Associations between motor unit recruitment and the rates of strain, force rise and relaxation

Sabrina S.M. Lee, Maria de Boef-Miara, Allison S. Arnold, Andrew A. Biewener, James M. Wakeling

1Department of Biomedical Physiology and Kinesiology, Simon Fraser University, Burnaby, Canada,
2Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, USA
sabrina_lee_4@sfu.ca

INTRODUCTION

Muscles are able to produce the forces required for a wide range of locomotor tasks — tasks requiring different fascicle strains and strain rates. Different motor unit types have specific physiological and mechanical properties (i.e. strain rates and activation-deactivation rates), and there is evidence that during rapid locomotor tasks, preferential recruitment of faster motor unit types occurs [1,2]. However, the mechanical factors that influence motor unit recruitment remain unclear. Myoelectric signals with higher frequency content have been associated with greater fascicle strain rates [1,2], suggesting that there may be a mechanical basis for preferentially recruiting faster motor units. However, whether preferential recruitment of faster motor units is also associated with faster force rise and relaxation rates is not known. The focus of this study is to determine if different motor units are recruited in task-specific patterns during locomotion and to assess whether recruitment is influenced by mechanical factors such as strain, strain rate, force, and force rise-relaxation rates.

METHODS

Six African pygmy goats (Capra hircus; 3 males, 3 females, age 21 ± 15.5 months, mass 25.85 ± 6.20 kg) were tested at Harvard University’s Concord Field Station. Electromyography (EMG), fascicle strain, and tendon force of the lateral and medial gastrocnemius muscles were recorded using surgically implanted offset twist-hook bipolar silver-wire electrodes (0.1mm, California Fine Wire Inc.), sonomicrometry crystals (2mm, Sonometrics Inc.), and a tendon buckle on the Achilles tendon, respectively. Recordings were made during different gaits (walk, trot, and gallop) on a level and incline surface on a treadmill (Fig. 1).

We used wavelet analysis, a time-frequency decomposition technique [3], and principal component analysis (PCA) to identify the major features of the myoelectric intensity spectra. The angle, θ, formed between the vector of the first and second principal component, PCI-PCII, loading scores and the PCII loading score axis was used to quantify the contribution of high and low frequency content in the myoelectric signal (Fig. 2). A signal with a small angle θ has a positive contribution from the PCII loading score and is interpreted as having relatively high frequency content associated with faster motor unit recruitment. Analysis of variance was conducted to compare myoelectric intensity, angle θ, and mechanical factors (muscle force, force rise-relaxation rates, fascicle strain, and strain rates) between muscles, gaits, and grades. A general linear model analysis of covariance was conducted to identify significant associations between angle θ and myoelectric intensity and the mechanical factors.

Figure 1: Representative lateral gastrocnemius force (blue), fascicle length (red), and myoelectric signals from fine-wire EMG (black) of a goat during different locomotor tasks. Shaded grey area indicates stance phase.
RESULTS AND DISCUSSION

Myoelectric intensity, fascicle strain, strain rate, force, and force rise-relaxation rates all increased as gait velocity increased from walking to trotting to galloping (p<0.05). These measures were greater during locomotion on an incline surface compared to the same level speed (p<0.001).

Angle θ decreased as gait velocity increased from level walking to trotting to galloping (Figure 2), suggesting that different motor units were recruited depending on the task. At faster speeds, the myoelectric signal contained higher frequency components. This shift to higher frequencies was due to a decrease in the low frequency components and an increase in the high frequency components of the spectra, indicating that a greater number of fast motor units were recruited while fewer slow motor units were recruited. These results support previous observations in other animals and man that faster motor units may be preferentially recruited for tasks that require rapid shortening-lengthening cycles [2,3]. EMG recordings from the LG had smaller values of angle θ (higher frequency content) than recordings from the MG. This finding is consistent with previous work on in situ motor unit recruitment in goats [4] and is mostly likely caused by the higher proportion of fast fibres within the goat LG (unpublished immunohistochemistry results).

Although we found no evidence that faster motor units were recruited for tasks that required rapid force rise-relaxation rates, we did find that preferential recruitment of faster motor units was associated with faster shortening fascicle strain rates in some cases (Table 1, p<0.001). Thus, the increased shortening velocities of faster motor units may provide benefits at faster locomotor speeds.

Figure 2: PCA of the myoelectric signals. PC I and II loading scores for MG (solid) and LG (dotted) during different locomotor tasks reveal differences in myoelectric frequency content and motor unit recruitment.

CONCLUSIONS

We observed that motor units in the goat LG and MG muscles are recruited in patterns that are task-specific during locomotion. We also observed cases where preferential recruitment of faster fibres was related to faster fascicle shortening strain rates. These findings offer crucial insight into the basic neuromechanical mechanisms of producing movement.

REFERENCES


ACKNOWLEDGEMENTS

We thank Drs. Jennifer Carr and Carlos Moreno for assistance during data collection. This work was supported by the NIH (R01AR055648).

Table 1: Summary of the effect of mechanical and excitation variables on angle θ. The arrows denote the direction of association: ↑ positive and ↓ negative when the covariates are significant (p<0.05).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total intensity</th>
<th>Strain</th>
<th>Strain rate</th>
<th>Force</th>
<th>Force rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force rise</td>
<td>↓</td>
<td></td>
<td>↑</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force relaxation</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
<td>↓</td>
<td></td>
</tr>
</tbody>
</table>