Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

A STUDY OF MUSCLE FATIGUE FOR PROLONGED STANDING USING SURFACE ELECTROMYOGRAM: A CASE STUDY

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The purpose of this study is to use surface Electromyogram (sEMG) for the investigation of muscle activities in the lower limbs of human subjects during prolonged standing. It has been suggested that prolonged standing leads to muscle fatigue. This is a single-subject investigation that involves a healthy female subject, performing 8 similar quiet standing trials for one hour on separate days. sEMG methods were used to record myoelectric activity from the Tibialis Anterior (TA), Peroneus Longus (PE) and Gastrocnemius muscles (GA). In the preliminary analysis, a progressive decrease in the median frequency curve has been observed in all muscle groups investigated and the trend was statistically significant ($p < 0.05$). The results of this study confirmed that muscle fatigue sets in during prolonged standing.

KEY WORDS: Muscle fatigue, Electromyogram, prolonged standing.

INTRODUCTION: Many activities in daily life, by extension sporting activities such as golf, shooting and archery demand prolonged standing with adequate postural control. It has been proposed that muscle fatigue is one of the factors affecting the ability of one in the control of posture (Adlerton, Moritz, & Moe-Nilssen, 2003; Mello, Oliveira, & Nadal, 2007; Suponitsky, Verbitsky, Peled, & Mizrahi, 2008). As such, there is a need for investigation into muscle fatigue for better fatigue management.

Prolonged standing requires a continuous activation of multitude of muscles (i.e. isometric contraction of the soleus muscles; isotonic contraction of the Gastrocnemius muscles) for support (Suponitsky, Verbitsky, Peled, & Mizrahi, 2008), and fine tuning so as to maintain the Centre of Gravity (CG) of body within its base of support. This constant stimulation of the motor units can evoke muscle fatigue, contributed by both the central and peripheral aspects (Kent-Braun, 1999; Nordlund et al., 2011; Schillings, Hoefsloot, Stegeman, & Zwarts, 2003). Two common strategies adopted for postural control of quiet standing have been reported: ankle strategy and hip strategy (Winter, 1995). For ankle strategy, quiet standing can be modelled as an inverted pendulum where the body above the ankle joints swayed as a stiff segment (Nashner, 1985). For the hip strategy, the body is seen as a multi-chain model with the hip joints as the axis (Adlerton, Moritz, & Moe-Nilssen, 2003). It was suggested that the change in the strategy adopted from ankle strategy to hip strategy take place when the adjustments at the ankle are not sufficient for stability control in single-leg stance (Tropp & Odenrick, 1988). A review of the published literature revealed that vast majority of the investigation of muscle fatigue of various lower limb muscles for quiet standing have been limited to single-leg stance (Adlerton, Moritz, & Moe-Nilssen, 2003; Suponitsky, Verbitsky, Peled, & Mizrahi, 2008) or fatigue effects have been evoked purposely for the studies through sustained effort (Borg, Finell, Hakala, & Herrala, 2007). There is a paucity of studies done on investigating the level of muscle activations in various lower limb muscles during prolonged standing.

The use of surface Electromyography (EMG) in fatigue assessment has been extensively documented. Muscle fatigue is reflected in the EMG signal in both the time and frequency domains. The development of fatigue is associated with a simultaneous increase in the root mean square (RMS) and a decrease in the median power frequency (MDF) of the EMG signal (Huysmans, Hoozemans, Van der Beek, De Looze, & van Dieën, 2008; Konrad, 2005). Therefore, the main purpose of this research was to use sEMG to investigate on muscle fatigue resulting from prolonged standing. Single-subject investigation was chosen for this study for two reasons. Firstly, single-subject designs eliminate the natural variability in performance and secondly, there was a limitation in the number of subjects available for testing. To use inferential statistics for group designs, the number of subjects participated in the study have to be relatively large to be considered significant.

METHODS: The subject participated in this study was a 22 year old female, height was 160 cm and body mass was 48 kg. The criterion for inclusion in the experiment was related to the ability to do quiet standing and maintaining the standing posture for one hour. The subject involved was free of diseases, neuromuscular pathologies or skeletal disorders, which could affect normal posture or impair balance. Participant gave her consent to being involved and had the right to withdraw that consent at any point of time during the study.
This study used an experimental design, requiring participant to perform quiet standing for one hour. The first phase of the study was done under ideal, controlled condition. Electrode placement sites were prepped in accordance to the European concerted action-Surface Electromyography for Non-Invasive Assessment of Muscles (SENIAM) where shaving of skin was done to remove hair and later abraded and cleansed with isopropyl alcohol pad with a gauze pad to reduce skin impedance. Surface Electromyographic readings were recorded using a sixteen channel Delsys Trigno^{TM} Wireless system (Delsys, Boston, MA) at a sampling rate of 2000Hz. EMG signals were obtained by attaching eight Trigno sensors, with fixed centre to centre spacing of 1cm over various lower limb muscles bilaterally: the belly of Tibialis Anterior (TA), Peroneus Longus (PE) and Gastrocnemius (GA) muscles, aligned parallel to the direction of the muscle fibres, all made in accordance with the SENIAM recommendations (Hermens et al., 1999). Following application of EMG electrodes and familiarization with the laboratory and test conditions, the subject was asked to stand shoulder-width apart, weight distributed evenly between both legs. To establish between-day reliability of the data, the subject performed 8 similar standing trials on separate days, with at least 5 days between tests. To ensure consistency in electrode placement between days, the electrode locations were marked with a small cross and transferred along with other marks (angiomas and/or scars) on the subject's skin to transparency sheets.
All raw EMG data obtained were processed using EMG analysis software, EMG Works (Delsys, Boston, MA). The raw signals were first demeaned, full wave rectified and then filtered using an eighth-order Butterworth digital filter with a bandpass filter of 5-500Hz. The median power frequency (MDF) was then calculated and plotted. The data was then exported to MATLAB (The Mathworks, Inc) where simple linear regressions with standard least-squares procedures were applied to evaluate the rate of change of MDF (i.e. the fatigue index). The significance of the trend for the linear regressions was determined statistically using F-test, set at $\alpha = 0.05$ significance level. Reproducibility of the EMG variables was analyzed by comparing the significance of the trend for all trials.

RESULTS AND DISCUSSION: The preliminary data obtained saw a progressive decrease in the MDF value for all muscle groups investigated when simple linear least square regression was done on the first trial. Figure 1 shows the mathematical representation of changes in the median power frequencies of one of the muscle groups, Gastrocnemius Medialis under investigated. Simple linear least squares regression analysis done shows a linear decline in slope for each muscle's median frequency tested over time, an indication of muscle fatigue taking place. This phenomenon was subsequently observed in the median frequency of the other muscle groups under investigated. The equations for the linear regression line and their significance, p determined using F-test for the various muscle groups investigated are shown in Table 1.
Statistical analyses indicate statistical significant ($p < 0.05$) for the slopes of the regression lines for all muscle groups investigated. The results of the separate between-day reliability analysis for EMG where subject performed 8 similar trials on separate days also revealed a high level of reproducibility. All muscle groups investigated in all the repeated trials revealed a linear decline in MDF over time, and the slopes of their regression lines were also found to be statistically significant ($p < 0.05$).

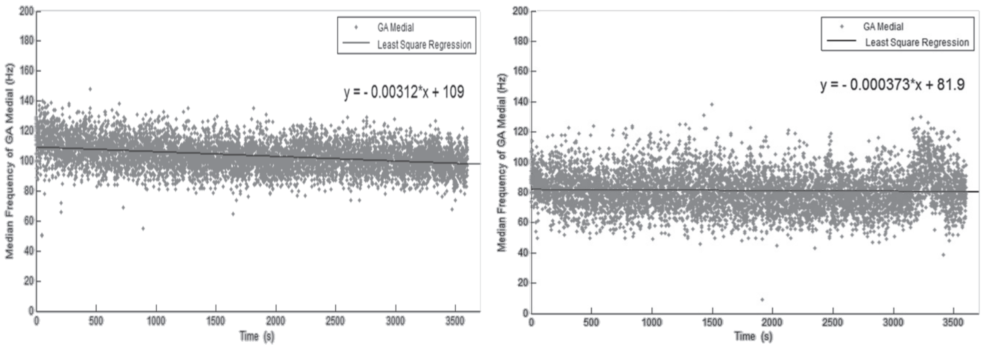

Figure 1: A mathematical representation of the median power frequency (MPF) curve obtained for Gastrocnemius (GA) Medialis muscles. From left, results for subject's left and right GA Medialis muscles respectively.

Table 1
Simple linear regressions predicting the muscle fatigue trend (i.e. fatigue index) and their significance for all lower extremities muscle groups investigated for the first trial

Muscle groups		Regression equation	P
Gastrocnemius Medial	Left	y = -0.00312x + 109	7.1334×10^{-179}
	Right	y = -0.000746x + 98.9	0.010852
Gastrocnemius Lateral	Left	y = -0.000304x + 86.3	0.00015801
	Right	y = -0.000746x + 98.9	3.9501×10^{-17}
Peroneus Longus	Left	y = -0.00297x + 80.8	0
	Right	y = -0.000259x + 77.8	0.00065622
Tibialis Anterior	Left	y = -0.000804x + 83.2	9.1647×10^{-16}
	Right	y = -0.00101x + 81.3	2.4946×10^{-26}

The results obtained in this study confirmed the study hypothesis, namely indicating that progressive fatigue development in the various lower limbs muscle groups is associated with prolonged standing. Furthermore, Suponitsky et al (2008) observed a decrease in the median frequency of shank muscles between pre- and post- selective fatiguing of muscle groups during single leg stance which lends support to this preliminary result obtained. It was suggested that this shift in the median frequency towards the lower end of the Total Power Spectrum was as a result of a decline in the muscle fibre conduction velocity (Eberstein A et al 1985; Sadoyama T, et al 1983) and a depletion of the metabolite reserve due to reflex slowing of recruitment (Ebenbichler et al., 1998). In addition, evaluation of the mean and standard deviation of MDF of different trials for the same muscle groups reflect a synergistic activity of the various lower limb muscles (Suponitsky et al 2008). It can be suggested that the variations in the mean and standard deviation of MDF obtained could be a result of compensatory mechanisms that have taken place in response to decreased ability in other muscle groups to maintain balance. It can thus be hypothesized that synergism in the various lower limb muscles (i.e. reduction in activity of fatigued muscles and simultaneous increased in activity of non-fatigued muscles) occurs to maintain the standing posture.

CONCLUSION: Preliminary result shows that muscle fatigue did occur for prolonged standing. This investigation can set the platform for future works into study on daily life activities or sporting activities that requires prolonged standing.

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