DOI:10.2478/v10237-011-0036-5

Review of Methods for the Evaluation of Human Body Balance

Andrej PANJAN • Nejc SARABON

The aim of this review paper is to thoroughly present all main tests used today in the field of body balance/equilibrium assessment and evaluation. After the introduction of some basic biomechanical and movement regulation concepts, a short revision of the metric characteristics that each test should contain is discussed. The latter encompasses validity, objectivity, repeatability, sensitivity, and some other elements that are of crucial importance for the practical use of every assessment. The major part of text is dedicated to the critical research based review of the body balance tests of different levels of technical and other complexity. Pros and cons of the presented assessment methods are discussed. First, the field motor tests and simple clinical tests are presented. Their primary use in school physical education, sports medicine, and rehabilitation is pointed out. Second, laboratory tests for the static balance assessment are described in details, including all the measured parameters, their informational value and limitations. And third, laboratory tests for the evaluation of dynamic balance are presented in an analogue way. In the discussion, we compare different tests through the scope of usefulness, economy, metric characteristics and informational value. The paper closes with a summary of the state-of-the-art on the field of balance and proposals for future research work.

Keywords: human body balance, static balance, dynamic balance, body balance tests

The Functional Role of Balance

Balance is a fundamental ability of human movement. Maintaining balance during anti-gravitational activities as well as proper body posture represent a ground-stone for the execution of other secondary movements. These are used to propel ourselves through space or manipulate with the surrounding environment (Winter, 1995). Most elaborate example of importance of balance, are fragile elderly. Due to different factors, balance is lost, increasing the risk of falling (Baczkowicz, Szczegielniak, & Proszkowiec, 2008). Falls represent one of the most serious health problems in elderly populations. Another important aspect of balance in sports is its connection with injury development. Poor balance has been shown to be affected by different pathologies and can even be their origin (de Noronha, Refshauge, Herbert, Kilbreath, & Hertel, 2006). On the other hand superior athletic skill demands good balance as well. For example a gymnast during a routine on a balance beam relies on good balance to perform different acrobatic elements.

A lot of attention has been devoted to the understanding of balance (Benvenuti, 2001; Winter, 1995; Winter, Patla, Ishac, & Gage, 2003). Mechanically it can be defined as the ability to sustain center of body mass in limits of the support surface (Sarabon, Rosker, Loefler, & Kern, 2010). Once an athlete is not able to meet these demands she starts to fall. Support surface can be defined by the area between the feet or with the area of the ground on which an athlete stands. For example support surface size can be decreased by positioning once feed narrower as well as by standing on a narrow rope in a circus.

Our bodies maintain balance using different strategies. Two most general are hip and ankle strategy (Winter, Patla, Ishac, & Gielo-Perczak, 1998; Winter, 1995). First is used by our bodies when the support surface translates, or when the perturbation to balance is bigger. The second strategy is usually used to compensate rotational or smaller perturbations. Strict differentiation between these two can be drawn only in simpler movements. As the intensity of balancing increases, they seem to work in synchrony, compensating for various types of perturbations or enabling execution of more demanding skills (Bardy, Oullier, Bootsma, & Stofrregen, 2002).

Equipped with the knowledge of mechanisms used to maintain balance, specific prevention and rehabilitation protocols have been devised (Alentorn-Geli et al., 2009; Hübscher et al., 2010). These usually have a specific focus like improving stability of an ankle joint after injury (Webster & Gribble, 2010) or gross body reactions in more functional training (Bean, Vora, & Frontera, 2004). Usually this type of training has been called balance, proprioception of sensory-motor training (Lephart, Riemann, & Fu, 2000).

Two main rationales for better understanding of balance can be drawn from above examples. If poor balance can be assessed in an uninjured athlete appropriate preventive measure can be drawn to prevent injury (Alentorn-Geli et al., 2009). Same holds true for elderly people (Karinkanta, Piirtola, Sievänen, Uusi-Rasi, & Kannus, 2010). The second rational advises us to assess balance in athletes as poor balance can have a negative effect on specific sports skills (Behm & Anderson, 2006; Hellström, 2009).

To be able to quantify balance deficits as well as training improvements different balance assessment methods are used in clinical as well as in sports practice (Le Clair & Riach, 1996; Tyson & Connell, 2009). These methods use different methodology, technology and differ in the level of balance assessment. Basic differences must be considered when coaches, clinicians or therapists decide which of the methods is most appropriate to apply to their specific demand.

In the following subsections we will first begin with the insight into the basic metric characteristics of the tests. This will be followed by summarizing the most frequently used clinical and simple field tests of balance; laboratory tests; and moreover, techniques and parameters used to assess static balance; and laboratory tests of dynamic balance. Basic characteristics of each test or a measured parameter will be described and additionally, strengths and weaknesses will be pointed out.

Basic Metric Characteristics of the Tests

Empirical measurements represent a constituent part of majority of the sport science studies; body balance and equilibrium research being no exception. In longitudinal experiments, at least two consecutive assessments separated by short or longer amount of time are typically carried out (for example pre-intervention/post-intervention). When body balance is the primary focus of the study, very often, more than one type of balance test is performed. In order to provide good sports, prevention and rehabilitation relevant results and conclusions only those tests characterized by the best possible metric characteristics should be included in a study. Each test has its own internal characteristics which can be evaluated by the analyses of objectivity, reliability, validity, and sensitivity. In order to have the optimal balance test all four basic characteristics should be as high as possible. On the other hand, there are minimal standards which need to be met if we want to pronounce the test useful at all.

Objectivity is understood as universal agreement; hence, two or more examiners should get the same results when testing the same subject with the same test protocol and with the same equipment. Thus, if it is possible, the results should be obtained with appropriate measurement equipment and not as a subjective score by an examiner (human evaluation is always subjective). For many reasons this is sometimes not possible. In such cases, the examiner should be properly trained for performing balance measurements.

Secondly reliability represents the variation of measures obtained by a balance measuring protocol. This characteristic has also been known as consistency. Different types of reliability are known: inter-rater or inter-observer reliability, test-retest reliability, parallel-forms reliability and internal consistency reliability. First, inter-rater reliability is used to assess the degree to which different raters/examiners give consistent estimates of the same phenomenon. In clinical practice balance testing is usually performed by various examiners, making it important to be aware of possible error resulting from poor inter-rater reliability. Second, test-retest reliability is used to assess the consistency of a measure from one time to another. This is simply the reliability between two or more trials performed by the same examiner on the same subject. This type of reliability is most frequently examined in evaluation of body balance, equilibrium and posture assessment methods. Third, parallel-forms reliability is used to assess the consistency of the results of two tests constructed in the same way from the same content domain. It could be used to select the best test among the selected tests for the same, i.e. presumably alike, functional ability. This, however, does not necessarily mean that this test is the best for the specific problem. Other test characteristics should be considered as well. Fourth, internal consistency reliability is used to assess the consistency of results across subjects within the test. It could be used to test reliability of specific measure of the test across group of subjects. The most commonly used coefficients of reliability are intra-class correlation coefficient (ICC) and coefficient of variation (CV).

An important category is validity of a test. It can be describe as tests relevance, or the degree to which the tool measures what it claims to measure. It can be evaluated by comparing the results obtained by a tested test with a gold standard test (well established test) for a specific problem. Validity is expressed as correlation coefficients between the two. If the balance test is not valid it cannot be used in balance and equilibrium assessment.

And finally, sensitivity is a factor that is able to detect small, but important, changes in performance of a subject. Difference between finishing as first or second can be very small in a sport event like sprint. For example balance tests should be sensitive to small changes in balance tasks used, like different feet positions. By these means important differences in function of balance mechanisms can be evaluated (Sarabon et al., 2010). Therefore, it is important to be able to detect small changes in a performance. Because every measurement is affected by a noise (e.g. signals), we should be very careful – we need to know whether small changes are really changes in performance or just a result of a noise. A quantitative value of sensitivity may be obtained by comparing results of the measurement-to-noise ratio, where the results are the percentage improvement in performance and the noise is the CV.

To sum-up, when considering which balance testing protocol to apply to sports practice, measurement equipment, and assessment procedure in general, should provide the test with good objectivity, reliability and sensitivity. It should precisely measure the balance task, performance or characteristic specific for a certain sub-type of balance.

Clinical and Simple Field Tests of Balance

Clinical and simple filed tests of human balance (Pérennou et al., 2005; Yelnik & Bonan, 2008) are tests that require none or little equipment, are very cheap and can be performed quickly (Figure 1). They consist of a different number of tasks that are evaluated either using a score on a predefined qualitative scale, counting balance loses or simple time measurements. The tests are performed on a subject whose quality of executing different tasks is evaluated by an expert. These assessment procedures are based on standardized test protocols; however, they remain to be influenced by a human factor (subjectivity) since they are based on the observational criteria of the examiner. The more difficult tests (Flamingo test, sharpened Romberg test, etc.) are also used in sports testing and screening protocols, while the less demanding ones have been frequently reported in the studies focusing on elderly adult population who are at risk for falls. Several clinical tests have been developed over the years and some of the most frequently used among them are described in the following paragraphs.

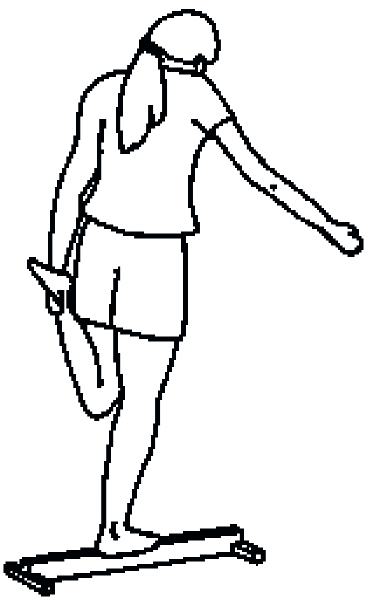

Figure 1. Example of clinical test - Flamingo test

Romberg test (Findlay, Balain, Trivedi, & Jaffray, 2009; Lê & Kapoula, 2008; Longridge & Mallinson, 2010; Ma et al., 2009; Mourey, Camus, & Pfitzenmeyer, 2000) is a commonly performed balance test which was first described by Moritz Heinrich von Romberg in the early 19th century. The exam is based on the premise that a person requires at least two of the three underlying body senses, which are crucial for the maintaining of equilibrium while standing, namely proprioception (the ability to know one's body in space), exteroception (the ability to feel touch or pressure) and vision (which can be used to monitor changes in balance). A subject who has a problem with proprioception can still maintain balance by using exteroceptive sensation and vision. The Romberg test is a test of the body's sense of positioning (proprioception), which requires healthy functioning of the dorsal columns of the spinal cord (Khasnis & Gokula, 2003). Besides balance testing, it is also used as an indicator for possible alcohol or drug impaired driving and neurological decompression sickness. To perform the test, the subject is asked to stand erect with feet together and eyes closed. It is recommended that examiner or assistant stand close to the subject as a precaution in order to stop him from falling over and hurting himself/herself. Watch the movement of the body in relation to a perpendicular object behind the subject (corner of the room, door, window, etc.). A positive sign is noted when a swaying, sometimes irregular swaying and even toppling over occurs. The essential feature is that the subject becomes more unsteady with eyes closed. First, the subject stands with feet together, eyes open and hands by the sides. Than the subject closes the eyes while the examiner observes for a full minute. Romberg's test is positive if the subject sways or falls while the subject's eyes are closed (Lanska & Goetz, 2000). Subjects with a positive result are said to demonstrate Romberg's sign or Rombergism. They can also be described as Romberg's positive. The basis of this test is that balance comes from the combination of several neurological systems, namely proprioception, vestibular input and vision. If any two of these systems are working, the subject should be able to demonstrate a fair degree of balance. The key to the test is that vision is taken away by asking the subject to close their eyes. This leaves only two of the three systems remaining and if there is a vestibular disorder (labyrinthine) or a sensory disorder (proprioceptive dysfunction), the subject will become much more imbalanced.

Sharpened Romberg test (Sofianidis, Hatzitaki, Douka, & Grouios, 2009), also known as the tandem stance test (Fitzgerald, 1996) was developed on the basis of Romberg test. In this case, a subject is asked to stand heel-to-toe (tandem position) with their arms crossed so that the open palm falls across the opposite shoulder. The subject closes his eyes once he is stable. He tries to maintain this position for a full minute. Evaluation is the same as with Romberg test. Under sharpened Romberg test also other stands (semi tandem, contra tandem, one leg (Figure 2)) and/or additional equipment (unstable surface such as Airex, Thera-

Band, Gymnic, and some other balance pads) are used to increase difficulty of the task. Poor sensitivity of the sharpened Romberg test was reported by Šarabon & Omejec (2007) who carried out a study on 102 healthy young subjects. The same study revealed a moderate level of test-retest repeatability (ICC = 0.49) of the Romberg test.

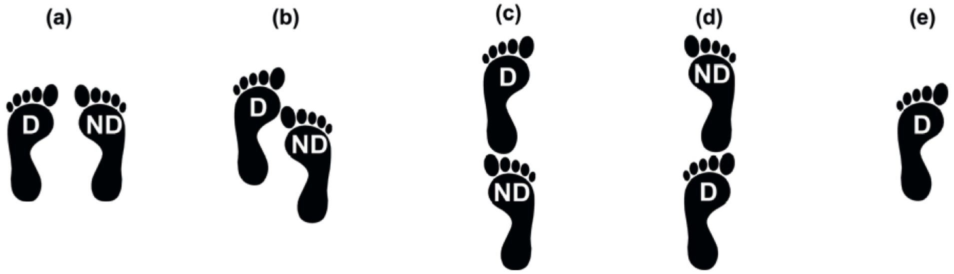

Figure 2. The five different foot positions used in SRT: (a) parallel, (b) semi-tandem, (c) tandem, (d) contralateral tandem, and (e) single leg. The leg dominance is marked by D (dominant leg) and ND (non-dominant leg).

Tinetti balance test (Kaufman et al., 2006; Kegelmeyer, Kloos, Thomas, & Kostyk, 2007; Kloos, Kegelmeyer, Young, & Kostyk, 2010; Köpke & Meyer, 2006; Muñoz et al., 2010; Rabbitt et al., 2006; Schumacher, Pientka, & Thiem, 2006; Rodrigues, Cader, Torres, Oliveira, & Dantas, 2010; "Tinetti test assessment form," n.d.) is an easily administered test to measure a subject's gait and balance ability (Figure 1). The test is used to evaluate subject's ability to perform specific tasks and is primarily used as a predictive measure for falls. Most commonly it is used on elderly adult population who are at most risk for falls, and it takes approximately 10 to 15 minutes to perform and score. The test is performed in two parts – a balance and a gait part. The subject is asked to perform very specific tasks listed and described on the assessment tool form. The therapist observes the completion of each task and scores the subject on a 0-2 scale based on how the task is completed. Score 0 represents the most impairment, while a 2 would represent independence of the subject. At the end of each part the therapist adds up the subjects total score and compares it to the test pre-assessed ranges. The total possible score for the balance part is 16 points and the total possible score for the gait part is 12 points. Subjects who score a total of 19 points or below are at high risk for falls, while subjects who score between 19 and 24 points have a moderate risk for falls and subjects with scores above 24 points are at limited risk for falls. Tools needed for this assessment include a chair, a stopwatch, and a 5-meter walkway. Inter-rater and intra-rater reliability of the test was performed on individuals with amyotrophic lateral sclerosis (Kloos et al., 2004).

High ICC values (> 0.90) were found for the total Tinetti test scores. Inter-rater reliability between three experts was 88% for individual maneuvers, while intra-rater reliability of 93% was observed for 6 experts. The results suggest that Tinetti test is reliable for examination of this specific group of individuals.

The Berg balance scale (BBS) or Berg balance test (Beauchamp, O'Hoski, Goldstein, & Brooks, 2010; "Berg balance scale assessment form," n.d.; Berg, Wood-Dauphinee, Williams, & Maki, 1992; Blum & Korner-Bitensky, 2008; Greene et al., 2010; Ortuño-Cortés, Martín-Sanz, & Barona-de Guzmán, 2008) was developed to measure balance among older people with impairment in balance function by assessing the performance of functional tasks. It is a valid instrument used for evaluation of the effectiveness of interventions and for quantitative descriptions of function in clinical practice and research. The BBS consists of 14 tests (each has a five-point scale 0-4) designed to measure balance of the older adult in a clinical setting. Equipment needed includes a ruler, two standard chairs (one with arm rests, one without), a footstool or step, a stopwatch or wristwatch, and a 5-meter walkway. It takes 15 to 20 minutes to perform test on one subject. Subjects who achieved 0-20, 21-40 and 41-56 are at high, medium and low risk of falling, respectively. The BBS has been evaluated in several reliability studies. A recent study of the BBS indicates that a change of 8 BBS points is required to reveal a genuine change in function between two assessments among older people. Bogle Thorbahn and Newton (1996) conducted a study on elderly people in which they wanted to determine whether the Berg balance test could be used to predict an elderly person's risk of falling. Although the Berg balance test demonstrated only 53% sensitivity, the results support the test developers' use of 45 (out of 56) as a generalized cutoff score. Older adults who scored higher than the cutoff score on the test were less likely to fall than were those adults who scored below the cutoff score. Decreased scores, however, did not predict increased frequency of falls. Study with the aim to determine test-retest reliability and minimal detectable change for the BBS, the Romberg Test (RT), and the Sharpened Romberg Test (SRT) with eyes open and closed was carried out on elderly people with Parkinsonism. The ICCs for test-retest reliability were above 0.90 for the BBS and SRT with eyes closed. The minimal detectable change values (calculated using a 95% confidence interval) were 5/56 for BBS and 19 seconds for SRT with eyes closed. Minimal detectable change values are useful to therapists in rehabilitation and wellness programs in determining whether change during or after intervention is clinically significant. High test-retest reliability of the scores for the BBS and SRT with eyes closed makes them trustworthy functional assessments in people with pathological conditions involving severe balance impairments (Parkinsonism, etc.).

The Flamingo balance test (Jakobsen, Sundstrup, Krustrup, & Aagaard, 2010; Sundstrup et al., 2010; Tsigilis, Douda, & Tokmakidis, 2002; Tsigilis & Theodosiou, 2008) achieves the requirements of simplicity, low cost, and it is proper for mass investigations. It is used to assess the ability to balance successfully on a single leg. This test is more difficult than the ones described above and it is most commonly used as field motor test of balance on healthy subjects or athletes. Only a stopwatch and a narrow beam (5 cm) with non-slip surface are necessary to perform the test. Sometimes the test is performed on a wide surface and not on the beam. In this test the subject is standing on a beam on his preferred foot, bends his free leg backwards and grips the back of the foot with the hand on the same side, standing like a flamingo. The procedure is as follows: start the stopwatch when subject is in described pose, stop the stopwatch each time the subject loses balance (let go of the foot being held), start timing again until he loses balance and counting the number of falls in 60 seconds of balancing. If there are more than 15 falls in the first 30 seconds, the test is terminated and a score of zero is given. Poor sensitivity of the test was reported in a study on young healthy people, due to a large number of subjects achieving the best results possible (Sarabon & Omejec, 2007). Also moderate repeatability (ICC = 0.61) was observed in the same study. Stabilometry of the flamingo test was assessed in the study performed by Barabas, Bretz and Kaske (1996). They conclude that stabilometry in Flamingo test position differentiates better the athletes with high level of the balance capabilities than the traditional Romberg test.

In the section about clinical and simple filed tests of human balance, few studies about prediction of person's risk of falling were pointed out. During the last two decades the sport science research devoted a great attention to the studies of elderly population and their related health and prevention issues. Among those, falls and related injuries are in the center of research devotions (Avdić & Pecar, 2006; Bauer, Rietsch, Gröger, & Gassmann, 2009; Giansanti, Maccioni, Cesinaro, Benvenuti, & Macellari, 2008; Huang & Wang, 2009; McMichael, Vander Bilt, Lavery, Rodriguez, & Ganguli, 2008; Michel-Pellegrino, Hewson, Drieux, & Duchêne, 2007; Schwesig, Kluttig, Kriebel, Becker, & Leuchte, 2009).

Laboratory Tests of Static Balance

Static balance of the human body is the ability to maintain specific posture. It is usually obtained in a standing subject with devices that measure the movements of the body or its center of gravity, or mostly the center of pressure (COP) (Figure 3). At first mechanical or magnetic recording devices connected to the waist (Dornan, Fernie, & Holliday, 1978; Lord, Clark, & Webster, 1991) or the hip region (Dean, Griffiths, & Murray, 1986) were used. Today the most common device is a force platform (Błaszczyk, 2008; Raymakers, Samson, &

Verhaar, 2005) which measures the COP of the whole human body, rather than just a segment, as previously mentioned devices. There are many possibilities of quantifying COP path of body sway. An extensive review of parameters that were used to assess body sway is presented in the rest of this section.

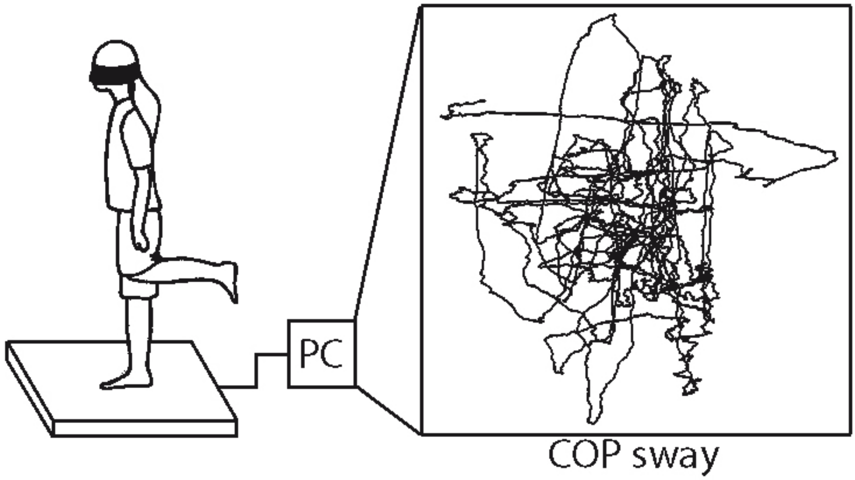

Figure 3. Example of static balance test on a force plate (single leg stance, eyes closed, arms free). An example of the COP sway of this test is on the right side.

Acquisition and signal processing of the COP sway is an essential part of a test. Usually, manufactures of a force plate systems offers software for acquisition of the COP, but we should still pay attention to the sampling frequency of the acquisition. If it is too low, then we might not be able to acquire small and high frequency changes of the COP. The recommended sampling frequency is between 100 and 1000 Hz. Higher sampling frequency are not necessary and they will only increase the amount of data acquired. Processing of acquired data consist of preprocessing and actual processing where final results are computed. Preprocessing usually consists of detection of outliers and data filtering. The latter is especially important when we acquire analog signal (e.g. COP components from the force plate). For mechanical signals band pass filters with cutoff frequencies of 0.1 and 15 Hz should be used because human is not able to surpass this frequency while moving.

Many different parameters of COP sway have been proposed over the years. In general we can classify them into two main categories; global and structural (Baratto, Morasso, Re, & Spada, 2002). Global parameters estimate the overall size of the COP sway, while structural parameters estimate the elements or smaller parts of the COP sway. Regarding the direction, parameters can be calculated as two-directional and/or one-directional, where the anterior-posterior (AP) and the medio-lateral (ML) are the two possible directions. The whole set of parameters known from literature is listed and described in a table that includes name, symbol, unit, directions and description of the parameter.

Table 1. Global parameters of COP sway

Name	Symbol	Unit	Directions	Description
Sway path	SP	mm	AP, ML and both	The length of the trajectory of the COP sway.
Sway velocity	SV	mm/s	AP, ML and both	The length of the trajectory of the COP sway divided by the measurement time.
Sway average amplitude	SAA	mm	AP and ML	The sum of amplitude divided by the number of changes in direction.
Sway maximal amplitude	SAM	mm	AP and ML	The amplitude between the two most distant samples of COP sway
Sway area	SA	mm	AP and ML	The time integral of the area swept by the COP trajectory with respect to platform center..
Sway area per second	SAa	mm^2/s	AP, ML and both	The time integral of the area swept by the COP trajectory with respect to platform center, divided by the time of measurement.
Oscillation amplitude	OA	mm	AP and ML	It is estimated by computing the ellipse which contains 90% of the data points of the COP trajectory.
Frequency of sway peaks	SFP	Hz	AP and ML	The frequency calculated as the number of peaks divided by the measurement time.
Mean frequency of sway	SFM	Hz	AP and ML	The mean frequency of amplitude spectrum.
Sway frequency band	SFB	Hz	AP and ML	The frequency band that contains a fraction of the area under the amplitude spectrum.

Structural parameters are divided on parameters based on the computation of diffusion plots or variograms proposed by Collins et al. (1993, 1995a, 1995b), and on parameters based on the analysis of sway density plots proposed by Jacono, Casadio, Morasso and Sanguineti (2004).

The underlying idea of the first approach of the computation based on diffusion plots (Baratto et al., 2002) is to model the stabilograms as fractional Brownian motions (Mandelbrot & Van Ness, 1968) and thus to decompose the sway patterns into two stochastic processes: a short-term process, interpreted as an open-loop control mechanism, and a long-term process, interpreted as a closed-loop mechanism.

Table 2. Parameters based on diffusion plots.

Name	Symbol	Unit	Directions
Variance	Var	mm^2	MLO, APO and RO
Critical time window	CW	s	MLO, APO and RO
Short-range slope in linear scale	DS	mm^2/s	MLO, APO and RO
Short-range slope in logarithmic scale	HS	mm^2/s	MLO, APO and RO
Long-range slope in linear scale	DL	mm^2/s	MLO, APO and RO
Long-range slope in logarithmic scale	HL	mm^2/s	MLO, APO and RO

The underlying idea of the second approach based on the analysis of sway density plots (Morasso & Schieppati, 1999) is that the feed-forward control is the prevalent mechanism in the postural stabilization process, thus breaking down the control process into a sequence of anticipatory motor commands. This idea is consistent with the empirical investigation reported by Gatev, Thomas, Kepple and Hallett (1999).

Parameters based on density plots:

- Populations mean value of the peaks in the sway density curve (MP) [number] and the corresponding intra-subject variability (SP) [number].

- Populations mean value of the time interval between successive peaks in the sway density curve (MT) [s] and the corresponding intra-subject variability (ST) [s].

- Populations mean value of the distance between successive peaks in the sway density curve (MD) [mm] and the corresponding intra-subject variability (SD) [mm].

Next, we will present also other techniques for the COP sway analysis that transform or decompose COP curve. The output of these techniques are new (one or more) curves and/or new (one or more) parameters.

Rambling (R) and trembling (T). R is the motion of a moving reference point with respect to which the body's equilibrium is instantly maintained, while T is the oscillation of COP around the reference point trajectory (Zatsiorsky & Duarte, 1999, 2000). Because rambling and trembling are curve which can be quantified with many different techniques (amplitude, frequency, etc.). In young healthy people, rambling amplitude was roughly three times larger than trembling amplitude, while the frequency was four times smaller (Zatsiorsky & Duarte, 2000).

Sample entropy (SE) (Richman & Moorman, 2000) provides information about the regularity or predictability of a time-series (COP path) and it is used to analyze complex stochastic systems. Small values of SE are associated with great regularity (high possibility of the same data) while large values of SE reflect great irregularity (low possibility of the same data). SE is mathematically defined as the negative natural logarithm of the conditional probability that a sequence of data points with length N, having repeated itself within a tolerance t for M points, will also repeat itself for M + 1 points, without allowing self-matches (Richman & Moorman, 2000). Related to Borg and Laxaback (2010) further research activities are necessary to identify the correct physiological interpretation of SE. SE was used in many studies of balance where different interpretations of it may be found (Cavanaugh, Mercer, & Stergiou, 2007; Deffeyes et al., 2009; Donker, Roerdink, Greven, & Beek, 2007; Duarte & Sternad, 2008; Haran & Keshner, 2008; Santarcangelo et al., 2009; Schmit, Regis, & Riley, 2005; Stins, Michielsen, Roerdink, & Beek, 2009).

Recurrence quantification analysis (RQA) is a nonlinear and multidimensional technique which does not assume data stationary and which provides a characterization of a variety of features of a given time series, including a quantification of deterministic structure and of nonstationarity (Riley, Balasubramaniam, & Turvey, 1999). These features make it an ideal tool for analysis of COP data with respect to the above concerns. Detailed instructions for implementing RQA are presented in Belaire-Franch, Contreras and Tordera-Lledo (2002). Five measures may be obtained by RQA: percent recurrence, percent determinism, the ratio of these quantities, entropy, and trend. The measures are explained in details by Webber and Zbilut (1994).

Detrended fluctuation analysis (DFA) is a technique that characterizes the pattern of variation across multiple scales (fractal-scaling) and is based on the assumption that variations due to intrinsic dynamics of the system exhibit long-range correlations If the outcome parameter α is between 0.5 and 1, this indicates the presence of long-range power-law correlations in the time series. This technique was presented and described in details by Peng, Havlin, Stanley and Goldberger (1995).

The largest Layapunov exponent (LLE) measures the system's resistance to small internal perturbations, such as the natural sway fluctuations present while standing upright. In other words, it detects presence of chaos in a dynamical system. Lyapunov exponents quantify the exponential divergence of initially close state-space trajectories and estimate the amount of chaos in a system (Rosenstein, Collins, De Luca, & Michael, 1993). If LLE is negative, then any perturbation exponentially damps out and initially close trajectories remain close. In contrast, for positive LLE, nearby points diverge as time evolves and produce instability; that is when the distance between the trajectories increases exponentially. LLE was commonly used in recent studies of COP (Donker et al., 2007; Kyvelidou, Harbourne, Shostrom, & Stergiou, 2010; Kyvelidou, Harbourne, Stuberg, Sun, & Stergiou, 2009; Mizuta, Tokita, Ito, Aoki, & Kuze, 2009).

Reliability of calculated parameters is important when we try to provide reliable conclusions. Because it is hard to form a well-defined sample of people (one would have to include many different people profiles: young, old, healthy, ill, etc.) and cover many static balance tests in a single study, we cannot talk about reliability of parameters in general, but we are limited to the sample that was included in the study. Some basic metric characteristics of the test were provided along test description in previous paragraphs. However, for some tests we were unable to find reports about some characteristics, thus, we believe there is a gap in research literature regarding this problem. We propose that authors of new methods provide information about basic characteristics of the test along with presentation of it. The same also applies to the protocol of the test. Each protocol should include description of all essential parts (measurement procedure, arms position, elimination of vision, stance, standing surface, number of introductory trials, number of trials, randomization of tests, etc.) which importantly influence the balance.

Laboratory Tests of Dynamic Balance

Dynamic body balance is required for normal daily activities, such as walking, running, and stair climbing. Sports activities also require proper balance control. Dynamic body balance (Figure 4) is the ability to maintain balance while moving, such as running, tumbling or walking. It can be maintained either on a moving surface or while the body is moving. The assessment of dynamic body balance during walking or running is even nowadays rather an exception then a rule. The reason probably lies in fact that the equipment needed for such experiment is more advanced, but on the other hand there has been very little research work done regarding this area, and moreover no standards were proposed. All commonly used tests of dynamic balance are more or less simple, except tests on specially designed machines (namely EquiTest® and Biodex Balance System SD) that are quite expensive. In following sections we present all regularly used tests in the latest studies.

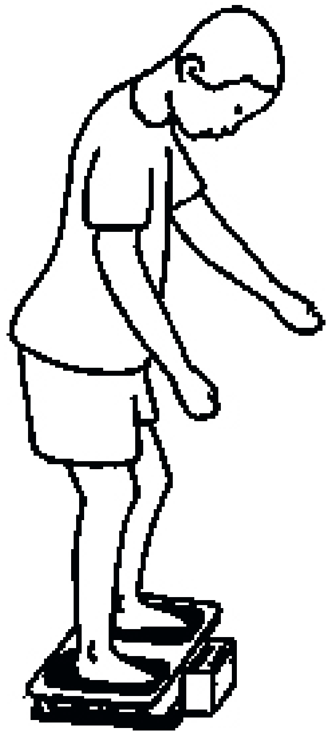

Figure 4. Example of dynamic balance test – Clever balance board. Analysis of the test and parameters calculation is performed by a microprocessor installed in the device.

The Star Excursion Balance Test (SEBT) is a functional test that incorporates a single-leg stance on one leg (e.g. right leg) whilst trying to reach as far as possible with the opposite leg (e.g. left leg). The participants stand in the center of the grid with 4 lines at 45° between adjacent ones, forming a star like shape (Figure 5).

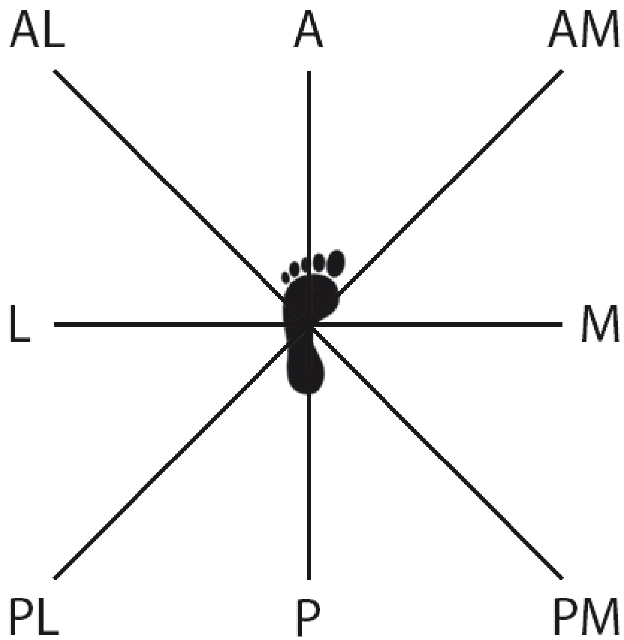

Figure 5. SEBT test directions for left leg stance (AL - antero-lateral, A - anterior, AM - antero-medial, M - medial, PL - postero-medial, P - posterior, PL - postero-lateral and L – lateral).

There are 8 individual directions possible and subject is required to reach out in these directions with the most distal part of his reach foot. The eight directions consist of antero-lateral, anterior, antero-medial, medial, postero-medial, posterior, postero-lateral and lateral. A standard tape measure or a force plate can be used to quantify the distance the subject had reached from the center of the grid (see Figure 1) to the point that the subject managed to reach along each diagonal line. The reliability of the test was performed on young healthy subjects who performed 12 sessions with five trials to gain ICC of 0.86 (Kinzey & Armstrong, 1998). According to the number of studies that included SEBT, it is the most frequently used test of dynamic body balance – for review see: Herrington, Hatcher, Hatcher and McNicholas, 2009; Plisky, Rauh, Kaminski and Underwood, 2006; Sabin, Ebersole, Martindale, Price and Broglio, 2010.

The Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Cushing, Chia, James, Papsin, & Gordon, 2008; Deitz, Kartin, & Kopp, 2007; Levine, 1987) is an individually administered test designed to assess motor skills in children ranging in age from four and 1/2 to fourteen and 1/2 years of age. It has been described as the most outstanding instrument of its kind, and one which fills a clinical void. The BOTMP is widely used by occupational therapists, educators, and psychologists and is often considered a necessary part of diagnostic testing, especially for children with learning disabilities. This individually administered test includes 46 items, grouped into eight subtests. Subtests include: running speed and agility, balance, bilateral coordination, strength, upper-limb coordination, response speed, visual-motor control, and upper-limb speed and dexterity. Items are arranged into three composites, and yield a comprehensive index of motor proficiency as well as separate measures of gross and fine motor skills. For each of these composites, normalized standard scores, percentile ranks, and stanines are available. Age equivalents are also available for the subtest scores. The entire battery takes about one hour to administer, or a short form can be administered in 20 minutes. Test-retest reliabilities for the battery composite range from 0.86 to 0.89, and for the short form 0.84 to 0.87. The gross motor composite reliabilities are slightly higher than those of the fine motor composite. Gross motor reliabilities range from 0.77 to 0.85, and fine motor composite reliabilities from 0.68 to 0.88. Individual subtest scores range from 0.29 to 0.89, and must be interpreted with extreme caution, if at all.

Functional Reach Test (FRT) (Duncan, Weiner, Chandler, & Studenski, 1990) is a single item test developed as a quick screen for balance problems in older adults. To perform the test a subject must be able to stand independently for at least 30 seconds without support and be able to flex the shoulder to at least 90 degrees. A stick is attached to a wall at about shoulder height. The subject is positioned in front of the stick and the examiner is about 2 to 3 meters away from the subject, viewing the subject from the side. The subject is instructed to stand with feet at shoulder distance apart and to make a fist and raise the arm up so that it is parallel to the floor. At this time the examiner takes an initial reading on the stick, usually spotting the knuckle of the third metacarpal. The subject is instructed to reach forward along the stick without moving the feet. Any reaching strategy is allowed but the hand should remain in a fist. The examiner takes a reading on the stick of the farthest reach attained by the subject without taking a step. The initial reading is subtracted from the final to obtain the functional reach score. For subjects that are unable to stand a modified FRT was developed by Lynch, Leahy and Barker (1998). High reliability (ICC between 0.85 and 0.94) for this test was reported. Question whether FRT really measure dynamic balance was raised in a study by Wernick-Robinson, Krebs and Giorgetti (1999). They conclude that FRT does not measure dynamic balance.

The jump-landing test is a simple test of dynamic postural stability, which can be defined as an individual's ability to maintain balance while transitioning from a dynamic to a static state (Goldie, Bach, & Evans, 1989). The test is performed on a force plate. A subject performs a both leg jump, to approximately 50% of maximal height, and lands on a single leg. After landing, the subject remains motionless in a single leg stance for a predefined time (usually from 10 to 30 seconds). Several parameters can be calculated for this test. The most common parameter calculated is the time to stabilization (Brown, Ross, Mynark, & Guskiewicz, 2004; Ross & Guskiewicz, 2003, 2004). The time to stabilization is defined as the time required to minimize resultant ground reaction forces of a jump landing to within a range of the baseline (static) ground reaction forces. As an aspect of motor control for the lower extremity, time to stabilization depends on proprioceptive feedback and preprogrammed muscle patterns, as well as reflexive and voluntary muscle responses (Johnston, Howard, Cawley, & Losse, 1998). Another parameter for jump-landing test is the dynamic postural stability index (Wikstrom, Tillman, Smith, & Borsa, 2005). This parameter is based on previous assessments of single-leg stance and single-leg hop stabilization tests with the underlying premise that dynamic postural stability depends on lower extremity kinematics at landing as well as on muscular activation patterns and eccentric control. The reliability of the time to stability and the dynamic postural stability index was assessed by Wikstrom et al. (2005). They observed higher ICC values (ICC = 0.96) for the dynamic postural stability index, while the time to stability ICC values were 0.66, 0.80 and 0.78 for medio-lateral, antero-posterior and vertical direction respectively.

A novel tool for the assessment of dynamic body balance for healthy individual named clever balance board was presented by Sarabon, Mlaker and Markovic (2010). The clever balance board consists of two main plates connected by an axis in horizontal plane and angle meter attached to the axis. That allows rotation of one plate around second one while angle between them is measured during a test. Several parameters are calculated based on angle waveform acquired. Reliability of these parameters was tested on a sample of 36 healthy male subjects. ICC values obtained were between 0.77 and 0.90 indicating that clever balance board could be a reliable tool for dynamic balance assessment in healthy and physically active individuals (Sarabon et al., 2010).

Active dynamic balance tracking test is a new technique for assessment of dynamic body balance invented by our group. The idea was adopted from hand grip and position tracking tasks originating from motor control studies. A force plate and special software is needed to perform this test. A random curve that has to be followed by a subject is created with software. The subject is placed on the force plate in any stance, the random curve and real time center of pressure is projected on a wall in front of the subject. The subject is asked to follow the random curve as good as possible with moving his center of pressure. The random curve can move in medio-lateral or antero-posterior or in both directions at the same time.

Computerized dynamic photography is a quantitative method for accessing upright balance function under a variety of tasks that effectively simulate conditions in daily life (Jacobson, Newman, & Kartush, 1997). The protocols are designed to eliminate sensory, motor and biomechanical components contributing to balance. The subject ability to maintain his balance is then analyzed. Special equipment was developed for this purpose (e.g. EquiTest, NeuroCom International and Balance System SD, Biodex) that includes different protocols of testing. Computerized dynamic photography was well researched by scientists (Bergson & Sataloff, 2005; Hrysomallis, McLaughlin, & Goodman, 2006; Mockford et al., 2010; Monsell, Furman, Herdman, Konrad, & Shepard, 1997; Vanicek, Strike, McNaughton, & Polman, 2009; Whipple, Wolfson, Derby, Singh, & Tobin, 1993).

Many studies regarding ankle stability were performed by evaluating dynamic balance of a subject. As found by previous studies (Arnold, De La Motte, Linens, & Ross, 2009; Brown & Mynark, 2007; Ross, Guskiewicz, Gross, & Yu, 2009), functional ankle stability/instability affects balance. Many studies considering this issue were conducted (Hale, Hertel, & Olmsted-Kramer, 2007; Lin, Liu, Hsieh, & Lee, 2009; Martínez-Ramírez, Lecumberri, Gómez, & Izquierdo, 2010; McKeon et al., 2008; Munn, Sullivan, & Schneiders, 2010; Ozunlu, Basari, & Baltaci, 2010).

Conclusion

In this paper we presented a great part of the tests, methods and parameters that are used to assess the ability of human body balance. Presented tests differ in complexity, costs of equipment required, amount of time required and their purpose. The simplest tests are clinical and simple field test, while the most complex tests to perform are the dynamic balance tests. Similar, the simplest methods and parameters used to evaluate balance are used for clinical and simple field test. On the other hand, the most complex ones are used for dynamic and static balance tests. Basic metric characteristics of methods are in most cases assessed on a limited population, therefore they cannot be considered for a general population. We propose that each new method is evaluated for all basic metric characteristics on a general population. However, we do not disagree with the proposal of methods for the specific type of population.

Clinical and simple field test are today mainly used to assess balance on elderly population and very rarely on athletes. They are not proper for athletes, because in most cases they score maximum number of points (some more difficult test can be exception here). Clinical test are widely used in risk for falls evaluation mainly on elderly population. As the sport science research devoted a great attention to the studies of elderly population and their related health and prevention issues, the majority of basic metric characteristics are assessed on this particular population. Nevertheless, evaluation of some basic metric characteristics is for some tests irrelevant (when all subjects score the maximum number of points) as reported by Sarabon and Omejec (2007). Therefore, scientists have to be aware of this problem. In laboratory tests of static balance, only one technique stands out, i.e. measurement of COP sway on a force place. Some other techniques (e.g. magnetic recording devices) can be used to measure COP sway; however, they measure only the sway of body part to which they are attached. Many methods and parameters for the analysis of the COP sway were proposed. Some of them are quite simple (e.g. SP, SV and SA) and some of them require more knowledge about signal processing and time series analysis (e.g. SE and DFA). At this point, no method or parameter is the best in the interpretation of balance, because this depends on a problem that needs to be explained. In general, the reliabilities of those parameters for the specific population were seldom higher than 0.90. This may indicate that only one parameter could not model balance well enough. Thus, combinations of parameters may explain (model) the behavior of balance more completely. Application of methods of machine learning or data mining tools could be useful in further research work of the human body balance.

Dynamic body balance is more complicated to evaluate than static body balance. Thus, test require more equipment (also more advanced one) and also methods are more complex than the one used in static balance analysis. Among dynamic balance test, there are some very simple (e.g. SBAT and FRT), mainly used for clinical practice. On the other hand, very advanced equipment (e.g. EquiTest and Balance System SD) is also used in some clinical cases and more often in a research work. As mentioned previously, regarding the analysis of the COP sway, also for the analysis of dynamic body balance could be more effectively and comprehensively analyzed with application of methods of machine learning or data mining tools.

Rerefences

Alentorn-Geli, E., Myer, G. D., Silvers, H. J., Samitier, G., Romero, D., Lázaro-Haro, C., & Cugat, R. (2009). Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 2: a review of prevention programs aimed to modify risk factors and to reduce injury rates. *Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA*, *17*(8), 859-879.

Arnold, B. L., De La Motte, S., Linens, S., & Ross, S. E. (2009). Ankle instability is associated with balance impairments: a meta-analysis. *Medicine and Science in Sports and Exercise, 41*(5), 1048-1062.

Avdić, D., & Pecar, D. (2006). Significance of specificity of Tinetti B-POMA test and fall risk factor in third age of life. *Bosnian Journal of Basic Medical Sciences/ Udruženje Basičnih Mediciniskih Znanosti = Association of Basic Medical Sciences, 6*(1), 50-57.

Baczkowicz, D., Szczegielniak, J., & Proszkowiec, M. (2008). Relations between postural stability, gait and falls in elderly persons--preliminary report. *Ortopedia, Traumatologia, Rehabilitacja, 10*(5), 478-485.

Barabas, A., Bretz, K., & Kaske, R. (1996). Stabilometry of the flamingo balance test. Presented at the 14 International Symposium on Biomechanics in Sports, Funchal, Madeira, Portugal.

Baratto, L., Morasso, P. G., Re, C., & Spada, G. (2002). A new look at posturo-graphic analysis in the clinical context: sway-density versus other parameterization techniques. *Motor Control, 6*(3), 246-270.

Bardy, D. G., Oullier, O., Bootsma, R. J., & Stofrregen, T. A. (2002). Dynamics of human postural transistions. Jurnal of Experimental Psychology: *Human Perception and Performance, 28*, 499-514.

Bauer, C., Rietsch, C., Gröger, I., & Gassmann, K. G. (2009). Mobility and safety for elderly (MoSi), a new intervention to improve mobility and gait in elderly people. *Zeitschrift Für Gerontologie Und Geriatrie: Organ Der Deutschen Gesellschaft Für Gerontologie Und Geriatrie, 42*(5), 360-364.

Bean, J. F., Vora, A., & Frontera, W. R. (2004). Benefits of exercise for community-dwelling older adults 1. *Archives of physical medicine and rehabilitation, 85*, 31–42.

Beauchamp, M. K., O'Hoski, S., Goldstein, R. S., & Brooks, D. (2010). Effect of pulmonary rehabilitation on balance in persons with chronic obstructive pulmonary disease. *Archives of Physical Medicine and Rehabilitation, 91*(9), 1460-1465.

Behm, D. G., & Anderson, K. G. (2006). The role of instability with resistance training. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 20*(3), 716-722.

Belaire-Franch, J., Contreras, D., & Tordera-Lledo, L. (2002). Assessing nonlinear structures in real exchange rates using recurrence plot strategies. *Physica D: Nonlinear Phenomena, 171*(4), 249-264.

Benvenuti, F. (2001). Physiology of human balance. *Advances in Neurology, 87*, 41-51.

Berg balance scale assessment form [on-line]. Http://www.aahf.info/pdf/Berg_Balance_Scale.pdf (accesed Nov 8th 2010)

Berg, K. O., Wood-Dauphinee, S. L., Williams, J. I., & Maki, B. (1992). Measuring balance in the elderly: validation of an instrument. *Canadian Journal of Public Health. Revue Canadienne De Santé Publique, 83* Suppl 2, S7-11.

Bergson, E., & Sataloff, R. T. (2005). Preoperative computerized dynamic posturography as a prognostic indicator of balance function in patients with acoustic neuroma. *Ear, Nose, & Throat Journal, 84*(3), 154-156.

Błaszczyk, J. W. (2008). Sway ratio - a new measure for quantifying postural stability. *Acta Neurobiologiae Experimentalis, 68*(1), 51-57.

Blum, L., & Korner-Bitensky, N. (2008). Usefulness of the Berg Balance Scale in stroke rehabilitation: a systematic review. *Physical Therapy, 88*(5), 559-566.

Bogle Thorbahn, L. D., & Newton, R. A. (1996). Use of the Berg Balance Test to predict falls in elderly persons. *Physical Therapy, 76*(6), 576-583.

Borg, F. G., & Laxaback, G. (2010). Entropy of balance--some recent results. *Journal of Neuroengineering and Rehabilitation, 7,* 38.

Brown, C., Ross, S., Mynark, R., & Guskiewicz, K. (2004). Assessing functional ankle instability with joint position sense, time to stabilization, and electromyography. *Journal of Sport Rehabilitation*, 122–134.

Brown, C. N., & Mynark, R. (2007). Balance deficits in recreational athletes with chronic ankle instability. *Journal of Athletic Training, 42*(3), 367-373.

Cavanaugh, J. T., Mercer, V. S., & Stergiou, N. (2007). Approximate entropy detects the effect of a secondary cognitive task on postural control in healthy young adults: a methodological report. *Journal of Neuroengineering and Rehabilitation, 4*, 42.

Collins, J. J., & De Luca, C. J. (1993). Open-loop and closed-loop control of posture: a random-walk analysis of center-of-pressure trajectories. *Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale, 95*(2), 308-318.

Collins, J. J., & De Luca, C. J. (1995). The effects of visual input on open-loop and closed-loop postural control mechanisms. *Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale, 103*(1), 151-163.

Collins, J. J., De Luca, C. J., Burrows, A., & Lipsitz, L. A. (1995). Age-related changes in open-loop and closed-loop postural control mechanisms. *Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale, 104*(3), 480-492.

Cushing, S. L., Chia, R., James, A. L., Papsin, B. C., & Gordon, K. A. (2008). A test of static and dynamic balance function in children with cochlear implants: the vestibular olympics. *Archives of Otolaryngology--Head & Neck Surgery, 134*(1), 34-38.

Dean, E. M., Griffiths, C. J., & Murray, A. (1986). Stability of the human body investigated by sway magnetometry. *Journal of Medical Engineering & Technology, 10*(3), 126-130.

Deffeyes, J. E., Harbourne, R. T., DeJong, S. L., Kyvelidou, A., Stuberg, W. A., & Stergiou, N. (2009). Use of information entropy measures of sitting postural sway to quantify developmental delay in infants. *Journal of Neuroengineering and Rehabilitation, 6*, 34.

Deitz, J. C., Kartin, D., & Kopp, K. (2007). Review of the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2). *Physical & Occupational Therapy in Pediatrics, 27*(4), 87-102.

Donker, S. F., Roerdink, M., Greven, A. J., & Beek, P. J. (2007). Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. *Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale, 181*(1), 1-11.

Dornan, J., Fernie, G. R., & Holliday, P. J. (1978). Visual input: its importance in the control of postural sway. *Archives of Physical Medicine and Rehabilitation, 59*(12), 586-591.

Duarte, M., & Sternad, D. (2008). Complexity of human postural control in young and older adults during prolonged standing. *Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale, 191*(3), 265-276.

Duncan, P. W., Weiner, D. K., Chandler, J., & Studenski, S. (1990). Functional reach: a new clinical measure of balance. *The Journal of Gerontology, 45*(6), M192.

Findlay, G. F. G., Balain, B., Trivedi, J. M., & Jaffray, D. C. (2009). Does walking change the Romberg sign? *European Spine Journal: Official Publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society, 18*(10), 1528-1531.

Fitzgerald, B. (1996). A review of the sharpened Romberg test in diving medicine. *SPUMS Journal / South Pacific Underwater Medicine Society, 26*(3), 142-146.

Gatev, P., Thomas, S., Kepple, T., & Hallett, M. (1999). Feedforward ankle strategy of balance during quiet stance in adults. *The Journal of Physiology, 514*(3), 915–928.

Giansanti, D., Maccioni, G., Cesinaro, S., Benvenuti, F., & Macellari, V. (2008). Assessment of fall-risk by means of a neural network based on parameters assessed by a wearable device during posturography. *Medical Engineering & Physics, 30*(3), 367-372.

Goldie, P. A., Bach, T. M., & Evans, O. M. (1989). Force platform measures for evaluating postural control: reliability and validity. *Archives of Physical Medicine and Rehabilitation, 70*(7), 510-517.

Greene, B., O'Donovan, A., Romero-Ortuno, R., Cogan, L., Ni Scanaill, C., & Kenny, R. (2010). Quantitative falls risk assessment using the timed up and go test. *IEEE Transactions on Bio-Medical Engineering.* doi:10.1109/TBME.2010.2083659

Hale, S. A., Hertel, J., & Olmsted-Kramer, L. C. (2007). The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. *The Journal of Orthopaedic and Sports Physical Therapy, 37*(6), 303-311.

Haran, F. J., & Keshner, E. A. (2008). Sensory reweighting as a method of balance training for labyrinthine loss. *Journal of Neurologic Physical Therapy: JNPT, 32*(4), 186-191.

Hellström, J. (2009). Competitive elite golf: a review of the relationships between playing results, technique and physique. *Sports Medicine (Auckland, N.Z.), 39*(9), 723-741.

Herrington, L., Hatcher, J., Hatcher, A., & McNicholas, M. (2009). A comparison of Star Excursion Balance Test reach distances between ACL deficient patients and asymptomatic controls. *The Knee, 16*(2), 149-152. doi:10.1016/j.knee.2008.10.004

Hrysomallis, C., McLaughlin, P., & Goodman, C. (2006). Relationship between static and dynamic balance tests among elite Australian Footballers. *Journal of Science and Medicine in Sport / Sports Medicine Australia, 9*(4), 288-291.

Huang, T., & Wang, W. (2009). Comparison of three established measures of fear of falling in community-dwelling older adults: psychometric testing. *International Journal of Nursing Studies, 46*(10), 1313-1319.

Hübscher, M., Zech, A., Pfeifer, K., Hänsel, F., Vogt, L., & Banzer, W. (2010). Neuromuscular training for sports injury prevention: a systematic review. *Medicine and Science in Sports and Exercise, 42*(3), 413-421.

Jacobson, G. P., Newman, C. W., & Kartush, J. M. (1997). *Handbook of balance function testing*. Cengage Learning.

Jacono, M., Casadio, M., Morasso, P. G., & Sanguineti, V. (2004). The sway-den sity curve and the underlying postural stabilization process. *Motor Control, 8*(3), 292-311.

Jakobsen, M. D., Sundstrup, E., Krustrup, P., & Aagaard, P. (2010). The effect of recreational soccer training and running on postural balance in untrained men. *European Journal of Applied Physiology*. doi:10.1007/s00421-010-1669-2

Johnston, R. B., Howard, M. E., Cawley, P. W., & Losse, G. M. (1998). Effect of lower extremity muscular fatigue on motor control performance. *Medicine and Science in Sports and Exercise, 30*(12), 1703-1707.

Karinkanta, S., Piirtola, M., Sievänen, H., Uusi-Rasi, K., & Kannus, P. (2010). Physical therapy approaches to reduce fall and fracture risk among older adults. *Nature Reviews. Endocrinology, 6*(7), 396-407.

Kaufman, K. R., Brey, R. H., Chou, L., Rabatin, A., Brown, A. W., & Basford, J. R. (2006). Comparison of subjective and objective measurements of balance disorders following traumatic brain injury. *Medical Engineering & Physics, 28*(3), 234-239.

Kegelmeyer, D. A., Kloos, A. D., Thomas, K. M., & Kostyk, S. K. (2007). Reliability and Validity of the Tinetti Mobility Test for Individuals With Parkinson Disease. *Physical Therapy, 87*(10), 1369-1378.

Khasnis, A., & Gokula, R. M. (2003). Romberg's test. *Journal of Postgraduate Medicine, 49*(2), 169-172.

Kinzey, S. J., & Armstrong, C. W. (1998). The reliability of the star-excursion test in assessing dynamic balance. *The Journal of Orthopaedic and Sports Physical Therapy, 27*(5), 356-360.

Kloos, A. D., Bello-Haas, V. D., Thome, R., Cassidy, J., Lewis, L., Cusma, T., & Mitsumoto, H. (2004). Interrater and intrarater reliability of the Tinetti Balance Test for individuals with amyotrophic lateral sclerosis. *Journal of Neurologic Physical Therapy, 28*(1), 12.

Kloos, A. D., Kegelmeyer, D. A., Young, G. S., & Kostyk, S. K. (2010). Fall risk assessment using the Tinetti mobility test in individuals with Huntington's disease. *Movement Disorders: Official Journal of the Movement Disorder Society.* doi:10.1002/mds.23421

Köpke, S., & Meyer, G. (2006). The Tinetti test: Babylon in geriatric assessment. *Zeitschrift Für Gerontologie Und Geriatrie: Organ Der Deutschen Gesellschaft Für Gerontologie Und Geriatrie, 39*(4), 288-291.

Kyvelidou, A., Harbourne, R. T., Shostrom, V. K., & Stergiou, N. (2010). Reliability of center of pressure measures for assessing the development of sitting postural control in infants with or at risk of cerebral palsy. *Archives of Physical Medicine and Rehabilitation, 91*(10), 1593-1601.

Kyvelidou, A., Harbourne, R. T., Stuberg, W. A., Sun, J., & Stergiou, N. (2009). Reliability of center of pressure measures for assessing the development of sitting postural control. *Archives of Physical Medicine and Rehabilitation, 90*(7), 1176-1184.

Lanska, D. J., & Goetz, C. G. (2000). Romberg's sign: development, adoption, and adaptation in the 19th century. *Neurology, 55*(8), 1201-1206.

Le Clair, K., & Riach, C. (1996). Postural stability measures: what to measure and for how long. *Clinical Biomechanics (Bristol, Avon), 11*(3), 176-178.

Le, T., & Kapoula, Z. (2008). Role of ocular convergence in the Romberg quotient. *Gait & Posture, 27*(3), 493-500.

Lephart, S. M., Riemann, B. L., & Fu, F. H. (2000). Introduction to the sensorimotor system. *Proprioception and neuromuscular control in joint stability*, 162–169.

Levine, K. J. (1987). *The Bruininks-Oseretsky test of motor proficiency: Usefulness for assessing writing disorders.* Englewood Cliffs, NJ: Prentice Hall.

Lin, W., Liu, Y., Hsieh, C. C., & Lee, A. J. Y. (2009). Ankle eversion to inversion strength ratio and static balance control in the dominant and non-dominant limbs of young adults. *Journal of Science and Medicine in Sport / Sports Medicine Australia, 12*(1), 42-49.

Longridge, N. S., & Mallinson, A. I. (2010). Clinical romberg testing does not detect vestibular disease. *Otology & Neurotology: Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, 31*(5), 803-806.

Lord, S. R., Clark, R. D., & Webster, I. W. (1991). Postural stability and associated physiological factors in a population of aged persons. *Journal of Gerontology, 46*(3), M69-76.

Lynch, S. M., Leahy, P., & Barker, S. P. (1998). Reliability of measurements obtained with a modified functional reach test in subjects with spinal cord injury. *Physical Therapy, 78*(2), 128.

Ma, J., Yao, Y., Ma, R., Li, J., Wang, T., Li, X., Han, W., et al. (2009). Effects of sleep deprivation on human postural control, subjective fatigue assessment and psychomotor performance. *The Journal of International Medical Research, 37*(5), 1311-1320.

Mandelbrot, B. B., & Van Ness, J. W. (1968). Fractional Brownian motions, fractional noises and applications. *SIAM review, 10*(4), 422–437.

Martínez-Ramírez, A., Lecumberri, P., Gómez, M., & Izquierdo, M. (2010). Wavelet analysis based on time-frequency information discriminate chronic ankle instability. *Clinical Biomechanics (Bristol, Avon), 25*(3), 256-264.

Mazoteras Munoz, V., Abellan van Kan, G., Cantet, C., Cortes, F., Ousset, P., Rolland, Y., & Vellas, B. (2010). Gait and balance impairments in Alzheimer disease patients. *Alzheimer Disease and Associated Disorders, 24*(1), 79-84.

McKeon, P. O., Ingersoll, C. D., Kerrigan, D. C., Saliba, E., Bennett, B. C., & Hertel, J. (2008). Balance training improves function and postural control in those with chronic ankle instability. *Medicine and Science in Sports and Exercise, 40*(10), 1810-1819.

McMichael, K. A., Vander Bilt, J., Lavery, L., Rodriguez, E., & Ganguli, M. (2008). Simple balance and mobility tests can assess falls risk when cognition is impaired. *Geriatric Nursing (New York, N.Y.), 29*(5), 311-323.

Michel-Pellegrino, V., Hewson, D. J., Drieux, M., & Duchene, J. (2007). Evaluation of the risk of falling in institution-dwelling elderly: clinical tests versus biomechanical analysis of stepping-up. *Conference Proceedings: ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society.* Conference, 2007, 6122-6125.

Mizuta, K., Tokita, T., Ito, Y., Aoki, M., & Kuze, B. (2009). Studies on the largest Lyapunov exponents of the standing posture in patients with unilateral vestibular dysfunction. *Nippon Jibiinkoka Gakkai Kaiho, 112*(12), 791-800.

Mockford, K. A., Mazari, F. A. K., Jordan, A. R., Vanicek, N., Chetter, I. C., & Coughlin, P. A. (2010). Computerized Dynamic Posturography in the Objective Assessment of Balance in Patients with Intermittent Claudication. *Annals of Vascular Surgery*. doi:10.1016/j.avsg.2010.07.021

Monsell, E. M., Furman, J. M., Herdman, S. J., Konrad, H. R., & Shepard, N. T. (1997). Computerized dynamic platform posturography. *Otolaryngology--Head and Neck Surgery: Official Journal of American Academy of Otolaryngology-Head and Neck Surgery, 117*(4), 394-398.

Morasso, P. G., & Schieppati, M. (1999). Can muscle stiffness alone stabilize upright standing? *Journal of neurophysiology, 82*(3), 1622.

Mourey, F., Camus, A., & Pfitzenmeyer, P. (2000). Posture and aging. Current fundamental studies and management concepts. Presse Médicale (Paris, France: 1983), 29(6), 340-344.

Munn, J., Sullivan, S. J., & Schneiders, A. G. (2010). Evidence of sensorimotor deficits in functional ankle instability: a systematic review with meta-analysis. *Journal of Science and Medicine in Sport / Sports Medicine Australia, 13*(1), 2-12.

de Noronha, M., Refshauge, K. M., Herbert, R. D., Kilbreath, S. L., & Hertel, J. (2006). Do voluntary strength, proprioception, range of motion, or postural sway predict occurrence of lateral ankle sprain? *British Journal of Sports Medicine, 40*(10), 824-828.

Ortuno-Cortés, M. A., Martín-Sanz, E., & Barona-de Guzmán, R. (2008). Static posturography versus clinical tests in elderly people with vestibular pathology. *Acta Otorrinolaringológica Espanola, 59*(7), 334-340.

Ozunlu, N., Basari, G. O., & Baltaci, G. (2010). The effects of carrying extra weight on ankle stability in adolescent basketball players. *Foot (Edinburgh, Scotland), 20*(2-3), 55-60.

Peng, C. K., Havlin, S., Stanley, H. E., & Goldberger, A. L. (1995). Quantification of scaling exponents and crossover phenomena in nonstationary heartbeat time series. *Chaos (Woodbury, N.Y.), 5*(1), 82-87.

Pérennou, D., Decavel, P., Manckoundia, P., Penven, Y., Mourey, F., Launay, F., Pfitzenmeyer, P., et al. (2005). Evaluation of balance in neurologic and geriatric disorders. *Annales De Réadaptation Et De Médecine Physique: Revue Scientifique De La Société Française De Rééducation Fonctionnelle De Réadaptation Et De Médecine Physique, 48*(6), 317-335.

Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *The Journal of Orthopaedic and Sports Physical Therapy, 36*(12), 911-919.

Rabbitt, P. M., Scott, M., Thacker, N., Lowe, C., Horan, M., Pendleton, N., Hutchinson, D., et al. (2006). Balance marks cognitive changes in old age because it reflects global brain atrophy and cerebro-arterial blood-flow. *Neuropsychologia, 44*(10), 1978-1983.

Raymakers, J. A., Samson, M. M., & Verhaar, H. J. J. (2005). The assessment of body sway and the choice of the stability parameter(s). *Gait & Posture, 21*(1), 48-58.

Richman, J. S., & Moorman, J. R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *American Journal of Physiology. Heart and Circulatory Physiology, 278*(6), H2039-2049.

Riley, M. A., Balasubramaniam, R., & Turvey, M. T. (1999). Recurrence quantification analysis of postural fluctuations. *Gait & Posture, 9*(1), 65-78.

Rosenstein, M. T., Collins, J. J., De Luca, C. J., & Michael, C. (1993). A practical method for calculating largest Lyapunov exponents from small data sets. *PHYSICA D, 65*, 117-134.

Ross, S., & Guskiewicz, K. (2003). Time to stabilization: a method for analyzing dynamic postural stability. *Athletic Therapy Today, 8*(3), 37–39.

Ross, S., & Guskiewicz, K. (2004). Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. *Clinical Journal of Sport Medicine: Official Journal of the Canadian Academy of Sport Medicine, 14*(6), 332-338.

Ross, S. E., Guskiewicz, K. M., Gross, M. T., & Yu, B. (2009). Balance measures for discriminating between functionally unstable and stable ankles. *Medicine and Science in Sports and Exercise, 41*(2), 399-407.

Sabin, M. J., Ebersole, K. T., Martindale, A. R., Price, J. W., & Broglio, S. P. (2010). Balance performance in male and female collegiate basketball athletes: influence of testing surface. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 24*(8), 2073-2078. doi:10.1519/JSC.0b013e3181ddae13

Santarcangelo, E. L., Scattina, E., Carli, G., Balocchi, R., Macerata, A., & Manzoni, D. (2009). Modulation of the postural effects of cognitive load by hypnotizability. *Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale, 194*(2), 323-328.

Sarabon, N., Mlaker, B., & Markovic, G. (2010). A novel tool for the assessment of dynamic balance in healthy individuals. *Gait & Posture, 31*(2), 261-264.

Šarabon, N., & Omejec, G. (2007). A Novel Testing Tool for Balance in Sports and Rehabilitation (Vol. 16). Presented at the 11th Mediterranean Conference on Medical and Biomedical Engineering and Computing 2007, Berlin, Heidelberg: Springer Berlin Heidelberg.

Sarabon, N., Rosker, J., Loefler, S., & Kern, H. (2010). Sensitivity of body sway parameters during quiet standing to manipulation of support surface size. *Journal of Sports Science and Medicine, 9*, 431–438.

Schmit, J. M., Regis, D. I., & Riley, M. A. (2005). Dynamic patterns of postural sway in ballet dancers and track athletes. *Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale, 163*(3), 370-378.

Schumacher, J., Pientka, L., & Thiem, U. (2006). Age-related differences in functional tests to assess the risk of falling in patients with knee pain. *Zeitschrift Für Gerontologie Und Geriatrie: Organ Der Deutschen Gesellschaft Für Gerontologie Und Geriatrie, 39*(4), 283-287.

Schwesig, R., Kluttig, A., Kriebel, K., Becker, S., & Leuchte, S. (2009). Prospective comparison of assessments to evaluate fall risk in a nursing home population. *Zeitschrift Für Gerontologie Und Geriatrie: Organ Der Deutschen Gesellschaft Für Gerontologie Und Geriatrie, 42*(6), 473-478.

Siqueira Rodrigues, B. G. D., Ali Cader, S., Bento Torres, N. V. O., Oliveira, E. M. D., & Martin Dantas, E. H. (2010). Pilates method in personal autonomy, static balance and quality of life of elderly females. *Journal of Bodywork and Movement Therapies, 14*(2), 195-202.

Sofianidis, G., Hatzitaki, V., Douka, S., & Grouios, G. (2009). Effect of a 10-week traditional dance program on static and dynamic balance control in elderly adults. *Journal of Aging and Physical Activity, 17*(2), 167-180.

Stins, J. F., Michielsen, M. E., Roerdink, M., & Beek, P. J. (2009). Sway regularity reflects attentional involvement in postural control: effects of expertise, vision and cognition. *Gait & Posture, 30*(1), 106-109.

Sundstrup, E., Jakobsen, M. D., Andersen, J. L., Randers, M. B., Petersen, J., Suetta, C., Aagaard, P., et al. (2010). Muscle function and postural balance in lifelong trained male footballers compared with sedentary elderly men and youngsters. *Scandinavian Journal of Medicine & Science in Sports, 20 Suppl 1*, 90-97.

Tinetti test assessment form [on-line]. Htpp://www.bhps.org.uk/falls/documents/TinettiBalanceAssessment.pdf (accesed Nov 8th 2010)

Tsigilis, N., Douda, H., & Tokmakidis, S. P. (2002). Test-retest reliability of the Eurofit test battery administered to university students. *Perceptual and Motor Skills, 95*(3 Pt 2), 1295-1300.

Tsigilis, N., & Theodosiou, A. (2008). The influence of multiple administration of a psychomotor test on performance and learning. *Journal of Strength and Conditioning Research/National Strength & Conditioning Association, 22*(6), 1964-1968.

Tyson, S. F., & Connell, L. A. (2009). How to measure balance in clinical practice. A systematic review of the psychometrics and clinical utility of measures of balance activity for neurological conditions. *Clinical Rehabilitation, 23*(9), 824-840.

Vanicek, N., Strike, S., McNaughton, L., & Polman, R. (2009). Postural responses to dynamic perturbations in amputee fallers versus nonfallers: a comparative study with able-bodied subjects. *Archives of Physical Medicine and Rehabilitation, 90*(6), 1018-1025.

Webber, C. L., & Zbilut, J. P. (1994). Dynamical assessment of physiological systems and states using recurrence plot strategies. *Journal of Applied Physiology (Bethesda, Md.: 1985), 76*(2), 965-973.

Webster, K. A., & Gribble, P. A. (2010). Functional rehabilitation interventions for chronic ankle instability: a systematic review. *Journal of Sport Rehabilitation, 19*(1), 98-114.

Wernick-Robinson, M., Krebs, D. E., & Giorgetti, M. M. (1999). Functional reach: does it really measure dynamic balance? Archives of physical medicine and rehabilitation, 80(3), 262–269.

Whipple, R., Wolfson, L., Derby, C., Singh, D., & Tobin, J. (1993). Altered sensory function and balance in older persons. *Journal of Gerontology, 48* Spec No, 71-76.

Wikstrom, E. A., Tillman, M. D., Smith, A. N., & Borsa, P. A. (2005). A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *Journal of Athletic Training, 40*(4), 305-309.

Winter, D. A., Patla, A. E., Prince, F., Ishac, M., & Gielo-Perczak, K. (1998). Stiffness control of balance in quiet standing. *Journal of Neurophysiology, 80*(3), 1211-1221.

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait & Posture, 3*(4), 193–214.

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait & Posture, 3*(4), 192-214.

Winter, D. A., Patla, A. E., Ishac, M., & Gage, W. H. (2003). Motor mechanisms of balance during quiet standing. *Journal of Electromyography and Kinesiology: Official Journal of the International Society of Electrophysiological Kinesiology, 13*(1), 49-56.

Yelnik, A., & Bonan, I. (2008). Clinical tools for assessing balance disorders. *Neurophysiologie Clinique = Clinical Neurophysiology, 38*(6), 439-445.

Zatsiorsky, V. M., & Duarte, M. (1999). Instant equilibrium point and its migration in standing tasks: rambling and trembling components of the stabilogram. *Motor Control, 3*(1), 28-38.

Zatsiorsky, V. M., & Duarte, M. (2000). Rambling and trembling in quiet standing. *Motor Control, 4*(2), 185-200.

Andrej PANJAN, PhD Student, (*Laboratory for Advanced Measurement Technologies, Wise Technologies Ltd.,* Ljubljana, Slovenia). After graduating at the Faculty of Computer and Information Science, University of Ljubljana, Ljubljana, Slovenia, he has been employed as a young investigator in industry at Wise Technologies Ltd. In parallel he is a student at Faculty of Mathematics, Natural Sciences and Information Technologies, University of Primorska, Koper, Slovenia. His research focus is modeling of human body balance with artificial intelligence methods. E-mail: andrej.panjan@wise-t.com

Nejc SARABON, Ph.D., (*University of Primorska, Science and Research Centre of Koper, Institute for Kinesiology Research,* Koper, Slovenia)He upgraded his background in physical therapy and sport science with the doctoral thesis and post-doc projects on the fields of motor control, motor behavior and injury prevention using primarily electrophysiological and biomechanical diagnostic tools. He is in continuous collaboration with several other research and development centers Worldwide. Currently, he is a professor at the University of Primorska and a head of the research and development group in a measurement and instrumentation company.