Journal of Electromyography and Kinesiology 23 (2013) 614–618

Contents lists available at SciVerse ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

The influence of whole body vibration on the plantarflexors during heel raise exercise

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ARTICLE INFO

Article history:
Received 15 March 2012
Received in revised form 26 November 2012
Accepted 26 November 2012

Keywords:
Whole-body vibration
Heel raise
Calf raise
Plantarflexors

ABSTRACT

Whole body vibration (WBV) during exercise offers potential to augment the effects of basic exercises. However, to date there is limited information on the basic physiological and biomechanical effects of WBV on skeletal muscles. The aim of this study was to determine the effects of WBV (40 Hz, 1.9 mm synchronous vertical displacement) on the myoelectrical activity of selected plantarflexors during heel raise exercise. 3D motion capture of the ankle, synchronised with sEMG of the lateral gastrocnemius and soleus, was obtained during repetitive heel raises carried out at 0.5 Hz on 10 healthy male subjects (age 27 ± 5 years, height 1.78 ± 0.04 m, weight 75.75 ± 11.9 kg). During both vibration and non vibration the soleus activation peaked earlier than that of the lateral gastrocnemius. The results indicate that WBV has no effect on the timing of exercise completion or the amplitude of the lateral gastrocnemius activity, however significant increases in amplitudes of the soleus muscle activity (77.5–90.4% MVC $P < 0.05$). WBV had no significant effect on median frequencies of either muscle. The results indicate that the greatest effect of WBV during heel raise activity is in the soleus muscles during the early phases of heel raise.

1. Introduction

The use of whole body vibration (WBV) as a novel exercise modality continues to grow in popularity with both exercise practitioners and the scientific community. Recent meta-analyses have established the benefits of WBV for improvement of strength (Marín and Rhea, 2010b) and power (Marín and Rhea, 2010a), building on previous reviews which have illustrated the benefits in lower limb muscular performance and balance (Rehn et al., 2007). However, some of the fundamental biomechanical and physiological changes have still not been fully investigated to explain the underlying mechanisms of these changes. To address issues of this nature surface electromyography (sEMG) provides a tool which is typically used to quantify the level of activation of muscles, the timing of activation of muscles, the force/sEMG signal relationship, and the use of the sEMG signal as a fatigue index (De Luca, 1997). Recently Pereira et al. (2010) reported that heel raise activity not only displayed different muscle activity, but resulted in changes in the frequency of muscle activity as participants approached fatigue. This reflects previous research considering the effect of heel raise exercise on the frequency of the plantarflexors muscle group (Matthijsse et al., 1987; Ament et al., 1993; Österberg et al., 1998). To date many of the whole body vibration studies of the lower limb have focused on static or squatting exercises, therefore do not provide directly comparable data. In order to ascertain some of the fundamental changes occurring in response to vibration, the aim of this study is to consider the impact of WBV on heel raise exercises. Heel raise exercise utilises the plantarflexors muscles (gastrocnemius and soleus) which are easily accessible for sEMG analysis. Previous reports have indicated that the medial and lateral gastrocnemius muscles have different skin-fold thicknesses, with the lateral gastrocnemius being closer to that of the soleus muscle (Bilodeau et al., 1994). The medial gastrocnemius has also been shown to be more sensitive to changes in knee angles than the lateral gastrocnemius (Cresswell et al., 1995). Therefore, the hypothesis of this study is that WBV will affect the myoelectrical activity of the lateral gastrocnemius and the soleus muscle during heel raise exercise with and without vibration.

2. Methods

Ten healthy male subjects who are recreationally active and without any current or recent lower limb injuries (age 27 ± 5 years, height 1.78 ± 0.04 m, weight 75.75 ± 11.9 kg) took part in this study and provided informed consent in accordance with University ethics guidelines. All heel raise exercises were performed on a Power Plate® pro6 (Power Plate International Ltd., London, UK) whole body vibrating platform (40 Hz 1.9 mm vertical displacement), with either no vibration (NVIB) or vibration (VIB) being utilised in six alternating sets of 15 s during which heel raises were performed. The initial set for each participant was randomised

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1050-6411/$ - see front matter
http://dx.doi.org/10.1016/j.jelekin.2012.11.015

(i.e. VIB or NVIB). The exercises were completed using a metronome operating at 1 Hz to ensure all exercises were completed at the same pace. The subjects were instructed to move at a pace of 0.5 Hz i.e. 1 s up on to toes to maximum heel raise and 1 s down to complete flat foot and to ensure each repetition was a full heel raise i.e. as far up onto their toes as possible. Subjects were also instructed to keep a light bend on their knees to prevent excessive transmission to their heads. During straight leg heel raise activity the soleus muscle contributes, but a greater contribution comes from the gastrocnemius which is in a mechanically better position to generate full power compared to whilst the knee is bent (Palastanga et al., 2004; Baechle and Earle, 2008).

Differential bipolar (10 mm centre to centre) surface electrodes (DE-2.3, Delsys Inc. Boston, MA, USA) were placed over the right lateral gastrocnemius and soleus muscles in accordance with SENIAM recommendations (Hermens et al., 2000). A single reference electrode was placed on C7 vertebrae and all leads connected to the electrodes were secured with tape to avoid artefacts from limb movements. Impedance was minimised by shaving and skin cleaning with alcohol swabs. sEMG signals were amplified (1 k gain) via a Delsys Bagnoli system (Delsys Inc. Boston, MA, USA) with a bandwidth of 20–450 Hz. sEMG activity was synchronously acquired with the kinematic data at 2000 Hz. Prior to undertaking any exercise maximal voluntary contractions (MVC's) were obtained in a seated position with the knee against a fixed resistance in order to provide a normalisation method for comparison of participant efforts. Normalisation was achieved by calculating sEMG amplitude as a percentage of the MVC. Ankle motion was captured from a 16 mm retroreflective marker located on the right lateral malleolus at 500 Hz using 10 infrared retro-reflective cameras (Oqus, Qualysis AB, Sweden) to ensure that heel raise exercises were consistent in height and speed of movement.

Marker motion was tracked and all synchronous data exported in C3D format for subsequent post processing in Visual3D (C-Motion). Maximal and minimal vertical displacements of ankle markers were defined and used to derive vertical ankle displacements. The ankle displacement, defined when the ankle was at the bottom or top of its movement cycles, the vertical displacement of the ankle and the total exercise time. sEMG data were initially filtered using a 60 Hz cut-off 2nd order bidirectional highpass Butterworth filter to remove any zero offset of the obtained signal mean. A full rectification was applied before the signal was filtered with a 2 Hz cut-off, 2nd order bidirectional low pass Butterworth filter. Peak amplitudes, normalised to the MVC, of each muscle and timings for peak activity relative to movement onset were then determined.

Data sequences of 0.6 s centred on the peak sEMG activity, 0.3 s before and 0.3 s after peak activity, were identified and exported for analysis in the frequency domain using an 'in-house' LabView virtual instrument (National Instruments Corporation, Austin, Texas). A Hanning window was applied to the data prior to fast Fourier transformation. Power spectra of the VIB sEMG data were used to identify the dominant frequency due to the vibration 'noise'. A 4th order Chebyshev bandstop filter was applied with low and high cut-off frequencies 2 Hz below and 2 Hz above the first vibration frequency as well as its 2nd and 3rd harmonics. The same process was then applied to the NVIB data and mean power frequencies calculated as the frequency centroid of the spectrum. sEMG amplitude, timing and frequency data were exported to MATLAB (The MathWorks Inc., Natick, MA) and tested for normality using Lilliefors test, data with a normal distribution was then tested for significant differences using paired t-Tests and non-normal distributions were analysed using Wilcoxon signed rank tests with an alpha level of 0.05. Mean and standard error of the mean values were also calculated for each variable.

3. Results

No significant differences were observed in range of motion (NVIB: 0.082 ± 0.02 m, VIB: 0.079 ± 0.002 m) or in the time taken to complete each heel raise (NVIB 1.96 ± 0.02 s, VIB: 1.96 ± 0.02 s) $p > 0.05$.

3.1. EMG amplitude

The mean, normalised amplitude of the lateral gastrocnemius did not display a significant change between vibration and non vibration conditions; however the soleus sEMG amplitude was significantly increased during vibration heel raises. Fig. 1 displays the mean sEMG amplitude with the error bars representing the standard error of the mean. The sample distribution was not normal therefore Wilcoxon signed rank tests were applied to both soleus and gastrocnemius sEMG amplitude data. The results for gastrocnemius VIB vs. NVIB conditions were not significant ($p > 0.05$), the results for soleus VIB vs. NVIB conditions were highly significant ($p < 0.01$).

3.2. Frequency Analysis

A small increase in the median frequency was seen in both the lateral gastrocnemius (105 ± 7 to 111 ± 7 Hz) and in the soleus muscle (102 ± 7.5 to 105 ± 7.5 Hz) during the vibration conditions. The data distribution was normal therefore changes were analysed with paired t-Tests, results were not significant ($p > 0.05$).

3.3. Timing of sEMG activity

sEMG activity during the movement cycle i.e. from when the heel was down through the heel raise back to the point when the heel was down is displayed in Figs. 2 and 3. The error bars represent the standard error of the mean. Each movement was paced via a metronome providing audible signals to aid participants a consistent movement rate of 0.5 Hz (average time for time for heel up and heel down movement during NVIB 1.96 ± 0.02 s and VIB: 1.96 ± 0.02 s). The introduction of vibration caused a small reduction in the time taken for participants to reach the peak sEMG activity of the lateral gastrocnemius during the movement, from 75.3% of the time to the peak of the movement i.e. half the total movement, during NVIB to 72.8% with VIB. This difference was not found to be significant.

The soleus sEMG activity also reached peak at an earlier time during the movement cycle (57.5% during VIB compared to 59.4% during NVIB) although the difference was again not significant.

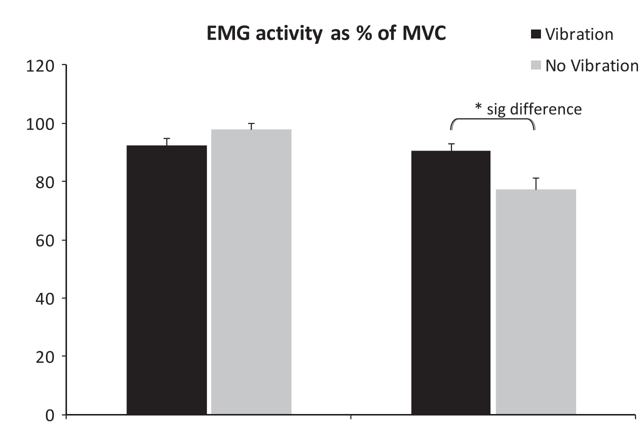

Fig. 1. Mean sEMG amplitude.