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MEDIAL GASTROCNEMIUS MUSCLE FUNCTION ADAPTATION DURING SINGLE-LEG HOPPING

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The purpose of this study was to determine whether there were changes to leg mechanics and muscle activation characteristics as fatigue increased during single-leg hopping. Twenty-seven healthy male participants performed three single-leg hopping (2.2 Hz) trials, each to volitional exhaustion on a forceplate, using either placebo, visual or tactile feedback to control the vertical height of hopping. Spatiotemporal, leg mechanical and muscle activation characteristics of the lower limb muscles were determined. Mean activation amplitude of the MG during the anticipatory period prior to initial contact significantly decreased from the start to end hopping periods when visual or tactile feedback was provided ($p<0.01$) and no significant change in the vertical displacement of the COM was observed ($p=0.25$; $p=0.93$).

KEY WORDS: Fatigue, Feedback, Stretch-Shortening Cycle, Electromyography

INTRODUCTION: Peak muscle activation characteristics and the time of onset of muscle activity have been previously shown to change during hopping concomitant to alterations in levels of fatigue (Padua et al., 2006). However, it remains unclear whether the changes in neuromuscular characteristics were attributable to the effect of fatigue only, or if there may have been a change in the motor performance of the hopping effort when the participant may be fatigued compared to the start of the effort. Fatigue has been shown to induce changes in motor performance as demonstrated during repetitive cycling and double-leg hopping (Dingwell, Joubert, Diefenthaeler, & Trinity, 2008; Padua, et al., 2006). Conversely, changes in motor performance have been shown to induce changes in muscle activation characteristics, as demonstrated by a decrease in amplitude of the surface electromyography (sEMG) signal when height of the centre of mass during hopping decreased and hopping frequency increased (Bobbert & Richard Casius, 2011; Hobara et al., 2010). Therefore, it is difficult to explicitly attribute changes to muscle activation due to fatigue when motor performance was not consistent. By ensuring that spatiotemporal characteristics of the performance remain unchanged during a fatiguing task, any neuromuscular changes may be more likely due to approaching fatigue and not a change in the performance parameters. Therefore, the purpose of this study was to determine whether there were changes to muscle activation characteristics of the lower limb muscles as they approached fatigue when there was no change in performance parameters during single-leg hopping.

METHODS: Twenty-seven healthy male participants performed three single-leg hopping trials, each to volitional exhaustion on a forceplate, using either placebo (yellow marker adhered to the sternum of the participant and observed in a mirror 2 m in front of the forceplate), visual (horizontal strip of tape adhered at the target hop height to a mirror 2 m in front of the forceplate) or tactile (elastic bands placed above the head at the target hop height) feedback to control the vertical height of hopping. A within-subject repeated measures design was used to determine any changes between pre- and post-fatiguing measures in the three different feedback conditions.

Vertical ground reaction force (vGRF) (Kistler Multicomponent force plate, model 9286B, Switzerland) and sEMG signals (PowerLab, Model 26T, Australia) of the medial gastrocnemius (MG), soleus, tibialis anterior (TA), vastus lateralis (VL) and biceps femoris (BF) muscles were recorded synchronously (Albertus-Kajee, Tucker, Derman, Lamberts, & Lambert, 2011) on a laptop computer (Lenovo, W700, USA) using Bioware (version 5.1, Type

2812A) and LabChart software (Version 7.3.5) respectively. All measures were recorded for each hopping trial on the self-selected dominant leg (Oliver & Smith, 2010; Padua, et al., 2006) during a single-leg hopping task performed at a frequency of 2.2 Hz (Oliver & Smith, 2010) controlled by an audible digital metronome (freeware: http://www.metronomeonline.com/). A five minute warm-up was performed followed by familiarisation trials where each individual's target hopping height was determined from the vGRF data. The order of hopping trials was randomised and each condition was performed until volitional exhaustion with a 10 min rest period between trials. Vertical GRF and sEMG recordings were sampled synchronously at 2000 Hz. Vertical GRF data were filtered using a Butterworth low pass filter with a cut-off frequency of 50 Hz (Bioware™, version: 5.1.0.0, Type 2812A). Surface EMG recordings were band-pass filtered from 50 to 500 Hz (LabChart™, version: 7.3.5). Filtered vGRF and sEMG data for each trial were exported to an Excel spreadsheet. Surface EMG recordings were full wave rectified (Microsoft Office Excel, 2007). Each trial was truncated to include the first and last complete hop cycles ensuring that the hopping frequency was within 5% of the target hopping frequency (2.2 Hz) (Oliver & Smith, 2010).

Dependant variables were determined for each hop cycle and included: temporal characteristics (duration of flight (t_f), loading (t_l) and contact phases (t_c)), spatial characteristics (height of hopping of the COM during flight (z_f), loading (z_l) and contact phases (z_c)), kinetics (normalised peak vGRF and normalised vertical leg stiffness (k_L)) and muscle activation characteristics (peak activation amplitude during the loading phase (VL, BF, MG, soleus & TA), duration of MG muscle activation prior to IC and mean muscle activation amplitude of the MG during the anticipatory period). Each dependant variable was calculated for the start (first 10 consecutive hop cycles) and end (last 10 consecutive hop cycles) periods as the mean of the 10 hop cycles for each period (Dingwell, et al., 2008; Maton & Pellec, 2001). Muscle onset detection for the MG was determined visually (Hodges & Bui, 1996) and the intra-tester, inter-tester reliability and typical errors calculated. The period between MG muscle onset and IC was labelled the anticipatory period (Enoka et al., 2011) and mean activation amplitude of the MG during the anticipatory period was determined for each hop cycle. The peak activation amplitude was defined as the maximum mean amplitude value determined over a 50 ms epoch during the loading phase (Albertus-Kajee, et al., 2011) for each of the lower limb muscles.

A two-way repeated measures ANOVA was used to determine within-subject differences for each dependant variable. If there was a significant interaction, a follow up post-hoc one-way ANOVA and paired t-tests were performed. Alpha levels were set *a priori* with significance accepted at $p<0.05$ and Bonferroni correction performed to reduce the risk of family wise error.

RESULTS: There was no significant difference detected for total hopping duration between hopping conditions (mean (SD) (placebo 76.63 s (33.63), visual 68.61 s (33.72) and tactile feedback 74.38 s (44.54)) with the order of the condition as a covariate ($p = 0.098$). There was no significant difference for normalised peak vGRF force from the start to end hopping period for all conditions ($p > 0.017$). There was no significant difference for k_L from the start to end hopping period for all conditions ($p > 0.017$).

There was a significant latency of the onset of MG activity ($p<0.001$) (Figure 1) and increase in peak activation amplitude of the soleus and VL muscles during the loading phase ($p\leq0.004$) from the start to the end periods for all three conditions. Mean activation amplitude of the MG during the anticipatory period prior to IC significantly decreased from the start to end hopping periods when visual or tactile feedback was provided ($p<0.01$) (Figure 1) and no significant change in the vertical displacement of the COM was observed ($p=0.25$; $p=0.93$). A decrease in mean activation amplitude of the MG during the anticipatory period contrasted the placebo condition in which there was no significant change to the mean activation amplitude of the MG ($p=0.139$) and a significant decrease in vertical displacement of the COM ($p=0.001$).

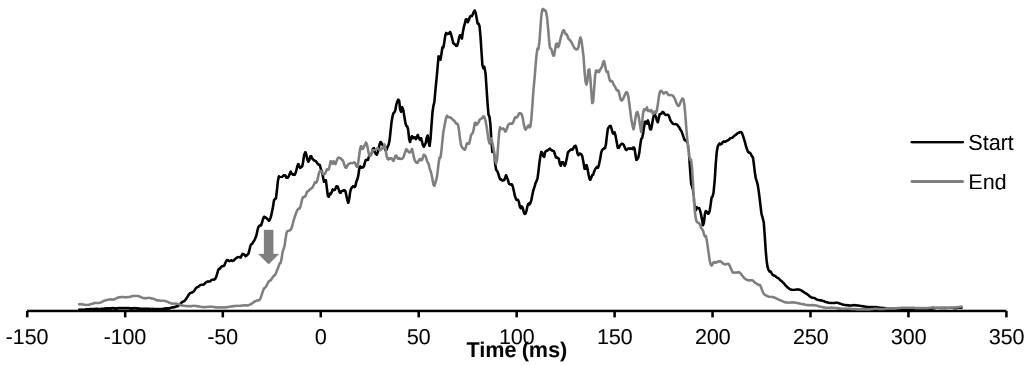

Figure 1: Surface EMG recording of the MG muscle for a single hop cycle at the start and end hopping periods from a single participant. There was a significant latency in the onset of MG activity (horizontal arrow) and decrease in the mean activation amplitude (vertical arrow) during the anticipatory period at the end compared to the start of the hopping trials with augmented feedback.

DISCUSSION: The main finding of this investigation was a significant decrease in the mean activation amplitude of MG in the anticipatory period when there was no significant change in spatiotemporal characteristics of the COM during single-leg hopping to volitional exhaustion. The MG muscle activity in the anticipatory period has been suggested to stiffen the ankle prior to the impending contact phase and was defined as the feed-forward response (Melvill-Jones & Watt, 1971; Santello, 2005). The analysis of muscle function during the anticipatory period during hopping was limited to the MG as it has been demonstrated to adapt to rapid loading tasks in contrast to other lower limb muscles that have been reported to have a relatively fixed time of onset with respect to loading (Santello, McDonagh, & Challis, 2001). The current study demonstrated that the mean activation amplitude of the MG during the anticipatory period was unchanged during the placebo feedback condition and contrasts the finding of a decrease when augmented feedback was provided to maintain hopping height. Moritani et al. (1990) also reported a reduction in mean activation amplitude of the MG during the anticipatory period during maximal hopping to 60 s when there was a decrease in k_l. However, the current study demonstrated this in submaximal efforts to volitional exhaustion when there was no change in k_l. Furthermore, in the current study MG activity in the anticipatory period was shown to remain unchanged when there was a decrease in z_c and k_l remained unchanged. Therefore, it may have been possible that as participants approached fatigue, the ability of the ankle to maintain adequate ankle stiffness, that was controlled by the central nervous system (Santello, 2005), was influenced by the approaching fatigue rather than a change in the vertical displacement of the COM. Decrease in amplitude of the muscle activity prior to landing has been associated with a decrease in vertical displacement of the COM (Santello, et al., 2001). This study adds to the literature that amplitude of muscle activity prior to landing may also be influenced by fatigue and not only a change in the height from which the body may fall. The current study suggests that a change in z_f does not affect the duration of EMG activity prior to landing, since it was demonstrated that the duration of EMG activity decreased whether there was a decrease in z_f or not (Santello, 2005). Although the current study demonstrated a similar k_l or vGRF with or without augmented feedback and between start and end periods, there may have been a change in kinematics of the lower limb joints that led to the maintenance of leg mechanics.

CONCLUSION: Adaptations in muscle activation amplitude of the MG muscle during the anticipatory period may be an underlying motor control strategy to maintain hopping at a submaximal effort. For example, as participants approached volitional exhaustion when hopping with augmented feedback, there was a decrease in MG recruitment in the anticipatory period which in effect may protect the ankle and plantar flexor muscles by allowing the ankle to have increased dorsiflexion ROM (Dierks, Davis, & Hamill, 2010) during the loading phase. This study highlights that there may be changes in neuromuscular function both in response to the approaching fatigue and that allow for maintenance of motor performance as fatigue approaches. Therefore, suggesting that task failure may not be due to peripheral muscle fatigue but possible central fatigue which may be a critical factor that influences on going performance during an exhaustive task

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