Changes in Electromyographic Activity after Conditioning Contraction

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Abstract. [Purpose] Post-activation potentiation is the increase in muscle twitch force in response to electrical stimulation after a conditioning contraction (CC) of maximum or near-maximum intensity. It is controversial whether muscular force during low-level voluntary contractions increases after maximum contraction. This study investigated the changes in electromyographic activity after CC. [Subjects and Methods] Fifteen healthy adults participated in this study. In the first experiment, a supramaximal electrical pulse was applied to the tibial nerve, and the isometric twitch force of plantar flexion was measured. After maximum voluntary contraction (MVC), i.e., CC, the twitch force elicited by electrical stimulation was monitored. In the second experiment, the surface electromyogram were recorded at an intensity of 20% MVC before and after CC. [Results] Results indicated the twitch force significantly increased by 30% within 30 s after CC. In the second experiment, the electromyographic activity significantly decreased by 16% for the gastrocnemius muscle but did not change for the soleus. Correlation coefficients between changes in the twitch force and electromyographic activity at 20%MVC were −0.54 for the gastrocnemius muscle and 0.04 for the soleus muscle. [Conclusion] Post-activation potentiation might work for daily physical activities compensating for reduced force output of the fatigued muscle.

Key words: Post-activation potentiation, Voluntary contraction, Conditioning contraction

INTRODUCTION

Post-activation potentiation (PAP) is the increase in muscular twitch force in response to electrical stimulation after a conditioning contraction (CC) of maximum or near-maximum intensity1, 2). PAP is related in principle to phosphorylation of the myosin regulatory light chain, which is induced by an increase in the sensitivity to Ca2+ of myofilaments3). The increased twitch force is observed when a muscle is activated by low-frequency stimulation1, 4), because high-frequency contraction induces Ca2+ accumulation, which reaches a saturation point and thus causing Ca2+ sensitivity to become inconsequential5).

We are interested in the physiological roles of PAP in daily physical and/or sports activities. PAP may be considered for warm-up exercises to enhance the performance of some activities. To date, studies dealing with the influence of PAP on muscular performance have reported yet not to identify a definite enhancement of maximum force output6–7). It is to be expected that a further increase of Ca2+ in the sarcomere has no more effect on muscular contraction after a certain higher level of Ca2+ concentration reached under a high-frequency contraction. Although PAP has little or no effect on maximum force, the rate of force development has been shown to increase during isometric contractions8, 9). An increase in jump height was also reported10). These results imply that the sensitivity to Ca2+ may contribute to a rapid increase in the force output, which may even occur in voluntary contractions of low intensities. When a contraction of low or sub-maximal intensity is regarded as equivalent to electrically-evoked muscular twitches, an increase in the voluntary force output can be expected, which may be considered as PAP seen at a low Ca2+ concentration level.

Several researchers have investigated the effects of PAP under sub-maximal contraction by measuring surface electromyography (EMG). Two studies found that the EMG activity did not change during constant sub-maximal contraction11–13), while another study reported force enhancement when subjects were asked to maintain a target EMG level14). These effects of PAP under sub-maximal contraction are controversial and few previous reports have demonstrated the EMG changes during low-level voluntary contraction after a conditioning contraction.

If the mechanism of PAP worked, EMG activity during a constant low-level contraction would decrease after CC, so that the same force output could be controlled before and after the conditioning contraction. Thus, to verify this hypothesis, we used visual and auditory biofeedback technique of the force output and measured EMG at a predetermined constant
force output. We also examined the changes of EMG activity during submaximal voluntary contraction and the relationship between EMG and twitch force.

SUBJECTS AND METHODS

Fifteen adults (8 men and 7 women; 31.7 ± 7.5 years of age; 1.66 ± 0.06 m in height; and 56.0 ± 7.7 kg in weight) were recruited from the co-medical staff of the Division of Rehabilitation Medicine Services, Kyorin University Hospital, Tokyo, Japan. The participants were healthy, with no history of neurological disorders or lower limb injuries in the 6 months prior to the study. They were instructed to refrain from consuming caffeine for a 24-h period before the experiments. Informed consent for the study was obtained from all of the participants.

Subjects were requested to sit on a seat with the backrest reclined at 30°. Their right knees were fully extended to measure the plantar flexion force of the right ankle using a Myoret RZ-450 dynamometer (Kawasaki Heavy Industries, Kobe, Japan). The right foot was firmly secured to the footplate of the dynamometer using Velcro straps. The center of rotation of the dynamometer was aligned with the center of the ankle joint. The ankle joint was set at 0° plantar flexion. Force signals were sampled at 1 kHz through an analog-to-digital converter and recorded in the memory of a personal computer that was connected to the EMG machine, Neuropack MEB2200 (Nihonkoden Corp., Tokyo, Japan). Neuropack MEB2200 was also used for electrical stimulation and recording of compound muscle action potentials (M-waves) and surface EMG. Twitch contraction of the triceps surae muscle was elicited by a rectangular electrical pulse of 0.2 ms in duration, which was delivered through a pair of silver disk electrodes (11 mm in diameter). The active electrodes were placed proximally one-third the distance between the fibular head and the heel for the lateral gastrocnemius and medially at two-third the distance between the medial condyle of the femur and the medial malleolus for the soleus in accordance with SENIAM recommendations. Reference electrodes were placed 2 cm apart proximally from the active electrodes. The skin was rubbed thoroughly with isopropyl alcohol before electrode placement. The ground electrode was attached over the fibular head.

The experiment consisted of 2 parts. First, the twitch force of the plantar flexors, which was elicited by the electrical stimulation of the tibial nerve, was measured before and after CC. Secondly, the EMG activities of the gastrocnemius and soleus muscles during 20% maximum voluntary contraction (MVC) were measured before and after CC. A schematic timetable of the experiments is shown in Fig.1.

The subjects sat on the seat for 20 min before examination. The supramaximal intensity of the electrical stimulation was determined before the experiment by increasing the stimulus intensity that was applied to the tibial nerve until the amplitude of the compound muscle action potentials or the M-waves of the triceps surae reached a plateau. The twitch force that was elicited by the predetermined supramaximal electrical stimulation was first measured in the pre-CC period.

After 1 min rest, the subjects were instructed to enforce maximum plantar flexion for 10 s, i.e., a CC of the triceps surae muscle. The maximum force measured for this 10 s was defined as 100% MVC that was used for CC through the experiments. Supramaximal electrical stimulation at the predetermined intensity was applied every 30 s until 150 s after the CC, i.e., the post-CC period, and plantar flexion force was measured while the M-wave amplitude was checked and confirmed to remain constant. Plantar flexor force and the M-wave amplitude recorded during this post-CC period were both expressed as percentages of the
An interval of more than 15 min was interposed before starting the second experiment to allow residual PAP effects to completely disappear. Ongoing plantar flexion force was presented on the oscilloscope, and subjects were instructed to maintain 20% MVC for 3 s in the pre-CC period. Two examiners checked whether the force was stable at 20% of the MVC level, and the EMG output of the gastrocnemius and soleus muscles was recorded for subsequent evaluation. After a 1-min rest, subjects were asked to exert maximum plantar flexion for 10 s, i.e., the CC, and to maintain 20% MVC for 3 s every 30 s for the total recording time of 150 s. Surface EMG was also recorded during this post-CC period. EMG signals were sampled at 1 kHz and band-pass filtered using a frequency range of 10 Hz to 5 kHz. The root mean square (RMS) of the EMG was calculated for the intermediate 1 s of the 3-s recording. The RMS of the post-CC period was normalized to that of the pre-CC period. The test-retest reliability of the twitch force and the RMS of the EMG in the pre-CC was evaluated by using intraclass correlation coefficients (ICC). Changes in the force and RMS after CC were statistically analyzed using one-way analysis of variance (ANOVA) and Dunnett’s post-hoc test. Pearson’s correlation coefficient was calculated to examine the relationship between the twitch force and RMS of EMG after CC. P-value of 0.05 was used as the significant limit.

### RESULTS

The ICC of the twitch force between the 2 trials was 0.96. The ICCs of the RMS of the EMG activities during the pre-CC were 0.98 for the gastrocnemius and 0.85 for the soleus.

Twitch force and MVC force are shown in Table 1. Table 2 shows the relative changes in twitch force. Twitch force significantly increased by 32% at 30 s after the CC. The force subsequently declined to 11% increase of the pre-CC level at 150 s. The M-wave amplitudes of both the gastrocnemius and soleus muscles did not change significantly (Table 3). The RMS of the gastrocnemius EMG was significantly lower (−16%) at 30 s after the CC than that of the pre-CC. However, changes in the RMS were insignificant thereafter. No significant changes were observed in the RMS of the soleus EMG (Table 4).

Table 1. Twitch and maximum voluntary contraction (MVC) force of the ankle plantar flexor

<table>
<thead>
<tr>
<th></th>
<th>force (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twitch force (pre-conditioning contraction, pre-CC)</td>
<td>10.8 ± 3.6</td>
</tr>
<tr>
<td>Twitch force (post-CC 30 s after CC)</td>
<td>14.3 ± 5.0</td>
</tr>
<tr>
<td>MVC</td>
<td>113.9 ± 41.1</td>
</tr>
</tbody>
</table>

The changes are expressed as percentage before conditioning contraction. (n = 15)

Table 2. Changes in twitch force after the conditioning contraction

<table>
<thead>
<tr>
<th>Time after CC</th>
<th>Change in twitch force (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30sec</td>
<td>32.4 ± 14.6*</td>
</tr>
<tr>
<td>60sec</td>
<td>20.2 ± 9.9*</td>
</tr>
<tr>
<td>90sec</td>
<td>14.1 ± 13.4*</td>
</tr>
<tr>
<td>120sec</td>
<td>13.6 ± 9.9*</td>
</tr>
<tr>
<td>150sec</td>
<td>11.0 ± 11.1*</td>
</tr>
</tbody>
</table>

The changes are expressed as percentage before conditioning contraction. (*p<0.05)

Table 3. Changes in amplitude of the compound muscle action potential

<table>
<thead>
<tr>
<th>Time after CC</th>
<th>Change in M-wave (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30sec</td>
<td>1.05 ± 21.1</td>
</tr>
<tr>
<td>60sec</td>
<td>−0.86 ± 31.9</td>
</tr>
<tr>
<td>90sec</td>
<td>−7.2 ± 28.5</td>
</tr>
<tr>
<td>120sec</td>
<td>−6.8 ± 33.4</td>
</tr>
<tr>
<td>150sec</td>
<td>−4.0 ± 24.5</td>
</tr>
</tbody>
</table>

The changes are expressed as percentage before conditioning contraction. There was no significant change.

Table 4. Changes in electromyography during voluntary contraction after the conditioning contraction

<table>
<thead>
<tr>
<th>Time after CC</th>
<th>Change in EMG (%)</th>
<th>Gastrocnemius</th>
<th>Soleus</th>
</tr>
</thead>
<tbody>
<tr>
<td>30sec</td>
<td>−15.5 ± 17.9*</td>
<td>2.5 ± 11.9</td>
<td></td>
</tr>
<tr>
<td>60sec</td>
<td>−4.7 ± 19.6</td>
<td>8.9 ± 31.2</td>
<td></td>
</tr>
<tr>
<td>90sec</td>
<td>−1.0 ± 23.1</td>
<td>10.0 ± 28.8</td>
<td></td>
</tr>
<tr>
<td>120sec</td>
<td>6.3 ± 23.2</td>
<td>10.2 ± 28.8</td>
<td></td>
</tr>
<tr>
<td>150sec</td>
<td>9.3 ± 16.8</td>
<td>0.4 ± 26.6</td>
<td></td>
</tr>
</tbody>
</table>

The changes are expressed as percentage before conditioning contraction. (*p<0.05)

Table 5. Relationship between changes in the twitch force and electromyography

<table>
<thead>
<tr>
<th></th>
<th>Gastrocnemius</th>
<th>Soleus</th>
</tr>
</thead>
<tbody>
<tr>
<td>correlation coefficient</td>
<td>r = −0.54*</td>
<td>r = 0.04</td>
</tr>
</tbody>
</table>

*p<0.05
DISCUSSION

This study was designed to show the effects of PAP on submaximal voluntary contraction of the triceps surae muscle. As hypothesized, PAP was demonstrated by a significant increase in the twitch force elicited by supramaximal electrical stimulation after CC, while the M-wave amplitude of both the gastrocnemius and soleus muscles remained unchanged. The results of PAP effects on twitch force were similar to those of previous studies. In this study, however, the EMG of the gastrocnemius muscle during 20% MVC was found to decrease significantly at 30 s after the CC. In addition, the decrease in the gastrocnemius EMG had a moderate correlation to an increase in the twitch force, while the soleus EMG did not change after CC.

The gastrocnemius EMG during 20% MVC plantar flexion decreased to 16% at 30 s after CC. The decrease was insignificant thereafter. Previous reports are available as to the relationship between EMG and muscular force after CC. Baudry and Duchateau showed changes in the adductor pollicis EMG during a ballistic contraction of 10–50% MVC in intensity after 100% MVC for 6 s. They found no EMG changes before and after this CC. Similarly, EMG changes were not found in the triceps brachii during 10–30% MVC after CC of 75% MVC for 5 s. Further, no changes were found for the EMG of the tibialis anterior at the target force of 50% MVC after CC of 100% MVC for 10 s. These findings are in contrast to the results of our study. On the contrary, Hutton reported that CC of 25–100% MVC induced subsequent force enhancement of the elbow flexors. Flexion force increased immediately after CC and then decreased rapidly. Subjects were required to maintain 3% MVC without knowledge about ongoing force in their study. Oskouei reported a 21% force enhancement after CC of 100% MVC for 6 s when subjects were asked to maintain 30% of the maximal EMG signals in the adductor pollicis. Different results were reported under different experimental conditions. Duration and intensity of CC and the level of test contraction may need to be strictly controlled to obtain consistent results.

Even though the gastrocnemius and soleus muscles are both plantar flexors, only the gastrocnemius EMG changed after the CC in the present study. Potentiation might be higher in the gastrocnemius than the soleus when stimuli are applied to the respective muscle bellies, as reported by Vandervoort. A similar study using the method of mechanomyography also showed higher potentiation in the gastrocnemius than the soleus muscles. Approximately half of the muscle fibers of the gastrocnemius are known to be type II fibers, while the soleus muscle is principally composed of type I fibers. In a study investigating the relationship between fiber-type composition and twitch potentiation, more type II fibers were counted in the muscles with higher potentiation than those with lower potentiation. A study of transgenic mice also showed that enhancement of contractile capability by PAP was seen in type 1b muscle fibers. These reports support the validity of the findings of this study. Different results might be ascribed to differences in fiber type composition in the gastrocnemius and soleus muscles.

Increases in twitch force of the plantar flexors as a result of PAP were correlated with a decline in the gastrocnemius EMG. The decline of the EMG during voluntary contraction appeared to compensate for the increased twitch force secondary to PAP. A similar phenomenon was found in the study by Klein. Our study examined RMS of EMG instead of the motor unit discharge count. RMS of EMG would change in parallel with motor unit discharge. Thus, we assume that EMG activity was depressed in the potentiated type II fibers in gastrocnemius muscle.

A significant decrease in the gastrocnemius EMG was observed only in the first 30 s but the EMG returned immediately to the same activity level as the pre-CC level. Some researchers have proposed that PAP would compensate for muscular fatigue. In our study, potentiation effects might have lasted for only 30 s after the CC but the reduction in EMG disappeared thereafter. No conclusion anyway can be drawn by the present study as to the mechanism of the temporary EMG reduction after CC. It would be for sure, however, that EMG reduction either secondary to fatigue or compensation for PAP would work fairly to maintain a constant muscular force after CC.

A question arose as to the percentage of the force from the gastrocnemius and soleus muscles in the total force of plantar flexion. Force output measured in this study might have been generated not only by the gastrocnemius and soleus muscles but also from other minor flexors, such as the tibialis posterior and flexor digitorum muscles. In addition, we only monitored the surface EMGs of the lateral gastrocnemius and soleus. The gastrocnemius, soleus, and other small flexor muscles have been shown to contribute 38%, 50%, and 12% of the summed flexor moment, respectively. Plantar flexion is mainly generated by the gastrocnemius and soleus muscles. However, other synergists may also play a role that may have resulted in individual differences in PAP and EMG seen in the present study. Another factor influencing the results is that the surface EMG pattern differs between the medial and lateral heads of the gastrocnemius. During 20% MVC of plantar flexion, the medial gastrocnemius was found to work more actively than the lateral head. The present study did not examine the EMG of the medial gastrocnemius. Further investigation is required to clarify this issue.

The reduction in the EMG activity during sub-maximal voluntary contraction was obvious just after CC, probably corresponding to increased twitch force induced by PAP, so that a constant force might be exercised. The decrease in EMG was correlated with an increase in the twitch force of the plantar flexor. The above finding was only observed in the fast-fatigable gastrocnemius muscle. PAP might work in the fast-fatigable muscles even during low-level daily activities. In our study, the twitch force increase induced by PAP and the corresponding EMG reduction in the fast-fatiguing muscles were seen during 20%MVC. Muscular force used in daily activities is known to be somewhere between 20–40% MVC. Therefore, utilizing CC in many ways, people might be able to use PAP in various activities to improve their performance.
REFERENCES


