ALTERATIONS IN MONO- AND BI-ARTICULAR MUSCLE ACTIVITY PATTERNS AFTER LEARNING TO DIRECT PEDAL FORCES

Christopher J. Hasson, Richard E.A. Van Emmerik, and Graham E. Caldwell
Biomechanics & Motor Control Laboratories, University of Massachusetts, Amherst, MA
cjhasson@excsci.umass.edu

INTRODUCTION
Mono- and bi-articular muscles may have separate roles in tasks where the direction of an external reaction force must be controlled. Previously, we reported that with training subjects could improve their ability to direct pedal forces in a specified direction, and that this improvement was accompanied by changes in pedal, crank, and joint kinetics (Hasson et al., 2006a,b). Changes in magnitude and timing of joint moments were found, with the most important at the knee. The present report focuses on the changes in muscle activity patterns from pre- to post-learning. Because biarticular muscles may have a unique role in “tuning” joint moments to control the applied force direction, we hypothesized that activity of the biarticular muscles would demonstrate more learning-related changes than the monoarticulars.

METHODS
Nine male subjects (age: 25±4 yrs; mass: 83±13 kg; height: 1.77±0.07 m) performed one-legged cycling on a bicycle mounted on a computerized ergometer and instrumented for pedal kinematics and kinetics. Subjects were instructed to direct their pedal forces perpendicular to the crank arm (target force direction), and to maintain a constant pedaling speed. Real-time visual feedback of both applied and target force direction and crank angular velocity was displayed to the subject. Subjects performed an initial baseline trial without the feedback, followed by 16 trials with the real-time feedback. Each trial consisted of 30 s of pedaling using only the left leg after a 15 s warm-up. Task performance was characterized by the RMS error between the applied and target force directions, and it was shown that subjects significantly reduced the error over these trials (see Hasson et al., [2006a,b] for more details).

Surface electromyographic (EMG) data were collected at 1 KHz from three monoarticular (tibialis anterior [TA], soleus [SO], and vastus lateralis [VL]), and three biarticular (rectus femoris [RF], semitendinosus [HAM], and medial gastrocnemius [GA]) muscles of the left leg. For each muscle, an EMG linear envelope was computed using bias removal, rectification, and smoothing with a 6 Hz low-pass Butterworth filter, and expressed as a function of crank angle using cubic spline interpolation. For each subject and muscle, the EMG linear envelopes were normalized to their maximum values.

In pilot work, the timing of muscle activity was determined by a traditional threshold detection method (Hasson et al., 2004). However, this method could not characterize some of the changes in coordination that were observed (e.g. some muscles remained active for the entire crank cycle). A more advanced method of evaluating changes in coordination of multiple muscles was desired; the structural EMG analysis method of Jansen et al. (2003) was used. For each crank cycle, two 3-dimensional EMG trajectories were defined: a monoarticular trajectory from the TA, SO, and VL, and a biarticular trajectory from GA, RF, and HAM. For each 30 s trial, a similarity matrix was computed to measure the common structure between all cycles for each
trajectory. A clustering algorithm was used to select a primary template (PT), which is a representative cycle that accounts for most of the variability in the data. For each subject, the similarity between the pre-learning baseline PT and the last trial PT (post) for the monoarticular muscles was compared. The same procedure was used to compare the pre- and post-training PTs for the biarticular muscles. A paired t-test was used to determine if the mono- and bi-articular similarity scores were significantly different from each other.

RESULTS AND DISCUSSION

PTs for one subject, decomposed into their constituent muscle linear envelopes, are illustrated in Fig. 1.

Each PT chosen represented the majority of cycles (>60%) within each trial for each subject (Table 1). The similarity scores for both the mono- and bi-articular muscles were different from zero (p < 0.05), indicating that the activity of both groups of muscles changed from pre- to post-learning. However, the similarity measures for the mono- and bi-articular PTs were not significantly different from each other (p > 0.05; Table 1). There was a large amount of variability, with some subjects showing more change in the monoarticular PTs and others showing more change in the biarticular PTs. This may indicate that subjects used different strategies for learning the task. Studying changes throughout the entire learning process may lead to further insight. In addition, other multidimensional analysis techniques, such as recurrence quantification analysis, may be useful in discovering more about the nature of the changes in coordination that occurred over the learning process.

SUMMARY

The present analysis showed that the PTs of both mono- and bi-articular muscle activity patterns changed after learning a force-directing task. However, the amount of change was not significantly different between mono- and bi-articular trajectories. This may be due to the relatively large amount of between-subjects variability. Further analysis on changes in individual subjects as well as across the entire learning of the task may be needed before the roles of mono- and bi-articular muscles can be fully elucidated.

REFERENCES

Hasson CJ, et al. (2006a) CSB 14th Meeting.
Hasson CJ, et al. (2006b) ASB 30th Meeting.

ACKNOWLEDGEMENTS

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<tr>
<th>Measure</th>
<th>Monoarticular</th>
<th>Biarticular</th>
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<tr>
<td>Average % Cycles Matching PTs</td>
<td>60.0 ± 5.8</td>
<td>66.0 ± 6.8</td>
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<tr>
<td>Similarity Between PTs (pre vs. post)†</td>
<td>82.0 ± 68.3</td>
<td>53.2 ± 45.9</td>
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†A similarity value of zero would be a perfect match.