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CLINICAL TECHNOLOGY

Measurement of balance in computer posturography: Comparison of methods—A brief review

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Summary Some symptoms related to disequilibrium may not be detected by a clinical exam. Therefore, objective study is important in assessing balance. In this paper, methods to measure balance in computer posturography are compared. Center of pressure (COP) displacement, equilibrium score (ES) and postural stability index (PSI), the main measures of assessing balance are described and their merits and disadvantages are discussed. Clinicians should apply that measure which suits the specific strategies in a specific situation.

Measuring devices such as Force plate, Balance Master and Equitest are also discussed. Although the Balance Master and Equitest devices are more costly compared to the force plate only, they are more useful for assessing balance relevant to daily life activities that might result in falls.

Introduction

Posture is the orientation of any body segment relative to the gravitational vector (Winter, 1995). Postural stability/Balance is an essential component in assessing the efficacy of interventions for improving balance (Berg et al., 1992; Horak, 1997). Balance is a generic term that means both postural steadiness (static) and postural stability (dynamic). ''Postural steadiness is the characterization of postural sway during quiet standing. The terms posturometry, posturography, stabilometry, and stabilography are usually associated with postural steadiness'' (Prieto et al.,

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1993). ''Postural stability, also referred to as dynamic posturography, is the postural response to an external or volitional perturbation of the postural control system'' (Johansson and Magnuson, 1991). Earlier methods for evaluating balance are summarized in (Terekhov, 1976). Postural steadiness can be determined directly by evaluating head, limb or trunk movements with ultrasonic distance sensors embedded on the head (Yoshizawa et al., 1991). Balance is also measured by assessing motor control function during sitting, standing and/or walking (Tyson and Desouza, 2002).

Clinicians have available only a limited number of clinical tests to quantify balance, such as seconds standing on one leg or performance on multiple observable tasks. Equipment which has previously been used primarily in a laboratory with biomedical engineering staff, is now more widely available for use in clinical settings. More clinicians will have access to this equipment, or to results done in more specialized balance clinic settings. However, there is a plethora of laboratory measures which can be confusing to the clinician. In this paper, the authors focus on methods of computerized dynamic posturography (CDP), since this has become an important tool for assessing balance in clinical settings (Fabio et al., 1998; Johansson et al., 2001; Piirtola and Era, 2006). As will be explained in the Methods section, common instrumentation includes force plates, Balance Master and Equitest. These three instruments measure ground reaction forces. From these ground reaction forces, one can compute center of pressure (COP) displacements, sway of the center of mass (COM), equilibrium score (ES), postural stability index (PSI) and other quantities. A detailed description of how ES and PSI are computed will be provided in the Methods section.

A key test in the Equitest (2001) device and Balance Master (2001) CDP systems, the Sensory Organization Test (SOT) provides information about the integration of the visual, proprioceptive and vestibular components of balance which leads to an outcome measure called the ES, reflecting the overall coordination of these systems to maintain standing posture (Chaudhry et al., 2004). The Equitest System consists of a support surface (platform) and a visual surround. The Equitest device performs a SOT with six conditions: conditions 1, 2 and 3 with the platform fixed and conditions 4, 5 and 6 with the platform moving. When the platform moves, it is referenced to the subject's sway such that as the individual leans forward, the platform tilts forward to minimize the degree of changed proprioceptive input from the self-generated sway. This platform adjustment is called ''sway-referenced motion''. Similarly, in conditions where the visual surround moves, the surround is referenced to the person's sway so as to minimize the ability to obtain visually relevant information about how far the individual is from the vertical. In other conditions, visual input is removed instead by asking the subject to close his or her eyes. Participants are asked to stand quietly and steadily for 3 trials in each of the following 6 conditions: (1) eyes open, surround and platform stable, (2) eyes closed, surround and platform stable, (3) eyes open, sway-referenced surround, (4) eyes open, sway-referenced platform, (5) eyes closed, sway-referenced platform and (6) eyes open, sway-referenced surround and platform.

Equipment used to measure balance

Force plate only

As the name implies, force plate is a device that measures ground reaction forces as the person stands quietly in conditions (1, 2) only, as described above and is used to determine the COP displacement. It is then used to obtain sway of the COM which can be used to determine the ES. Its estimated cost is $6500.

Balance Master

This device consists of a movable support surface (force plate) and a visual surround with a harness to prevent fall during testing. Its estimated cost is $50,000. It can determine the COP displacement as well as the sway of COM in conditions 1, 2, 4 and 5. It cannot be used for conditions 3 and 6 since the surround cannot move in a sway-referenced manner. It can be used to determine the ES and PSI.

Equitest (see Figure 1)

This device also consists of a movable support surface (force plate) and a visual surround, which can move in a sway-referenced manner, along with a harness to prevent fall during testing. Its estimated cost is $100,000. It can determine the COP displacement as well as the sway of COM. in conditions 1—6. It can be used to determine the ES and PSI.

Methods to measure balance

Center of pressure (COP)

The COP is the location of the vertical ground reaction vector on the force platform (Winter, 1995). This is different from the vertical projection of the center of gravity (COG). Under static conditions, COP coincides with the COG projection. COP is usually measured by the force plate in conditions 1 and 2 only. However, it can also be measured in all six conditions of the SOT from the Equitest device and in conditions 1, 2, 4 and 5 from the Balance-Master. Since the COP reflects the movement of the body to keep the COG over the base of support, its displacement from its equilibrium position is generally greater in magnitude than the displacement of the COG (Prieto et al., 1993). The controlled variable, i.e., COG/COM, is seen to be virtually in phase with the controlling variable, COP (Winter et al., 2003). In both anterior—posterior (AP) and medial—lateral (ML) directions, a simple inverted pendulum model (Winter et al., 1998) for quiet standing showed that:

$$\mathrm{COP} - \mathrm{COM} = K\,(\text{horizontal acceleration of COM})$$

where $K = \frac{I}{Wh}$.

Here I is the total body moment of inertia about the ankles, W is the body weight and h is height of the COM above the ankles.

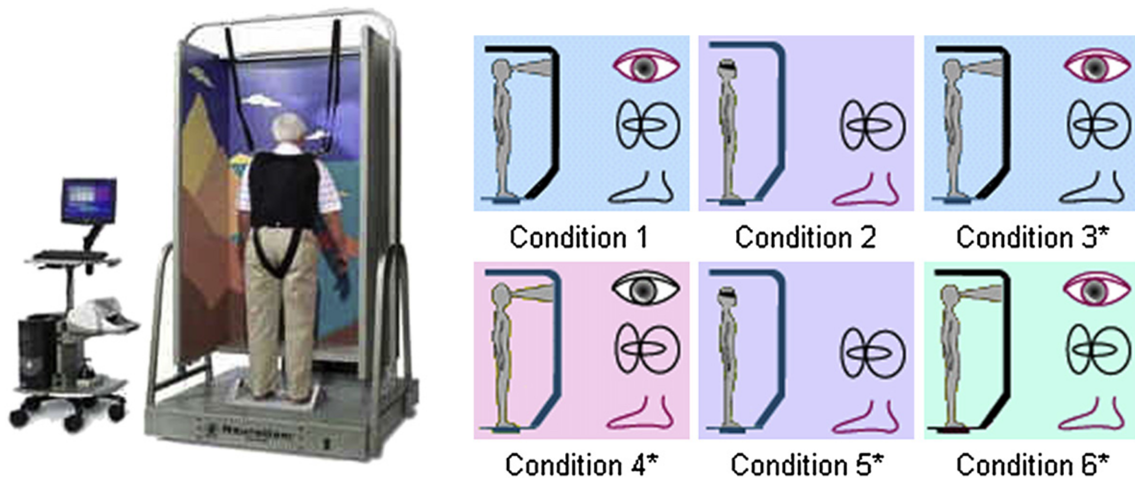

Figure 1 NeuroCom EquiTest System. The NeuroCom EquiTest System consists of a support surface with sensors at the corners below the surface and a visual surround. The EquiTest device performs a sensory organization test (SOT) with six conditions: conditions 1, 2 and 3 with the platform fixed and conditions 4, 5 and 6 with the platform moving. Participants are asked to stand quietly and steadily for 3 trials for each of the following 6 conditions: (1) eyes open, surround and platform stable, (2) eyes closed, surround and platform stable, (3) eyes open, sway-referenced surround, (4) eyes open, sway-referenced platform, (5) eyes closed, sway-referenced platform and (6) eyes open, sway-referenced surround and platform.

A dual force plate is used to locate the position of the COP for the left foot and the right foot separately. The combined COP can be determined from the COP of each foot and the weight supported by each foot. When one force plate is used, only the combined COP is available. It has been demonstrated (Clair and Riach, 1996) that the test duration on the force plate is important for the reliability and validity of stability measures based on COP, with longer duration tests providing more valid results. Doyle et al. (2007) reported that COP measures reached acceptable levels of reliability (for displacement, average velocity and 95% confidence ellipse area) with five 60 s trials. Postural sway has been found to increase as a result of narrowing the base of the support (Amiridis et al., 2003).

Six different conditions were used by Melzer and Kaplanski (2004) to assess COP measurements. Subjects were asked to stand still on a single force plate in the following conditions: (1) wide stance, (1a) eyes open, (1b) eyes closed, (1c) eyes open standing on foam and (2) same as in (1a—1c) in narrow stance (heals and toes touching).

Six different force-platform-based balance instruments have been used by different researchers to measure postural balance (Piirtola and Era, 2006). The references to the papers by these researchers are given in Piirtola and Era (2006). All these instruments measure COP displacement.

Movement of the COP in quiet standing may be influenced by internal dynamics associated with the respiratory (Jeong, 1991) and cardiovascular systems (Goldie et al., 1989). ''COP measures of postural steadiness can be classified as time domain measures of distance, area or velocity; and frequency-domain measures of spectral magnitude or distribution'' (Prieto et al., 1993). ''Time domain measures include characterization of the COP path, average distance from its geometric mean, mean velocity of the COP, total distance traveled by the COP, the range of the COP, the enclosed area as a percentage of the base of support area and the confidence ellipse area. Frequency-domain measures are usually calculated from the power spectral density'' (Prieto et al., 1993).

A stability criterion was proposed to assess the standing condition of a subject from the COP measurements (Popovic et al., 2000). In this criterion, four stability zones, i.e., high preference, low preference, undesirable and unstable zones are identified. The boundaries of stability zones are modeled using ellipses to capture the two-dimensional form and orientation of the stability zone. However, in practice it is difficult for physicians to identify these stability zones to assess postural stability of a patient and assign a quantitative measure of the balance. In addition, this technique does not assign a single value to assess the stability of a subject. It is preferable that a single number (as will be seen for ES and PSI) representing postural stability/instability be assigned to a subject before and after a specific intervention. From the before and after values, the clinician can quickly determine the efficacy of the intervention.

It is also not clear from the COP studies as to which parameter(s), i.e., area, velocity, total distance, or frequency should be used to quantitatively assess balance. However, COP displacements can be used to compare balance between two different groups, such as the young and the elderly, fallers and non-fallers. Those having higher magnitudes of any of the above parameters are considered less stable.

In the study done by Piirtola and Era (2006), medio-lateral (ML) movements of the COP during normal standing, the mean amplitude of the ML movements of the COP and the root-mean square value of the ML displacement of the COP, all with eyes open and closed were the indicators that showed significant association with future falls. But the strength of association/correlation is not evaluated in this study. Similarly, the findings by Benjuya and Kaplanski (2004) show an increase in ML sway in fallers in older people for narrow base stance studies.

The authors of the current article note that although poor postural balance is one of the major risk factors for falling and can be measured by ES and PSI, the method usually used for prediction of falls is based upon the COP displacement in conditions 1 and 2 only.

Comments on COP measurements of area and distance (excursion)

In a recent study by the authors of this article regarding COP trajectories (Figure 2) of a subject during quiet standing in different conditions and trials, it was found that there is large variation in the area and excursion length in three trials for the same test condition. This does not allow one to arrive at a specific conclusion about assessing the balance using COP measurements.

Examples of the plots of COP trajectory are shown below. In these plots, the calculated values of their corresponding 95% confidence ellipse area (Prieto et al., 1996) and total excursion are also displayed, where ''*A*'' is for the corresponding 95% confidence ellipse area in cm^2 and ''*L*'' is for the total excursion of the COP in cm. Trajectory 11 means trajectory for condition 1 and trial 1. Similarly, trajectories 12 and 13 mean trajectory for condition 1 and trials 2 and 3, respectively. AP means Anterior—posterior, and ML means medial—lateral. The values of area and excursion for conditions 1, 2 and 3 of the same subject are summarized in Table 1.

Equilibrium score (ES)

The force plate, the Balance Master and the Equitest are used to calculate the ES in conditions 1 and 2; 1, 2, 4 and 5; and conditions 1—6, respectively. ES for each trial in each condition is calculated according to a simple formula:

$$ES = \frac{12.5 - [\theta_{max}(\text{ant}) - \theta_{max}(\text{post})]}{12.5} \tag{1}$$

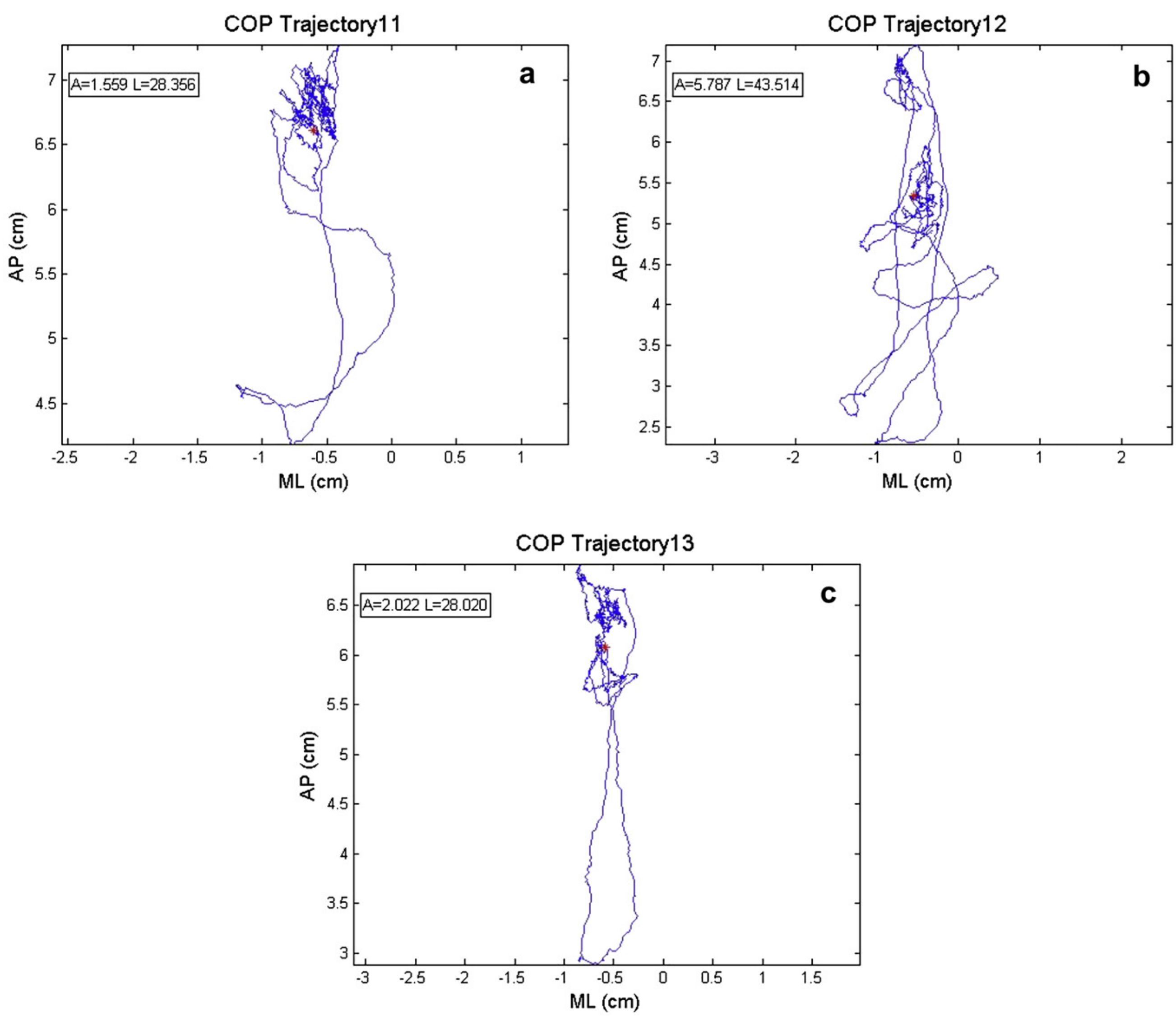

Figure 2 (a—c) COP trajectories of a subject during quiet standing in condition 1 for three 20-s duration trials. Trajectory 11 means trajectory for condition 1 and trial 1. Similarly, trajectory 12 and trajectory 13 mean trajectory for condition 1 and trials 2 and 3, respectively. AP means anterior—posterior and ML means medial—lateral.

Table 1 Excursion length and area for a subject over 3 trials in each of 3 conditions.

	Trial 1	Trial 2	Trial 3	Mean	SD
Excursion (cm)					
Condition 1	28.356	43.514	28.020	33.30	8.85
Condition 2	27.351	27.164	25.340	26.62	1.11
Condition 3	24.716	25.046	24.555	24.77	0.25
Area (cm^2)					
Condition 1	1.559	5.787	2.022	3.12	2.32
Condition 2	0.481	0.230	0.299	0.34	0.13
Condition 3	0.197	0.171	0.274	0.21	0.05

where θ (ant) is the maximum anterior sway angle in degrees during a trial; θ (pos) is the maximum posterior sway angle in degrees during the same trial; 12.5 is the limit of sway in degrees in the sagittal plane for normal stance; and 12.5° is assumed to be the limit of stability for a normal individual (Balance Master, 2001, PO-5, Appendix, 6).

No movement of the subject results in a perfect score of ''100''. If the subject falls or the value of the ES is negative, the subject receives a score of ''0''. Thus, the ES ranges between 0 and 100.The Composite ES is evaluated as a weighted average of the scores from the six conditions of the SOT of a subject, where each condition consists of three identical, 20-s trials with force data sampled at 100 Hz. The composite ES in three trials is evaluated according to the formula:

$$\mathrm{CES} = \frac{\mathrm{ES}(1) + \mathrm{ES}(2) + 3[\mathrm{ES}(3) + \mathrm{ES}(4) + \mathrm{ES}(5) + \mathrm{ES}(6)]}{14}$$

where CES is the composite equilibrium score, ES(1) is the average of ES in all three trials in condition 1. Similarly, ES(2) is the average of ES in all the three trials, in condition 2 and so on. Note that the ES in the most challenging conditions (3—6) is given 3 times the weight of conditions 1 and 2.

Ambiguities/disadvantages of ES

Ambiguities/disadvantages of ES include the following (Chaudhry et al., 2004):

1. For some subjects, the limits of stability may vary significantly from the age- and height-matched norms, i.e., the limit of sway may be more or less than 12.5°, say 11° or 14°. Thus, the assumptions about the overall magnitude of the limits of stability can introduce errors into the ES calculation for individuals.
2. It is also known from experimental results (Balance Master, 2001, PO-3, Appendix, 7) that functional stability limits for the average adult subject are approximately 7° of anterior sway and 5° of posterior sway. Thus, there is an asymmetry in the usual limit of stability that is disregarded in the ES calculation.
3. Many combinations of anterior and posterior sway across the same overall range can give the same ES. For example, the overall limit of stability of 6° can be made up of the many combinations (e.g., 6° of anterior sway and 0° of posterior sway; or 3° of anterior sway and −3° of posterior sway, etc.). These combinations would result in the same composite ES. Yet, a subject with a +6/0° of sway combination, has a greater risk of falling than a subject with a +3/−3. combination, since the former is close to the functional stability limit on the anterior side, and is therefore indicative of greater risk of fall on the anterior side, whereas the second combination is not close to the functional stability limit on either side, and therefore indicates a smaller risk of fall either on the anterior or the posterior side. Therefore, the ES which would be identical in these two situations, can be insensitive to functionally relevant differences in postural stability.
4. To assess postural stability, the formula for a stability measure should include important biomechanical information, such as mass and height of the subject and ankle torque produced to maintain stability. These are absent in the formula for ES.
5. The ES considers only the two extreme values of the sway angle in a given trial, not the complete sway history (2000 data points) in a trial of 20 s.
6. It was reported by Chaudhry et al. (2005) that the composite ES score increases as composite ankle stiffness increases (Figure 3). This is counter-intuitive.
7. It was also demonstrated by Chaudhry et al. (2004), by performing experiments on 30 subjects, that as the average sway angle, which is an important facet of balance (Lee et al., 2001; Stalenhoef et al., 2002; Stel et al., 2003), increases, the composite ES also increases (Figure 4). This is also counter-intuitive.
8. The effect of the shear force as well as the mass and rotation of the force plate are ignored in the formula for machine-reported ES.

In order to overcome the above ambiguities, Chaudhry et al. (2004) devised a new formula for assessing stability/balance, known as PSI that reflects balance or postural stability. PSI incorporates a broader range of biomechanical aspects of upright stance. PSI is described in the following section.

Postural stability index (PSI)

PSI overcomes the ambiguities in ES as described above. The BalanceMaster and the Equitest devices are used to evaluate PSI in conditions 1, 2, 4 and 5 and 1—6, of the SOT, respectively.

To assess postural stability, the effort (stabilizing torque) needed to maintain stability should be considered (Chaudhry et al., 2004). The total value of the stabilizing torque is considered to counteract the destabilizing torque due to gravity in quiet standing. PSI is defined as the percentage ratio of the total stabilizing ankle torque, τ, and the total destabilizing torque due to gravity (obtained from the product of the weight, height and the sine of the sway angle) during quiet standing in any of the six conditions (see Figure 3). Since the sway angle is typically small, the approximation $\sin\theta \approx \theta$ is traditionally applied to simplify the calculations. A value of 100 indicates perfect stability. The amount of instability is reflected in how much the PSI is less than 100, and the range of PSI is 0—100. In mathematical terms, PSI is expressed as

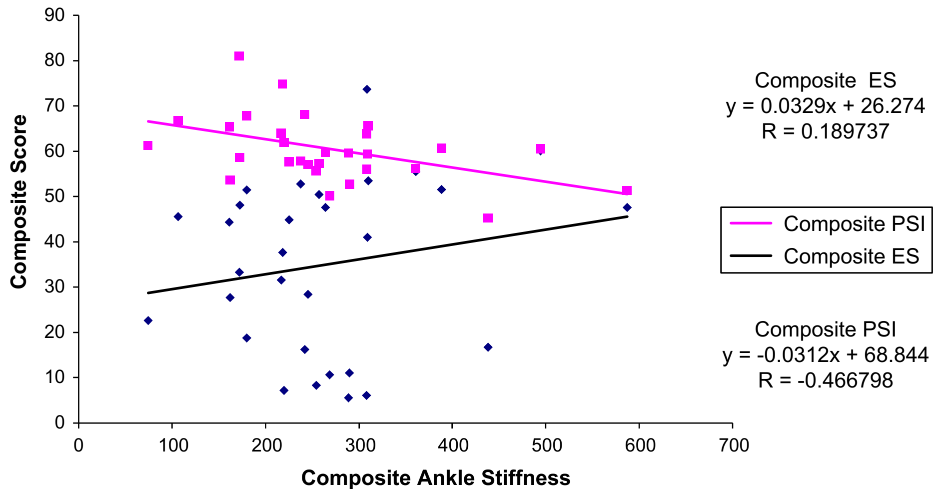

Figure 3 Composite ES and PSI vs. composite ankle stiffness. The units of ankle stiffness.

$$\mathrm{PSI}=\frac{\sum|Mgh\theta(t)|}{\sum|\tau(t)|} \tag{2}$$

In Eq. (2), M is the mass of the subject, g is acceleration due to gravity, h is 0.55 times the height of the subject (the average distance of COM from the platform, based on anthropometric data), $\tau(t)$ is the stabilizing torque at the ankle at any time t, the vertical bars indicate the absolute value, $\sum$ is the summation of the values inside the bars and $\theta(t)$ is the sway angle of COM in radians at any time t during the test (Ji et al., 2004). In Eq. (2), when the numerator and the denominator are equal, the PSI is 100%, and the subject is perfectly stable. When the numerator is greater than the denominator, the PSI is calculated as the ratio of the denominator to the numerator. Eq. (2) can be used to independently calculate a PSI value for each condition. The composite PSI is evaluated in the same way as the composite ES described above.

In this model, the sway angle θ and the torque τ at 2000 data points (20 s at 100 Hz) are given by

$$\theta(t)=\frac{Mh[(F_F-F_R)d+F_He-mga]+IF_H}{M^2gh^2-I[(M+m)g-((F_F+F_R)/(k+1))]} \tag{3}$$

and

$$\tau(t)=(F_F-F_R)d+F_He-mga\cos\frac{k\theta(t)}{k+1} \tag{4}$$

The detailed derivation of these equations is given in Ji et al. (2004). The calculated sway angle θ of COM has been validated by comparing the theoretical curve for sway with the experimental one (Ji et al., 2004). Thus, the torque τ given by (4) is also valid.

It is noted that the above formula for evaluating PSI is based upon using an ankle strategy, i.e., hip muscles are ignored. It is noted that ''normal individuals move primarily about the ankle joints when stable, and shift to hip movements as they become less stable.'' [SmartEquitest System, p. 1]

> Hip movements generate horizontal (shear) forces against the support surface that are proportional to the second derivative of the hip joint angle, i.e. the angular acceleration. During hip movements, the vertical force position changes only when the hip movement also causes change in the COG (center of gravity) sway angle [SmartEquitest System, 2001, PO-7].

Mok et al. (2004) showed that ''in normal adults, postural adjustments in bilateral stance on a flat surface are generally achieved using an ankle strategy in which ankle torque maintains the COM over the base of the support. In this strategy, muscle activity occurs in a distal to proximal sequence. If the support surface is short in relation to foot length, this strategy is replaced by a hip strategy that involves operation of horizontal shear forces from torques at the hip, rather than shifting the center of vertical foot pressure by the torques at the ankle. This strategy involves motion at the trunk and hip, using a proximal—distal sequence of muscle activation''. They also showed by studying 24 participants with chronic low back pain (LBP) and 24 matched controls that ''the hip strategy was reduced with increased visual dependence in study participants with LBP. The failure rate was more than 4 times that of the control in the bilateral standing task on short base with eyes closed. Analysis of COP motion also showed that they have inability to initiate and control a hip strategy''.

Postural strategies associated with somatosensory and vestibular loss have been studied by measuring flexion at ankle and hip joints (Horak et al., 1990). Postural responses at the ankle and hip have been described in terms of feedback control gains (Park et al., 2004). The torques at ankle and hip can be studied by using a multi-joint inverted pendulum model (Colobert et al., 2006; Horak and Nashner, 1986; Guihard and Gorce, 2002; Rungea et al., 1999).

The parameters involved in Eq. (2) can be seen in Figures 3 and 4. Note that a (in Eq. (4)) is not shown in Figure 4 since it is very small. It is the perpendicular distance from the line through the ankle and pin joints to the COM of the foot (see also Figures 5 and 6).

Total angular momentum of all body segments

In studying the postural control of young and elderly adults when stance is perturbed, Gu et al. (1996) used the

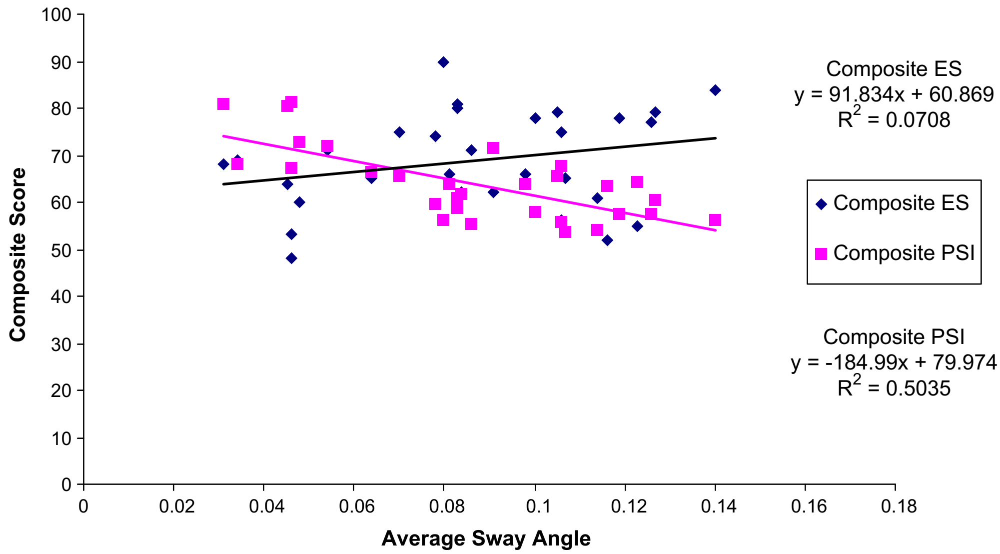

Figure 4 Composite ES and PSI vs. Average Sway Angle (radians).

criterion that ''peak values of total body angular momentum of all body segments about the ankles are measures of instability. The rate at which consecutive peak values diminish when a standing person is subjected to various types of perturbations indicates the extent to which control of balance is achieved. For these reasons, the time history of the total angular momentum was computed for each response from the measured kinematic data and the scaled anthropometric data''. Shepard et al. (1993) also used this criterion in comparing the instability of young and elderly adults. The Equitest and BalanceMaster devices can be used to assess the total angular momentum of all the body segments. However, according to Gu et al. (1996) ''total angular momentum does not fully quantify the task difficulty. That quantification requires knowledge not only of how much angular momentum must be arrested, but also what moment can be developed to do that arresting''. In view of the above comments, this method may not be appropriate for assessing balance since the quantitative values of the arresting angular momentum have not yet been established.

Comparison of ES and PSI

(i) Two individuals with different magnitudes of anterior and posterior sway, but with the same overall sway range will have the same ES (see Eq. (1)), but typically, they will have different PSI values (see Eq. (2)) (Chaudhry et al., 2004). That is because ES depends only on the overall sway range, whereas PSI depends on the entire sway history, and on the individual's mass, height and the torque at the ankle. Thus, the PSI relies on biomechanical data recorded from each individual, whereas the ES relies heavily on a normative assumption.

(ii) Again, it was demonstrated by Chaudhry et al. (2004) that the ES of two subjects can be the same while one might spend more of the test duration near the stability limit than the other does. For one particular case, they found two subjects with ES of 74, where one subject spent 9.44 s at the boundary and the other subject spent 11.25 s at the boundary in condition 5 in a trial lasting 20 s. The PSI calculated for the former subject is 61.37, whereas the PSI for the latter subject is 45.41. Here, the subject who spent less time near the stability boundary had higher PSI, indicating better stability.

With respect to the ambiguities 6 and 7 in ES, mentioned above, it is demonstrated in Chaudhry et al. (2004, 2005) that:

(iii) Composite PSI decreases as composite ankle stiffness increases, as expected (Figure 3), contrary to the results obtained in ES.

(iv) As the average sway angle, which is an important facet of balance (Lee et al., 2001; Stalenhoef et al., 2002, Stel4) increases, the composite PSI decreases as expected (Figure 4), contrary to the results obtained in ES.

In view of the above findings, it was concluded that PSI is a more valid measure of stability than ES. However, the above formula for PSI is based upon ankle strategy only (Chaudhry et al., 2005).

The software for ES is installed in the BalanceMaster as well as in Equitest machines to give the ES results directly from the machines. The software for PSI based upon the formula for PSI needs to be installed to obtain the results directly from the machines. However, the PSI calculation can be obtained easily by feeding the input data into a computer.

Discussion

The authors of this article have described the methods and equipment commonly used in measuring balance, and discussed the advantages and disadvantages of each. However, the most appropriate method and the equipment may depend on the specific situation. For example, if

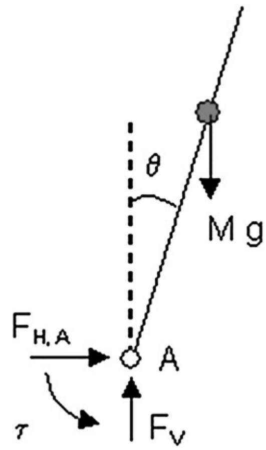

Figure 5 Free-body diagram of body (above ankle). The ankle is at the small open circle. Here, M is the mass of the body above the ankle, θ is the absolute sway angle with respect to a fixed vertical reference, F_V is the vertical force acting at the ankle joint, $F_{H,A}$ is the horizontal force acting at the ankle joint, τ is the torque acting at the ankle joint and g is acceleration due to gravity.

future falls are to be predicted, the ML movements of the COP during normal standing, or the mean amplitude of the ML movements of the COP or the root-mean square value of the ML displacement of the COP, all with eyes open and closed may be used as they show significant association with future falls (Piirtola and Era, 2006). For assessing balance before and after interventions, PSI or ES may be employed. However, PSI may be used in preference to ES due to many ambiguities in ES as discussed above.

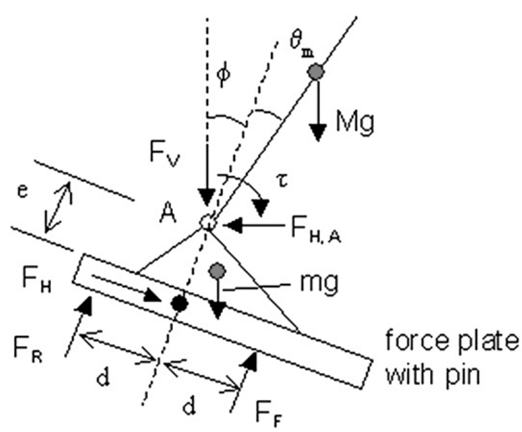

Figure 6 Free-body diagram of feet with force plate. Here, F_F, F_R are reaction forces measured with front and rear force transducers respectively, d is the distance from the force transducer to the pin axis on the force plate, F_H is the horizontal reaction force (shear force) measured with force transducer at the pin joint of the force plate, e is the distance from the horizontal force transducer to the ankle joint, F_V is the vertical force at the ankle joint, m is the total mass of the feet and the force plate, M is the mass of the body above the ankle joint, φ is the rotation angle of the force plate during sway-referenced motion, g is the acceleration due to gravity, θ_m is the measured relative sway angle with respect to the line perpendicular to the force plate and $F_{H,A}$ is the horizontal force acting at the ankle joint.

Objective measurements of stability are important since subjects and clinicians often cannot detect symptoms related to disequilibrium (Kaufman et al., 2006; Sataloff et al., 2005). Kaufman et al. (2006) compared subjective and objective measurements of balance disorders following traumatic brain injury. They report that ''objective measurement (such as SOT and COM motion) can quantify the patient's functional deficits. Therefore, objective measurement techniques should be used to assess the clinical complaints of imbalance for patients with TBI (Traumatic Brain Injury)''. Sataloff et al. (2005) reported that although ENG caloric testing (for diagnosing inner eye disease based on eye movements) was normal in 33 dizzy patients, CDP showed abnormal disequilibrium in these patients.

A force plate, although cheaper compared to the BalanceMaster and the Equitest devices, measures the balance in the ideal conditions 1 and 2 only in quiet standing by measuring COP displacements. But in daily life activities, inside and outside the home, one encounters sudden up and down slopes, stairs, conflicting visual stimuli such as busy shopping malls, large moving objects, abrupt changes in smooth and rough ground surfaces, loud noises, etc. The SOT takes into account many of these situations so that balance is more realistically assessed by evaluating ES and PSI, using the BalanceMaster and Equitest devices. Although these are more costly compared to the force plate, they have greater applicability.

It has been noted earlier in this paper that it is so far unclear from COP studies using force plates, as to which parameter(s), i.e., area, velocity, total distance or frequency should be used to assess balance. Also in the authors recent study of COP trajectories of a subject during quiet standing in different conditions and trials, it was found that there is large variation of area and excursion in three trials for the same subject and for the same condition. However, Doyle et al. (2007) reported that COP measures reached acceptable levels of reliability with five trials of 60 s duration for each trial. More research on the uses of COP needs to be performed to allow researchers and clinicians to come to definite conclusions about the preferable COP parameters for assessing balance.

It is observed that most of the models ignore the nonlinear behaviors of viscoelastic loading at the joints in the free-body diagrams. However, recently Kuczynski and Ostrowska (2006) used a viscoelastic model to investigate the effect of viscoelasticity on 37 postmenopausal women (aged 42—79 years) diagnosed with osteopenia or osteoporosis. They found that irrespective of age, increased ML viscosity was the sole predictor of falls. As people lean forward at the ankle, the calf muscle fibers paradoxically shorten (Loram et al., 2004); this implies that the fascial and ligamentous structures must be lengthening even more than required by the amount of forward lean. While Loram concludes from his studies that neural control of length of the musculature is important for balance, he ignores the influence of fascial and other connective tissues to the total length of the muscular complexes. Furthermore, Huijing et al. (2007) has shown substantial extramuscular myofascial force transmission of up to 40% of the total muscle force generated, between both synergistic and antagonistic muscles, which is particularly important at lower firing frequencies (Meijer et al., 2006). These recent research findings suggest that the fascial system may also have an important bearing on balance and that this system also needs investigation. Indeed, bodywork directed at the fascial system (Structural Integration or Rolfing) does improve balance measured by computerized posturography (Findley et al., 2004). Current research does not suggest specific palpatory and other observational findings of the fascial system related to balance, but that these are fruitful subjects for further fascial research. Such areas include the fascial connection between the hamstring and the calf muscles which transmits hamstring forces directly to the foot (Wicke and Zajac, 1981) but has been little studied since its report more than 25 years ago.

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