Evaluation of Postural Stability during Quiet Standing, Step-Up and Step-Up with Lateral Perturbation in Subjects with and without Low Back Pain


Abstract

The evaluation of postural stability during quiet stance, step up and step up task with perturbation using posturography could be useful in treatment and outcome monitoring in chronic low back pain rehabilitation (CLBP). The aim of this study was twofold and investigating 1) differences of postural stability measures between CLBP patients and healthy participants during above mentioned tasks. 2) postural stability characteristics between control and movement impairment groups of CLBP patients on above tasks. Fourteen CLBP and fifteen normal individuals participated and posturography outcome variables were obtained during above tasks. The low back pain subjects showed significant different anterior-posterior ($p=0.01$) as well as medio-lateral ($p=0.05$) postural stability characteristics during the step up task with external perturbation, whereas quiet standing and simple step up task did not show any differences. In addition to these values, in CLBP population, the maximum COP excursion ($p=0.01$), standard stability ($p=0.02$) and the stability scores ($p=0.02$) were also found significant in step up with perturbation task compared to healthy participants. Sub-group analysis in CLBP patients ($p=0.005$) shows significant differences only in medio-lateral COP excursions during normal standing. As the task difficulty increases CLBP patients exhibited significantly different postural stability characteristics compared to healthy participants. Subgroup analysis of CLBP population revealed no significant differences in tasks with higher difficulty such as step up and step up task with lateral perturbation conversely significant difference was observed during quiet standing in this study.

Keywords: Postural Balance; Posturography; Chronic Back Pain; Step Up Task
4.1 Introduction

Musculoskeletal disorders have significant influence on balance performance (Byl and Sinnott 1991; Wegener et al. 1997) and limit the use of corrective movement strategies during balance perturbations (Shumway-Cook 1996). Byl and Sinnott (1991) reported that low back pain patients had a greater degree of sway, a greater use of hip strategy and a more posterior center of pressure, in erect stance when compared to healthy participants. Mok et al (2004) suggested that people with low back pain demonstrated an inability to control hip strategy for balance recovery in response to an anterior-posterior balance challenge.

Postural stability is achieved as the result of the interaction between the sensory and motor systems, for a given task and environment, which ultimately produces postural forces that result in movement of the center of pressure (COP) to maintain balance or posture and it is totally independent of the center of mass (COM). According to Winter (1995) the COP always lies at the stance foot, but in case of bilateral stance the COP lies somewhere between the two feet, depending on the relative weight taken by each foot. COP displacements are commonly recorded using force platforms and gives major information about the postural control for a given task, performed on the forceplate (Nardone and Schieppati 1988; Noe et al. 2003; Slijper and Latash 2000).

A variety of tasks and test situations used to examine postural stability in CLBP patients have been reported in literature. They were obtained from subject induced perturbations (voluntarily generated) or external force induced perturbations that challenged postural control. Some reported methods were stepping (Burleigh et al. 1994; Chang et al. 1999; Mann et al. 1979), bipedal to unipedal support (Poleyn et al. 1998), slow and fast extremity movements (Rogers and Pai 1993), sit to stand (Magnan et al. 1996; Shum et al. 2005, Shum et al. 2009), reaching and pick up tasks (Silfies et al. 2005; Shum et al. 2007), surface translations (Hitt et al. 2006), limb loading (Leinonen et al. 2007) and calibrated force transducers-induced perturbations (Radebold et al. 2000; Stokes et al. 2006).

Recent studies have reported problems in the domain of functional activities of the CLBP patients on the task specific perspective of the motor control rehabilitation i.e., impaired thorax, lumbar and pelvis segmental coordination and poor erector spinae activity patterns during walking (Lamoth et al. 2002; Lamoth et al. 2006(a); Lamoth et al. 2006(b)) and decreased power flow of the pelvic and lower limb segments and altered load.
sharing strategies during the sit-to-stand and stand-to-sit activities (Shum et al. 2005; Shum et al. 2009).

On the other end, numerous studies have demonstrated dysfunction in the muscular domain i.e., altered neuromuscular recruitment patterns, temporal and amplitude insufficiencies in the activity of deep abdominal and para-spinal muscles of CLBP patients compared to healthy individuals during activities such as bending and spinal loading (Hodges and Richardson 1996; Hodges 2001; Radebold et al. 2000; Watson et al. 1997).

In many studies quiet standing was commonly used for postural stability assessment despite the fact that most onset of back pain reported during dynamic functional activities. These assessments may be helpful in evaluating and screening back pain but the clinical use of these results in back pain rehabilitation was found to be limited. Conversely these kinds of simple tasks particularly voluntarily generated tasks can be used as a training modality in the early functional back rehabilitation or along with other active exercise interventions such as walking and bicycling (Kerr et al. 2007; Smeets et al. 2006). Studies have also advocated concurrent muscle (strength) training as well as postural stability training for comprehensive back rehabilitation (Kollmitzer et al. 2000; Luoto et al. 1998) and successful functional restoration programe (Pfingsten 2001; Poiraudreau et al. 2007)

However postural stability variables for these functional tasks and their processes are not well understood in back pain rehabilitation, despite its potential as a window into functional back rehabilitation. Hence detailed kinetics, kinematics and postural stability characteristics need to be determined before applying into clinical practice. As postural control fundamentally relies on two domains and in view of the goal of postural control, such task should represent and concern ability in both maintaining a given posture and ensuring equilibrium in position change (Massion 1994; Horak 2006).

Hence in this study step up task was used to examine the postural stability in CLBP patients compared to healthy participants. Further Sims and Brauer (2000) reported that the step up task provided a greater challenge to medio-lateral (m-l) postural stability than step forward. An external perturbation during mid of step-up task was introduced to examine the effect of external perturbation on step-up mediated postural control responses in CLBP and healthy participants. The direction of perturbation was kept to the lateral side to examine the influence of laterally induced postural adjustments during step-up rather than sagittal fashion commonly used in many studies. Hence, the primary aim of this study was to investigate differences in postural stability or sway characteristics between groups with
and without low back pain during quiet standing, voluntary step up and step up with external lateral perturbation.

On the other hand studies reported larger COP displacements (Della Volpe et al. 2006; Popa et al. 2007) with narrow and self-selected natural stance widths. Hence we hypothesized with wider stance width CLBP population demonstrate reduced likelihood of greater resultant COP displacements. Further an attempt was made to investigate whether a difference exist between movement and control impairment groups of CLBP subjects (O’Sullivan 2005) on medio-lateral postural responses. This study also aimed to test this hypothesis. This sub-grouping approach was used to differentially analyze postural stability characteristics in complex heterogeneous CLBP population.

4.2 Methodology

4.2.1 Selection and Description of Participants

Chronic low back pain participants were recruited from the affiliated hospitals and rehabilitation centers of SCPTRC Mangalore, Karnataka, India. Informed consent was obtained from all the subjects, which was approved by the university ethical committee. Data were collected from fourteen individuals with chronic non-specific low back pain and fifteen healthy individuals.

CLBP subjects had a mean age of 36.8(2.8(SD)) years, mean height of 165.7(8.8) centimeters, mean body mass index (BMI) of 22.3(3.3) and healthy participants had a mean age of (SD) 32.7(1.2) years, mean height of 163.8(9.0) centimeters and BMI of 20.9(3.6).

Patients with chronic localized low back pain lasting more than 6 months and radiating no further than the buttock with normal neurological examination were included in this study. Among these LBP subjects, none of them reported any history of neurological disorders or major musculoskeletal disorders. Any history of sciatica or radicular involvement, previous lumbar or abdominal surgery was also excluded. An orthopedic surgeon performed the examination.

All CLBP subjects were instructed to avoid medication 24 hours before the test. Prior to the experiment, the CLBP patients completed visual analog scale (VAS) [(Mean (SD)) 4.72(2.5)] for actual pain intensity ratings (0= no pain, 10= most severe pain), had a disability level of 7.7(4.7) measured by the Ronald Morris Disability Questionnaire (RMDQ) (0= no disabilities, 24= severe disabilities) and also had the Fear Avoidance Belief for Work score component of 19.8(1.2) (0 = minimal score, 42 = maximum score)
and Physical activity score component of 14(4.5) (0 = minimal score, 24 = maximum score) measured by the Fear Avoidance Belief Questionnaire (FABQ).

A musculoskeletal assessment to identify movement impairment or control impairment based on guidelines provided by O’Sullivan (2005) was performed by a sports physiotherapist with 6 years of clinical experience in back rehabilitation trained under Curtin University, Australia. This classification system was based on set of substantially reliable essential characteristics proposed by Dankerts and O’Sullivan et al. (2006). The control impairment group were identified by the presence of “pain with minimal radiation and absence of impaired movement of the symptomatic segment in the painful direction of movement or loading (based on clinical joint motion palpation examination)”. If hypomobility or the presence of impaired movement was judged at involved segment, the subject was categorised into movement impairment group.

BERTEC forceplate, (Balance Screener Setup) Columbus, Ohio 43229, U.S.A. was used to record the COP displacements during normal quiet standing, voluntary step-up, and step-up with perturbation. The force plate’s COP measurements were found valid and reliable in determining postural stability parameters (Goldie et al. 1989; Spradley et al. 1996).

For step-up with lateral perturbation task, initially Digital Acquire setup was used to determine the weight shift on the stepping leg. Based on the COP displacements postural stability outcomes were measured using screener setup and their calibration procedures were reported in Annexure 1 (Parker 1973; http://bertec.com/uploads/pdfs/manuals/BalanceCheck%20Screener.pdf).

4.2.2 Normal Quiet Standing

A marked foot chart with the inter-malleolar distance of 25-cm placed on the forceplate was used as a reference. While standing on the foot chart participants were instructed to fix their gaze at a point on the wall with visual gaze at their eye level to minimize head tilting and to stand for 30 second on the forceplate.

4.2.3 Voluntary Step-Up

The subjects were asked to stand 10 cm in front of the forceplate which height was adjusted to 10 cm. In order to minimize the abnormal postural strategies the step height was kept low in this study. The subjects were informed to step-up on the forceplate using natural speed. A metronome was used to coordinate the step-up task for 5 consequent beeps to complete the entire step-up task. The entire step up task was completed within 10 seconds and data was stored.
4.2.4 Step-Up Task with Lateral Perturbation

All participants were informed to achieve and maintain half of their body weight on the forceplate monitor using their stepping leg while maintaining the stance foot on the ground. Once the participants achieved the necessary weight level on the forceplate, an external perturbation was provided at the stepping leg’s side through pendulum setup. COP excursion of above 2 standard deviations for 50 milliseconds from quiet standing in Medio-Lateral direction was kept as minimal requirement of perturbation and weight on the pendulum was calculated as reference weight. This was determined by ‘Digital Acquire’ setup of the forceplate. Perturbations which triggered stumbling reactions were excluded and weights on the pendulum were readjusted to identify the exact reference weight through maximum of three trial tasks.

The pendulum weights were adjusted to produce similar perturbation on the Bertec screener setup. To minimize the amount of measurement error, particularly to achieve 50% body weight on forceplate, up to three trials were provided to become fully comfortable and familiar with the testing protocol. The pendulum setup was suspended from the ceiling and the resting position of pendulum was positioned at midpoint of base of support on the foot chart on the forceplate. The perturbation was given at shoulder level by moving the pendulum laterally and released manually by the operator. Their weights were adjusted based on above minimal COP M-L shift excursion criteria. Mean values of three trials of each task were taken for statistical analysis. Up to four trials were performed to achieve valid recordings from the forceplate during step-up with lateral perturbation. Independent t-test was used to analyze the difference between CLBP and normal participants. A p-value of less than 0.05 was used to determine significance (Appendix E, Figure V to VII)

4.3 Results

Postural sway characteristics in medio-lateral, anterior-posterior (a-p) direction, maximal COP amplitudes, percentages of maximum standard stability, and stability scores were significantly different in step-up with lateral displacement task between CLBP and healthy participants (p<0.05). Quiet standing and step-up task did not demonstrated significant difference between both the population (p<0.05).
4.4 Discussion

4.4.1. Analysis of Quiet Standing and Step-Up Task

This study found no differences in COP excursions on medio-lateral and anterior-posterior directions, maximal COP excursions and maximum standard stability scores during step-up and quiet standing between healthy participants and CLBP subjects (Figure 1,2,3). In our study CLBP patients reported COP sway characteristics (amplitude) similar to healthy participants contrary to smaller postural sway commonly reported in CLBP population during usual standing and sitting tasks (Van dieen 2010; Van daele 2010; Bouche 2006; Luoto 1998) or larger postural sway (Byl and Sinnott 1991) in literatures.

These non significant changes in COP (m-l) excursions, COP (a-p) excursions, maximum COP excursions and standard stability scores during quiet standing and stepping up tasks found in CLBP patients compared to healthy participants clearly indicating that with a wider base of support abnormal postural strategies can be minimized in CLBP population.

The results support the hypothesis that abnormal propensity of COP oscillations can be reduced by altering the stance width from narrower to wider in CLBP population. Non significant larger stability score also support this notion, 93.3% and 94.3% respectively in CLBP and healthy participants indicates that the patient population was able to maintain perfect stillness as close to healthy participants in wider stance width (Fig 4).

Some aspects of our methodology warrant attention particularly step-up task and their non significant COP excursions in CLBP versus healthy participants. The height and length of step-up (10cm) used in our study was relatively lower compared to exigencies of day-to-day activities. Hence step height alterations can be varied in future studies to determine the relationship between postural stability and COP displacements in CLBP patients.

4.4.2. Analysis of Step-Up with Lateral Perturbation

During step-up with lateral destabilization postural responses CLBP subjects exhibited significant increase in COP excursions on medio-lateral as well as anterior-posterior directions (Fig 1,2).

During step-up with perturbation task, CLBP patients further demonstrated significant increase in maximum COP excursions ($p=0.01$) and maximum standard stability ($p=0.02$) (Fig 4). Maximum COP excursion indicates the magnitude of the movement in the direction of maximum movement. The smaller value in healthy
participants indicated better postural adjustments during step-up with perturbation compared to CLBP population.

Maximum standard stability scores represented how much of the standard limit of stability was used during the test in the direction of maximum movement. A higher score of CLBP (41%) compared to the scope of the healthy participants (28%) indicated a larger standard limit of stability used by CLBP patients during step-up with perturbation task. This indicates the inability of the CLBP population to prepare and resist the pre-informed lateral displacement applied in this study and tendency to lean larger in m-l direction for lateral displacement predisposing them to fall laterally. However healthy participants were well prepared and resisted the suddenly applied lateral displacement and demonstrated significantly smaller lean in m-l direction.

Stability scores represent the ability to maintain balance during the test. 100% indicates that the patient was able to maintain perfect stillness. 0% indicates that the patient used all the standard limit of stability during the test. The obtained stability scores for CLBP patients (58%) compared to healthy participants (71%) during step-up with lateral perturbation task was significantly lower (p<0.02, Figure 5) indicating CLBP patients were unable to maintain balance during the step-up with lateral perturbation.

Further, CLBP subjects demonstrated no significant changes compared to healthy participants in minimum COP excursion, minimum/maximum COP excursion ratio, minimum stability, and direction of instability parameters during step-up with perturbation task, step-up and quiet standing. The above results clearly indicate that frontal and sagittal plane control dysfunction in CLBP subjects while encountering demanding postural task during this study.

The findings of this study support the literatures reporting relation between COP displacements and stance width. Larger medial-lateral sway and COP oscillations were reported with narrow stance width in healthy participants (Kirby et al. 1987; Henry et al. 2001). Henry et al (2001) also reported more trunk displacements in narrow stance due to larger changes in COP oscillations in response to lateral perturbations. They further reported during wide stance, equilibrium control relied on passive stiffness resulting from changes in limb geometry where as narrow stance relied on active postural strategy regulating loading and unloading of the limbs.

Further studies have reported increased stiffness of legs-pelvis and the hip-ankle coupling (Day et al. 1993), and hip abductor/ adductor muscles mediated stiffness control for frontal plane motion with wider stance width (Winter et al. 1996; 1998).
sagittal plane control dysfunction found in our study may be attributed to dysfunction in hip strategy (Mok et al. 2004) and corrosion of postural control of above-mentioned mechanisms during exigent situations in CLBP patients.

To test the other hypothesis, i.e., to identify the differences between movement and control impairment in CLBP population, the values of COP excursions on medio-lateral direction was analyzed as this was the direction of the perturbation in our study. Statistical analysis revealed significant differences between movement and control impairment groups only during quiet standing (p<0.05) and did not reveal any difference during step-up task and step-up with lateral perturbation task (Figure 6). Control impairment group (n=6) demonstrated significantly higher mean COP (m-l) oscillations than the movement impairment group (n = 8). These results provide preliminary evidence for the importance of sub-grouping of CLBP patients for their specific interventions. However sub-grouping them further into larger group of ‘flexion pattern’, ‘active extension pattern’ and ‘multiple pattern’ could have provided more distinct information on postural control characteristics rather than generally classifying them into movement and control impairment group while examining task specific postural control responses.

4.5 Implications

These simple functional tasks, if practiced repeatedly and cyclical in manner, specific muscle training can be achieved that invariably facilitate the desired functional task with minimal abnormal postural strategies in CLBP patients (for e.g. recumbent cycling for the sit-to-stand and step-up tasks). Further the use of these robust, highly flexible cyclic movements such as stepping and step-up can benefit from the advantage of sequentially stretching and shortening of the muscles involved to produce more work (force) and use of spinal neural oscillators that optimize the postural control strategies related to locomotion (Kerr et al. 2007; Smits-Engelsman et al. 2006)

The assessment of postural stability characteristics of these simple functional tasks may help clinicians to quantify the impairments associated with these tasks, may provide effective intervention strategies aimed at optimizing abnormal postural control variables and may help in assessing the efficacy of treatment strategies for the training of the particular task.

Our findings suggest that use of wider stance width during exercise sessions of early functional and motor/postural control specific back rehabilitation can be helpful in
reducing abnormal postural strategies commonly reported with patients selected or narrow stance width.

4.6. Limitations

Perturbation was induced by manual method and adjusted accordingly with the postural adjustments responses produced during familiarization trials. It may be possible that some participants might have developed rapid adaptation to the test situations. Larger step length, step height, maximum foot width and foot length with narrow to wider base of support combinations should be considered in future studies to examine the postural stability related parameters in back pain patients. More precise sub-grouping of CLBP patients could have resulted in significant different postural responses during tested tasks in this study. Larger sub-group sample size with improved research methods are needed to substantiate the results.

4.7 Conclusion

CLBP population demonstrated frontal and sagittal plane control dysfunction while encountering demanding postural task during this study. No significant difference was observed in subgroups of CLBP population while encountering difficult postural adjustments. Using wider stance width and adequate monitoring of postural stability responses during early functional specific back rehabilitation can curtail the problem of inducing abnormal postural strategies in CLBP patients as poor stability and control may influence abnormal spinal loading and sustain the production of peripheral nociception.
4.8 References


Figure Captions

Figure 1: COP (m-l) excursions during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent ‘t’ test results.

Figure 2: COP (a-p) excursions during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent 't' test results.

Figure 3: Maximum COP excursions during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent 't' test results.

Figure 4: Maximum Standard Stability% during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent 't' test results.

Figure 5: Stability scores% during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent 't' test results.

Figure 6: Sub-group analysis of COP(m-l) excursions during step-up with perturbation, step-up and quiet standing task between movement impairment and control impairment CLBP groups with paired 't' test results.
Figure 1: COP (m-l) excursions during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent ‘t’ test results

Figure 2: COP (a-p) excursions during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent ‘t’ test results
Figure 3: Maximum COP excursions during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent 't' test results

Figure 4: Maximum Standard Stability% during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent 't' test results
Figure 5: Stability scores% during step-up with perturbation, step-up and quiet standing task in CLBP and healthy participants with independent ‘t’ test results

![Stability Score CLBP vs Stability Score Normals](image)

Figure 6: Sub-group analysis of COP(m-l) excursions during step-up with perturbation, step-up and quiet standing task between movement impairment and control impairment CLBP groups with paired ‘t’ test results

![COP(m-l) MovImp vs COP(m-l) ConImp](image)
Annexure-1

COP (m-l) Excursions: The amount of movement of the Center of Pressure in the lateral plane. It is calculated as the projection of the 95% confidence ellipse on the lateral axis. (95% Confidence Ellipse - The ellipse containing 95% of the Center of Pressure points. It is determined by multiplying the standard deviation of the coordinates of the Center of Pressure points by 1.96).

COP (a-p) Excursions: The amount of movement of the Center of Pressure in the sagittal plane. It is calculated as the projection of the 95% confidence ellipse on the sagittal axis.

Maximum COP Excursions: The maximum movement of the Center of Pressure in the Direction of Maximum Instability. (Direction of Max Instability - The direction in which the patient is less stable, and therefore most likely to fall. It corresponds to the angle between the patient’s posterior-anterior (forward) direction and the major axis of the ellipse. Angles to the left are indicated as negative numbers)

Maximum Standard Stability %: How much of the Standard Limits of Stability was used in the patient’s Direction of Maximum Instability.

Stability Scores %: is a score of the patient's ability to maintain balance during the test. It is calculated as percentage of $S_{standard} - A_{max} / S_{standard}$, where $A_{max}$ is the major semi-axis of the 95% confidence ellipse and $S_{standard}$ represents the Standard Limits of Stability, calculated as $S_{standard} = 0.55 H \sin 6.25^0$. H is the patient's height.

Minimum COP Excursion: The maximum movement of the Center of Pressure in the direction of minimum instability (Direction of Min Instability - The direction in which the patient is more stable, and therefore less likely to fall).

Minimum/maximum COP Excursion Ratio: Min/Max CoP Excursion Ratio - The ratio between the Minimum CoP Excursion and the Maximum CoP Excursion.

Minimum Stability: This is an evaluation of the patient's ability to maintain balance. It is calculated as min $[R_{NS\cdot EO} / R_{LoS}]$ % where $R_{NS\cdot EO}$ is the distance from the origin of any point of the 95% confidence ellipse for the normal stability - Eyes Open test and $R_{LoS}$ is the corresponding distance on the ellipse representing the patient's Limits of Stability.