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The effect of summation of contraction on acceleration signals in human skeletal muscle

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ABSTRACT

The purpose of this study was to determine the effects of summation of contraction on acceleration signals in human skeletal muscle. The torque parameters of dorsiflexion and acceleration signals in the tibialis anterior muscle were measured during evoked isometric contractions. In an examination of two-pulse trains with different inter-pulse intervals, the torque and accelerometer responses to inter-pulse intervals of 10–100 ms were recorded. In an investigation of the effects of different numbers of stimuli, the torque and accelerometer responses to 1–8 pulses with a constant inter-pulse interval of 10 ms were recorded. The present study found that there was a difference in acceleration amplitude between the single-pulse and two-pulse trains with an inter-pulse interval of 10 ms but not two-pulse trains with an inter-pulse interval of 20 ms or more. In the investigation of different numbers of stimuli, we found a similar MMG amplitude across 2–8 pulses. Moreover, we observed that the maximal time to the peak acceleration signal was ~27 ms. In a comparison of torque parameters with acceleration signals, the present study clearly shows that acceleration amplitude is poorly correlated to changes in force parameters when the inter-pulse interval or the number of stimuli are increased. These results suggest that the absence of associated changes in acceleration peak is due to the long interval for the subsequent pulses relative to the time at which acceleration peak is achieved (~27 ms). These findings will provide useful information concerning the method for assessing summation of contraction with an accelerometer.

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1. Introduction

The force generation process is coupled with muscle architectural changes such as the shortening of contractile components during isometric contraction. This muscle architectural change generates muscle surface vibrations, which are detectable by positioning an accelerometer over the muscle belly (Barry, 1992; Barry et al., 1992; Orizio, 1993). Barry et al. (1992) reported that the amplitude of the acceleration signal was strongly correlated with the twitch force evoked during fatigue. They concluded that the changes in the acceleration signal during exercise reflect fatigue-induced changes in the contractile properties of the muscle. Ce et al. (2008) reported a stretching-induced reduction in the acceleration signal during electrically evoked contraction. This study suggested that the stretching-induced reduction in muscle function was reflected by changes in the acceleration signal during evoked contraction. In addition, Shima et al. (2006) revealed that the evoked acceleration signal reflects the enhanced force output elicited by post-activation potentiation. These previous studies suggested that the surface vibrations detected by accelerometers during evoked contraction could be used to assess changes in muscle function.

It is well known that increases in muscle force are related to not only increased motor unit recruitment and an increased firing rate, but also the summation of contraction. In particular, a dramatic increase in peak force is observed during the early phase of tetanic summation. For example, the force response evoked by two closely spaced stimuli is larger than that induced by two or three single-twitch responses (Cooper and Eccles, 1930; Stein and Parmiggiani, 1981; Ohta et al., 2010). In this early phase of tetanic summation, structural changes in the muscle thin filaments (Matsuo and Yagi, 2008) and tendinous tissue (Ohta et al., 2010) were observed between the first and second stimulation during the application of two closely spaced stimuli. These results suggest that structural changes in the muscle–tendon component between the first and second stimuli generate muscle surface vibrations. If this is true, then an accelerometer would be able to detect the mechanical muscle changes caused by the summation of contraction. However, no systematic tests have been undertaken to evaluate the changes

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in acceleration signals during the early phase of tetanic summation. Thus, the characteristics of the acceleration signals produced in human skeletal muscle during the summation of contraction remain unknown. Since the summation of contraction is a fundamental phenomenon in muscle physiology, it is necessary to clarify the relationship between the changes in acceleration signals and force parameters during the early phase of tetanic summation.

The present study investigated the acceleration signals produced under several summation conditions because force summation profiles are affected by the inter-pulse interval of two-pulse trains as well as the number of stimuli. When the inter-pulse interval of two-pulse trains was decreased and the number of stimulation pulse was increased, the evoked peak torque increased due to the summation of contraction. Therefore, we hypothesized that the changes in peak torque induced by two or more stimuli would be reflected by the amplitude of the acceleration signal because changes in the acceleration amplitude reflect changes in the peak twitch torque (Barry, 1992; Barry et al., 1992; Shima et al., 2006). The purpose of this study was to determine the effects of the summation of contraction on the acceleration signals produced by human skeletal muscle.

2. Materials and methods

2.1. Subjects

Eight males (mean ± SD: age = 27 ± 3.1 years; height = 171 ± 9.8 cm; weight = 73 ± 4.9 kg) volunteered for this study. Prior to the experiment, all of the subjects were given a full explanation of the purpose of the study based on the descriptions approved by the Ethics Committee of Osaka University of Health and Sport Sciences. All subjects gave their written informed consent before participating.

2.2. Experimental setup and signal detection

The subjects were seated in a custom-built isometric dynamometer with their right ankle positioned at 20° of plantar flexion, and an angle of 90° at both the hip and knee joints. A padded belt was strapped to the dynamometer in order to support the limb and maintain its position during the test. Each subject's foot was tightly secured to a footplate using two straps in order to maintain the ankle angle. The subjects' arms were folded in front of their chest. All subjects performed a few voluntary contractions of their dorsiflexor muscles as a warm-up prior to testing.

The isometric torque responses of the dorsiflexor muscles in response to electrical stimulations were measured with a dynamometer (Kin-Com, 500H, Chattecx, Inc., USA). The footplate was modified to give a more stable and rigid attachment and to ensure the optimum transfer of the force to the Kin-Com load cell. The surface electromyogram (EMG) signal was recorded from the tibialis anterior muscle (TA) using bipolar surface electrodes (Ag–AgCl electrodes with a diameter of 5 mm and an inter-electrode distance of 20 mm) placed on the muscle belly. The EMG signals were amplified with an AC amplifier, and band pass filtering was set with both low (time constant of 0.03 s) and high (1 kHz) cut-offs (AB-621G, Nihon Koden, Japan). The EMG signals were only used to check the activation of the TA muscle by electrical stimulation. The acceleration signal was detected with a uniaxial accelerometer, which was 9 mm square with a thickness of 4.5 mm and a mass of 0.75 g (sensitivity = 500 mV/g (g = 9.8 m/s^2); MP110-10-101, Medisens INS, Japan). The accelerometer was secured with double-sided adhesive tape over the TA, close to the EMG. The acceleration signal was amplified and filtered using an alternating current (AC) amplifier with a bandwidth of 0.1–1 kHz. The torque, EMG, and acceleration signals were recorded by software at a sampling rate of 4 kHz via an analogue to digital (A/D) converter (PowerLab 8sp, ADInstrument, Australia), before being analyzed by the software (Chart v5.4.2, ADInstrument).

2.3. Electrical stimulation and experimental procedure

To examine the effects of different numbers of stimuli, the torque and acceleration signals produced by a single stimulus, two-pulse trains, three-pulse trains, four-pulse trains, seven-pulse trains, and eight-pulse trains delivered to the common peroneal nerve with a constant inter-pulse interval of 10 ms (100 Hz) were recorded. To examine the effects of two-pulse trains with different inter-pulse intervals, the torque and acceleration signals produced by inter-pulse intervals of 10, 20, 30, 40, 50, 80, and 100 ms were recorded.

Stimulation was applied using a 0.5 ms square-wave pulse isolated (SIU5D, Grass Telefactor, USA) from a constant voltage stimulator (S88 k, Grass Telefactor, USA). The cathode electrode (1 cm diameter) and the anode electrode (1 cm diameter) were placed near to the fibular head. The distance between the cathode and anode was 5 cm. Successive stimuli were separated by 1–5 min of rest. The stimulus intensity was 20% greater (supramaximal) than that required to produce a maximal single-twitch torque during the resting state. The torque and acceleration signals were measured three times under each stimulation condition in a random order, and the mean was used as representative value for each parameter.

2.4. Analysis of experimental signals

The evoked twitch data recorded under each stimulation condition were used to measure the peak twitch torque. The peak velocity and twitch torque acceleration were measured. The peak velocity and twitch torque acceleration were calculated from the first and second derivatives of the twitch response for each stimulation condition. The amplitude of the first peak of the evoked acceleration signal was measured under each stimulation condition (Ohta et al., 2007). The time to peak torque and peak acceleration amplitude were also measured under each stimulation condition. We defined the times to peak torque and peak acceleration amplitude as the time interval between the onset of electrical stimulation and the peak torque response and that between the onset of electrical stimulation and the peak acceleration amplitude, respectively.

2.5. Statistical analysis

All data are presented as the mean ± standard error (SE). The changes in the torque, acceleration amplitude, peak velocity, and twitch torque acceleration and the times to peak torque and the times to peak acceleration amplitude for different numbers of pulse stimuli and two-pulse trains with different inter-pulse intervals were analyzed by one-way analysis of variance (ANOVA) with repeated measurements. In the examination of two-pulse trains with different inter-pulse intervals, Tukey's post hoc test was used to determine the differences between stimulation with a single-pulse and stimulation with two-pulse trains with different inter-pulse intervals. In the examination of different numbers of stimuli, Tukey's post hoc test was performed for single stimulus vs. two-pulse trains, two-pulse trains vs. three-pulse trains, three-pulse trains vs. four-pulse trains, four-pulse trains vs. seven-pulse trains, and seven-pulse trains vs. eight-pulse trains. The significance level was <5%. SPSS software (Statistical Package for the Social Sciences, SPSS for Windows, version 11.0, USA) was used for all statistical analyzes.

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