Detection of the Temporal Sequence of Muscle Recruitment During Cycling Exercise Using MRI

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Introduction

Electrically stimulated stationary cycling is used for rehabilitation of patients with neuromuscular deficits. Emulating the spatial and temporal muscle recruitment patterns used by healthy subjects may provide a robust template for electrical stimulation strategies for patients. While it is known that cycling is generally brought about by extensor muscle activation during the portion of the pedal cycle from 0° - 90° and flexor muscle activation during the portion of the pedal cycle from 120° - 230°, creating an optimal template requires verifying that the spatial and temporal patterns of muscle recruitment in voluntary cycling are faithfully replicated in electrically stimulated cycling. A lack of depth sensitivity and the presence of stimulation artifact preclude the use of electromyography (EMG) for this purpose.

However, it may be possible to detect muscle recruitment patterns using the post-exercise T_2 contrast that occurs between recruited and non-recruited muscle (1). The amount of contrast depends on the relative work rate (2), but as a post-exercise measurement is not inherently capable of detecting the temporal aspects of muscle recruitment. However, it may be possible to vary the work rate over a restricted arc of the pedal cycle in a way that selectively loads specific muscle groups; and by then repeating this procedure with different loading arcs, infer not just the spatial pattern but also the temporal pattern of muscle activation. Therefore, we modified a cycle ergometer to enable varied work rates over an individual pedal cycle and determined if temporal patterns of muscle recruitment could be detected using MRI, and validated by EMG.

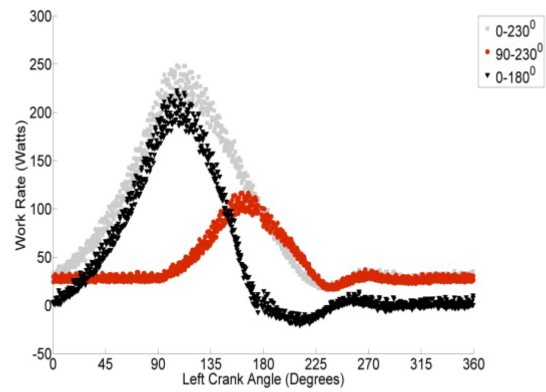

Figure 1: Work rate distributions spanning above baseline from 0-230° (gray), 90-230° (red) and 0-180° (black) work rates.

Methods

Subjects: Six young healthy male subjects performed six minutes of left leg-only cycling at 50 revolutions per minute during each of two different variable work rate conditions.

Work Rates: The first work rate condition covered an arc between 0° and 230° of the pedal cycle with a peak of 248 W occurring at 106° (Figure 1). The second work rate condition covered the arc from 90 to 230° with a peak of 116 W occurring at 160°. We hypothesized that the 0-230° condition would recruit both flexors and extensors, while the 90-230° condition would recruit only the flexors. The difference between the conditions produced a virtual condition spanning from 0-180° that allowed the calculation of the extensor only recruitment.

EMG: MR compatible electrodes were placed over the vastus lateralis, vastus medialis, rectus femoris and biceps femoris muscles. Recruitment was assessed from EMG as the greatest integrated voltage recorded for any 30° segment of the loaded arc (IEMG).

MRI: Muscle recruitment was assessed from MRI as ΔT_2 in images of the thigh muscles acquired before, and <2 minutes after, each bout of exercise. Images were acquired in a single slice with TR=1500 ms and TE=20,40, 60…160 ms, 200×400×8 mm field of view, and a 256×256 matrix.

Data Analysis: T_2 maps were created by fitting image signals to an exponential decay. Mean ΔT_2 values were obtained from regions of interest specified in the maps. ΔT_2 values from the vastus lateralis, vastus medialis, and vastus intermedius were averaged to represent extensor action; IEMG values from the vastus lateralis and medialis were averaged to represent extensor action. ΔT_2 values from the gracilis, semitendinosus, and short head of the biceps femoris were averaged to represent flexor action. The biceps femoris signal was used to represent flexor action for IEMG measurements. The ΔT_2 and IEMG data were analyzed statistically by using a 2 factor repeated measures ANOVA (Work Rate×Muscle Group).

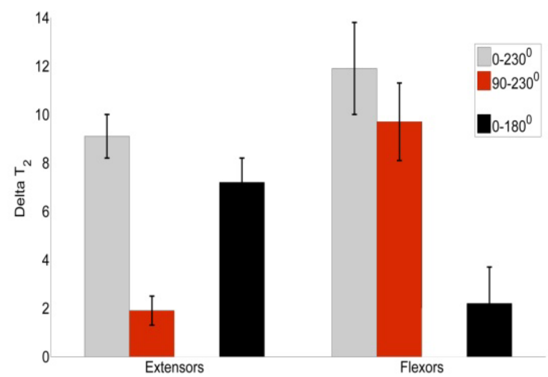

Figure 2: Mean (SE) ΔT_2 from extensor and flexor muscle groups under the 0-230° (gray), 90-230° (red) and 0-180° (black) work rates. There was a Work Rate × Muscle Group interaction ($p < 0.007$).

Results and Discussion

For the 0-230° work arc, the mean (SE) ΔT_2 values were 9.1 (0.9) and 11.9 (1.9) ms for the extensors and flexors, respectively (Figure 2). IEMG activity was 49.3 (7.4) mVs for extensors and 37.7 (5.4) mVs for flexors. For the 90-230° work arc, the ΔT_2 for the extensors was 1.9 (0.6) ms and for the flexors was 9.7 (1.6) ms. IEMG activity was 17.9 (2.5) mVs for extension and 27.1 (5.6) mVs for flexion. ANOVA revealed an interaction between Work Rate and Muscle Group for ΔT_2 ($p<0.007$) and IEMG ($p=0.01$). The ΔT_2 values for the 0-180° virtual work arc were 7.2 (2.2) and 2.2 (3.2) ms for the extensors and flexors, respectively. These results support the hypotheses that the 0-230° work rate recruited extensors and flexors and that the 90-230° work rate recruited predominantly flexors. The similarity between flexor values under different conditions for both ΔT_2 and IEMG also provides evidence for the validity of calculating the virtual extensor recruitment by subtraction.

Conclusion

By generating or calculating extensor-only and flexor-only loading conditions, we have used MRI to demonstrate leg extensor muscle activity during the 0-180° portion of the pedal cycle and flexor muscle activity during the 90-230° portion of the pedal cycle. These data are consistent with known and IEMG-measured activation patterns and support the coupling of measurements of post exercise T_2 changes with variable work rate technology for the determination of the spatial and temporal patterns of muscle recruitment during cycling. To our knowledge, this is the first use of post-exercise muscle T_2 data to determine the temporal sequence of muscle activation.

References

1. Meyer *et al*. ESSR 2000 28:89-92
2. Reid *et al*. JAP 2001 90:897-902

Acknowledgments

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T32-EB001628
1 UL1 RR024975