MATHEMATICAL MODEL FOR EVALUATING THE VARIABILITY OF THE SUPERIMPOSED TWITCH FORCE IN VOLUNTARY CONTRACTIONS

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INTRODUCTION

The superimposed twitch technique (Merton, 1954) is a commonly used approach to determine the active state of a muscle (e.g., Belanger and McComas, 1981). In this technique, an artificial, electrical stimulation (twitch or doublet) is superimposed on the voluntary contracted muscle. This superimposed twitch will produce a force beyond the voluntary force if not all motors units are recruited at high frequencies. Clinically, the superimposed twitch has been used frequently to assess muscle inhibition during maximal voluntary contractions in patients with musculoskeletal problems such as ligament loss (Hurley et al, 1994), swelling of the joint (Fahrer et al, 1988) or pain (Suter et al, 1998). One of the limitations of the superimposed twitch technique has been its variability (Suter et al., 1996). Even under precisely controlled laboratory conditions, the superimposed twitch force may vary by 50% for repeat measurements. This variability does not appear to be associated with measurement problems, but with an intrinsic inability to reproduce tests reliably. We have speculated that the variability in the superimposed twitch technique is associated with the stochastic nature of the firing of the twitch application relative to the stimulation pulses of the ongoing voluntary contraction of the motor units. The purpose of this study was to test whether the random firing of the motor units and the stochastic nature of the superimposed twitch can explain this observed variability.

METHODS

We developed a mathematical model of the neuro-motor control system to simulate the effects of a superimposed, artificial, electrical twitch on voluntary contractions. To accommodate experimental observations, the force of the superimposed twitch was assumed to be greater if it fell within 10ms of the pulse of the voluntary stimulation train (Burke et al, 1975) than if it fell outside the 10ms window. The superimposed twitch force was assumed to be inversely related to the motor unit firing frequency. In the first simulation, the number of motor units was assumed to be large to allow for a continuous probability distribution of the firing frequency range. In the second simulation, we considered a discrete case, in which the number of motor units was assumed to be small (between 100 and 300 motor units).

RESULTS

In the continuous and discrete simulations, we quantified the variability of the enhanced force following a superimposed twitch for three different levels of excitation: (1) a uniform distribution of the firing frequencies within the range of 20Hz-50Hz; (Figure 1) (2) a great number of motor units firing at high frequencies; and (3) a great number of motor units firing at low frequencies (Figure 2). In all cases, we found a low variability of the enhanced force compared to the observed experimental variability. However, the discrete case produced more variability in the superimposed twitch force than the continuous case.

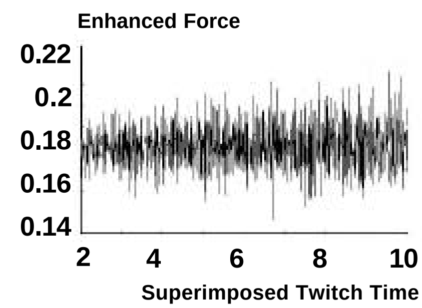

Figure 1. Variability of the enhanced force for a discrete uniform distribution of the firing frequencies.

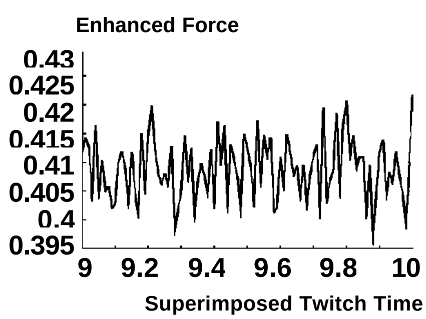

Figure 2. Variability of the enhanced force for a discrete low frequency distribution of motor unit firing rates.

CONCLUSIONS

The low variability of the enhanced force following a superimposed twitch is in disagreement with experimental observations. There could be two reasons for this discrepancy: first, our model is not correct, or second, our model is inherently correct, but it does not contain the factor that causes the great experimental variability. Most of our model assumptions regarding the number of motor units, their firing rates, and the local force enhancements as a function of timing, are based on experimental evidence, and therefore should be reasonable. However, two features of motor unit firing were not incorporated into the model: inter-pulse variation and synchronization across motor units. Realistically, only the latter of the two features can influence our results. Therefore, synchronization of motor units during voluntary contraction might have to be included into the model to obtain the great variability observed experimentally.

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