

## APPLICATION OF SURFACE EMG DECOMPOSITION TO IDENTIFY CHANGES IN NEUROMUSCULAR CONTROL DURING FATIGUING EXERCISE

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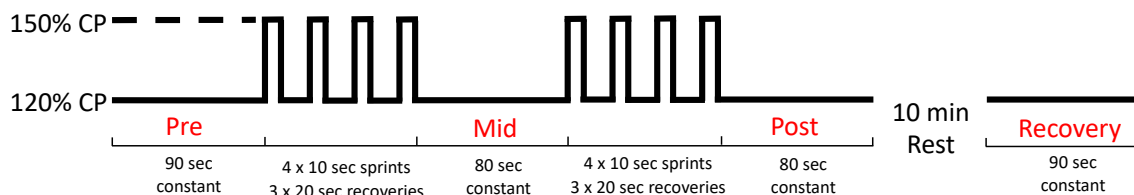
The purpose of this study was to apply surface EMG decomposition to identify changes in neuromuscular control of lower limb muscles during fatiguing exercise. Trained participants ( $n=15$ ) completed a repeat sprints cycling fatigue protocol. Motor unit firing rates and motor unit recruitment timings were identified for six muscles. A moderate to strong correlation between firing rates and recruitment timings were identified for individual participant data ( $r = -0.46$  to  $r = -1.00$ ). No significant group effects were reported when each muscle was examined independently (repeat measures ANOVA; slope, intercept;  $F < 1.84$ ,  $p > 0.119$ ). However, changes in regression parameters were identified for individual participant data. Surface EMG decomposition provides a novel approach for identifying individual changes in neuromuscular control of lower limb muscles during fatiguing exercise.

**KEYWORDS:** MOTOR UNITS, MUSCLE FATIGUE, CYCLING, LOWER LIMB

**INTRODUCTION:** Evidence suggests that muscle fatigue affects motoneuron signaling with subsequent changes in neuromuscular control of individual muscles during a fatiguing task (Contessa et al., 2018). In the case of sport and exercise, changes in neuromuscular control are often associated with loss of performance and increased injury risk (Jones, Griffiths & Mellalieu, 2017; Zemková & Hamar, 2018). Increasingly, performance metrics such as vertical jump height are used to monitor muscle fatigue in an applied setting and identify changes in neuromuscular control, but these changes are inferred rather than directly measured (Claudino et al., 2017; Alba-Jiménez, Moreno-Doutres & Peña, 2022). Currently, methods to directly measure changes in neuromuscular control are invasive and have limited scope in applied settings (Gruet et al., 2013; Brownstein, Millet & Thomas, 2021). Therefore, there is a need for techniques to directly measure changes in neuromuscular control associated with the development of muscle fatigue for individual muscles in an applied setting.

Surface EMG decomposition is a non-invasive method to measure neuromuscular control with the capacity to detect individual differences in muscle responses in an applied setting (De Luca et al., 2015). The technique works by recording the raw EMG signal from electrodes on the skin and applying mathematical techniques to identify individual motor unit signals embedded within. Here we apply this technique to identify changes in neuromuscular control of six lower limb muscles during a high intensity cycling fatigue protocol.

**METHODS:** Following informed consent and institutional ethical approval, 15 trained participants (8 male, 7 female, age  $29 \pm 8$  years, height  $173 \pm 53$  cm, mass  $75 \pm 12$  kg) completed a three-minute maximal effort cycling test (Vanhatalo, Doust, & Burnley, 2007) on an SRM ergometer at 90 RPM with critical power (CP;  $220 \pm 65$  Watts) determined from the average power output during the final 60 seconds. Following a minimum 48-hour rest period participants completed a repeat-sprint (150% CP) and constant work rate (120% CP) cycling fatigue protocol (Figure 1) on an SRM ergometer at 90 RPM. Power output was displayed on a monitor throughout.



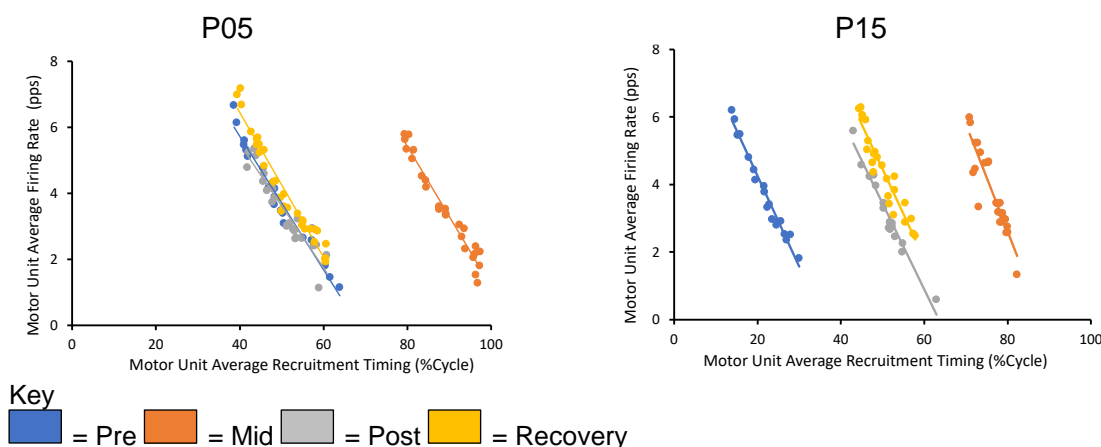
**Figure 1: Repeat-sprint cycling fatigue protocol at 90 RPM. CP = critical power. Participants were asked to match their power output (displayed on a monitor) to 120% CP during the constant cycling periods and 150% CP during each 10 sec sprint. Pre, Mid, Post and Recovery indicate specific time periods throughout the protocol.**

Surface EMG was recorded for six muscles on the participant's right side (rectus femoris, vastus lateralis, gastrocnemius medialis, tibialis anterior, biceps femoris and semimembranosus) using Galileo surface EMG sensors (Delsys, Boston, USA). Recordings were made during the constant cycling periods and allocated as either pre, mid, post or recovery (Figure 1). Recordings were decomposed to determine individual motor unit firing instances (NeuroMap, Delsys, Boston, USA). From this, average motor unit firing rates were calculated using a one second Hanning window (NeuroMap) and motor unit recruitment timings were identified by time normalising individual firings from bottom dead centre 0% to bottom dead centre 100% of the cycling pedal cycle (determined by motion capture) using a custom MATLAB script. 15 consecutive pedal cycles were analysed from the middle of each trial.

For each participant, for each muscle and recording, Pearson's  $r$  was used to determine the association between average motor unit firing rates and motor unit recruitment timings. Linear regression analysis was applied to motor unit recruitment timings (x-axis) versus average motor unit firing rates (y-axis). Regression parameters (slope, intercept) were used to quantify neuromuscular control. Group effects for changes in individual regression parameters (slope, intercept) akin to changes in neuromuscular control were assessed using a repeat measures ANOVA for each muscle.

**RESULTS:** Pearson's  $r$  for individual participant data for each muscle ranged from  $r = -0.46$  ( $p = 0.432$ ) to  $r = -1.00$  ( $p < 0.001$ ) indicating a moderate to strong correlation between motor unit recruitment timings and motor unit average firing rates. There were no significant group effects ( $F < 1.84$ ,  $p > 0.119$ ) for changes in slope or intercept for each muscle as muscle fatigue developed during the cycling fatigue protocol indicating no significant changes in neuromuscular control at the group level. However, changes in neuromuscular control were observed when exploring individual participant data. Specifically, an increase in intercept was identified for most participants for the vastus lateralis during the cycling fatigue protocol (Figure 2) resulting from a shift in recruitment timing to later in the pedal cycle. For the semimembranosus, there was also a shift in recruitment timing for some participants, but the effect was less pronounced.

For some participants, average motor unit firing rates for the rectus femoris and biceps femoris increased as muscle fatigue developed with the effect being more pronounced for the rectus femoris during the final two recordings for each participant. For the gastrocnemius medialis and tibialis anterior, changes in average motor unit firing rates and motor unit recruitment timings were less pronounced.



**Figure 2: Linear regression analysis for two participants for the vastus lateralis showing changes in motor unit recruitment timing relative to the pedal cycle (bottom dead centre 0% to bottom dead centre 0%) between recording conditions (Pre, Mid, Post & Recovery).**

**DISCUSSION:** With the application of surface EMG decomposition, changes in neuromuscular control were identified for lower limb muscles during a cycling fatigue protocol. A delay in recruitment of vastus lateralis motor units was observed for most participants. This might be explained by physiological impairments in muscle fibre contraction with the development of muscle fatigue (Celichowski & Krutki, 2019). Changes in motor unit recruitment timing for the semimembranosus identified may be compensatory action by some participants to maintain target force during the fatigue protocol (Contessa, DeLuca & Kline, 2016; Contessa et al., 2018).

For the rectus femoris and biceps femoris, increases in average motor unit firing rates were observed in addition to changes in motor recruitment timing for some participants. Previous literature has identified increases in average motor unit firing rates related to peak target force output during isometric ramp and hold contractions (DeLuca & Hostage, 2010; DeLuca & Contessa, 2012, Miller et al., 2019). In the case of the rectus femoris and biceps femoris during a fatigue cycling protocol this may suggest an increase in activity of the biarticular muscles for some participants to maintain target power output as muscle fatigue develops.

Changes in neuromuscular control of lower limb muscles with the development of muscle fatigue were individual and muscle specific. This may be due to individual differences in muscle fatigue accumulation associated with muscle fibre characteristics of each participant (Decorte et al., 2010; Thomas et al., 2015). As well, individual differences in neuromuscular control may be related to differences in a person's ability to tolerate and endure peripheral sensory feedback during high intensity exercise (Hureau, Ducroca & Blain, 2016; Hureau, Romer & Amann, 2018).

**CONCLUSION:** Surface EMG decomposition was applied to identify changes in neuromuscular control of six lower limb muscles during a cycling fatigue protocol. These changes were individual and muscle specific. Potential implications involve a person-centred approach to monitoring changes in neuromuscular control during fatiguing exercise with information readily provided on individual muscle responses, informing evidence-based decision making for athletes, coaches, and sports practitioners aiming to improve performance.

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