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Evaluation of the Limits of Stability (LOS) Balance Test

by
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The main objective of this study was the estimation of intrasession reliability of the limits of stability (LOS) test conducted on a force platform as an alternative measurement to standard posturography in quiet standing. Fifteen healthy adults took part in the experiment. The standardized measurement protocol of the LOS test was proposed. It consists of three phases – 1st phase – 10s of quiet standing, 2nd phase – the maximal forward leaning in a self paced manner, and 3rd phase – maintenance of maximal forward leaning position. The analysis of variance Friedman's ANOVA and Repeated Measures ANOVA/MANOVA was used to diagnose the differences between 10 consecutive trials of the LOS test. In order to establish reliability of the test, the intraclass correlation (ICC) procedure was used. We presented different ways of maximal center of pressure (COP) excursion estimates. The results of this study show no significant differences between the chosen parameters of the LOS test. Moreover, the measurement of the range of COP excursion, which is most commonly analyzed in such tests, showed to be quite reliable with $ICC_{2,1}$ above .85. LOS test conducted along the standard procedure should be considered as a very useful method in clinical and research conditions. Still the specific parameters of the LOS test should be given more thorough insight, but it is a very good alternative to quiet standing posturography.
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Introduction

Maintaining upright body posture is fundamental for humans. Therefore, research concerning balance control and postural stability are very diverse. Several clinical and laboratory methods have been developed which enable researchers to asses different dimensions of the postural control system (Horak, 1997; Blaszczyk et al., 2003; Mikołajec and Rzepka, 2007). Experimental protocols are usually designed to asses postural steadiness or postural balance. Postural balance refers to the ability to stay upright within the base of support, or to recover equilibrium after external dynamic perturbation, whereas postural steadiness refers to standing as still as possible on a force plate.

Centre of pressure (COP) emerges as the most common variable among others registered with the use of force plates. It is defined as the point of application of ground reaction forces under the feet. COP is the outcome of the inertial forces of the body and equilibrium restoring forces of the postural control system. COP displacement is used to investigate neurological and biomechanical mechanisms of postural control. The lack of an exact understanding of the postural sway in quiet standing produces difficulty in interpreting this process. The influence of the postural sway on the COP variability of voluntary COP shifts, also remains unexplained (Latash et al., 2003; Duarte and Freitas, 2005). Another study suggest that simple global measures of 'balance' do not provide enough information to predict the failing of the postural control system in specific environments and situations (Horak, 2006). Therefore, in addition to standard measurements of postural steadiness, one can use several different protocols and clinical tests to assess functional stability limits (FSLs). Functional stability limits can be defined as the percentage of the base of support that individuals are willing to extend their center of pressure. One commonly used measure of stability limits is the clinical functional reach (FR). It is the difference between arm's length and maximal forward reach, using a fixed base of support (Duncan et al., 1990). Authors postulate that the FR may be useful for detecting balance impairment, change in balance performance over time, and in the design of modified environments for elderly impaired, however, it is only an approximator of the margin of stability in the clinical environment. There are several modifications to FR. For example, the multi-directional reach test or FR using an elastic stick (Newton 1997, 2001; Holbein-Jenny 2007; Demura and Yamada, 2007). These modifications improve the procedure and have been proven to be quite reliable. However, FR itself is strongly dependable on the movement strategy performed by and individual. Wernick-Robinson and collaborators (1999) suggest that the FR distance (arm displacement) alone does not measure dynamic balance and additional indispensable assessment of movement strategies is needed to have proper postural control evaluation. Otner studies disapprove the high predictive value of functional stability tests in identificating fallers and nonfallers, especially in the case of FR (Brauer et al, 2000; Eagle et al., 1999; Jonsson, 2002). The differences between these studies can be caused by differences in test protocols and procedures. Standardization of these tests is needed. Another approach to stability limits is the case of functional tests conducted in laboratories. With the use of computerized dynamic posturography, one can objectively measure the postural components of balance. LOS test measures volitional control of centre of gravity (COG). In essence, it should measure similar components of balance as FR. However, Wallmann (2001) reports that there is no significant relationship between FR measures and anterior displacement on the LOS test, suggesting that the reaching task is not the same as a forward leaning task. Still, there is no consensus between different views and particular measure of balance should be considered the 'gold standard'.

Even when the instrument used for the analysis of postural control is very accurate, it does not suggest that the measurement of this phenomenon is reliable. It is important for researchers to be aware of possible measurement errors and able to correct them if necessary. Furthermore, for any measure of postural control, it is crucial to ask whether the results from a single measure are representative of an individuals' balance performance. Therefore, the main goal of this study was to estimate the intrasession reliability of the limit of stability measures in healthy adult people. We suspected that the LOS test performance in consecutive trials will be subject to the process of learning.

There is a need for standardized procedures for measuring stability, which can be reliably examined and successfully applied to different populations and environments – clinical and laboratory.

Methods

The study was conducted on 15 healthy male students form the Academy of Physical Education. Their average age, mass, and height were, respectively, 22 years, 78 kg and 180 cm. They had no documented history of postural or skeletal disorders. All subjects agreed to participate in the experiment voluntarily. Their participation was previously approved by the academy bioethics board. A force platform (AMTI Accugait) was used in the experiment to register COP displacements. Ground reaction forces and moments were registered at 50Hz.

Subjects were instructed to stand barefoot on force platform with their feet in a comfortable position, and their arms along their sides with palms directed toward thighs. They were looking straight ahead with their head erect. The fixation point was placed 2m away from the subjects on the wall in front of them. Subjects performed 10 consecutive trials of maximal voluntary forward leaning (limits of stability test - LOS test) with approximately 2 minutes rest between them. During the rest period subjects were asked to step off the platform and sit in order to avoid excessive fatigue. Each trial in the procedure started with 10 seconds of quiet standing, after which an acoustic signal was triggered to initiate the forward leaning phase. The subjects executed the leaning movement at their own pace until they reached their maximal range. Maximal leaning position achieved by the subjects was maintained until the end of the trial (15 seconds on average). Time of each trial was 30 seconds. During this time subjects were instructed not to raise their heels while performing the task. Otherwise the trial had to be repeated. Subjects were asked to execute the leaning phase mainly by changes in ankle joint angle. Center of foot pressure displacement in the anterior – posterior plane (COPA/P) from each trial were calculated and used in further analysis.

Data analysis

The main task of this custom made software was preliminary processing of registered COPA/P data, and saving the results to an ASCII file, which can later be used in standard data analysis. The same procedure can be conducted with the commonly used Matlab software. Thanks to preliminary data processing, one can obtain parameters with values that are independent of a subjective assessment. With regard to the LOS test, three phases are determined and analyzed: 1st phase - 10 seconds of quiet standing, 2nd phase - dynamic leaning phase, and 3rd phase - maintenance of the maximal forward leaning position.

Common parameters for all three phases included: beginning and end points of the phase, characterized by time and position of the subject's COPA/P (T1, T2, T3). Regression coefficients B1 and B3 – characterizing the slopes of regression lines for the COP trajectory in the A/P plane, accordingly in 1st phase (10s of quiet standing) and 3rd phase (maintenance of maximal forward leaning position); and B2 being the regression line coefficient for the 2nd phase, which in essence describes the speed of forward leaning movements (see figure 1A).

In our opinion, the most important parameters specific for each phase are the following: S – mean value of COPA/P position with appropriate index denoting the phase of trial (1, 2 or 3); Min – minimal value of COP trajectory in A/P plane in each phase; Max – maximal value of COPA/P trajectory with an appropriate index according to the phase; R (Range) – position of COP between the maximal and minimal position in A/P direction in a specific phase. R1 – the distance between the maximal and minimal position of COPA/P in the 1st phase, R2a – the distance between maximal and minimal position of COPA/P in the 2nd phase, and R3 – the distance between the max. and min. position of COPA/P in the 3rd phase. Additionally, the R2b parameter was estimated in order to assess the effective stability limits between mean values of COPA/P trajectory in the 1st and 3rd phases of the trial (see figure 1B).

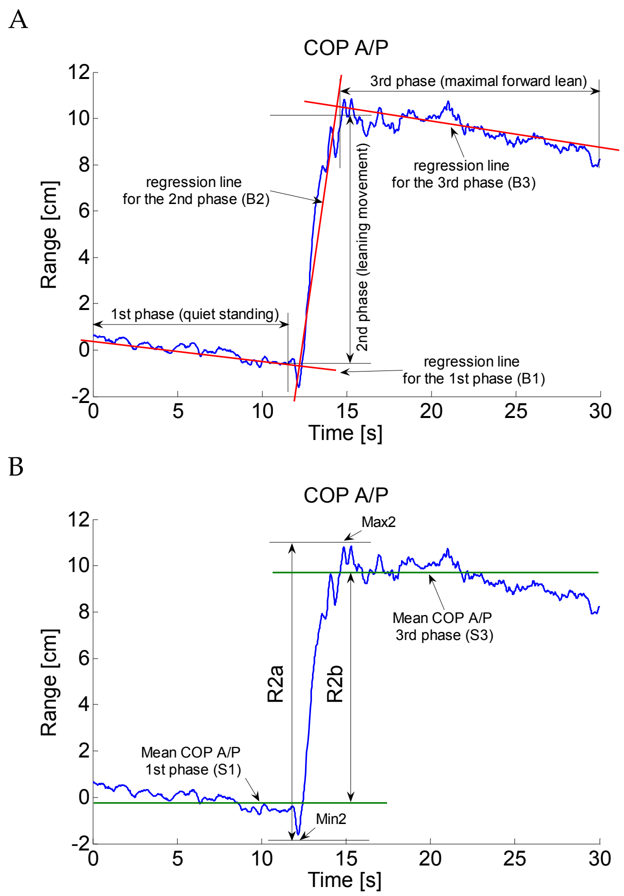

Fig. 1

Phases representing subject's $COP_{A/P}$ excursion during a single trial with regression lines for each phase (A) and two ways of estimation of the maximal range of forward $COP_{A/P}$ excursion - R2a, R2b (B).

The data analysis was conducted in two stages. We suspected that during 10 consecutive trials, subjects will learn to lean further with each trial. To confirm this hypothesis the differences between trials were examined. Firstly, Friedman's Two Way ANOVA and multiple analysis of variance MANOVA was used to examine the differences between selected parameters. Secondly, the reliability of the LOS test variables was estimated by the use of intraclass correlation coefficients (ICCs), described by Shrout and Fleiss (1979). Derived from the ANOVA results, the ICC compares within subject variability with between subject variability. This model considers random effects over time (equation 1);

$$ICC_{2,1} = \frac{MS_B - MS_E}{MS_B + (n-1)MS_E + n(MS_R - MS_E)/k} \quad (1)$$

where MS_B, MS_R, and MS_E are the mean squares of the 2-way ANOVA, n is the number of subjects, and k the number of trials. *Statistica* software procedures were used to estimate the reliability coefficient R by averaging k-trials as well as the number of trials (k) to be averaged to obtain a target reliability coefficient R (Table 1). Our team primarily analyzed the parameters from the 2nd and 3rd phases, because they appeared to be the most commonly used in other studies, and when considering the functional stability limits, they were the most informative.

Results

A plot of a typical COP recording during a single trial obtained from a representative subject was presented in Figure 2. One can easily distinguish specific phases of the LOS test. Greater variability of COP in the leaning position is clearly visible. Further processing of this signal allowed for distinction of specific parameters of the test.

Because the statistical assumption of normal distribution for data in the B2 variable (coefficient of the regression line in the 2nd phase) was not met, the differences were estimated by means of Friedman's two way ANOVA. Results showed no significant differences (chi-square (13, 9) = 4.599; p=.868, at p< .05). The remaining measures did not meet statistical assumption of sphericity, therefore, we used multiple analysis of variance MANOVA. Results of Wilks' statistics for COP range in specific phases of the LOS test showed no significant differences: R2a – (Wilks' Λ =.563; F=.484; p=.827), R2b – (Wilks' Λ=.389; F=.697; p=.701), R3 – (Wilks' Λ=.499; F=.626; p=.736), and mean trajectory of COP in the 3rd phase (S3) – (Wilks' Λ =.322; F=.936; p=.574). The null hypothesis was true in all cases.

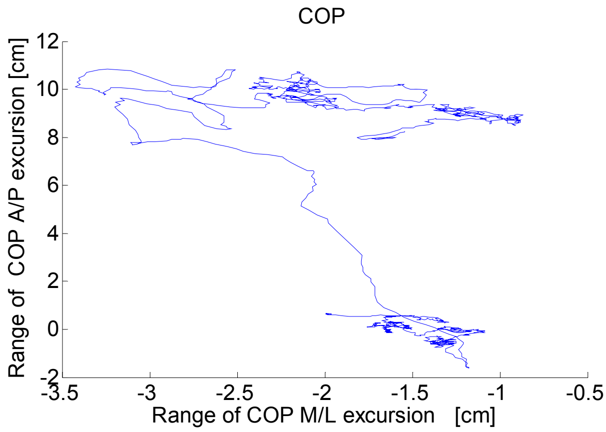

Fig. 2

COP of representative subject

ICCs values for one trial ($ICC_{2,1}$) and estimation of the reliability coefficient R by averaging k-trials ($ICC_{2,k}$) are presented in Table 1.

Table 1

ICC values of 1 and k trials, number of trials (k) to be averaged in order to obtain an ICC ≥.90 of analyzed variables

Phase	Variables	$ICC_{2,1}$	$ICC_{2,k}$	*k* ICC≥.90
1st	S1	0.552	0.925	8
2nd	B2	0.514	0.914	9
	R2a	0.86	0.984	2
	R2b	0.871	0.985	2
3rd	S3	0.868	0.985	2
	B3	0.421	0.879	13
	R3	0.323	0.827	19

Discussion

This study demonstrated that the LOS test is a reliable tool to assess the functional stability in healthy adults. For the most common variables, such as the range of the functional forward lean (R2a, R2b), only two trials need to be averaged to obtain the ICC over .90. While the other parameters like regression line coefficients (B2, B3), which describe the behavioral tendency of COP during the phases of the test, are less reliable and strongly dependent on the task constraints.

Maintaining balance in an upright position is a complex neuromuscular mechanism involving vision, peripheral proprioceptive and vestibular inputs, lower extremity strength, and vertebrobasilar function. One of the commonly used indicators of balance ability is postural sway. The measure of the postural sway is the amount of centre of gravity or COP excursion during static stance. Even though it is a common measure, there are several different protocols of postural sway assessment which can give different results. Lanford et al. (2004) assessed the reliability of 3 different trials of COP measurements and they concluded that its reliability increases with duration of a trial. According to these authors, the reliability of COP measures can be also increased by averaging several trials. Even with a good reliability of postural sway measurement, it is difficult to interpret the results (Duarte and Freitas, 2005). Therefore, we postulate more appropriate measures of static balance, which is the measure of stability limits. The goal of most tests measuring limits of stability (LOS) is to examine an individual's ability to control their center of gravity (COG). Traditionally, stability limits are considered to be dependent on the area of the base of support (BOS – the anterioposterior length of the foot and the mediolateral width of stance), the position of the center of mass (COM), and weight of the mass controlled by the individual. The actual limit of stability of a person may be defined as the distance he or she is willing and able to move without losing balance and taking a step. This distance is referred to as perceived limit of stability (Shumway-Cook and Woollacoot 2001).

There are several tools assessing stability limits available on the market, ranging from the most accessible, such as the Functional Reach (FR) (Duncan et al. 1990) to more sophisticated balance systems offered, for example, by NeuroCom Int. (NeuroCom International, 2001). A number of studies compared different limits of stability measurements (Clark et al., 1997; Clark et al., 2005; Horak, 1997; Woollacott and Shumway-Cook, 1996); however, there is no consensus which one is most suitable for different applications – clinical or research. Relatively, the most reliable are those based on digital signal processing using different force platforms. Earlier studies show that the FR and LOS tests should not be applied interchangeably, and it is obvious that measurements based on digital signal processing will be more adequate and reliable. The differences between FR and LOS tests emerge probably from the specificity of a task. Moreover, the FR test is proven not to be an appropriate indicator for differentiating elderly nonfallers from fallers which is one of the main goals of such tests (Wallman, 2001; Clark et al., 2005). Therefore, keeping in mind all the limitations of the FR test, we advocate utilization of the LOS tests conducted on a standard force platform.

The main goal of this study was to estimate the intrasession reliability of limits of stability measures in healthy adults. We propose a standardized measurement procedure, and additionally, a way of COP data analysis. Due to many different experimental protocols, encountering differences in results may occur. This is the main reason why the procedure of the LOS test should be standardized. Of course, the differences between the studies examining the functional stability limits can be caused by the different experimental groups. Certain flexibility in the test protocol should be admissible, but there should be a consensus when it comes to data processing.

One of the set-backs of these measurements is the method used in the study. COP registered during the task execution on the force platform represents forces and moments exerted by the subject. A straight forward interpretation of this signal in the LOS test can lead to wrong conclusions. Therefore, one should be careful in calculation of individual stability limits. There might be at least three options available. The first, and probably the least accurate, is the distance between the most distal points of $COP_{A/P}$ stabilogram. The error of estimation of stability limits can easily occur because of the different COM velocities during the task performance, which translate to the resultant forces and force moments exerted by the base of support (feet) on the platform. In this way, one is not able to correctly appoint the effective stability limit, or the effective range of COG excursion in forward A/P direction. The second possibility in establishing the real stability limits of an individual might be the calculation of the distance between mean trajectory of COP in the initial phase of quiet standing and the final phase of maximal lean (forward lean in case of this study) – this will be our R2b. This appears to be the most adequate way to achieve the most accurate results. It should be emphasized that the R2b variable (effective range) proved to be very reliable in consecutive trials. Additional option was briefly described in the introduction but was not analyzed in this study.

In reference to COP measurements in quiet standing, which became one of the most common measurements in posturography, the reliability of these tests increase with trial duration (Lanford et al., 2004). It is impossible to extend the trial duration with the LOS test, especially with an older population, which was the target group for this measurement. The workload during the task execution would exceed the ability of older population to maintain balance without taking a step or falling. Therefore, we suggest that in order to obtain reasonably reliable results, one should average at least three, 30s trials. A high number of trials should be averaged in order to obtain ICCs of about .90 in case certain parameters of the LOS test are caused by task constraints. This is strongly dependent upon the task instruction and individuals' performance. Strict instructions should be rigorously followed by subjects in order to avoid misleading results. It is especially noticeable in case of the B2 parameter, interpreted as the speed of active forward leaning. It is rarely reproducible through trials and if not restricted to a specific time window, one trial is almost always different from the next. However, it is a very interesting parameter characteristic for functional stability, and with adequate instructions, one can obtain information about how quickly an individual can attain the stability limit. This in turn, can have many practical applications in daily life and sports, when it is necessary to move the COG in a desired direction as fast as possible. We want to emphasize that similar procedures can be applied to backward lean, as well as M/L direction, but more thorough analysis of these signals is desired in the future.

This study shows that parameters characteristic for the LOS test are much more reliable than those analyzed in studies concerning postural sway in quiet standing. The differences between reliability of the quiet standing measurement and functional balance test can be observed in the proposed procedure of the LOS test, in favor of functional balance. In some cases, test parameters are more reliable in the 3rd phase than in the 1st, which is not true in opposite direction. One could expect that functional stability depends mainly on functional/anatomical and physical constraints. This study shows that functional stability is not subject to the process of learning, which is of importance to the researchers. It is interesting how visual feedback influences the perceived limit of stability of an individual. Recent studies show such positive influences (Clark et al., 2005). LOS test measures one aspect of balance utilized in daily life, and has potential as a measure of improvement in balance resulting from rehabilitation, or of decline in balance over time. Considering the advantages of the LOS test, such as the high efficiency in early identification of falls in elderly, high reliability of its parameters, and its ease of execution, it should be at least as popular in clinical and laboratory environments as simple global measures of balance.

Conclusions

Results of this investigation indicate that among several parameters of the limits of stability test, the most reliable is the range of COG excursion (S3 and R2b in this study) when administered to healthy adults. Using only two repetitions allowed for reliable measurement of functional stability. We suggest averaging three trials for the LOS tests. Based on the results of this study, one can conclude that the LOS test is a reliable measure of functional stability, which can greatly improve the assessment of balance abilities, and makes an interesting alternative to measures of COP in quiet standing.

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