Design and Development of Stability Limits and Postural Stability Protocols for a Computerized Dynamic Posturography

A. Yazdani*
Biomedical Engineering Department, Science and Research Branch, Islamic Azad University, Tehran, Iran
E-mail: Azadi.yazdani@yahoo.com
*Corresponding author

N. Fatouraee
Biomechanics Department, Biomedical EngineeringFaculty, AmirkabirUniversity of Technology (Polytechnic Tehran), Iran
E-mail: Nasser@aut.ac.ir

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Abstract: Upright balance control is an important human skill which can be impaired by aging and different disorders. Therefore, clinical and laboratory measures of balance assessment were established. The latest technology in the laboratory methods is a stabilometer with a computer or computerized dynamic posturography which assesses static and dynamic balance using body sways. A computerized dynamic posturographysystem consists of a computer and a stabilometer which is an unstable platform under patient's feet and calculates center of pressure on the platform to display it immediately on the screen. For these purposes, two protocols of "Limits of stability" (LOS) and "Postural stability" (PS) were designed and developed in the present study for a prefabricatedstabilometer with a max.of 20 degrees deviation from horizontal in all directions to achieve the mentioned purposes. The protocols calculate and display the person's functional characteristics that can be saved to the computer of computerized dynamic posturographyto demonstrate a diagram of the patient's functional progression. In addition to the balance assessment, the device improves balance and neuromuscular strength, and is useful in medicine, laboratory researches, physiotherapy and bodybuilding.

Keywords: Balance, CP, Center of Balance, CDP, Postural Stability, Stabilometer

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Biographical notes: A.Yazdani received her BSc in Software Engineering from IAU University, Tehran North branch in 2003 and her MSc in Biomechanics Engineering from IAU University, Science and Research branch in 2010. Her field of interest in Biomechanics is assessing and improving human balance. **N.Fatouraee** is an associate professor and head of Biomechanics and Sports Engineering Department in Biomedical Engineering Faculty at Amirkabir University of Technology, Tehran, Iran. He received his MSc and PhD in Mechanical Engineering from Laval University in Quebec, Canada in 1995 and 2000, respectively. He did his postdoctoral studies at Washington University Medical Center, MO, USA from 1999 to 2001. His research interests are human posture stability, Biomechanics of spine, rehabilitation equipment design, instrumentation&numerical methods in Biomechanics, biological fluid flow, heat transfer, and magnetic resonance angiography (MRA).

1 INTRODUCTION

Human is a bipedal creature with a smaller base of support compared to animals, and his center of mass is located in a higher distancefrom the earth. These factors result in more instability in human balance compared to the animals [1-3]. The instability and imbalance are increased by aging [3-7], and impairments like stroke [8-10], mutilation or dysfunction of lower limbs [11-13], Parkinson's disease [14-15], etc. Physicians use multiple methods and tools to evaluate the patient's ability to maintain balance [2-3], [16-20]. One of the mentioned tools is computer dynamic posturography (CDP) which records constantly the center of pressure (COP) sway on the under foot surface as a point. According to the related studies, increased COP movements are witnessed in the persons with less balance stability and higher risk of fall [21-22]. Additionally, COP has a high repeatability in the balance test and thus, is counted as a reliable parameter [23-25]. The sequence of recorded points of COP results in a trajectory which is used as a measure of balance [3], [16], [18], [26-28] and an analysis of its velocity and direction gives more information on the patient's balance problems.

CDP systems are built to assess static and dynamic balance using this method [18], [26-29]. A CDP must evaluate a person's dynamic balance which is relevant to his weight shift and body's response to the external perturbations [1], [3], [17], [26], [30-32]. Moreover, the relevant researches have proved that rehabilitation of patients with balance disorders under conditions of external perturbations and voluntary movements of the body has a considerable effect on the recovery process [32-34]. Accordingly, CDP systems have a wide variety of applications in rehabilitation and report of the patient's balance conditions during rehabilitation. When such a system was made mechanically, some protocols are required to work with it and evaluate person's balance control. In the current job two Postural Stability and Limits of Stability protocols were designed for a prefabricatedstabilometer called Testpa.Testpa can work in one of the twelve dynamic stability levels or in a static level which makes it to work as a forceplate.

The Postural Stability protocol is developed to assess patient's ability forbalance recovery. It measures the platform rotations about X-axis (perpendicular to anterior-posterior plane) and Y-axis (perpendicular to medial-lateral plane) and converts them into a point called center of balance which is shown on the screen. This creates a feedback for the patient's function which enables him to find platform deviations and eliminate them by proper foot pressure or body.

The Limits of Stability protocol is developed to evaluate the maximum angular distance a person can travel from the center which is his stability region. A person falls down when passing these limits or he must grasp something to avoid falling.In this protocol, there is a circle target in each direction representing the limit of stability. If the persongets the target by leaning his body, the score of limit of stability would be considered for him in that direction. This protocol is executed in three difficulty levelsin which the center of pressure is considered as a key parameter.Whereas the protocols use center of pressure and center of balance in assessments, Testpamust be capable of providing the required data to be calculated,and changing the stability levels. This paper prepares a brief introduction to Testpa system and a more detailed lookintothe protocols.

2 THE HARDWARE

A picture of Testpa is shown in Fig. 1 in which the outer frame and upper plates are removed and the internal parts can be seen easily. The overall maximum allowed tilt for the platform is 20 degrees from the horizontal in all directions. Here the plates 1 and 2 which transfer the weight to load cells and universal joint are removed and internal division including springs, potentiometers, chains for transmission the motor power etc. can be seen.

Fig.1 The stabilometer used in the study without outer frame and upper plates

2.1. The Mechanical Division

Testpaincludes a polyamide surface on which the person stands. There are two other plates under the above surface located on a universal joint which makes them all rotate about two horizontal axes. Fig. 2 shows the mechanical division in details.The maximum allowed tilt of the platform is set by eight springs located on the plate 4. A motor can move plate 4 up and down which increases/decreases the applied force of the springs on plate 2 and makes the platform more/less stable with an intended maximum tilt.The locks help to stabilize the platform for the desired maximum tilt in one of the twelve stability levels or in static level which can be set in the software. The plate, on which the springs are located, moves up with the means of a motor that rotates the gears and chains to increase force on the above surface or moves down to decrease the force.

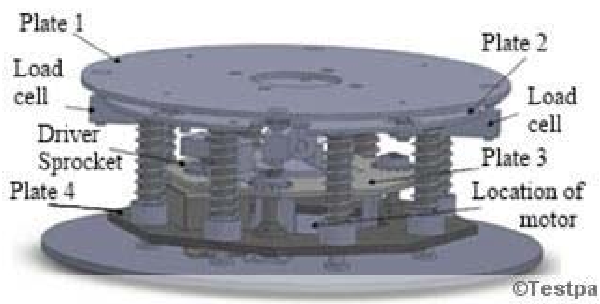


Fig.2 3D design of the stabilometer without the above surface

2.2. The Electronic Division

The electronic division -measurement equipment and control division, consists of four load cells with a measurement range of 113 Kg to measure the loading, two potentiometers located on two axes to measure rotation, a microcontroller with a serial port, and a displacement sensor to measure the distance between plates and ground to set levels of stability by means of a motor [35]. The microcontroller is programmed to receive commands to rotate motor, set the stability level, read data from load cells, and read angle of rotation around each horizontal axis. There are also commands to transmit data to the computer. The potentiometer and load cells are used to calculate centers of pressure and balance.

3 THE COMPUTATIONAL PARAMETERS

To evaluate balance, the current CDP works with two major parameters: center of pressure –COP, and center of balance –COB, which are designed to be calculated by the whole stabilometer. The required calculations are described as follows.

3.1. Center of Pressure

Astabilometeris assumed as a rotating force plate. Force plates are built to calculate center of pressure and usually consist of four load cells [26]. As shown in Fig. 3, the weight specified by F is resolved to components parallel and perpendicular to the plate in rotating. The mechanism of translating force to the load cells is designed to translate only the perpendicular component F_z. The distance between the perpendicular component of force and center of plate yields the coordination of COP. In local coordinate system attached to the plate, the torque $M_o$about axis of rotation is not sensed and is equivalent to zero.

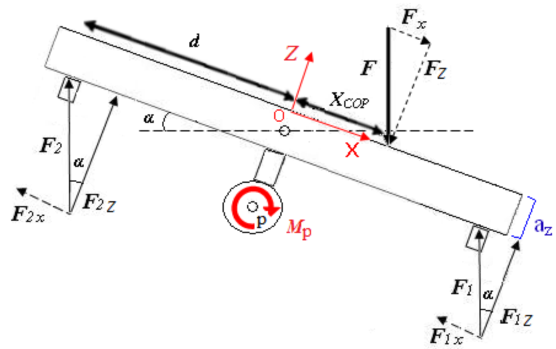


Fig. 3 The analysis of the applied loads to the platform during thedeflection

The current stabilometer has four load cells attached to the plate 2 (Fig. 2) and when it is static, it uses the same calculations a force plate uses. But in dynamic situation when the surface rotates as shown in fig. 3, the load cells rotate at the same angle with respect to horizontal. These angles are zero in force plates whereupon total load calculated by load cells is equal to the person's weight [26]. In dynamic situation the weight is not perpendicular to the surface and has components parallel and perpendicular to the inclined surface (Fig. 3).

Considering a local coordinate system on the center of the surface that can rotate with it, when the angle of rotation changes and the center of mass moves, two parallel and perpendicular components would have different values in the local coordinate system. Hence, the vector addition of them gives the person's weight. Thetorque is zero in the local coordinate system, as shown in Fig. 3:

$$d(F_{1z} - F_{2z}) - a_z.F_x = F_z.X_{COP} \quad (1)$$

$$X_{COP} = \frac{d(F_{1z}-F_{2z})-a_z(F.sin\alpha)}{F_{1z}+F_{2z}} \quad (2)$$

Total weight (F) which is a constant value is obtained by totalizing all the applied loads to the load cells, while the stabilometer is in static position. The angle of deviation (α) will be read from potentiometers.Fig. 3 and Eq. (2) represent a head-on view of the platform in which only two load cells are shown. The other two load cells are along the line normal to the form that intersects the point 'o'. This line is Y-axisas one of the axes parallel to the surface where the angle of rotation (α) is the result of rotation of surface around it. Accordingly, if the surface angle of rotation around X-axis is called β (which cannot be seen in Fig.3), and when weight is applied to all load cells, the equations 3 to 8 will be obtained:

$$F_{1z} + F_{2z} + F_{3z} + F_{4z} = F_z \quad (3)$$

$$F_x = F.sin\alpha \quad (4)$$

$$F_y = F.sin\beta \quad (5)$$

In the local cordinate system, the torque is zero aboutY-axis, thus:

$$d(F_{1z} - F_{2z}) - a_z.F_x = F_z.X_{COP} \quad (6)$$

$$X_{COP} = \frac{d(F_{1z} - F_{2z}) - a_z(F.sin\alpha)}{F_{1z} + F_{2z} + F_{3z} + F_{4z}} \quad (7)$$

Accordingly:

$$Y_{COP} = \frac{d(F_{3z} - F_{4z}) - a_z(F.sin\beta)}{F_{1z} + F_{2z} + F_{3z} + F_{4z}} \quad (8)$$

The vertical (a_z) and horizontal (d) distance between load cells and the center of the plate are constant values. To ensure that only the vertical components of weight would be transferred to the load cells, plate 1 lies on plate 2 by balls and bowls (Fig. 2).
To calculate the necessary resolution for weight, equation 8 (static mode) is used to obtain coordinate Y of the COP. Since COP is coincident with the center of the plate, the plate is balanced and the angle β is zero. In this case, the loads applied to the load cells 3 and 4 (opposite load cells along Y-axis) are equal. Thus:

$$Y_{COP} = \frac{d(F_{3z} - F_{4z})}{F_{1z} + F_{2z} + F_{3z} + F_{4z}} = 0 \quad (9)$$

For 1 mm displacement of COP, the person should shift a part of his weight fromback to front. This means that a load equivalent to Δw is removed from load cell 4 at back and is applied to load cell 3 at front to transfer COP, 1 mm to front. Δw is the required resolution for the displacement that the resolution of the load cell must be equal to or better than that.

Δw = 21.45 gram (10)

The measurement range of the load cell should be digitalized to enable computer receive data from load cells. For a load cell with 113kg capacity and a resolution of 22g, an analog-to-digital converter with at least 13 bits of resolution is required. Four 16-bit ADCs were used to decrease the hysteresis effect and nonlinearity. This yields the following resolution for each load cell which is much better than the required one:

113,000 gram/2^{16} = 1.72 gram (11)

The overall relation between the weight and the output of load cell is equivalent to equation 12:

Y=aX+b (12)

Where Y and X are the weight and the raw output of the load cell, respectively. Since each load cell must be calibrated separately, factors ‘a’ and ‘b’ are different for each load cell.

3.2. Center of Balance

In the current paper, the center of balance is an abstract concept defined to convert the sways of the platform about AP (Y-axis) and ML (X-axis) axes into a point to represent them on the display. Hence, the sum of angles between a plate and two horizontal axes in space is equal to the angle between normal vector on the plate and vertical axis (Z-axis). As a matter of fact, the sum of angles between a vector in space and three axes (two horizontal and one vertical) is 180 degrees.
Here, the amount of rotation of normal vector to the plate about X-axis (angle a) and Y-axis (angle b) would be obtained through potentiometers, and subtracting sum of these angles from 180 gives the angle between normal vector to the plate and Z-axis which is the angle of deflection of the plate from horizontal level.

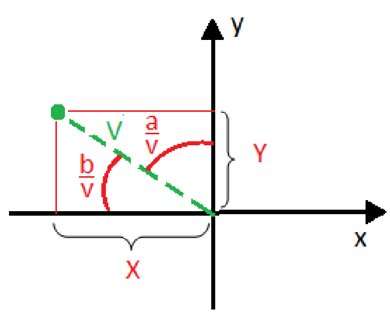


Fig. 4 The representation method for center of balance

COB is a point which requires two values (x and y) to be represented or it can be demonstrated with a position vector which has a distance (|v|) and two angles. The magnitude of vector V is equal to the sum of the absolute values of the angles ‘a’ and ‘b’. While demonstrating vector V on the display, the direction of vector must determine the horizontal axis about which a larger angle of the rotation takes place. Hence, the angle of vector V with Y-axis and X-axis are considered as $a/|V|$ and $b/|V|$ respectively. Consequently, X and Ycoordinates of COB will be calculated using equations 13-15. In fact, Fig. 4 represents platform from above and along Z-axis.

$$|V| = |a| + |b| \tag{13}$$

$$X = |V| * Sin(\frac{a}{|V|}) \tag{14}$$

$$Y = |V| * Sin(\frac{b}{|V|}) \tag{15}$$

The magnitude of vector V is obtained by adding the angles of rotation of the platform about X-axis (angle b) and Y-axis (angle a). The angle between vector V and each axis is equal to the ratio of the respected angle to the magnitude of vector V.

Fig. 5 Start form. This form is executed at the software startup and takes the stabilometer to a fixed situation. Then choosing one of Testing or Training buttons launches the proper mode. It is also possible to view the previous results of a specific patient or perform the settings of CDP.

4 THE SOFTWARE

Once the data read from sensors passed the microcontroller and was received by computer, a program with real-time processing is required to process and display it instantly on a display. The C# language was selected to develop the program. The functionality of the program and the order of windows forms are described as follows. When the software is launched, at the beginning, the motor rotates and takes the stabilometer to the static mode if it is not stable, to help persons climb the stabilometer easily. The first shown form contains four buttons (Fig. 5).

The "Utility" button takes the program to the calibration mode or enables it to receive data used in producing a normal diagram for comparing patients with the population. By pressing "View Results" button and selecting a patient tested before with recorded results, a diagram will be produced to demonstrate his progression in balance for analyticalpurposes. The other buttons takes the program to testing or training mode.

In testing mode which is done to assess the balance control ability of a specified person, the test duration, number of test trials, time interval between two trials, stability level of the platform at the beginning and end of a trial and further options will be set and the results of the test can be saved if desired. Training mode is to learn the functionality of device and also to perform physiotherapy and body building exercises in which the stability of the platform can be changed during a test. In this mode the results cannot be saved, but printable. By selecting each of the mentioned modes, the patientinformation will be entered in the next form or he can be selected from a list of saved patients.

4.1. The Centering Process

Once the patient informationwas imported or the operator of the device selected him/her from a list of patients, the program goes to a form to perform centering process in static mode as shown in Fig. 6. In this form, a target circle containing a coordinate system is displayed on which the calculated COP is shown as a black point.

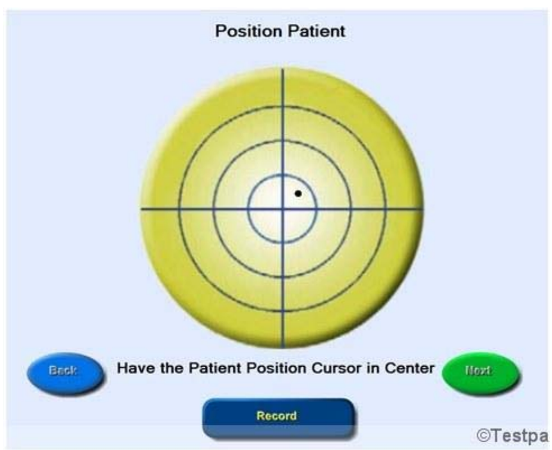


Fig. 6 The Centering Process form. The person is engaged to position feet such that the black point of COP on the circle target intersects the origin. Then pressing Record stops the process and coordinates of the feet are imported by the operator. This process is called Centering

If the loads read from four load cells are equal, the COP will be located on the center of target circle which is coincident with the center of the coordinate system. Otherwise, the black point approaches the side of the circle equivalent to the position of the load cell which has sensed a greater load. The COP is calculated and represented 30 times in second.

The person standing on the platform must try to put his feet such that his Center of pressure intersects the center of target circle without trying hard. Then by pressing Record button the process ends up and the operator of the device enters the coordinates of the person's feet on the surface to the program. Since then, the person is not allowed to stir his feet. This process is called *centering* which makes COP really locate the center of coordinate system when platform is stable and all the future displacements of the COP and COB from Center take place only because of the person's voluntary movements of body COM or hisinability in controlling the under foot surface.In the next form, choosing one of *Postural Stability* or *Limits of Stability* buttons performs the selected protocol.

4.2. Postural Stability

This protocol is only executed in dynamic mode and evaluates the person's ability in balance recovery which is a component of dynamic balance. It calculates the coordinates of COB by reading data from potentiometers and displays it as a black point on the circle (Fig. 7).

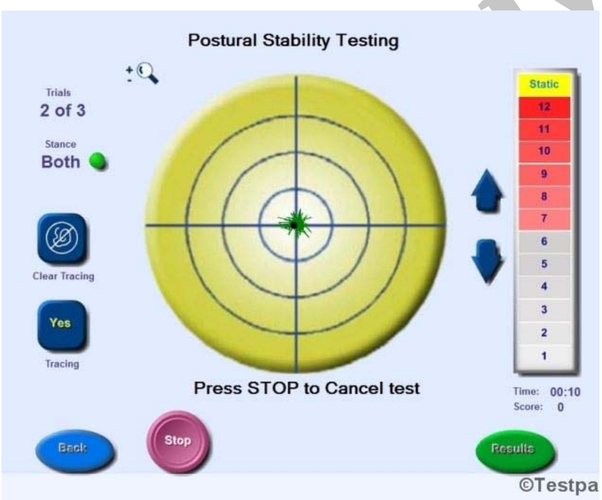


Fig. 7 Postural Stability protocol in testing mode. One must hold the black point specifying center of balance on the origin. By combining continuous positions of COB a green line is produced which is called the Excursion Line of COB. Before starting the test, some options such as test duration, stability level at the start and end of test, etc., can be set. During the test, if the primary and final stability levels are not equal, the motor rotates to set the required stability. By the end of the test, the person's functionality resultants are reported which can be printed

The person must try to keep the surface horizontal and prevent its sways as much aspossible by keeping the black point on the center of the target. It is also possible to position some red points on the target area of the display and persuade the person to control the sways of the surface as the black point of COB reaches the red points. This exercise helps to increase the person's ability in weight shifting and muscle strength for movement in different directions (Fig. 7).

4.3. Limits of Stability

This protocol is executed in both static and dynamic modes and evaluates the person's ability in voluntary movements of COM by reading data from load cells and potentiometers to calculate center of pressure based on equations 7 and 8.

There is a circle as a target in the center of the display which is coincident with the person's COP calculated in centering process and 8 similar peripheral targets encircle it. The test starts by pressing *Start* button and the central target starts blinking then. If the black point of COP is on the central target, it stops blinking and one of the 8 peripheral targets starts blinking. The person should move his body without lifting feet up so that the black point of COP can reach the blinking target. The hold time for reached targets which is 250 mschangeable by the operator, means that the COP must not leave the reached target less than this duration. If so, the reaching score is considered for the person. When the central target was reached a peripheral one, it starts blinking and by reaching the central target will start blinking again. In testing mode, the person should reach each target twice to finish each test trial (Fig.8).

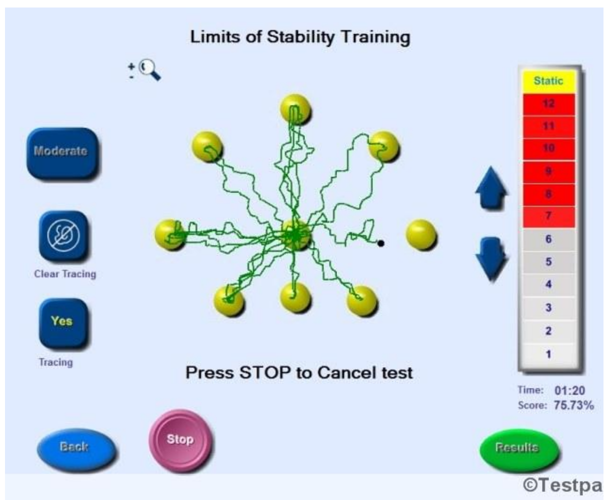


Fig. 8 Limits of Stability protocol in training mode. The person should transmit the black point representing COP to the blinking target to score moving in the relevant direction. In training mode, the test may not have a time limit and the stability level can be changed by means of the right column

The limits of stability is the maximum angular distance a person can intentionally displace his center of gravity, i.e. lean his body in a given direction without losing balance, stepping, or reaching for assistance. Once the LOS exceeds a fall, stumble or step will ensue. LOS in normal adults is eight degrees anterior, four degrees posterior, and 16 degrees in the lateral direction [1], [28-29].

By considering Fig. 9 and equations16 and 17 it is comprehensible that the person's height affects the calculations of LOS using COP.SinceCOM is positioned in 55% of person's height,a taller person has a higher position for COM [28] which yields more displacements of COP to achieve the same angular distance of LOS. Alsoan angle 2.3 degrees is entered in the triangle considering that the upright stance is always 2.3 degrees inclined forward the vertical line passing the ankle joint [28].

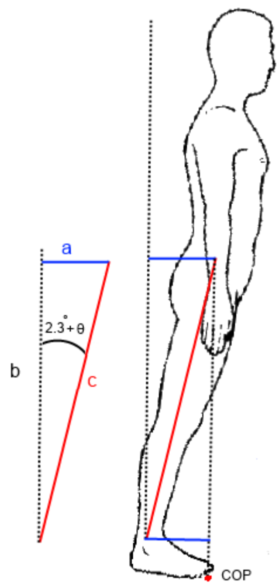


Fig. 9 Converting the angular limits of stability to a linear distance. The relation among the person's height, COP and limit of stability is shown by a triangle. The ankle is considered attached to ground as a part of that.

$$SinA = \frac{a}{c} \tag{16}$$

$$Sin(\theta + 2.3) = \frac{Y_{COP}}{0.55*Height} \tag{17}$$

The LOS protocol has three difficulty levels. Easy skill level is 50% (4 degrees anterior, 2 degrees posterior), moderate skill level is 75% (6 degrees anterior, 3 degrees posterior), and hard skill level is 100% (8 degrees anterior, 4 degrees posterior) of the sway envelop. Test is usually done at moderate skill level [29].

5 THE RESULTANTS

The resultants for two protocols are different which arepresented below.

5.1. The Resultants for Postural Stability Protocol

Once a postural stability test finished, multiple results are presented including time percentage in each quarter of the target circle, time percentage in each zone of circle and stability indices. To calculate time percentage in each zone, notice that the circle target consists of four concentriccircles. The smallest circle represents 0 to 5 degrees of deflection of the platform, and the biggest one represents 16 to20 degrees as shown in Fig. 10.

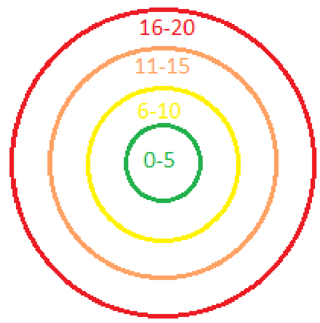


Fig. 10 Balance zones. The circle target for Postural Stability protocol consists of four concentric circles which each represents a zone for angle deflections shown by COB. COB for people with better balance functionality falls in the smallest zone

Stability Index represents the variance of platform displacement in degrees from level, for motion in the sagittal plane [29]. The horizontal level was determined as the mean level in centering process which is equivalent to the center of circle target. Thus, the deflections of horizontal level are considered as dispersion and the Stability Index is the Standard deviation of them [29], [36]. A high number of Stability Index means a lot of movements and less stability, which is also called Sway Index. Stability Index has three components:

Overall Stability Index (SI):

The variance of platform displacement in degrees, from level for motion in the sagittal plane. Here the starting point COB (x=0; y=0) is used as a perfectly balanced state (equation 18) [29].

$$(\mathrm{DI})^2 = \sqrt{\frac{\sum(0-X)^2 + \sum(0-Y)^2}{n}} \quad (18)$$

$$\mathrm{DI} = \sqrt{(\mathrm{DI})^2}$$

Anterior/Posterior (AP) Stability Index:
The variance of foot platform displacement in degrees, from level for motion in the sagittal plane (equation 19) [29].

$$\mathrm{DI_y} = \sqrt{\frac{\sum(0-Y)^2}{n}} \quad (19)$$

Medial/Lateral (M/L) Stability Index:
The variance of foot platform displacement in degrees, from level for motion in the frontal plane (equation 20) [29].

$$\mathrm{DI_x} = \sqrt{\frac{\sum(0-Y)^2}{n}} \quad (20)$$

Mean Deflection is the average position for all motions and deflections of the platform throughout the test. When calculated, the relevant standard deviation is computed in three conditions [29].

OverallMean Deflection:
Average position for the patient in all motions throughout the test. When calculated, the relevant standard deviation is computed in three conditions [29].

$$\frac{\sum_n \sqrt{x_n^2 + y_n^2}}{n} \quad (21)$$

A/P Mean Deflection:
Average position of side-to-side motion for the patient throughout the test [29].

$$\frac{\sum_n Y_n}{n} \quad (22)$$

M/L Mean Deflection:
Average position for the patient in the frontal plane throughout the test.

$$\frac{\sum_n X_n}{n} \quad (23)$$

Standard Deviation:
The amount of variability in the statistical measure, where this variable is calculated using the corresponding mean deflection. A low standard deviation demonstrates close relationswithin the values from which the mean was calculated. Equation 24 demonstrates the relation between Mean Deflection and Standard Deviation.

$$\frac{\sum_n \sqrt{(X_n - \bar{X})^2}}{n} \quad (24)$$

In all the above equations:

$n: numberofsamples$
$\bar{X}: meandeflection$

5.2. The Resultants for Limits of Stability Protocol
During test running, a number is computed and displayed as a percentage under the column of stability level which is named Direction Control Score.

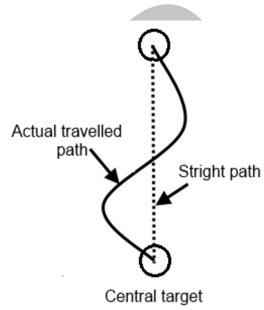


Fig. 11 Direction Control. This is a measure to assess the person's ability to control COP toward the target. Direction Control Score is computed by dividing the intended straight path by the actual traversed path and multiplying the resultant in 100

This score is computed continuously while the software receives new data from load cells and potentiometers, and demonstrates how much straight line distance the person has traveled between two sequential targets for which a number close to 100 is desirable [29]. Figure 11 demonstrates the Direction Control Score. This score is calculated as follows:

$$DirectionControlScore\% = \frac{\text{Straight path}}{\text{Actual travelled path}} \times 100 \quad (25)$$

Furthermore, at the end of a LOS test, multiple indices are presented named as Directional Control [28]. Directional Control is defined similar to Direction Control Score as:

$$\frac{A-B}{A} * 100 \quad (26)$$

Where:

A = STD of intended movement
B = STD of extraneous movement

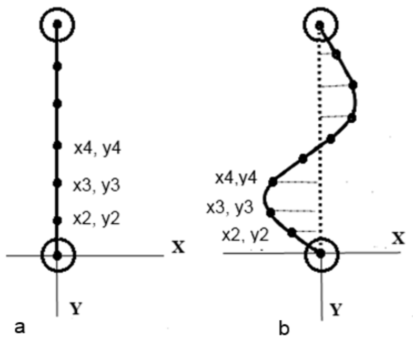
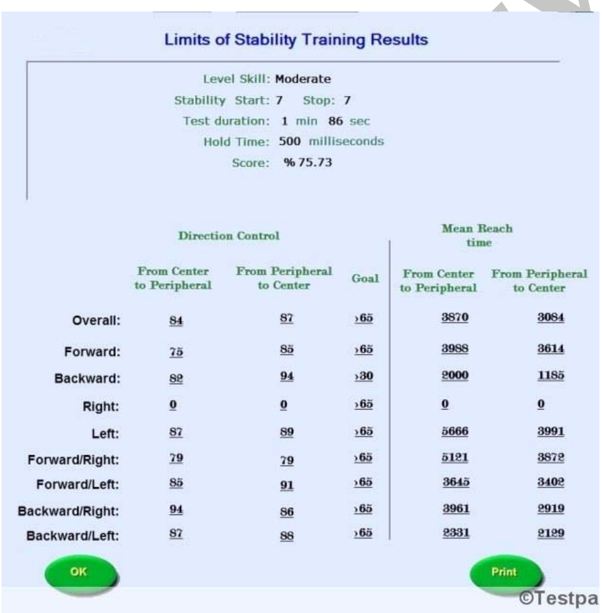


Fig. 12 The concept of Directional Control. If the patient moves in a straight line from the center to the target, as in diagram a, all the X values will be at or very close to 0. Thus, Directional Control will be 100%. If the patient moves off axis as in diagram b, each data point will have both X and Y values, and DC will be a number between 0 and 100%. A higher number is intended here

The calculation of intended movement and extraneous movement are based on the position vectors in Fig. 12. Every data in COP trajectory has coordinates X and Y. If a person, as shown in diagram a, travels from the central target toward the peripheral one in a straight line, then all X values will be equal or very close to 0. But if he travels out the straight line, as shown in diagram b, every COP data will have non-zero values for X and Y. Then the program calculates standard deviation for both Y (intended movement) and X (extraneous movement) and applies them in Eq. (26).


Limits of Stability Training Results

Level Skill: Moderate
Stability Start: 7 Stop: 7
Test duration: 1 min 86 sec
Hold Time: 500 milliseconds
Score: % 75.73

	Direction Control			Mean Reach time	
	From Center to Peripheral	From Peripheral to Center	Goal	From Center to Peripheral	From Peripheral to Center
Overall:	84	87	›65	3870	3084
Forward:	75	85	›65	3988	3614
Backward:	82	94	›30	2000	1185
Right:	0	0	›65	0	0
Left:	87	89	›65	5666	3991
Forward/Right:	79	79	›65	5121	3872
Forward/Left:	85	91	›65	3645	3402
Backward/Right:	94	86	›65	3961	2919
Backward/Left:	87	88	›65	2331	2129

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Fig. 13 The windows form for the outcomes of limits of stability protocol. At the end of test, the amount of Directional Control and Mean spent time to reach targets in eight directions for round trips are reported

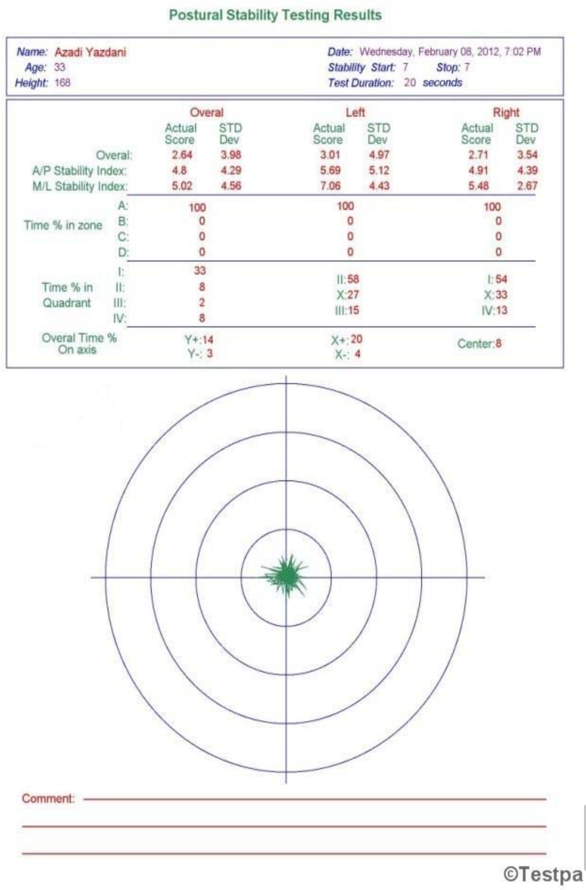
The resultant would be a number between 0% (worst performance, all movement off axis), and 100% (best performance, i.e., a straight line to the target). The mean elapsed time to achieve target in each direction is computed as well.
Finally, a report form is presented as shown in Fig. 13 which contains the results of the LOS test. The results are printable on paper if desirable. In testing mode, the results can be saved in database, comparable in future with the next ones.

6 DISCUSSION

As mentioned in previous sections, the present study involves design and development of comprehensive software to evaluate balance control as a human skill. All the related process is defined functional and clinical based on mechanical relations. The mentioned software can provide scientific researches with raw data recorded from patients in numeric form. It is also capable of receiving data to provide a statistical population. After running a test, CDP devices present important indiceswhich according to commercial use of these devices, the necessary information to gain such indices are not presented accurately in scientific papers and documents of vendors. In this paper, some variables such as center of balance were derived and presented for the first time. The following provides a brief analysis of the presented variables.

6.1. Discussion on Postural Stability

Figure 14 shows a printed sample of the reported results. These results refer to the test described in Fig. 7. The test information including test duration, stability levels, date and time of test, and personal information of the patient are seen in the above rectangle of the report.
The results of postural stability test are shown below the rectangle. The *Overall*, *Left* and *Right* show the functionality in overall terms, left leg and right leg, respectively. Each of them includes Sway Index or Stability Index shown as *Actual Score* and overall, AP and ML Standard Deviations calculated by equations 24 to 30. A significant number of these results indicate a high sway and less ability in balance control for the person.
As shown in Fig. 14, Sway Indices for the right leg in overall and both directions are better than those of the left leg. The whole test time has elapsed in the small circle, meaning that the sways of the platform have never exceeded 5 degrees which conveys the person's ability in balance control. The report also contains the elapsed time in each quadrant, coordinateaxis and origin for both legs and in overall.



Postural Stability Testing Results

Name: Azadi Yazdani
Age: 33
Height: 168
Date: Wednesday, February 08, 2012, 7:02 PM
Stability Start: 7 Stop: 7
Test Duration: 20 seconds

		Overal Actual Score	Overal STD Dev	Left Actual Score	Left STD Dev	Right Actual Score	Right STD Dev
Overal:		2.64	3.98	3.01	4.97	2.71	3.54
A/P Stability Index:		4.8	4.29	5.69	5.12	4.91	4.39
M/L Stability Index:		5.02	4.56	7.06	4.43	5.48	2.67
Time % in zone	A:	100		100		100	
	B:	0		0		0	
	C:	0		0		0	
	D:	0		0		0	
Time % in Quadrant	I:	33		II:58		I:54	
	II:	8		X:27		X:33	
	III:	2		III:15		IV:13	
	IV:	8					
Overal Time % On axis		Y+:14 Y-: 3		X+: 20 X-: 4		Center:8	

Comment:

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Fig. 14 A sample of printed reports for postural stability protocol. The Stability Indices, standard Deviation for Mean Deflection, the time elapsed in each quadrant; zone, axis and origin are reported for overall conditions, left and right legs

A look at the time elapsed in quadrants 1 and 3 and the positive X-axis compared to the time elapsed in quadrants 2 and 4 and the negative X-axis shows that the time elapsed in right half is longer than the time elapsed in left. It may be an indication of weakness in the leftleg meaning that the force applied by the left leg is not sufficient and the plate deflects to the right. Also regarding the time elapsed in quadrants 1 and 2 and positive Y-axis compared to the elapsed time in quadrants 3 and 4 and negative Y-axis, it is perceptible that the platform sways forward more than backward which means that the person has a tendency to lean forward or has an inability in calf to return the platform to equilibrium. The tendency to lean forward and right are shown in both legs that are comparative.

6.2. Discussion on Limits of Stability

Figure 13 presents the results of the Limits of Stability test shown in Fig. 8. The test was performed in training mode with stability level of 7 and no time limit. The test took 1minute and 20 seconds and stopped before reaching the right target. Consequently, the outcomes of the respected target were all equal to zero. The Direction Control Score and the hold time were also listed. There are three columns for the Directional Control values obtained by equation 26. The Left column reports the values for traveling from center to peripheral targets and the middle column reports the values of the way back. The acceptable scores shown in the right column are values more than 65 for all motions except fordeparture to backward and vice versa that is a score more than 30 [29].

Comparing the left and middle columns shows that departure from equilibrium position –center- to peripheral is more difficult than return to equilibrium position. This phenomenon is more obvious in healthy people because they can stand erect with no problem. Their muscles and nervous system, thus, consume less energy to return to equilibrium position compared to traveling to limits of stability. This may be in reverse in patients and is assessable.

Two columns at right express the mean time spent to reach peripheral targets from center and vice versa in milliseconds. Regarding the higher scores for Directional Control in return to center compared to traveling from center, the spent time for return is principally less than that of departure to peripheral.

For equivalent angular distances, while equal directional control scores are obtained, it is expected to have equal spent time which would entailalso equal directional control scores. The score of directional control for leaning forward is 75% in Fig. 13, and the spent time for that is equivalent to the score of leaning backward/right which is 94%, while the angular distance of both are homological. The possible cause in this connection is that the person has had a stop meanwhile, and consumed time in a point which does not increase the COP dispersion but increases the reach time. It may be studied by using raw COP points recorded as well.

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