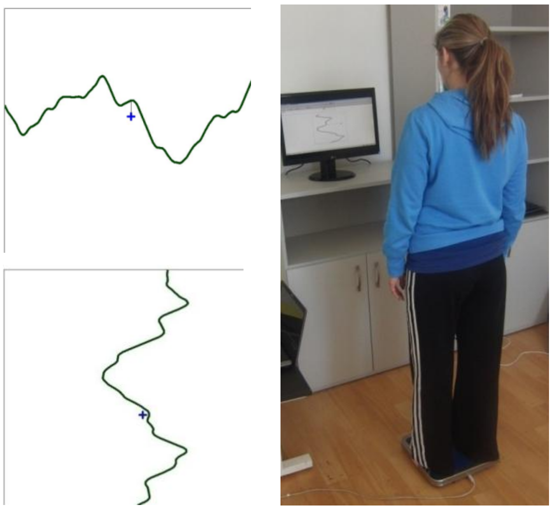


Figure 4 Visually-guided CoM tracking task using the FiTRO Sway Check system

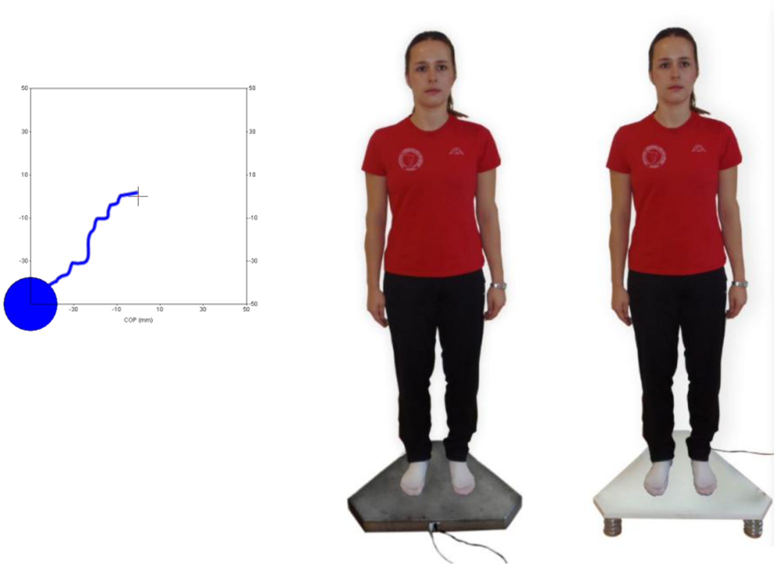


Figure 5 Visually-guided CoM target-matching task using the FiTRO Sway Check system

Load release balance test

Subjects stand barefoot on a force platform with their arms hold horizontally forward, a shoulder width apart (Figure 6). They are required to hold a bar in their hands with a 2 kg load fixed to the bar. A signal from the computer triggers a random release of the load over a 5 second period following the initiation of the test, thus the subject receives no cues as to when the perturbation would occur. The release of the load produces a sudden change in the external forces acting on the subject, leading to a small anterior and then a larger posterior displacement of the subject's CoP. The perturbation after the load fall causes only a postural sway response, i.e. the subject do not need to take a step to maintain balance. The perturbation is quantified by the maximal anterior and posterior displacement, within one second after the load drop. The recording ends 2-3 seconds after the load-drop.

A series of three trials are conducted in random order under varied conditions: (a) bipedal stance on a force platform with eyes open, (b) bipedal stance on a force platform with eyes closed, (c) bipedal stance on a foam surface placed on a force platform with eyes open, and (d) bipedal stance on a foam surface placed on a force platform with eyes closed. The best result of each of the three trials is selected for evaluation. Peak anterior displacement of the subject´s CoP, the time to peak anterior displacement of the subject´s CoP, peak posterior displacement of the subject´s CoP, the time to peak posterior displacement of the subject´s CoP, total anterior to posterior displacement of the subject´s CoP, and the time from peak anterior to peak posterior displacement of the subject´s CoP, are registered by using the FiTRO Sway Check system, completed with a special program for Load Release Balance Test (FiTRONiC, SVK) (Figure 7). The force platform data are sampled at a frequency of 100 Hz.

Previous study identified that test-retest reliability of parameters of the load release balance test was good to excellent, with high values of ICC (0.78-0.92) and low SEM (7.1%-10.7%) (Zemková et al., 2016a). The area under the ROC curve >0.80 for these variables indicates good discriminatory accuracy.

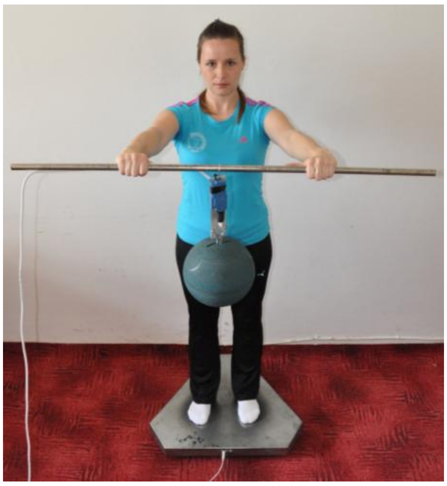


Figure 6 Load release balance test using the FiTRO Sway Check system completed with a special program for Load Release Balance Test

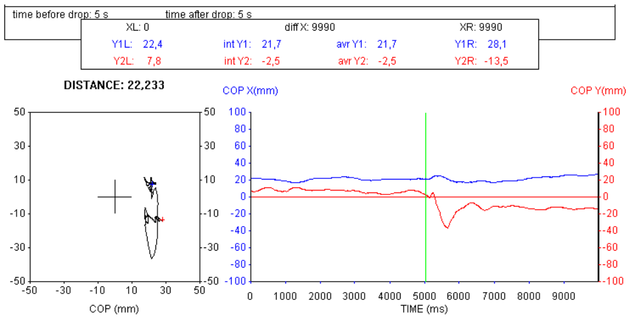


Figure 7 An example of results

Utilizing techniques based on motion analysis or accelerometry recordings while evaluating head, limb and trunk movements could provide additional data for a more complete diagnostics. The use of trunk accelerometry has been recently introduced as a cost-effective and easily applied solution for measuring human movement (balance, gait, chair rising, etc.). Lamoth et al. (2009) suggest that a combination of stochastic dynamics with accelerometry may allow the quantification of the time-varying structure of postural sway pattern. Additionally, Whitney et al. (2011) reported that accelerometry is a valid quantitative measure of postural sway which is more strongly related to task-based measures. Accelerometry measurements correlated well with the CoP during Sensory Organization Test conditions. The ACC measures identified a moderate to good test-retest reliability (ranging from 0.63 to 0.80), comparable to those using the CoP, with the normalized path length of the ACC and CoP displaying the best reliability. Similarly, Kamen et al. (1998) reported the intraclass correlation coefficient >0.75 for standing balance tasks using an accelerometer. The low frequency response of the accelerometer should be 0.1 Hz. Sensitivity on the order of 0.001G's is required to differentiate between eyes-open and eyes-closed conditions (Moe-Nilssen, Helbostad, 2002; O´Sullivan et al., 2009). With the advent of fast wireless technology and low-cost accelerometers, their use for field-testing of balance is now feasible. However, although trunk accelerometry is a sensitive measure of postural abnormalities in patients with untreated Parkinson's disease for example (Mancini et al., 2011), this still requires verification in patients with other diseases.

Conclusions

The present study provided an overview of tests designed for the assessment of balance under a variety of conditions. Platform posturography can bridge the gap from balance research to clinical practice. This requires linking the postural parameters with the underlying neurophysiology and identifying those that are able to distinguish various levels of balance capabilities. We believe that proposed tests could be implemented in the functional assessment of patients with certain diseases and after injuries as a complement to existing testing methods.

Acknowledgment: This work was supported by the Slovak Research and Development Agency under the contract No. SK-AT-2015-0031.

References

1. Buchanan, J. J., Horak, F. B. Emergence of postural patterns as a function of vision and translation frequency. Journal of Neurophysiology. 1999, roč. 81, č.5, s. 2325-2339.
2. Carlton, L. G. Visual processing time and the control of movement. In: L. Proteau & D. Elliott (Eds.). Vision and motor control. North-Holland: 1992, s. 3-32.
3. Collins, J. J., De Luca, C. J. Open-loop and closed-loop control of posture: A random walk analysis of center-of-pressure trajectories. Experimental Brain Research. 1993, roč. 95, č. 2, s. 308-318.
4. Collins, J. J., De Luca, C. J. Upright, correlated random walks: A statistical-biomechanics approach to the human postural control system. Chaos. 1995, roč. 5, č. 1, s. 57-63.
5. Collins, J. J., De Luca, C. J., Burrows, A., Lipsitz, L. A. Age-related changes in open-loop and closed-loop postural control mechanisms. Experimental Brain Research. 1995, roč. 104, č. 3, s. 480-492.
6. Delignières, D., Deschamps, T., Legros, A., Caillou, N. A methodological note on nonlinear time series analysis: is the open- and closed-loop model of Collins and De Luca (1993) a statistical artifact? Journal of Motor Behaviour. 2003, roč. 35, č. 1, s. 86-97.
7. Dickin, D. C., Clark, S. Generalizability of the sensory organization test in college-aged males: obtaining a reliable performance measure. Clinical Journal of Sport Medicine. 2007, roč. 17, č. 2, s. 109-115.
8. Ebenbichler, G., Doblhammer, S., Pachner, M., Anner, P., Herceg, M., Kerschan-Schindl, K., Jaksch, P. Test to retest reliability of SMART EquiTest postural control and performance measures in sarcopenic lung transplant recipients. 7th International Posture Symposium. Smolenice: 2015, s. 34.
9. Ebenbichler, G., Doblhammer, S., Gibley, J., Pachner, M., Anner, P., Jaksch, P. Re-test reliability of different apparative postural performance measures in subacute rehabilitation after lung transplantation. 20th European Congress of Physical and Rehabilitation Medicine. Estoril-Lisbon: 2016.

10. Ford-Smith, C. D., Wyman, J. F., Elswick, R. K. Jr, Fernandez, T., Newton, R. A. Test-retest reliability of the sensory organization test in noninstitutionalized older adults. Archives of Physical Medicine and Rehabilitation. 1995, roč. 76, č. 1, s. 77-81.
11. Hamar, D., Zemková, E. Assessment of balance: From theoretical background to practical applications. Journal of Sports Science & Medicine. 2009, roč. 8, suppl. 11, s. 30-31.
12. Jansen, E., Larsen, R., Mogens, B. Quantitative Romberg´s test. Measurement and computer calculation of postural stability. Acta Neurologica Scandinavica. 1982, vol. 66, č. 1, s. 93-99.
13. Jørgensen, M. B., Skotte, J. H., Holtermann, A., Sjøgaard, G., Petersen, N. C., Søgaard, K. Neck pain and postural balance among workers with high postural demands - a cross-sectional study. BMC Musculoskeletal Disorders. 2011, roč. 12, č. 176, s. 1-7. doi: 10.1186/1471-2474-12-176.
14. Kamen, G., Patten, C., Du C. D., Sison, S. An accelerometry-based system for the assessment of balance and postural sway. Gerontology. 1998, roč. 44, č. 1, s. 40-45.
15. Karayannis, N. V., Smeets, R. J., van den Hoorn, W., Hodges, P. W. Fear of movement is related to trunk stiffness in low back pain. PLoS One. 2013, roč. 8, č. 6, s. e67779.
16. Kováčiková, Z., Štefanovský, M., Zemková, E. Postural stability and visual feedback control of body position in physically active children and young individuals. 6th International Posture Symposium. Smolenice: 2011, s. 51.
17. Lamoth, C. J., van Lummel, R. C., Beek, P. J. Athletic skill level is reflected in body sway: a test case for accelometry in combination with stochastic dynamics. Gait & Posture. 2009, roč. 29, č. 4, s. 546-551.
18. Leitner, C., Mair, P., Paul, B., Wick, F., Mittermaier, C., Sycha, T., Ebenbichler, G. Reliability of posturographic measurements in the assessment of impaired sensorimotor function in chronic low back pain. Journal of Electromyography and Kinesiology. 2009, roč. 19, č. 3, s. 380-390.
19. Mancini, M., Horak, F. B., Zampieri, C., Carlson-Kuhta, P., Nutt, J. G., Chiari, L. Trunk accelerometry reveals postural instability in untreated Parkinson's disease. Parkinsonism & Related Disorders. 2011, roč. 17, č. 7, s. 557-562. doi: 10.1016/j.parkreldis.2011.05.010.
20. Mergner, T., Schweigart, G., Maurer, C., Blumle, A. Human postural responses to motion of real and virtual visual environments under different support base conditions. Experimental Brain Research. 2005, roč. 167, č. 4, s. 535-556.

21. Michaelson, P., Michaelson, M., Jaric, S., Latash, M. L., Sjölander, P., Djupsjöbacka, M. Vertical posture and head stability in patients with chronic neck pain. Journal of Rehabilitation Medicine. 2003, roč. 35, č. 5, s. 229-235.
22. Mitchell, S. L., Collins, J. J., De Luca, C. J., Burrows, A., Lipsitz, L. A. Open-loop and closed-loop postural control mechanisms in Parkinson's disease: increased mediolateral activity during quiet standing. Neuroscience Letters. 1995, roč. 197, č. 2, s. 133-136.
23. Moe-Nilssen, R., Helbostad, J. L. Trunk accelerometry as a measure of balance control during quiet standing. Gait & Posture. 2002, roč. 16, č. 1, s. 60-68.
24. Newell, K. M., Slobounov, S. M., Slobounova, E. S., Molenaar, P. C. Stochastic processes in postural center-of-pressure profiles. Experimental Brain Research. 1997, roč. 113, č. 1, s. 158-164.
25. Oddsson, L. I. E., Bloomberg, J. J., Zemková, E., Dwyer, A., Chow, A., Meyer, P. F., Wall, C. Development of in-flight countermeasures with multimodal effects: Muscle strength and balance function. 7th Symposium on the role of the vestibular organs in space exploration. Noordwijk: 2006, s. 1.
26. Oddsson, L. I. E., Karlsson, R., Konrad, J., Ince, S., Williams, R. S., Zemková, E. A rehabilitation tool for functional balance using altered gravity and virtual reality. Journal of NeuroEngineering and Rehabilitation. 2007, roč. 4, č. 25, s. 1-7.
27. O´Sullivan, M., Blake, C., Cunningham, C., Boyle, G., Finucane, C. Correlation of accelerometry with clinical balance tests in older fallers and non-fallers. Age and Ageing. 2009, roč. 38, č. 3, s. 308-313. doi: 10.1093/ageing/afp009.
28. Peterka, R. J. Postural control model interpretation of stabilogram diffusion analysis. Biological Cybernetics. 2000, roč. 82, č. 4, s. 335-343.
29. Redfern, M. S., Jennings, J. R., Martin, C., Furman, J. M. Attention influences sensory integration for postural control in older adults. Gait & Posture. 2001, roč. 14, č. 3, s. 211-216.
30. Reeves, N. P., Narendra, K. S., Cholewicki, J. Spine stability: the six blind men and the elephant. Clinical Biomechanics (Bristol, Avon). 2007, roč. 22, č. 3, s. 266-274. doi:10.1016/j.clinbiomech.2006.11.011.
31. Silfies, S. P., Cholewicki, J., Reeves, N. P., Greene, H. S. Lumbar position sense and the risk of low back injuries in college athletes: A prospective cohort study. BMC Musculoskeletal Disorders . 2007, roč. 8, č. 1, s. 129. doi:10.1186/1471-2474-8-129.

32. Sturnieks, D. L., Menant, J., Delbaere, K., Vanrenterghem, J., Rogers, M. W., Fitzpatrick, R. C., Lord, S. R. Force-controlled balance perturbations associated with falls in older people: A prospective cohort study. PLoS One. 2013, roč. 8, č. 8, s. e70981. doi: 10.1371/journal.pone.0070981.
33. Štefániková, G., Ollé, G., Zemková, E. Static balance and visual feedback control of body position in young and elderly individuals. 6th International Posture Symposium. Smolenice: 2011, s. 85.
34. Štefániková, G., Zemková, E. Vizuálne spätnoväzobné riadenie pohybu ťažiska tela u detí mladšieho školského veku. Zborník vedeckých prác „Od výskumu k praxi v športe". Bratislava: 2013a, s. 283-288. ISBN 978-80-227-4113-2.
35. Štefániková, G., Zemková, E. Vplyv rôznych foriem balančného tréningu na parametre rovnováhových schopností detí mladšieho školského veku. Zborník vedeckých prác. Nitra: 2013b, s. 10-16. ISBN 978-80-558-0385-2.
36. Štefániková, G., Zemková, E. The effect of different forms of sensorimotor training on body balance in young children. International Scientific Conference "Sport, Physical Activity and Health". Bratislava: 2014, s. 91-92.
37. Taube, W., Leukel, C., Gollhofer, A. Influence of enhanced visual feedback on postural control and spinal reflex modulation during stance. Experimental Brain Research. 2008, roč. 188, č. 3, s. 353-361.
38. Teasdale, N., Bard, C., Larue, J., Fleury, M. On the cognitive penetrability of postural control. Experimental Aging Research. 1993, roč. 19, č. 1, s. 1-13.
39. Valkovič, P., Štefániková, G., Kováčiková, Z., Lipková, J., Schmidt, F., Hlavačka, F., Zemková, E. Static and task-oriented balance tests in early stages of Parkinson´s disease. Parkinsonism & Related Disorders. 2012, roč. 18, suppl. 2.
40. Vlašič, M., Zemková, E. Vplyv 12- týždňového senzomotorického tréningu na parametre sily a rovnováhy u športovcov po plastike predného skríženého väzu. Česká kinantropologie. 2011, roč. 15, č. 1, s. 79-89.
41. Whitney, S. L., Roche, J. L., Merchetti, G. F., Lin, C. C., Steed, D. P., Furman, G. R., Musolino, M. C., Redfern, M. S. A comparison of accelerometry and center of pressure measures during computerized dynamic posturography: A measure of balance. Gait & Posture. 2011, roč. 33, č. 4, s. 594-599.
42. Wrisley, D. M., Stephens, M. J., Mosley, S., Wojnowski, A., Duffy, J., Burkard, R. Learning effects of repetitive administrations of the sensory organization test in healthy

young adults. Archives of Physical Medicine and Rehabilitation. 2007, roč. 88, č. 8, s. 1049-1054.

43. Zemková, E., Hamar, D. Reliabilita parametrov stability postoja na dynamometrickej platni. Národný kongres telovýchovného lekárstva. Tále: 1998, s. 40.
44. Zemková, E., Hamar, D., Böhmerová, Ľ. The dynamic balance - reliability and methodological issues of novel computerized posturography system. Medicina Sportiva. 2005a, roč. 9, č. 3, s. 76-82.
45. Zemková, E., Viitasalo, J., Hannola, H., Blomqvist, M., Konttinen, N., Mononen, K., Pahtaja, V., Sirviö R. Sensory Organization Test in diagnostics of post-exercise postural stability in athletes. Sport Science. 2005b, roč. 39, č. 1, s. 26-32.
46. Zemková, E., Dwyer, A., Chow, A., Oddsson, L. I. E. Effects on balance and strength following resistance exercise performed on an unstable surface in a ninety degree tilted environment. XVI International Congress of the International Society of Electrophysiology and Kinesiology. Torino: 2006, s. 211.
47. Zemková, E., Oddsson, L. I. E., Dwyer, A., Chow, A. The effect of squats performed on an unstable surface in an altered-G environment on strength and balance. 12th Annual Congress of the European College of Sport Science. Jyväskylä: 2007, s. 346.
48. Zemková, E., Vlašič, M. The effect of instability resistance training on neuromuscular performance in athletes after anterior cruciate ligament injury. Sport Science. 2009, roč. 2, č. 1, s. 17-23.
49. Zemková, E. Sensorimotor exercises in sports training and rehabilitation. In: M. J. Duncan & M. Lyons (Eds.). Trends in Human Performance Research. New York: Nova Science Publishers, Inc. 2010, s. 79-117. ISBN: 978-1-61668-591-1.
50. Zemková, E., Hamar, D. Reliability and sensitivity of the test based on visually-guided COM tracking task. Acta Facultatis Educationis Physicae Universitatis Comenianae. 2010, roč. L č. I, s. 75-85.
51. Zemková, E., Lipková, J., Hamar, D. Visual feedback control of body position under altered stance support conditions in elderly women. Medicina Sportiva. 2010, roč. 14, č. 4, s. 188-192.
52. Zemková, E. Assessment of balance in sport: Science and reality (Invited review). Serbian Journal of Sports Sciences. 2011, roč. 5, č. 4, s. 127-139.
53. Zemková, E., Vlašič, M., Hamar, D. Posudzovanie silových a rovnováhových schopností v neskoršej fáze rehabilitácie dolných končatín. Česko-slovenský kongres telovýchovného

lekárstva „Aktuálne problémy telovýchovného lekárstva“. Bratislava: Peter Mačura - PEEM, 2011, s. 32-34. ISBN 978-80-8113-046-5.

54. Zemková, E. Assessment and training of functional balance in sport. Zborník vedeckých prác „Od výskumu k praxi“. Bratislava: 2012, s. 7-16. ISBN 978-80-227-3854-5.
55. Zemková, E. Assessment of balance: from static to functional tests. 9th International Symposium on Computer Science in Sport. Istanbul: 2013a.
56. Zemková, E. Functional balance and its assessment in children and youth. 6th Asia-Pacific Conference on Exercise and Sports Science. Taipei: 2013b.
57. Zemková, E., Chren, M., Kováčiková, Z., Lipková, J., Štefániková, G., Štefanovský, M., Hamar, D. Functional balance control in subjects of different age and skills level. 8th Interdisciplinary World Congress on Low Back & Pelvic Pain. Dubai: 2013, s. 675.
58. Zemková, E. Sport-specific balance. Sports Medicine. 2014a, roč. 44, č. 5, s. 579-590. doi: 10.1007/s40279-013-0130-1.
59. Zemková, E., Hamar, D. Physiological mechanisms of post-exercise balance impairment. Sports Medicine. 2014, roč. 44, č. 4, s. 437-448. doi: 10.1007/s40279-013-0129-7.
60. Zemková, E., Hamar, D. Between-subjects differences in CoP measures on stable and unstable spring-supported platform. World Congress of the International Society for Posture & Gait Research. Sevilla: 2015, s. 131.
61. Zemková, E., Muyor, J. M., Štefániková, G., Svoboda, Z. Janura, M. Nestabilné podmienky diferencujú fyzicky aktívnych jedincov a so sedavým spôsobom života s rôznou úrovňou stability postoja a trupu. Medicina Sportiva Bohemica & Slovaca. 2015a, roč. 24, č. 3, s. 147.
62. Zemková, E., Muyor, J. M., Štefániková, G., Jeleň, M., Kováčiková, Z. A new age for health and fitness professionals: Assessment of postural and core stability. World Congress of the International Society for Posture & Gait Research. Sevilla: 2015b, s. 8.
63. Zemková, E., Jeleň, M., Poór, O., Štefániková, G. Inovované metódy posudzovania stability postoja a trupu v športe a rehabilitácii. 19. ročník medzinárodnej vedeckej konferencie o športe “Od výskumu k praxi”. Bratislava: 2015c, 11 s.
64. Zemková, E., Kováčiková, Z., Jeleň, M., Neumannová, K., Janura, M. Methodological issues of dynamic posturography specific to the velocity and the displacement of the platform perturbation. Zborník vedeckých prác „Od výskumu k praxi v športe“. Bratislava: 2015d, 10 s. ISBN 978-80-227-4485-0.
65. Zemková, E., Štefániková, G., Muyor, J. M. Load release balance test under unstable conditions effectively discriminates between physically active and sedentary young adults.

Human Movement Science. 2016a, roč. 48, s. 142-152. doi:10.1016/j.humov.2016.05.002.

66. Zemková, E., Kyselovičová, O., Ukropec, J., Ukropcová, B. Unique functional performance testing for the overweight and obese. Medicina Sportiva Practica. 2016b, roč. 17, č. 1, s. 1-8.
67. Zemková, E., Kováčiková, Z., Jeleň, M., Neumannová, K., Janura, M. Postural and trunk responses to unexpected perturbations depend on the velocity and direction of platform motion. Physiological Research, 2016c (In press).

Kontaktné údaje:

Prof. Mgr. Erika Zemková, Ph.D.
Department of Sports Kinanthropology
Faculty of Physical Education and Sports
Comenius University in Bratislava
Nábr. arm. gen. L. Svobodu 9
814 69 Bratislava
Slovakia
E-mail: zemkova@yahoo.com
Tel: +421 2 206 69 951

Recenzované: 13.7.2016
Prijaté do tlače: 12.9.2016