SUBMAXIMAL STIMULATION AND HISTORY-DEPENDENT PROPERTIES EXPLAIN HOW SIMILAR MUSCLES CAN FUNCTION DIFFERENTLY

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INTRODUCTION

Even when experiencing identical strain and stimulation, two hindlimb muscles of the cockroach, *Blaberus discoidalis*, function differently under dynamic, *in situ* conditions (Fig. 1). Muscles 178 and 179 are two of six coxa-femur extensors that are innervated by the same, single excitatory motor neuron, extend a single degree-of-freedom joint, and have similar twitch kinetics and similar force-length and force-velocity properties when maximally stimulated (Ahn and Full, in prep). The muscles do not operate as antagonists negating each other's functions, but rather generate force at different phases of the contraction cycle (Fig. 1).

In vivo neural activation and muscle strain patterns in animals often differ from those conditions imposed during traditional *in vitro* studies of maximally stimulated muscle. In the present study, I test the hypotheses that extensor 178 force is greater under *in vivo* stimulation conditions than force generated by extensor 179; and secondly, that the two muscles exhibit different history-dependent properties, such as force enhancement due to passive stretch (Mutungi and Ranatunga, 1999). These infrequently examined properties may contribute to the differing mechanical functions of muscles 178 and 179 when strained and stimulated identically (Fig. 1).

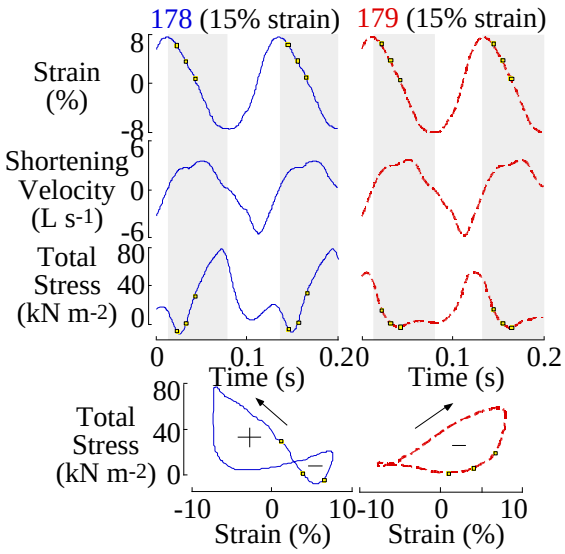

Fig. 1. Strain, shortening velocity, and force when muscles 178 and 179 operated under identical strain and stimulation conditions. The shaded area represents the shortening phase of the oscillatory cycle. The yellow squares represent spikes of stimulation. The arrows indicate the directions of the loops.

METHODS

A servo motor (Cambridge Technologies) was used to measure muscle force while controlling muscle length. The muscle was stimulated (Grass stimulator) through the

motor neuron using a suction electrode. Isometric contractions were elicited with trains of current pulses that served as the stimulation pattern. The *in vivo* stimulation pattern during preferred speed consists of a burst of 3 stimuli at 100 Hz (3s; Full et al., 1998).

RESULTS AND DISCUSSION

In submaximally stimulated muscle, the force at resting length was 82% and 72% of the maximum, normalized force in muscles 178 and 179, respectively (Fig. 2). As muscle length decreased, the difference in force generation between the muscles increased. For example, at -10% strain, muscle 178 generated twice the force generated by muscle 179 (Fig. 2).

Differences between the two muscles in their submaximal force-length relationships (Fig. 2) and in force enhancement after a passive stretch (shown for muscle 178 in Fig. 3) accounted for as much as 85% of the difference in peak force generated between the two muscles during oscillatory contractions. Using *in vivo* conditions and examining the history-dependent properties of these muscles provide clues to how the muscles function differently under identical cyclical conditions. In the insect leg system, simple neural control can result in functional diversity in seemingly synergistic muscles due to differences in contractile properties under *in vivo* conditions.

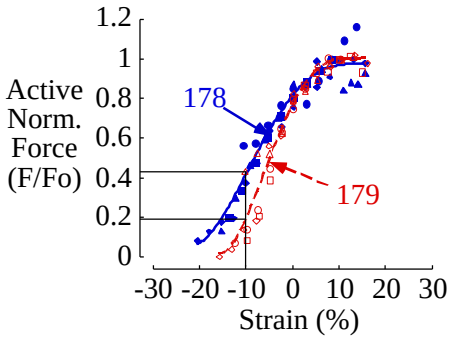

Fig. 2. Force-length relationship using the stimulation pattern during running (3s) comparing muscles 178 and 179.

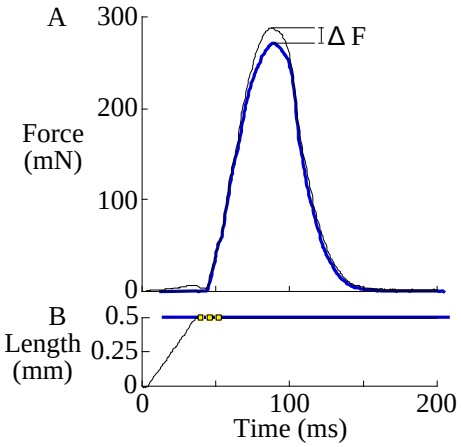

Fig. 3. Force enhancement in muscle 178. The thick and think lines are the forces generated by 178 during an isometric contraction vs. when stretched just prior to an isometric contraction, respectively. Force enhancement (ΔF) for this trial is 6%.

REFERENCES

Ahn, A. N. and Full, R.J. (in prep).

Full, R. J., et al. (1998). *J. exp. Biol.* **201**, 997-1012.

Mutungi, G. and Ranatunga, K. W. (1999). *J. Physiol.* **518P**, 88P-89P.