The Influence of Stimulation History on Muscle Performance: Within Burst Potentiation in Human Tibialis Anterior Muscle

P. Mela[1], P.H. Veltink[1], P.A. Huijing[1,2]

[1] Institute for Biomedical Technology (BMTI), Biomedical Signals and Systems, Department of Electrical Engineering, University of Twente
P.O. Box 217, 7500 AE Enschede, The Netherlands
[2] Faculteit Bewegingswetenschappen, Vrije Universiteit
Amsterdam, van de Boechorststr 9, 1081 BT, The Netherlands

Abstract

For muscle activation, electrical stimulation with varying frequency was reported to be optimal. However, effects of such patterns are, most often, evaluated at one muscle length only. The purpose of this study is to show the influence of ankle joint angle (i.e. muscle length) on effects of activation history within a tetanic contraction in human tibialis anterior muscle (TA).
TA of healthy subjects (n=5) was stimulated under isometric conditions. Moment at the ankle was measured at three ankle angles. Bursts of two seconds were used, with constant stimulation frequencies (CSF: 50, 25, 16, 8 Hz) and with decreasing stimulation frequencies (DSF). Each DSF tetanus consisted of four 0.5 second bursts of the different frequencies (50, 25, 16, 8 Hz).
To evaluate the effect of preceding higher stimulation frequency (DSF), the average moment at corresponding time intervals in the DSF and CSF trials were compared for 25, 16, 8 Hz.
Preceding higher stimulation frequencies cause increase of the moment elicited by a given frequency. Such potentiation is frequency and ankle angle dependent ($p<0.001$), and shows significant interaction between these effects ($p<0.001$). The effect of DSF was higher for lower frequencies, and decreased from dorsiflexion to plantar flexion (i.e. with higher muscle length).

Introduction

During volitional activation of muscle, motor neurons do not usually fire at constant frequencies: their discharge rate exhibits short term (i.e., pulse to pulse) and long term variations (i.e., changes over seconds to minutes) [2]. Many authors have reported the "catch-like property" of animal and healthy human muscles during maximal voluntary isometric contractions: an initial brief high frequency burst can enhance muscle force during a following constant lower frequency train [1,3]. With the purpose of optimally activating muscle by means of electrical stimulation, stimulation patterns with varying frequency have been investigated as variations in the motor unit activation rate have been shown to maximize force and minimize fatigue. However, the effects of such patterns are, in most cases, evaluated at one muscle length, mainly optimum length for maximal activation.
With this study we want to show the influence of ankle joint angle (i.e. muscle length) on the effect of activation history within a tetanic contraction in human tibialis anterior (TA) muscle of healthy subjects.
Stimulation protocols consisting of either constant and decreasing stimulation frequency bursts have been used. The effect of previous higher stimulation frequency on a following constant frequency, here defined as within burst potentiation, has been evaluated for four different stimulation frequencies at different ankle joint angles.

Methods

TA muscles of five healthy subjects were studied during isometric contractions at three different ankle angles (dorsiflexed, intermediate, plantar flexed, corresponding to low, close to optimum and high muscle length), under conditions of stable recruitment. The stimulation protocols used were: (1) constant stimulation frequency bursts (CSF) of two seconds at 50, 33, 25, 20, 6, 12, 8 Hz; and (2) decreasing stimulation frequency bursts

(DSF) in which the two second bursts were composed of four successive pulse trains (0.5 s each) at 50, 25, 16, 8 Hz . At each ankle angle the protocols were applied in a random order, each trial being repeated three times. One-minute recovery time was allowed between consecutive bursts.
For comparison of DSF and CSF results, mean moments were calculated over corresponding time intervals (the last 0.1 sec of each single pulse train of the DSF). Such difference (fig.1) was then divided by the moment elicited by the CSF protocol.

Results

Fig.1 shows experimental moment traces elicited by the CSF and the DSF protocols for corresponding stimulation frequencies.

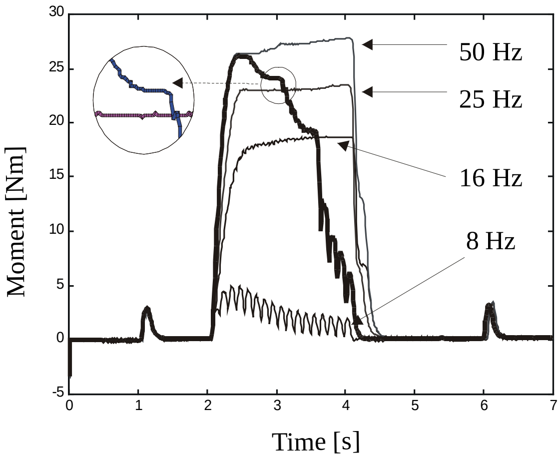
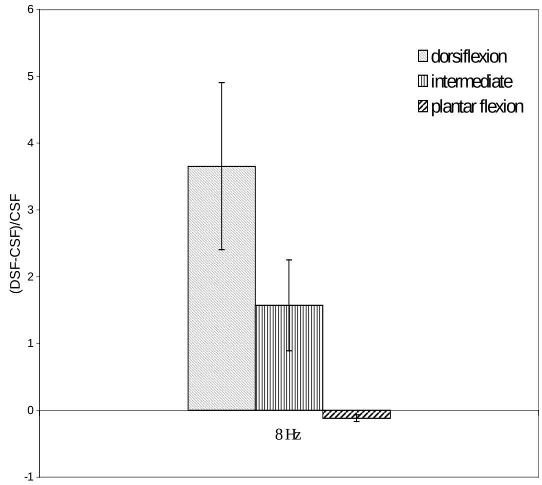
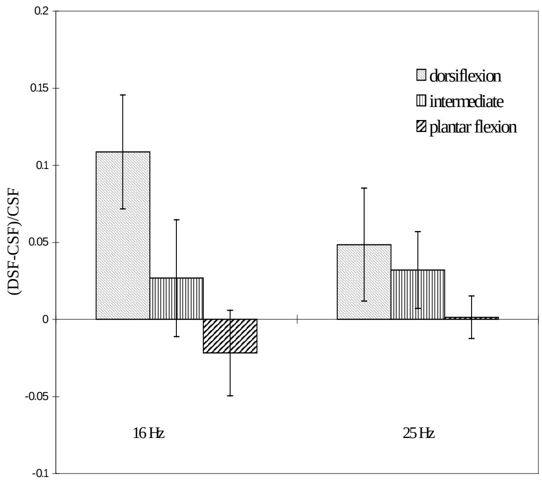


Fig.1: Example of experimental traces. CSF moments for 50, 25, 16, 8 Hz and DSF with corresponding frequencies (bold line) taken at intermediate ankle joint angle. The inset shows the difference between moments elicited by the DSF protocol (upper curve) and the CSF protocol for 25 Hz.

The DSF protocols elicited potentiation of moment output: the same pulse train produced a higher moment output when preceded by trains of higher frequencies. However, this effect was joint angle dependent: at 8 Hz (fig.2a), the difference between DSF and CSF normalized to the CSF values decreased from dorsiflexion to plantar flexion (i.e. with increasing muscle length).
For higher stimulation frequencies the moment was potentiated to a smaller, still substantial, extend (fig.2b).
A repeated measurements ANOVA test shows that such potentiation is frequency and ankle angle dependent ($p<0.001$). The interaction between frequency and angle on potentiation is significant as well ($p<0.001$).



Frequency [Hz]
a)



Frequency [Hz]
b)

Fig.2: Within burst potentiation of DSF protocol on a) 8 Hz and b) 16, 25 Hz. Note the difference in scale between the two charts.

The advantage of having a preceding higher frequency of stimulation was always present at dorsiflexed ankle positions, for all frequencies, while at plantar flexed positions CSF trials gave moments similar or greater than those elicited by DSF contractions.
It is worth noticing that the very high potentiation of the 8 Hz DSF train at dorsiflexed ankle positions (~350%) is a consequence of the fact that in those positions the moment elicited by a CSF contraction is rather small. Furthermore, it appears from fig.1 that 0.5 s was not a long enough interval to reach a steady level for 8 Hz, in contrast to what was found for other stimulation frequencies.

Discussion

This study shows that the effects of activation history on potentiation in human tibialis anterior muscle are joint angle dependent. The increase in the moment elicited by a given frequency within the DSF patter in comparison with the CSF trial at the same frequency decreased going from dorsiflexion to plantar flexion (i.e. increasing muscle length) when the muscle was submaximally stimulated.

The mechanisms underlying the enhancement of force after an initial high frequency burst are still subject of discussion. Furthermore, the influence of muscle length on such mechanisms is often neglected.

Parmiggiani and Stein [5] suggested that the initial high frequency burst increases the stiffness of the muscle by eliminating the slack of the elastic component. Under these conditions, the successive stimuli would develop a higher force. This might be in agreement with our results as the advantage of such an initial burst decreased at higher lengths where the tendon was already stretched.

The myosin regulatory light chain (RLC) phosphorylation may also be responsible for force potentiation by reducing the lateral separation of actin and myosin filaments and consequently increasing the access of attached cross bridges to the force producing state [4]. Since myosin light chain phosphorylation continues after calcium concentration returns to control values, it produces a history dependent force output [4]: a muscle which has recently been active, with myosin still in the phosphorylated state, responds to stimulation in a different way than it would do in a relaxed state. This observation could explain the within contraction potentiation of the DSF pattern: an initial higher stimulation frequency would give a higher level of phosphorylation causing the muscle to react with greater force to subsequent submaximal stimulation.

The potentiating effect due to previous activation was most pronounced at dorsiflexed positions and hardly present at intermediate positions. This dependence on ankle joint position is consistent with findings of Yang et al. [6]; according to these authors a reduction in the interfilament spacing due to muscle lengthening has the same effect of RLC phosphorylation on force development, therefore RLC phosphorylation has minimal effect when the myosin heads are already close to the actin binding sites.

Enhancing muscle performance by optimizing the stimulation pattern is an interesting possibility for applications of electrical stimulation. The results of this study suggest that length effects should be taken into account in optimizing muscle force output by means of frequency modulation.

Acknowledgment

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