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Effect of conditioning contraction intensity on postactivation potentiation is muscle dependent

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ABSTRACT

We aimed to examine whether the influence of conditioning contraction intensity on the extent of postactivation potentiation (PAP) is muscle dependent. Eleven healthy males performed both thumb adduction and plantar flexion as a conditioning contraction. The conditioning contraction intensities were set at 20%, 40%, 60%, 80%, or 100% of the maximal voluntary isometric contraction (MVC).

Before and after the conditioning contraction, twitch torque was measured for the respective joint to calculate the extent of PAP. In plantar flexion, the extent of PAP became significantly larger as the conditioning contraction intensity increased up to 80% MVC ($p < 0.05$). In contrast, the extent of PAP in thumb adduction increased significantly only up to 60% MVC ($p < 0.05$), but not at higher intensities.

These results indicate that the influence of the conditioning contraction intensity on the extent of PAP is muscle dependent. Our results suggest that a conditioning contraction with submaximal intensity can sufficiently evoke sizable PAP in the muscle where most of muscle fibers are recruited at submaximal intensities, thereby attenuating muscle fatigue induced by the conditioning contraction.

1. Introduction

A twitch torque generated by a muscle increases after a contraction of the same muscle. This phenomenon is called postactivation potentiation (PAP) (Vandervoort et al., 1983; Sale, 2002), and the contraction for inducing PAP is called conditioning contraction (Tillin and Bishop, 2009). The PAP is attributable to the myosin regulatory light chain phosphorylation induced by the conditioning contraction (Manning and Stull, 1982; Grange et al., 1993; Sweeney et al., 1993; MacIntosh, 2010; Stull et al., 2011).

Previous studies reported that the intensity of the conditioning contraction affected the magnitude of PAP: the higher the conditioning contraction intensity, the more the muscle is potentiated (Vandervoort et al., 1983; Sasaki et al., 2012). For instance, Vandervoort et al., 1983 reported that substantial PAP was confirmed when the intensity of conditioning contraction was over 75% of maximal voluntary isometric contraction. It is unknown, however, whether this "threshold" of PAP-inducing conditioning contraction intensity differs between muscles. Considering the primary mechanism of PAP, that is, myosin regulatory light chain phosphorylation induced by conditioning contraction (Sweeney et al., 1993), recruiting all muscle fibers during the conditioning contraction should be important to obtain the full magnitude of PAP because only muscle fibers recruited during conditioning contraction can be phosphorylated. In addition, the force-increment strategy of muscle (recruitment and firing frequency) as a function of contraction intensity differs between muscles (Kukulka and Clamann, 1981; Oya et al., 2009). Thus, it is reasonable to assume that the aforementioned threshold is different between muscles with an apparent difference in motor unit recruitment strategy.

The present study aimed to clarify whether the influence of conditioning contraction intensity on the magnitude of PAP is muscle dependent. It has been shown that the recruitment of all motor units in the adductor pollicis is completed at or above 40% MVC (Kukulka and Clamann, 1981). In contrast, the recruitment of motor unit in the soleus is not completed even at 90% MVC in the soleus (Oya et al., 2009). The former a small muscle (physiological cross sectional area: 2.01 cm^2) (Stamenkovic et al., 2013) while the latter is very large (physiological cross sectional area: 51.79 cm^2) (Ward et al., 2009) and muscle fiber composition, which is known to affect

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the magnitude of PAP (Moore and Stull, 1984), is similar between the two muscles (Johnson et al., 1973). Therefore, these muscles are suitable for examining the influence of recruitment of muscle fibers on the magnitude of PAP. We hypothesized that the threshold of the intensity of PAP-inducing conditioning contraction is lower in the adductor pollicis than in the soleus.

2. Methods

2.1. Subjects

Eleven healthy subjects (age: 24.0 ± 1.4 years, height: 1.68 ± 0.08 m, body mass: 62.1 ± 8.8 kg, means ± SDs) were recruited for this study. Each subject signed a written informed consent form. This study was approved by the Ethics Committee on Human Research of Waseda University. On the day of experiments, the subjects did not take caffeine that is known to affect the magnitude of PAP (MacIntosh and Gardiner, 1987).

2.2. Experimental design

To compare the influence of conditioning contraction intensity on the magnitude of PAP between the adductor pollicis and the soleus, two experiments were conducted. In Experiment 1, thumb adduction was used to test the adductor pollicis, and in Experiment 2, plantar flexion with the knee flexed by 90° was used to test the soleus. The latter experimental setup is based on a previous report of negligible force provided by the gastrocnemii in the above position (Kawakami et al., 1998). The experimental procedures were identical for the two experiments. First, MVC was performed at least two times, and peak torque attained during MVC was adopted as the 100% MVC value. After the completion of the MVC tasks, a rest interval of 10 min was taken to avoid the effect of PAP induced by the MVC on the subsequent tasks. Then a twitch contraction was elicited. Next, the subjects performed voluntary isometric contraction as a conditioning contraction for 10 s. The conditioning contraction intensity was set at each of 20%, 40%, 60%, 80%, or 100% of MVC in a randomized order. After the completion of the conditioning contraction, a twitch contraction was elicited again. The interval between the end of the conditioning contraction and the twitch contraction was 10 s. After the twitch torque was recorded, subjects rested for 10 min to avoid the effects of PAP induced by the conditioning contraction on the subsequent tasks. The next measurement in another condition was performed after confirming that the difference of the twitch torque was within ±10% deviation compared to the twitch torque recorded before the first conditioning contraction. The interval between the two experiments was more than two days.

2.3. Experimental set up

2.3.1. Experiment 1

Fig. 1 shows the setup of Experiment 1. The subject sat on the chair, and the right hand was fixed on the custom-made apparatus with a non-elastic strap. The thumb of the right hand was fixed at 60° (full adduction of the thumb: 0°), and the other fingers and wrist were fixed with a non-elastic strap to prevent their movement during the experiment. The torque during thumb adduction was obtained by multiplying the force measured from a load cell (±100 N, LUR-A-100NSA1, Kyowa, Japan) by the distance between the load cell and center of rotation (0.2 m) (Fig. 1). The center of rotation of thumb adduction and that of custom-made apparatus was visually aligned.

The surface EMG signal of the adductor pollicis was recorded by two Ag/AgCl electrodes (11 mm diameter; Blue sensor N-00-S, Ambu, Denmark) that were placed on the skin over the muscle belly of the palmar side of adductor pollicis. The distance between the two electrodes was 20 mm. The reference electrode was placed on the pisiform bone. We abraded the skin of the muscle belly of the adductor pollicis with sandpaper and cleaned the skin surface with alcohol before placing the electrodes. We confirmed that the inter-electrode resistance was under 5 kΩ.

The anode and cathode of the stimulating electrodes (Ag/AgCl, 11 mm diameter; Blue sensor N-00-S, Ambu, Denmark) were located alongside on the ulnar nerve at the wrist. Single rectangular pulses with 500 μs were delivered from a high-voltage stimulator (SEN-3301, Nihon Kohden, Japan) with a specially modified isolator (SS-1963, Nihon Kohden, Japan). Prior to the experiment, the stimulus intensity was determined by increasing the voltage until the corresponding torque reached a plateau. The stimulus intensity was set at 20% above the intensity at which a further increase in twitch torque of the thumb adduction was not confirmed.

2.3.2. Experiment 2

In Experiment 2, plantar flexion was performed with the hip and knee joints flexed to 90° (Fig. 2) (Kawakami et al., 1998). The right foot of each subject was secured to a dynamometer (CONTREX, CMV AG, Switzerland) with a non-elastic strap. The angle of the ankle joint was set at 0° (anatomical position). The centers of rotation of ankle joint were visually aligned to the rotation axis of the dynamometer.

The surface EMG signals were recorded from the soleus. Two Ag/AgCl electrodes (11 mm diameter; Blue sensor N-00-S, Ambu, Denmark) were placed on the medial side with respect to the Achilles tendon and on the distal side of the soleus to avoid the cross talk from the gastrocnemii. The distance between two electrodes was 20 mm. The reference electrode was located on the lateral malleolus of the left leg. Abrasion with a sand paper, cleaning the medial side of the soleus with alcohol and confirmation of the inter-electrode resistance were conducted in the same manner as in Experiment 1.

An anode of the stimulating electrode (40 × 50 mm; VIASYS, Healthcare, USA) was placed over the ventral aspect of the thigh near the patella, and a cathode (Ag/AgCl, 11 mm diameter; Blue sensor N-00-S, Ambu, Denmark) was placed over the popliteal fossa. The stimulation protocol was same as that in Experiment 1.

2.4. Data analysis

The EMG signals of the two experiments were recorded after band-pass filtered between 5 and 1000 Hz (Gain: ×1000; MEG-6116, Nihon Kohden, Japan). All torque and EMG analog signals were digitally converted using a 16-bit analog-to-digital converter (Power-lab/16SP, ADInstrument, Australia). The sampling frequency was set at 4 kHz.

The peak value of the twitch torque in each of the thumb adduction and plantar flexion and the peak-to-peak amplitude of the M-wave in each of the adductor pollicis and soleus during the twitch contraction were adopted as the twitch torque and M-wave amplitude, respectively. The relative changes of the twitch torque (i.e., the magnitude of PAP) and M-wave values in the five conditioning contraction intensity conditions were calculated by using the following formula: (value recorded after the conditioning contraction/value recorded before the conditioning contraction) × 100. For each conditioning contraction, the average values of the torque and root mean square value of EMG signals (RMS_{EMG}) and mean power frequency of EMG signals were calculated for the first and last one second periods during the conditioning contraction to examine the influence of muscle fatigue on the magnitude of PAP.

2.5. Statistics

Descriptive data are presented as mean ± SD. A two-way repeated-measures analysis of variance (ANOVA) (muscle ×