



Research Protocol

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Quantitative Characterization of Postural Sway During Quiet Stance Under Muscle Fatigue in Healthy Young Adults

Isha S Akulwar*¹ and Ishita J Sheth²¹M.P.Th. in Neurosciences Physiotherapy, Associate Professor, K. J. Somaiya College of Physiotherapy, Mumbai, India²B.P.Th., Intern, K. J. Somaiya College of Physiotherapy, Mumbai, India

***Corresponding author:** Isha S Akulwar, M.P.Th. Neurosciences Physiotherapy, Associate Professor, K.J. Somaiya College of Physiotherapy, Mumbai, India, Email: drishasa@yahoo.co.in.

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Introduction

Postural control is a complex task that requires the integration of visual, vestibular and somatosensory inputs from all over the body to assess the position and motion of the body in space and the ability to generate forces to control body position [1]. The task of maintaining upright balance is a critical component in performing most daily activities. Numerous studies [2-15] have investigated the effects of muscular fatigue on the regulation of bipedal quiet upright standing. Generally, a deterioration of postural control with muscular fatigue was reported. Considering postural control as a sensorimotor process [16], it is conceivable that muscular fatigue, known to alter the peripheral proprioceptive system, the central processing of proprioception but also the force-generating capacity [17], affects both the sensory and the motor side of the process. There is substantial evidence on the detrimental effect of fatigue on postural control in older adults [6]. However previous research on healthy young adults has been inconsistent as some studies have shown that postural control in quiet standing and during various dynamic perturbations can be maintained during muscle fatigue [18,19]. Muscle fatigue has been proposed to cause a change in postural control strategy and several researchers have posited that changes in postural control do not necessarily imply a decrease in postural stability [17]. Compensatory postural strategies are triggered to counteract the disturbance of postural control due to muscle fatigue. Most of the investigations cited above referred to postural control following lower limb efforts or general body fatigue. The effects of local fatigue differ according to the localization of the muscles solicited. In recent years, a growing number of studies have reported increased postural sway during quiet standing with muscle fatigue localized at the lower back [7-15]. Various parameters that quantify postural control have been assessed. However, there is no

consensus in the literature as to which variable most accurately represents changes seen in postural control. Thus, this study aimed to determine the effect of trunk extensor muscle fatigue in healthy young adults using various posturography measures. Based on the findings from previous research, we hypothesized that localized fatigue of trunk extensor muscles would significantly reduce static postural stability in healthy young adults.

The effects of muscle fatigue appear to elicit a transient means of postural instability however the recovery of postural stability after fatiguing exercise has not been extensively studied. Thus another purpose of the study was to determine the time period for which the effect of trunk extensor muscle fatigue on postural stability would persist.

Methodology

This was a prospective, experimental study with within-subject, repeated measures design. 50 healthy adults in the age group of 18-25 years volunteered to participate in this study. All the subjects were physically active university students. Individuals with back or lower limb pain, any musculoskeletal or neurological condition or vestibular impairment were excluded from participation. All the subjects provided their informed written consent. The procedures followed protocol and accord with the ethical standards of the institutional review board.

Postural stability was assessed under three conditions:

Condition 1: No fatigue

Condition 2: Fatigue (immediately after fatigue has set in)

Condition 3: Recovery (after every five minutes till complete recovery to No fatigue condition)

The No fatigue condition served as a control condition. Postural stability was assessed from Center of Pressure (COP) based measures obtained using Basic balance master (Neurocom International, version 8.6). Postural sway characteristics were measured during quiet stance. For this test, the subject was instructed to stand barefoot on the force platform with hands relaxed by the side, lateral malleolus perpendicular to the horizontal line marked on the force plate. Test was performed under eyes closed condition to remove vision from contributing to the task of postural control. The footprints were marked to ensure constant foot position and base of support during subsequent assessments in all three conditions. Each condition involved three trials of 10 seconds each. The parameters recorded were COP sway velocity and LOG alignment.

To induce fatigue of trunk extensor muscles the subject was made to perform static trunk extension using modified Sorenson extensor endurance test until maximum exhaustion (Vuillerme et al., 2007). For this task, the subject lay prone on a bench with the upper body unsupported in the horizontal plane and the lower limbs secured to the bench with straps at the hips, knees and ankles. During the test, the subject was instructed to raise his/her upper body to a horizontal position with the head and neck in neutral position and depending on the individual's muscle strength, the arms either remained by the side of the body or were held across the chest. The aim was to induce 100% fatigue. Subject was instructed to hold this position as long as possible till he/she was unable to continue due to muscle fatigue. Verbal encouragement was given to ensure that the subject worked maximally. The subjective exertion level for the fatiguing task was assessed through the Borg 6-20 scale [20].

After termination of this task (Fatigue condition) postural stability was assessed immediately (within 10 seconds) on force platform as described earlier. For recovery of induced trunk extensor muscle fatigue, rest was given in supine lying position. To observe recovery of postural stability (Recovery condition) the COP sway velocity was assessed as described earlier repeatedly after every 5 minutes till the complete recovery to No fatigue condition was achieved.

All the assessments were carried out under standardized conditions. Subjects were asked to refrain from any strenuous physical activity for past 48 hours. Also, use of any medication which can have an effect on neuromuscular fatigue or postural control was prohibited for past 24 hours. Considering the time-of-day effects on fatigue and postural control, assessment was carried out during the same time of the day (afternoon) for all the subjects. All the trials were performed during a single experimental session. All the tests were administered by the same investigator and in an identical manner under all three conditions. Data thus collected was subjected to statistical analysis.

Results

Subjects' mean age, height and BMI were 20.98 ± 1.07 years, 151.98 cm and 22.05 kg/m² respectively. The mean hold time for the modified Sorenson's test was 0.56 seconds. The mean rating of

perceived exertion for the fatiguing task was 17.45 ± 1.39 on Borg scale 6-20. Variables distribution was tested using Kolmogorov-Smirnov test which exhibited significant departures from normality, and therefore nonparametric tests were used for all the analyses. Statistical significance was set at $p < 0.001$.

For the COP sway velocity the average of the three trials was taken as the final reading for analysis. Wilcoxon matched-paired signed rank test was used to compare postural sway velocity in No fatigue and Fatigue condition. A significant increase in the mean COP sway velocity from No fatigue condition (0.32 ± 0.08 , (95% confidence interval (CI)=0.29-0.33) to Fatigue condition (0.44 ± 0.16) (95% CI = 0.39- 0.48), (one-tailed $P < .0001$) was observed.

To analyse the COP sway variability among the three trials, Freidman test with post-test (Dunn's multiple comparison's test) was performed separately for the No fatigue and Fatigue condition. It was observed that fatigue significantly increased the COP sway variability in the Fatigue condition ($p < 0.001$). It was also observed that there was a change in the LOG alignment in the fatigue condition with an anterior shift demonstrated by 71% subjects. These results indicate that postural stability in quiet stance was significantly reduced in the Fatigue condition as compared to the No Fatigue condition.

To determine the recovery period for postural stability, mean values of the consecutive readings for postural sway taken during the Recovery condition were compared with the No fatigue condition. The time during Recovery condition when the postural sway velocity became equal to No fatigue condition was considered as the recovery time for the individual subject. It was observed that mean recovery time for COP sway velocity was 5.1 minutes.

Discussion

The purpose of the present study was to determine the effect of trunk extensor muscle fatigue on postural stability during quiet stance in healthy young adults. Postural stability was assessed from COP time series obtained before and after the fatiguing protocol. Trunk extensor muscle fatigue significantly affected static postural stability as indicated by an increase in postural sway velocity, increased sway variability and forward shift of LOG from No fatigue to Fatigue condition. These results confirm our hypothesis in accordance with previous reports.

The model for spinal stability has the following components:

- Muscles of the spine help to maintain an upright posture.
- The bones and ligamentous structures which provide stability by acting as a passive restraint towards end range of motion.
- The neural control system co-ordinates muscle activity to respond to expected as well as unexpected forces.

Trunk extensors are physiologically postural muscles being rich in type I muscle fibres [21,22]. The erector spinae and multifidi are found to be tonically active in quiet standing and the erector

spinae contract eccentrically to control trunk flexion from a standing position and also when the head or upper limb is moved forward. Both strength and endurance are required to maintain the stability during daily activities as well as unpredictable activities like falls, sudden load on the spine or quick movements. Thus, trunk extensors play a role of continuous activity throughout the day to maintain the posture but pain and inactivity alter the muscles so that they fatigue in normal situations.

Muscle fatigue is defined as an exercise induced reduction in the ability of the muscle to produce force or power whether or not the task can be sustained [23]. Fatigue acts as a disturbance to the postural control system and affects both sensory and motor components leading to decrease in function of postural control system. Thus, neuromuscular fatigue represents a major constraint on the postural control system. It has been suggested from studies that muscular strength and sensory detection are two important factors in fatigue and postural control [11-13,24,25]. Indeed, it is well documented that fatigue in the extensor muscles of trunk reduces trunk's local dynamic stability [26,27]. Trunk muscle fatigue was shown to impair the ability to sense a change in lumbar position, to delay the reaction time of the muscles in response to a sudden load, to reduce the force generating capacity and to increase its variability. Reduction in paraspinal muscle stiffness and force generating capacity, modified trunk muscle [28-46] recruitment with increased co-activation of the trunk flexor musculature, delay in feedback responses, modified paraspinal muscle reflex response with fatigue have been suggested as potentially influencing neuromuscular control of movement and spinal stability.

In this study, the visual and vestibular system was not likely affected by neuromuscular fatigue as the subjects stood with eyes closed on a firm surface and head was aligned upright. Additionally, studies by Allum et al. and Bloem et al. [28,29] have indicated that trunk and hip proprioceptive inputs may provide the triggers for most balance corrections. However, proprioceptive feedback of trunk position is impaired by lumbar extensor fatigue as reported by Taimela et al. [24], Davidson et al. [4]. Considering the lesser role of trunk musculature strength and more reliance on proprioceptive inputs from these muscles, the decrease in static stability during quiet stance as observed in this study can therefore be explained by the diminished proprioceptive feedback from fatigued trunk extensors. This explanation can further be reinforced by studies which suggest that altered neck proprioception due to neck extensor fatigue affects postural control during quiet stance [30-32].

A force platform which was not a component of the biofeedback system was used to measure the displacement of the COP as a gold standard system for assessment of postural control during quiet upright standing. COP velocity: In this study, an increase in the COP sway velocity was observed from No Fatigue to Fatigue condition. COP velocity represents the total distance travelled by the COP over time. This parameter is determined by dividing the total excursion by the trial duration. COP velocity has been shown to be reliable

between sessions when a double legged stance is used ($R = .84$) [33]. Numerous researchers and clinicians [34-41] have used COP velocity to assess changes in COP. An increase in COP velocity is thought to represent a decreased ability to control posture COP variability- Second, post-fatigue an increase in the variability in COP sway from trial 1 to trial 3 was observed. COP variability is thought to measure a central postural-control mechanism [47] in which changes in velocity measures might represent the strategy the body adopts to maintain postural stability [48,49]. This parameter may reflect an additional measure of fatigue-related change on postural stability. To our knowledge, this research is the first to examine the effect of fatigue with this method of analysis.

A change in the LOG alignment: An interesting finding of the study is that 71% of the subjects assumed a slight forward lean post-fatigue as evidenced by an anterior shift of the LOG. This may reflect adoption of a compensatory strategy to maintain postural control in the fatigue condition. Considering the limited literature available in this regard, more studies are warranted to explore these results further. Fatigue protocol: Muscle fatigue can be defined as "an exercise-induced reduction in the ability of muscle to produce force or power whether or not the task can be sustained". 50% or more decreased maximum voluntary contraction resulted in balance deterioration in previous studies. The fatigue protocol used in this study was designed to induce maximum fatigue of bilateral trunk extensor muscles. Subjects were asked to perform the task till they were unable to continue due to muscle fatigue and also, verbal encouragement was given to ensure that they worked maximally. We considered a rating of 17 (very hard) and above on the Borg RPE scale 6-20 as adequate fatigue which reportedly corresponds to approximately more than 90% VO₂ max and maximum heart rate [20]. The fatigue protocol produced desired fatigue in all the subjects as indicated by the reported rating of 17.45 ± 1.39 on RPE scale.

Recovery pattern of Postural stability:

The mean recovery time for fatigue-related changes in postural stability was 5.1 minutes. Few researchers have investigated the recovery rates after trunk extensor muscle fatigue in healthy young adults. It was found that postural sway parameters did not return to pre-fatigue values after 30 minutes (Davidson et al., Pline et al [5,10]) for quiet standing and 20 minutes for one leg balance test (Parreira et al [9]). In yet other studies using different muscle groups, Yaggie JA, McGregor SJ, 2002 reported 20 minutes of recovery for unilateral stance and lean test after lower extremity fatigue and Nardone et al, 1997 reported that fatigue effects during quiet standing lasted until about 15 minutes from the end of fatiguing treadmill exercise. The disparities observed in recovery rates across these studies can be likely due to the methodological variation in terms of type of fatigue protocol and outcome measures used.

Clinical implications

Muscle fatigue represents an inevitable phenomenon for physical and daily activities and is one factor which can affect integrity of neuromuscular system. Postural control is essential to many daily

life activities and to physical and sports practices. Along with the existing evidence results of this study stress the importance of intact trunk extensor muscle function on the regulation of postural stability and thus can have important implications in ergonomic, clinical and rehabilitative areas. For results to be applicable in these areas we recommend future research. Nonetheless findings of this study suggest that trunk extensor fatigue could potentially lead to loss of balance which can be a major concern for certain occupations, neuromuscular conditions and geriatric population. Fatigue-related changes in spinal stability may contribute to the risk of low back injury during fatiguing occupational tasks. The findings reported here indicate that one mechanism by which fatigue contributes to low back disorders may be spinal instability. This information may contribute to the development of ergonomic countermeasures to help prevent low back disorders. Fatigue level effect imply dose-response relationship between localized muscle fatigue and risk of falling that can have important implications in work/rest cycle scheduling for occupations at risk of injurious falls. Considering the significant effect of fatigue on postural stability which lasts for ~ 5 minutes, laboratory assessment of postural stability should be performed before or after 5.1 minutes of assessment or exercises of trunk extensors.

It is important to mention that results of this study should be interpreted in proper context. Fatigue protocol used in this study intended to induce acute and localized fatigue of trunk extensor muscles to maximum exhaustion. However, fatigue experienced during day to day activities and due to some neuromuscular pathology could be different. Posturography parameters allow to objectively estimate the effect of fatigue on postural stability and are sensitive to changes of postural control due to fatigue. Thus, it is plausible to use the posturographic analysis to investigate the effects of conditions that modify sensorimotor integration and could be a useful marker of work-induced fatigue. Results of the present study provide justification for using COP variables to detect alterations in postural control due to fatigue. An important aspect of this study is that along with the COP sway velocity, additional measures of postural sway viz. its variability and LOG alignment was also analysed.

However, there is lack of physiological evidence illustrating why alterations occur in various COP variables. Further research must be conducted to determine the physiological changes occurring in the postural control system when alterations in COP variables are detected. Similar findings were observed in our previous study [50] in which fatigue was induced by repetitive dynamic contractions of trunk extensors and clinical scales of balance viz. one leg standing test and Functional reach test were used to assess the effect of fatigue. Thus, in trying to advance our understanding of how localized fatigue affects the postural control system, it appears that multivariate measures of postural stability are necessary. In addition, we need to focus on which variables provide the greatest reliability and validity, under the condition of fatigue, for clinical quantification of postural stability.

Study Limitations

One of the possible limitations of the study is the subjective nature of the criteria used for muscle fatigue. Another limitation is that dynamic postural stability was not assessed in this study.

Conclusion

Trunk extensor fatigue significantly reduces static postural stability in healthy young adults as observed from an increase in postural sway during quiet stance. Effect of fatigue takes 5.1 minutes to recover completely. We recommend future studies incorporating additional measures of postural control and in individuals with neuromuscular disorders.

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Conflict of Interest

The authors hereby declare that there are no conflicts of interest.

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