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THE MAGNITUDE AND THE TIME DEPENDENT STRUCTURE OF FORCE FLUCTUATIONS ARE NOT MUSCLE-LENGTH DEPENDENT

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INTRODUCTION

The force fluctuations produced during sustained isometric contractions have important implications for successful movement performance and the accurate control of muscle force. These fluctuations have been examined for different muscle groups, age groups, and for subjects before and after strength training (e.g., Enoka et al. [1]). However there has been no systematic evaluation of the effect of muscle length on the fluctuations in force during an isometric contraction. It is reasonable to suppose that aspects of the force fluctuations may be different for different muscle lengths since there is evidence that the optimal stimulation pattern of muscle is different for different muscle lengths [2]. In order to effectively study the relationship between the nature of the force fluctuations and muscle length in vivo, abduction of the index finger was studied as it caused by only one muscle, the First Dorsal Interosseus (FDI) [3].

The purpose of this study was to quantify the magnitude and time dependent structure of the fluctuations in force during sustained isometric contractions for different effort levels, at different muscle lengths in the FDI. It was hypothesized that length dependent differences in the neural recruitment strategy would show up as differences in these measures.

METHODS

Twelve subjects, five females and seven males were recruited; mean age 26 ± 6 years, mean mass 72.5 ± 16.7 kg, mean height 1.72 ± 0.1 m. All subjects provided written informed consent before participating and the Institutional Review Board at The Pennsylvania State University approved all procedures. A custom built rig was used to restrain the thumb at an 80 degree angle to the index finger and the wrist was restrained using Velcro straps at a 45 degree angle to the hand. A uni-axial force transducer (PCB 208-C01) was placed against the distal phalangeal head of the proximal phalanx of the index finger in order to measure the force due to isometric index finger abduction. Care was taken to align the axis of the transducer with the line of action of the force applied by the finger.

Subjects performed familiarization contractions then performed maximal isometric finger abduction contractions in three finger positions: long FDI muscle length, medium FDI muscle length, and short FDI muscle length. Neuromuscular stimulation was delivered during one of the maximum efforts in each finger position (square wave percutaneous stimulation applied at a frequency of 100 Hz to the motor point using a Sys Stim 270A stimulator at a level that was tolerable for the subject, but that produced a rapid finger abduction movement on application of the

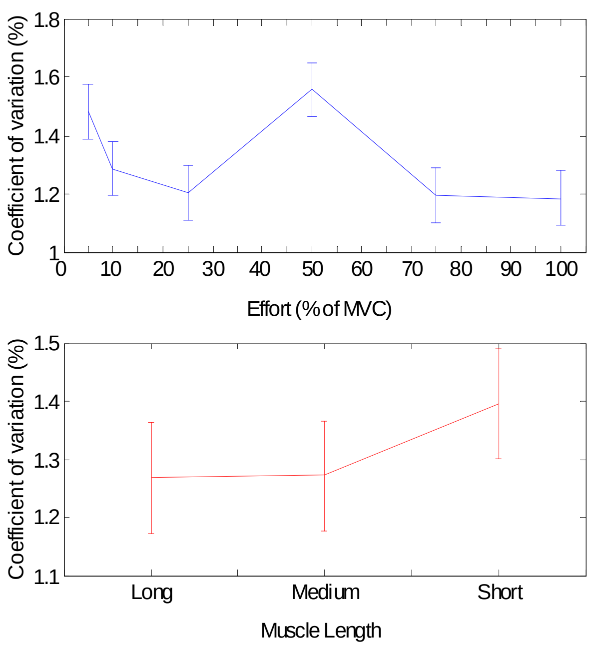

Figure 1: Mean coefficient of variation (bars show standard error) for a) each effort level where means are taken across all muscle lengths and subjects; and, b) for each muscle length where means are taken across all effort levels and subjects.

stimulation). Subjects then produced isometric contractions at long, medium and short muscle lengths at 5%, 10%, 25%, 50%, 75% and 100% of the maximum in each finger position by targeting a force displayed on a computer monitor in a Labview 8.2 environment. A one minute rest was given between each effort and five minutes rest was given between finger positions. The force signal was sampled at 160Hz and low pass filtered at 40Hz. A minimum variance criterion was used to select a window for further analysis from the force record. The magnitude of the fluctuations was quantified using the coefficient of variation (CV) (the standard deviation of force divided by the mean force). The fractal scaling index, alpha, was calculated using the Detrended Fluctuation Analysis (DFA) algorithm [4]. A surrogate analysis of the data showed that the DFA results were due to signal properties, not measurement system noise. Statistical comparisons on the DFA and CV response variables were performed using a three way ANOVA.

RESULTS AND DISCUSSION

While the neuromuscular stimulation was at a level sufficient to increase force if the subjects were not able to fully recruit the muscle voluntarily, all subjects were able to fully recruit the muscle in at least one of the finger positions. A Chi-Square test showed no association between finger position, and therefore muscle length, at which subjects were not able to fully activate the muscle (p=0.937).

The magnitude, as quantified by CV, of the fluctuations in force was significantly increased at short muscle lengths (p=0.012) (Figure 1). The DFA indicated different scaling behavior for short muscle lengths (Figure 2) that was statistically significant (p=0.010). This may be due to different motor unit firing characteristics required to achieve full activation at short muscle lengths.

The relationship between CV and effort level, and between alpha and effort level, may be due to the relative contributions of motor unit recruitment and rate coding to force gradation in the FDI.

CONCLUSIONS

The results showed that there was no systematic inability to maximally activate the FDI at short muscle lengths, as evidenced by the lack of increase in force when a maximal effort was supplemented by neuromuscular stimulation. However, there was a statistically significant increase in the magnitude of the force fluctuations, quantified by the CV, of force, and a statistically significant change in the time dependent structure of the force fluctuations, quantified by the alpha value, of the fluctuations. Taken together the results indicate that full activation of the FDI is possible at short muscle lengths, but that an alternative recruitment strategy is necessary to achieve this. These findings have implications for the accurate control of movement and force production.

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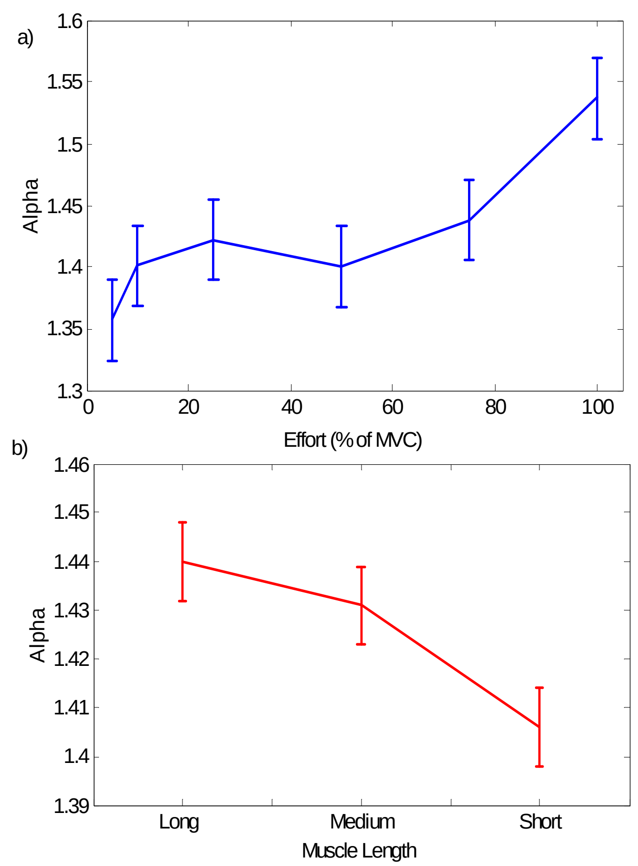

Figure 2: Mean alpha value (bars show standard error) for a) each effort level where means are taken across all muscle lengths and subjects; and, b) for each muscle length where means are taken across all effort levels and subjects.