Twitch summation with double stimulation

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SUMMARY

Both the mechanical and the EMG responses to a pair of electrical impulses depend upon the interpulse interval (PI) and the structure of the muscle. The latter can therefore be investigated using the paired stimuli technique and information concerning twitch summation and refractory period may be obtained. We documented how the force twitch and the electrically elicited response are affected by the PI and the pulse amplitude. Our findings showed that the maximum synergic effect of the doublet, that is the ratio between the peak force produced by a doublet and that produced by a single pulse, is between 3 and 4 and is obtained for PI between 3.5 ms and 30 ms. The absolute refractory period average value was 2.2±0.1 ms. Muscle fiber conduction velocity (CV) is higher for the second response. Repeatability of mechanical and electrical responses is poor and methodology must be improved.

STATE OF THE ART

The mechanical response of muscle to multiple pulses has been shown to be a non linear summation of the evoked twitches. The use of N-let impulse train in FES applications, following the terminology introduced by Karu et al /1/, is a well known technique aimed to increase force with a concomitant reduction of muscular fatigue /1/2/. Most of the published works focused on the time course of the force signal as the available information to monitor fatigue /3/4/5/6/7/. It is well known that mechanical manifestations of fatigue are related to muscular endurance and that they are anticipated by changes in the electromyographic signal /8/. The effect of N-let impulse train on myoelectric signal is not discussed in the literature. For this reason the aim of the present work is to evaluate the effect of double impulses on both force and EMG signals and to assess the repeatability of mechanical and electrical responses in different days.

MATERIALS AND METHODS

We define *doublets* as the stimulus pattern made by two rectangular pulses separated in time by the pulse interval (PI) and *singlets* the stimulus made by one single rectangular pulse. Five subjects (27.8±3.8 years) were involved in this experiment. The protocol consists of one session made of five different trials in the following order: 25 singlets, 200 doublets with PI randomly chosen in the range 1-5 ms, 200 doublets with PI in the range 1-20 ms, 200 doublets with PI in the range 1-100 ms and, finally, 25 singlets. Each stimulus was supramaximal and was generated once a second; trails were separated by 10 minutes of rest. The whole session was repeated in three different days on the biceps brachii muscle to test the repeatability of the measures. The force twitches generated by these impulse trains were recorded by means of a load cell mounted on an aluminum arm designed to avoid resonance frequencies in the force signal bandwidth. The EMG signals were recorded by means of a four electrode bar array placed distally on the muscle between the innervation zone and the tendon region. The proper electrode position was determined for each subject by means of a multi-channel linear electrode array according to the findings described elsewhere /9/10/. The variables under study were: the peak of force (PF) the time to reach the peak (TTP), the half relaxation time (HRT), the twitch area (TA), the conduction velocity (CV) and the correlation coefficient (CC) between two double differential signals used to estimate CV.

Supramaximal constant current stimulation was applied in monopolar mode with one small electrode (Ø = 3 cm) on the motor point of the biceps and one large electrode (10x12 cm) on the triceps.

RESULTS

Comparison between the 25 singlets stimuli at the beginning and the end of each session (included in the protocol to check the *stability* of the experiment) show great differences, indicating instability of the response during the experiment. Hence, if fatigue or, more probably, movements of the stimulation and/or of the recording electrodes occur, the three trials within each session may be different not only because of the PI variation but also because of uncontrolled factors. As a consequence also the day to day repeatability may be affected and was indeed poor. For such reasons the best session for each subject was selected by means of a multi-criteria method based on CC value, twitch and double differential signals morphology, trends of CV and PF and uniformity and superimposition of the force plots in the three PI ranges (see Figure 1).

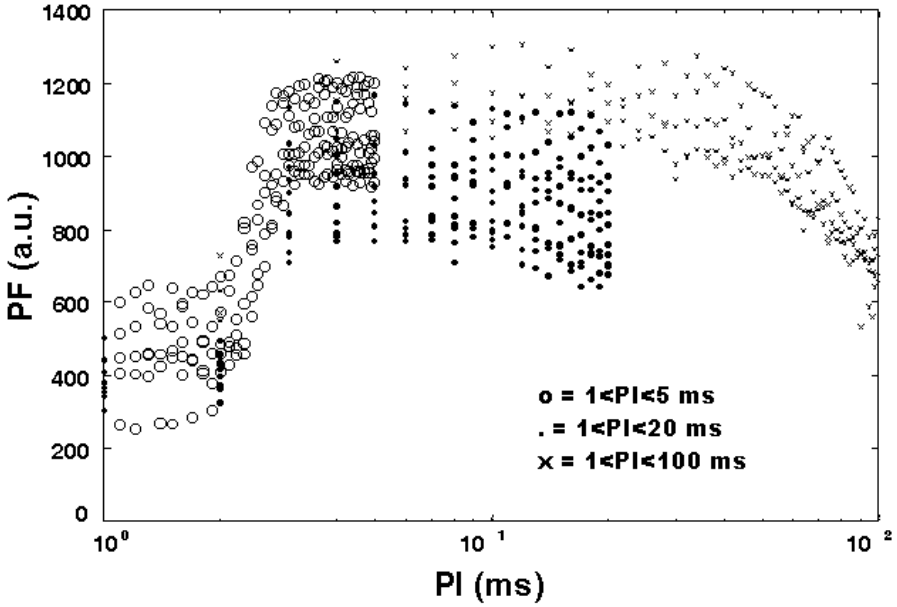

Figure 1. Example of a selected session showing PF in the three trials as a function of the PI (log X axis).

The pattern of force plotted with respect to the PI (for PI in the range 1:5 ms) allows to evaluate the average value, among five subjects, of the Absolute Refractory Period (ARP) as 2.2±0.1 ms. This result is in agreement with those found by Buchthal and Engbaek extrapolated for the temperature of 35 °C /11/.
As well known, the use of N-let pulse trains allows to increase, in a non-linear fashion, the force induced by the stimulus. The average maximal ratio between PF obtained with doublets and with singlets was 2.79±0.93 (range 2.12 - 3.96), quite constant within subjects (the average standard deviation between days was 0.28) and was obtained for PI = 3.5±0.1 ms (see Figure 2).

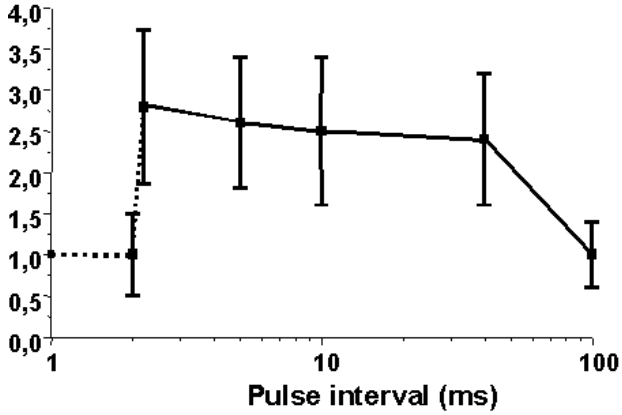

Figure 2. Ratios between the PFs obtained with a doublet and a reference force obtained from a single stimulus (mean and std. dev, N=5)

The TTP is always greater in double response with respect to singlets for PI>ARP. The mechanical summative effect due to the second stimulus always occurs for PI>ARP. Up to values of 70-80 ms the two twitches are fused together and the second peak is higher: this explain the TTP increase. The minimum values of TA correspond to the singlets. The maximum values is observed immediately after the ARP and decreases slightly in the range ARP-30 ms.
For PI>30 ms the two stimuli in each doublet generate two M-waves. The second M-wave has CV significantly larger (Wilcoxon paired test, $p < 0.01$) than the first for 30<PI<100 ms in four subjects out of five (see for example the behavior of one subjects in Figure 3).

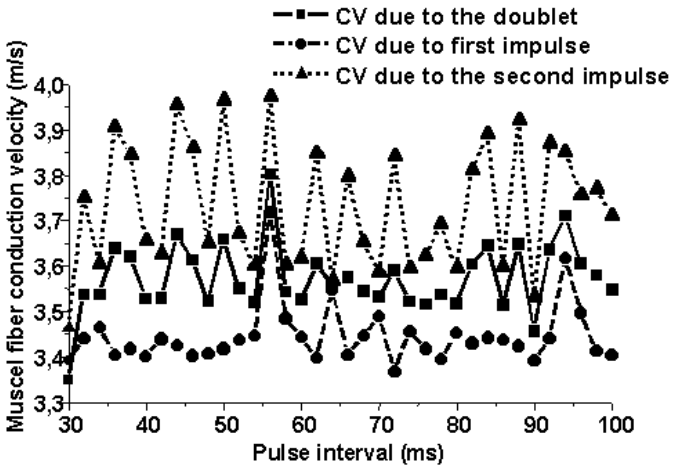

Figure 3. Comparison of CV values of the myoelectrical responses due to the doublet as a whole and due to the two separate stimuli in the range 30-100 ms.

Referring to the work of Hopf et al /12/ where a clear correlation between CV and TTP was found (although by using invasive techniques), we plotted the first variable versus the second one. TTP, in fact, could be considered as a good estimate of the contractions time when the stimuls is a singlet and in the case of doublet with PI<ARP. The two variables have shown large variability and poor correlation, hence the method seems not useful to properly estimate the contraction time.

DISCUSSION

The values of PI intervals corresponding to the ARP and to the maximal increase of PF were found to be highly stable and repeatable. On the contrary, other parameters, such as PF, TTP, TA, where subject to large fluctuations when electrodes were repositioned, when the subject slightly changed position or straps were adjusted. It is clear that the technique for investigating this phenomenon must be improved in order to study fatigue and any other long term effect. Nevertheless, it is unquestionable that the motor axons (or their terminal branches) have a refractory period of 2.2 ± 0.1 ms and the maximum PF is obtained for PI=3.5±0.1 ms but longer pulse intervals have similar effects. The first pulse has a conditioning effect upon the muscle fiber membrane which presents a higher CV value at the second pulse. This phenomenon has been previously reported /13/ and seems to be unaffected by PI within the range 30-100 ms.

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