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# Reliability of Center of Pressure Measures of Postural Stability in Patients With Unilateral Anterior Cruciate Ligament Injury

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**Abstract:** The aim of this study was to estimate the test-retest reliability of some commonly used center of pressure measures in postural control investigations of sport injuries under the diverse stressful postural conditions. Twelve patients with anterior cruciate ligament injury were evaluated on two separate sessions. The center of pressure was recorded from force platform and the following measures were calculated (1) standard deviation of amplitude (2) mean velocity (3) standard deviation of velocity (4) phase plane parameters and (5) area (95% confidence ellipse). Relative and absolute reliability was assessed using intra-class correlation coefficient and coefficient of variation, respectively. Mean velocity and total phase plane parameters were the most reliable measures having high to very high correlation across all postural conditions. The mean and range of intra-class correlation coefficient for mean velocity and total phase plane parameters were 0.88 (range: 0.80 to 0.96) and 0.81 (range: 0.71 to 0.88), respectively. Interestingly, pattern of the coefficient of variation values was, to a great extent, consistent with the intra-class correlation coefficients. Therefore, mean velocity and total phase plane parameters may be sensitive center of pressure measures to differentiate balance between Anterior Cruciate Ligament (ACL) injured patients and to evaluate the effect of a rehabilitation program in this population.

**Key words:** Rehabilitation, posture, reliability, injury

## INTRODUCTION

The maintenance of an erect stance is an integral part of several goal directed actions (Corbeil *et al*., 2004). The importance of this motor behavior is so that in sport injuries especially Anterior Cruciate Ligament (ACL) injury, return to play decision is dependent on optimal postural control (Henriksson *et al*., 2001).

Impaired postural control has been reported after ACL injury (Gauffin *et al*., 1990; Lysholm *et al*., 1998). These studies have typically used force platform to calculate the location of the resultant ground reaction forces from the foot, termed the Center of Pressure (COP) (Lafond *et al*., 2004).

Like any other measures, postural control measures are affected by measurement error thus establishing the reliability of force platform measures is critical (Corriveau *et al*., 2001; Lafond *et al*., 2004). Small measurement error in repeated administration of a test indicates good reliability (Batterhama and George, 2003).

Identifying the measurement error is a major concern for clinicians when they use COP measures to differentiate balance performance between individuals as well as to detect changes in balance following an intervention program which requires determining relative and absolute reliability, respectively (Atkinson and Nevill, 1998; Domholdt, 2005). With regard to evaluative purposes, a balance intervention is effective when the clinical

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Table 1: Summary of reliability studies of different postural parameters

| Authors | Postural parameter | Participant | Sample size | Outcome |
|---|---|---|---|---|
| Lafond *et al.* (2004) | COP mean velocity | Healthy elderly | 7 | ICC = 0.83, 0.94 for AP and ML direction |
| | COP RMS | (one group) | | ICC = 0.58,0.58 for AP and ML direction |
| | COP range | | | ICC = 0.52, 0.62 for AP and ML direction |
| | Power frequency | | | ICC = 0.44, 0.30 for AP and ML direction |
| | COP area | | | ICC = 0.41 |
| Corriveau *et al.* (2000) | COP-COM RMS | Healthy elderly (one group) | 7 | ICC = 0.79, 0.69 for AP and ML direction |
| Doyle *et al.* (2005) | COP peak velocity | Healthy young | 20 | ICC = 0.05 to 0.29 |
| | COP range | (one group) | | ICC = -0.28 to 0.72 |
| | COP area | | | ICC = -0.01 to 0.95 |
| | Fractal dimension | | | ICC = 0.62 to 0.90 |
| Benvenuti *et al.* (1999) | COG area | Healthy and patient | 36 | ICC = 0.71 |
| | COG velocity | elderly (one group) | | ICC = 0.76 |
| | COP mean velocity | | | ICC = 0.74 |
| Corriveau *et al.* (2001) | COP-COM RMS | Healthy and patient elderly (one group) | 60 | ICC = 0.89 to 0.93 for AP direction<br>ICC = 0.74 to 0.79 for ML direction |

difference of COP measures be greater than the measurement error (Corriveau *et al*., 2000). So the minimally metrically detectable change (MMDC) is used to estimate this difference between two measurements (Corriveau *et al*., 2000; Lafond *et al*., 2004).

Most of the stabilometric parameters selected for this study have been used extensively in postural control investigations following ACL injury/reconstruction (Gauffin *et al*., 1990; Henriksson *et al*., 2001; Lysholm *et al*., 1998). However, no evidence is available supporting which parameter is the best indicative measure of sway profile after a ligament injury. Thus, this test-retest reliability study was conducted to find the best measures having the most discriminative and evaluative powers for detecting sway behavior of ACL injured population. In addition, there have been few attempts to establish the reliability of COP measures in healthy young and elderly population (Doyle *et al*., 2005; Lafond *et al*., 2004; Santos *et al*., 2008) (Table 1) but reliability is not invariant across populations and different patient groups (Domholdt, 2005). Therefore, the objectives of this study were to determine the test-retest reliability of some commonly used COP measures in postural control studies of sport injuries in ACL injured population and to provide the estimate of the MMDC of these COP measures in these patients.

## MATERIALS AND METHODS

**Patients:** This study was conducted between Sep. 2007 and Mar. 2008. A total of 12 male patients were included in the study. Inclusion criteria were as: (1) age between 18 and 36 years, (2) unilateral, non operated, non acute ACL rupture with or without associated meniscal injury, (3) uninjured contralateral limb, back or neck, (4) no history of neurological disease or visual/vestibular disturbance and (5) no pain more than grade two according to visual analogue scale on the test session. Most patients of this study have damaged following a recreational football playing. The common age limit for this injury may be between 18-36 years. Also, this age limit of patient selection was used in a number of postural control studies following ACL tearing (Ageberg *et al*., 2004). All subjects signed an informed consent before participating in the study, which had been previously approved by the university human research ethics committee. The knee injury and osteoarthritis outcome score (KOOS) was used as a measure of disability (Roos and Lohmander, 2003). It includes five sub-scales with scoring range of 0-100. Higher scores represent lesser knee problems. Descriptive results for age, height, weight, time since injury and KOOS sub-scales are shown in Table 2.

Table 2: Mean and Standard deviation of patients' characteristics

| Characteristics | Mean±SD |
|---|---|
| **Demographic data** | |
| Age (year) | 27.5±6.80 |
| Height (cm) | 178.1±6.50 |
| Weight (kg) | 88.0±12.4 |
| Time since injury (year) | 2.5±3.10 |
| **KOOS data**[a] | |
| Pain | 67.0±15.7 |
| Symptom | 59.8±11.9 |
| Activity of daily living | 77.0±16.7 |
| Sport and recreation | 35.8±23.9 |
| Quality of life | 27.1±20.0 |

[a]Range of scores is from 0 to 100

**Procedures:** COP data were collected using a strain gauge Bertec 9090-15 force platform and Bertec AM-6701 amplifier (Bertec Corporation, Columbus, Ohio, USA).

Postural sway was assessed in quiet stance with controlled, varying levels of postural difficulty. Participants were instructed to stand relaxed on the central region of force platform, breath normally, let their arms hang at their sides and looking forward. To change the level of postural task difficulty in double limb stance, two types of sensory feedbacks were manipulated: (1)

visual feedback: eyes open and close and (2) foot proprioceptive feedback: standing on rigid surface and compliant surface with 60×60 cm dimensions, 10 cm thick medium-density foam. Combination of these factors made three conditions in double limb stance with feet together including standing on the rigid surface with eyes open, standing on the rigid surface with eyes close and standing on foam with eyes close. For single limb stance, participants were instructed to stand on affected and healthy limb alternatively, on the rigid surface with eyes open. COP data of three trials in each condition were collected in double and single limb stance with sampling frequency of 200 and 500 Hz, respectively. Every trial took 30 sec in double limb stance and 20 sec in single limb stance. The reason of choosing a higher sampling frequency for single limb condition was to capture the more variable dynamics of this condition and to provide enough signal information for future analyses with non-linear tools (Stam, 2005). To familiarize the subjects with the task, 1 to 3 preliminary trials were performed in each condition (Benvenuti *et al.*, 1999). Order of postural conditions was randomized with five minutes rest between each condition to avoid fatigue. For the test-retest study, each subject was evaluated on two sessions in the same environmental laboratory by the same experimenter, at the same time of day, under the same postural conditions and with a time interval of 48 h between two sessions.

**Data analysis:** The average of three trials of the COP measures for each condition was used to determine the reliability coefficient. All data were stored on a Pentium-based PC and then exported to MATLAB for calculation of COP measures. Anteroposterior (AP) and mediolateral (ML) displacements of COP were measured along the y-axis and x-axis, respectively. Residual analysis on COP data showed a cut-off frequency of 8 Hz as the best compromise to reject noise power, however to avoid rejecting portions of signal power and to be in the safe side, a cut-off frequency of 10 Hz was selected (Winter, 2005). Therefore, COP signals were filtered using a zero-phase, sixth-order, Butterworth low-pass filter with a cut-off frequency of 10 Hz (Santos *et al.*, 2008). The following COP measures were calculated and used in this study: (1) Standard Deviation (SD) of amplitude, (2) mean velocity, (3) SD of velocity, (4) phase plane parameters (Riley *et al.*, 1995) and (5) area (95% confidence ellipse) (Suarez *et al.*, 2003). Phase plane parameters are the square root of variances of velocity and displacement that were used to quantify the phase plane information and changes in stance stability (Riley *et al.*, 1995).

**Statistics:** In this study, paired t-test on the differences between two averaged scores obtained at test-retest sessions was used to determine the absence of systematic bias. Alpha level was set at 0.05 for all statistical analyses.

Intra-Class Correlation Coefficient (ICC) is the most common index used to report relative reliability (Santos *et al.*, 2008). Since the magnitude of the ICC is highly dependent on data heterogeneity; a 95% Confidence Interval (CI) was calculated and reported to indicate precision of the estimates (Batterhama and George, 2003). In this study, the $ICC_{2,3}$ was used to express relative reliability of the measures (Shrout and Fleiss, 1979). Range of reliability coefficients described by Munro was used to report the degree of reliability: 0.00 to 0.25-little, if any correlation; 0.26 to 0.49-low correlation; 0.50 to 0.69, moderate correlation; 0.70 to 0.89, high correlation and 0.90 to 1.00, very high correlation (Mathur *et al.*, 2005).

Coefficient of Variation (CV) was used to express absolute reliability and was calculated by dividing SD to mean multiplied by 100 (Atkinson and Nevill, 1998).

The MMDC was defined as the 95% confidence interval of standard error of measurement (±1.96 SEM) (Corriveau *et al.*, 2000). The SEM was calculated from root mean square error term of ANOVA table (Weir, 2005).

## RESULTS AND DISCUSSION

Table 3 shows descriptive statistic of postural parameter scores (mean and standard deviation) for each condition in each session.

Paired t-test demonstrated no significant difference between the averaged scores of all parameters in test and retest sessions ($p>0.05$) with the exception of area (95% ellipse) for one condition; double limb stance on the rigid surface with eyes open ($p = 0.03$).

The ICC (95% CI), CV (%) and MMDC are shown in Table 4.

All parameters across most conditions of postural difficulty had moderate to high correlation. Mean velocity and total phase plane parameters were the most reliable measures having high to very high correlation across all postural conditions. The mean and range of ICC for mean velocity and total phase plane parameters were 0.88 (range: 0.80 to 0.96) and 0.81 (range: 0.71 to 0.88), respectively. Area (95% ellipse) was the least reliable parameter (mean: 0.55, range: 0.10 to 0.75).

Pattern of the CV values was, to a great extent, consistent with the ICCs so that mean velocity, total phase plane and both SD of velocity and phase plane in

Table 3: Descriptive data for COP measures

| | Double limb stance | | | | | | Single limb stance | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (Healthy limb) | | (Affected limb) | |
| | Foam surface Eyes close | | Rigid surface Eyes close | | Rigid surface Eyes open | | Rigid surface Eyes open | | Rigid surface Eyes open | |
| Postural parameters | Test | Retest | Test | Retest | Test | Retest | Test | Retest | Test | Retest |
| **ML** | | | | | | | | | | |
| SD of velocity | 3.86±0.74 | 3.94±0.88 | 2.43±0.49 | 2.38±0.39 | 1.58±0.28 | 1.58±0.28 | 2.67±0.59 | 2.90±0.51 | 2.96±0.80 | 2.94±0.64 |
| SD of amplitude | 1.19±0.24 | 1.14±0.29 | 0.78±0.20 | 0.74±0.13 | 0.59±0.17 | 0.50±0.13 | 0.57±0.11 | 0.57±0.11 | 0.58±0.14 | 0.61±0.13 |
| Phase plane | 4.04±0.77 | 4.11±0.91 | 2.56±0.51 | 2.50±0.40 | 1.69±0.32 | 1.66±0.29 | 2.82±0.58 | 2.96±0.51 | 3.02±0.80 | 3.01±0.64 |
| **AP** | | | | | | | | | | |
| SD of velocity | 3.66±0.66 | 3.43±0.97 | 2.09±0.50 | 2.07±0.63 | 1.44±0.35 | 1.35±0.23 | 2.88±0.68 | 2.70±0.78 | 2.75±0.77 | 2.85±0.52 |
| SD of amplitude | 1.34±0.40 | 1.24±0.31 | 0.68±0.19 | 0.68±0.18 | 0.50±0.15 | 0.45±0.10 | 0.73±0.16 | 0.75±0.21 | 0.74±0.25 | 0.78±0.24 |
| Phase plane | 3.91±0.70 | 3.66±0.99 | 2.20±0.52 | 2.19±0.65 | 1.52±0.38 | 1.42±0.25 | 2.98±0.67 | 2.81±0.77 | 2.85±0.80 | 2.97±0.56 |
| **Total** | | | | | | | | | | |
| Mean velocity | 3.90±0.74 | 3.80±0.84 | 2.31±0.54 | 2.28±0.44 | 1.54±0.25 | 1.49±0.20 | 3.05±0.72 | 3.11±0.66 | 3.19±0.81 | 3.10±0.66 |
| Phase plane | 5.67±0.90 | 5.54±1.31 | 3.39±0.70 | 3.35±0.69 | 2.30±0.44 | 2.20±0.35 | 4.13±0.83 | 4.11±0.84 | 4.18±1.00 | 4.26±0.75 |
| Area (95% ellipse) | 30.9±12.6 | 28.3±14.5 | 9.93±5.29 | 9.38±4.24 | 6.41±3.49 | 3.92±1.67 | 8.30±3.28 | 7.87±4.14 | 8.92±4.98 | 9.59±4.59 |

Values are shown in mean±SD, COP: Center of Pressure, SD: Standard Deviation, AP: Anteroposterior, ML: Mediolateral, Units of COP measures are as follows: cm (SD of amplitude); cm $sec^{-1}$ (SD of velocity/mean velocity); $cm^2$ (Area). Phase plane is in an arbitrary unit

Table 4: Test-retest reliability analysis of COP measures

| | Double limb stance | | | | | | | | | Single limb stance | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | (Healthy limb) | | | (Affected limb) | | |
| | Foam surface Eyes close | | | Rigid surface Eyes close | | | Rigid surface Eyes open | | | Rigid surface Eyes open | | | Rigid surface Eyes open | | |
| Postural parameters | ICC (95% CI) | CV | MMDC | ICC (95% CI) | CV | MMDC | ICC (95% CI) | CV | MMDC | ICC (95% CI) | CV | MMDC | ICC (95% CI) | CV | MMDC |
| **ML** | | | | | | | | | | | | | | | |
| SD of velocity | **0.88** (0.64 0.96) | 20.7 | 0.55 | 0.61 (0.07 0.87) | 18.2 | 0.51 | 0.69 (0.20 0.90) | 17.7 | 0.27 | **0.72** (0.31 0.91) | 19.3 | 0.51 | **0.93** (0.77 0.97) | 24.3 | 0.33 |
| SD of amplitude | **0.73** (0.32 0.91) | 22.7 | 0.20 | 0.52 (-0.03 0.83) | 21.8 | 0.20 | 0.50 (-0.05 0.82) | 27.8 | 0.18 | **0.71** (0.24 0.90) | 19.8 | 0.10 | **0.80** (0.48 0.94) | 22.6 | 0.10 |
| Phase plane | **0.88** (0.64 0.96) | 20.6 | 0.55 | 0.65 (0.16 0.88) | 18.1 | 0.51 | 0.69 (0.22 0.90) | 18.2 | 0.27 | **0.72** (0.31 0.91) | 18.7 | 0.51 | **0.92** (0.77 0.97) | 23.7 | 0.39 |
| **AP** | | | | | | | | | | | | | | | |
| SD of velocity | 0.46 (-0.10 0.80) | 22.4 | 1.16 | **0.84** (0.53 0.92) | 27.1 | 0.43 | 0.67 (0.22 0.59) | 21.1 | 0.27 | **0.83** (0.54 0.94) | 26.2 | 1.74 | 0.59 (0.04 0.95) | 23.1 | 0.82 |
| SD of amplitude | 0.45 (-0.11 0.80) | 27.7 | 0.51 | 0.66 (0.15 0.89) | 27.4 | 0.20 | 0.61 (0.12 0.86) | 26.5 | 0.14 | **0.72** (0.27 0.91) | 25.3 | 0.20 | **0.84** (0.55 0.95) | 32.1 | 0.18 |
| Phase plane | 0.49 (-0.06 0.81) | 22.4 | 1.18 | **0.84** (0.53 0.95) | 26.5 | 0.43 | 0.66 (0.21 0.88) | 21.3 | 0.33 | **0.83** (0.54 0.94) | 24.8 | 0.55 | 0.61 (0.08 0.87) | 23.2 | 0.82 |
| **Total** | | | | | | | | | | | | | | | |
| Mean velocity | **0.89** (0.68 0.96) | 20.4 | 0.47 | **0.87** (0.62 0. 96) | 21.3 | 0.33 | **0.80** (0.48 0.94) | 14.9 | 0.18 | **0.88** (0.66 0.96) | 22.3 | 0.43 | **0.96** (0.86 0.98) | 23.3 | 0.20 |
| Phase plane | **0.71** (0.25 0.90) | 19.7 | 1.20 | **0.88** (0.65 0.96) | 20.6 | 0.43 | **0.83** (0.52 0.94) | 17.4 | 0.27 | **0.88** (0.64 0.96) | 20.2 | 0.55 | **0.79** (0.43 0.93) | 21.2 | 0.80 |
| Area (95% ellipse) | **0.65** (0.17 0.88) | 45.7 | 15.74 | **0.74** (0.32 0.61) | 49.3 | 4.86 | 0.10 (-0.27 0.55) | 49.9 | 4.98 | 0.53 (-0.04 0.84) | 46.0 | 5.08 | **0.75** (0.35 0.93) | 51.7 | 4.68 |

ICCs greater than 0.70 are in bold, ICC: Intraclass Correlation Coefficient; CI: Confidence Interval; CV: Coefficient of Variation; MMDC: Minimal Metrically Detectable Change

ML direction had the lowest values across most conditions (CV range = 14.9 to 24.3%) and area (95% ellipse) had the highest values (CV range = 45.7 to 51.7%).

The main purpose of this study was to determine the test-retest reliability of COP measures with a level of standardization that would be generalized to most clinical settings. Therefore, partially standardized approach was used (Domholdt, 2005) so that, the experimenter, time, environment and conditions were the same for both sessions but the order of conditions was random between sessions.

Although, there have been several clinical studies that have used COP measures to evaluate postural stability in patients with ACL deficiency (Bonfim *et al*., 2003; Gauffin *et al*., 1990; Henriksson *et al*., 2001; Lysholm *et al*., 1998), to date no methodological research has been conducted to determine test-retest reliability of these COP measures in this population. In addition, the inappropriate use of healthy subjects to establish the reliability of clinical measures has the potential to inflate reliability estimates because healthy participants may be easier to measure than patients (Domholdt, 2005). Addressing this knowledge void encouraged us to conduct our research in a group of patients with ACL injury.

Participants were tested under the diverse stressful postural conditions. These postural conditions are commonly used by researchers to evaluate balance under positions of instability and/or decreased availability of sensory inputs (Doyle *et al*., 2005). The rationale for choosing of the presented COP measures among numerous measures was their common use in research which allows the comparison of results across different studies. Also, some parameters like minimum, maximum and peak-to-peak amplitude are not suggested to be used because they use one or two data points among the entire data points recorded in a trial which can cause great variance between subjects and trials (Palmieri *et al*., 2002).

In a reliability study, the possibility of any systematic bias must be detected. Systematic bias is a non-random change in the values between two trials whereby all participants perform consistently better in one trial resulting from learning or fatigue effects (Batterhama and George, 2003). In this investigation, the absence of systematic bias demonstrated that the protocol was less likely caused fatigue or learning effects between sessions (Santos *et al*., 2008).

Present results showed that all parameters across most conditions of postural difficulty had moderate to high correlation. Mean velocity and total phase plane parameters were the most reliable measures having high to very high correlation across all postural conditions. This acceptable correlation decreases the risk of type 2 error or, in other words, increases the power of mean velocity and total phase plane parameters to discriminate the balance performance between groups. Consistent with these results, Riley *et al*. (1995) concluded that both phase plane and velocity parameters were highly discriminating COP measures between the healthy and bilateral vestibular hypofunction groups. Lafond *et al*. (2004) concluded that COP mean velocity is the most discriminating parameter which can be used to assess the age-related changes of postural control.

Present results showed low to moderate correlation for some COP measures in some conditions. Increase in the number of trials needed to be averaged in each testing session as well as the trial duration may obtain acceptable reliability for these COP measures (Carpenter *et al*., 2000; Lafond *et al*., 2004). However, we need to have enough time and cost required for the number and length of trials necessary for desired reliability. Furthermore, if measurements are taken in a clinical setting, patients may not be able to tolerate these repeated measurements over long durations because of fatigue (Santos *et al*., 2008).

An interesting result of the current study was that consistent with relative reliability; absolute reliability was higher for mean velocity and total phase plane parameters relative to other measures in most experimental conditions, that is the measurement error was small on repeated measurements (Atkinson and Nevill, 1998). Therefore, the authors suggest these reliable measures for both discrimination between healthy and ACL injured population (between subject design) and detection of balance training effects in these patients (within subject design). In agreement with this suggestion, Ageberg *et al*. (2003) concluded that average speed of postural sway is sensitive in detecting the effects of exercise in healthy subjects.

This study also estimated the MMDC of these COP measures. MMDC values represent the lower limit of the clinically significant amount of difference that can be resolved to monitor the patient's balance improvement after a clinical intervention (Lafond *et al*., 2004).

Reliability is a population-specific measurement property. Most reliability designs have targeted young healthy and/or elderly patient individuals as the study populations and necessarily have not compared the reliability results of between-group individuals (Table 1). Thus, because there have been several studies to investigate the reliability of COP measures in healthy participants, we did not recruit a control group in our study but it is suggested that a healthy, aged match control group be included in the future study to have a comparison between reliability results of healthy and ACL injured populations.

This study acknowledged by small sample size as one of the limitations of the present study. However, to investigate if the results can be generalized to a larger sample of patients with ACL injured patients, we compared the distribution and ability of different COP parameters to discriminate three levels of postural difficulty between 12 patients participated in the present study and a larger group including 27 patients participated in another study, methodologically similar to this study conducted by our research group. The analysis revealed no significant differences of mean and variances of parameters between the groups, indicating the homogeneity of two groups and hence increasing the generalizability of the results to a larger sample.

## CONCLUSION

Present results showed acceptable reliability of mean velocity and total phase plane parameters in all conditions of postural difficulty among some classic COP measures. However, further studies are needed to investigate the parameters used in the present study both in injured and non injured subjects.


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## REFERENCES


Ageberg, E., D. Roberts, E. Holmstrom and T. Friden, 2003. Balance in single-limb stance in healthy subjects-reliability of testing procedure and the effect of short-duration sub-maximal cycling. BMC Musculoskelet Disord., 4: 14-14.

Ageberg, E., D. Roberts, E. Holmstrom and T. Friden, 2004. The effect of short-duration sub-maximal cycling on balance in single-limb stance in patients with anterior cruciate ligament injury: A cross-sectional study. BMC Musculoskelet Disord., 5: 44-44.

Atkinson, G. and A.M. Nevill, 1998. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports Med., 26: 217-238.

Batterhama, A.M. and K.P. George, 2003. Reliability in evidence-based clinical practice: A primer for allied health professionals. Phys. Ther. Sport, 4: 122-128.

Benvenuti, F., R. Mecacci, I. Gineprari, S. Bandinelli and E. Benvenuti *et al.*, 1999. Kinematic characteristics of standing disequilibrium: Reliability and validity of a posturographic protocol. Arch. Phys. Med. Rehabil., 80: 278-287.

Bonfim ,T.R., C.A. Jansen Paccola and J.A. Barela, 2003. Proprioceptive and behavior impairments in individuals with anterior cruciate ligament reconstructed knees. Arch. Phys. Med. Rehabil., 84: 1217-1223.

Carpenter, M.G., J.S. Frank, D.A. Winter and G.W. Peysar, 2000. Sampling duration effects on center of pressure summary measures. Gait Posture, 13: 35-40.

Corbeil, P., J.S. Blouin and N. Teasdale, 2004. Effects of intensity and locus of painful stimulation on postural stability. Pain, 108: 43-50.

Corriveau, H., R. Hebert, F. Prince and M. Raiche, 2000. Intrasession reliability of the Arch. Phys. Med. Rehabil., 81: 45-48.

Corriveau, H., R. Hebert, F. Prince and M. Raiche, 2001. Postural control in the elderly: An analysis of test-retest and interrater reliability of the COP-COM variable. Arch. Phys. Med. Rehabil., 82: 80-85.

Domholdt, E., 2005. Rehabilitation Research: Principles and Applications. 3rd Edn. Elsevier Saunders, USA., ISBN: 0-7216-0029-8, pp: 260-270.

Doyle, T.L., A.F. Newton and R.U. Burnett, 2005. Reliability of traditional and fractal dimension measures of quiet stance center of pressure in young, healthy people. Arch. Phys. Med. Rehabil., 86: 2034-2040.

Gauffin, H., G. Pettersson, Y. Tegner and H. Tropp, 1990. Function testing in patients with old rupture of the anterior cruciate ligament. Int. J. Sports Med., 11: 73-77.

Henriksson, M., T. Ledin and L. Good, 2001. Postural control after anterior cruciate ligament reconstruction and functional rehabilitation. Am. J. Sports Med., 29: 359-366.

Lafond, D., H. Corriveau, R. Hebert and F. Prince, 2004. Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. Arch. Phys. Med. Rehabil., 85: 896-901.

Lysholm, M., T. Ledin, L.M. Odkvist and L. Good, 1998. Postural control-a comparison between patients with chronic anterior cruciate ligament insufficiency and healthy individuals. Scandinavian J. Med. Sci. Sports, 8: 432-438.

Mathur, S., J.J. Eng and D.L. MacIntyre, 2005. Reliability of surface EMG during sustained contractions of the quadriceps. J. Electromyogr. Kinesiol, 15: 102-110.

Palmieri, R.M., C.D. Ingersoll, M.B. Stone and B.A. Krause, 2002. Center-of-pressure parameters used in the assessment of postural control. J. Sport Rehabil., 11: 51-66.

Riley P.O., B.J. Benda, K.M. Gill-Body and D.E. Krebs, 1995. Phase plane analysis of stability in quiet standing. J. Rehabil. Res. Dev., 32: 227-235.

Roos, E.M. and L.S. Lohmander, 2003. The knee injury and osteoarthritis outcome score (KOOS): From joint injury to osteoarthritis. Health Qual. Life Outcomes, 1: 64-64.

Santos, B.R., A. Delisle, C. Lariviere, A. Plamondon and D. Imbeau, 2008. Reliability of centre of pressure summary measures of postural steadiness in healthy young adults. Gait Posture, 27: 408-415.

Shrout, P.E. and J.L. Fleiss, 1979. Intraclass correlation: Uses in assessing rater reliability. Psychol. Bull., 86: 420-428.

Stam, C., 2005. Nonlinear dynamical analysis of EEG and MEG: Review of an emerging field. Clin. Neurophysiol., 116: 2266-2301.

Suarez, H., M. Arocena, A. Suarez, T.A. De Artagaveytia, P. Muse and J. Gil, 2003. Changes in postural control parameters after vestibular rehabilitation in patients with central vestibular disorders. Acta Otolaryngol., 123: 143-147.

Weir, J.P., 2005. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. J. Strength Cond. Res., 19: 231-240.

Winter, D.A., 2005. Biomechanics and Motor Control of Human Movement. 3rd Edn., John Wiley and Sons Inc., Hoboken, N.J., New York, ISBN: 978-0-471-44989-8, pp: 49.