**Effect of Postactivation Potentiation on the Maximal Voluntary Isokinetic Concentric Torque in Humans**

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**Abstract**

Miyamoto, N, Kanehisa, H, Fukunaga, T, and Kawakami, Y. Effect of postactivation potentiation on the maximal voluntary isokinetic concentric torque in humans. *J Strength Cond Res* 25(1): 186–192, 2011—The purpose of this study was to examine whether postactivation potentiation (PAP) influences dynamic torque development in humans. Nine recreationally active men performed sets of 3 maximal isokinetic concentric plantar flexions at 180 degrees/second in the following sequence: before and immediately (5 seconds) after a 10-second maximal voluntary contraction (MVC) and then every 1 minute until the 5-minute point, followed by 1 more stimulation at the 10-minute point. Twitch responses were recorded before every set of 3 concentric contractions to examine whether the PAP exists. The twitch and concentric torques were potentiated at 0 through 5 minutes and 1 through 3 minutes post-MVC, respectively (p < 0.05), whereas there was no significant difference in concentric torque in the control (without MVC) condition (p > 0.05). For electromyographic signals during concentric contractions, muscle activity of the medial gastrocnemius was significantly depressed only immediately after the conditioning MVC (p < 0.05). These results indicate that a brief maximal voluntary isometric contraction enhances voluntary dynamic performance through PAP, within proper recovery interval. From a practical point of view, in sports activities we suggest undertaking PAP through high-intensity contractions 1 to 3 minutes before voluntary ballistic or plyometric actions for improved performance.

**Keywords:** plantar flexion, twitch response, electromyography, constant angular velocity

**Introduction**

Twitch torque is increased after a brief submaximal or maximal voluntary contraction (MVC). This phenomenon has been referred to as postactivation potentiation (PAP) (1,11,21). The PAP is maximal immediately after the conditioning MVC and declines exponentially over time until finally it disappears completely in 10 to 15 minutes (18,21). The most likely mechanism responsible for PAP is the phosphorylation of myosin regulatory light chains during the conditioning contraction that increases sensitivity of actin-myoosin to Ca²⁺ released by the sarcoplasmic reticulum (15,20).

In strength and conditioning fields, based on the theory of PAP, alternating a high-load resistance exercise with a dynamic exercise such as plyometric and ballistic actions has been used (12,16). Recently, many studies have examined effects of a high-load resistance exercise on following dynamic ballistic performance. For example, Güllich and Schmidtbleicher (10) have observed significant increases in jump height after 3 to 5 sets of 5-second isometric maximal voluntary contraction of leg press. Similarly, Young et al. (23) have reported that loaded vertical height was enhanced by performing a 5 repetitive maximum (RM) half-squat exercise prior to the jump test. In contrast, Mangus et al. (14) have failed to find a significant increase in vertical jump height after a half- or quarter-squat exercise with 90% of 1RM. It has also been reported that there was no significant improvement in jump performance after a 5RM squat (13). These discrepancies could be, at least in part, a result of the recovery time between the end of the conditioning contraction and the beginning of the subsequent performance and/or the complexity of the jump movement. With regard to the recovery interval, Sale (18) speculated that a proper interval between the end of the conditioning contraction and the beginning of dynamic performance might be required for the recovery from fatigue by conditioning contraction despite the decline of PAP effect with time. For example, Gossen and Sale (7) have shown, even under the existence of PAP assessed by twitch response, no significant potentiation of angular velocity or peak power during dynamic knee extension within 1 minute after...
a 10-second MVC. In contrast, with a long recovery interval (7 minutes) at which time PAP would diminish (21), Smith and Fry (19) have shown that, although twitch responses were not measured, no significant enhancement of explosive knee extension power was observed after a 10-second MVC. Taken together, when PAP effects on voluntary dynamic performance are examined, the recovery interval could be a key factor (i.e., a brief recovery interval can maximize both the PAP and fatigue effects), and potentiation effects may be lost if the recovery interval is too long.

Therefore, the purpose of the present study was to examine the effect of a conditioning contraction on the voluntary dynamic performance over time, in terms of PAP and fatigue effect of conditioning contraction, through recording of twitch characteristics, voluntary torque, and electromyographic activities of the muscles involved. We hypothesized that PAP affects dynamic torque production performed voluntarily and that there is an optimal recovery time for improvement of voluntary dynamic performance.

**METHODS**

**Experimental Approach to the Problem**

This study was a 1-group experimental design with control (CON) and PAP sessions in random order. Vertical jump and bench-press tasks used in previous studies consist of multi-joint movements, which require coordination of many muscle groups with various structural and contractile properties. To accurately examine the effect of PAP on voluntary dynamic performance, the use of movements that minimize the contribution of other muscle groups and number of working joints is necessary. Therefore, in this study, plantar flexion exercise was used as a single-joint task. A 6-second isometric maximal voluntary plantar flexion was used as the conditioning contraction to induce PAP because previous studies showed that maximal PAP occurred with MVC of 5 to 10 seconds duration (21). The dependent variables (maximal isometric concentric peak torque, twitch peak torque, and electromyographic activities of muscles involved) were chosen to describe the voluntary dynamic performance, the existence of the PAP, and the influence of the neuromuscular activities on the performance, respectively. To examine the effect of the recovery interval on potentiation of the voluntary dynamic performance, these variables were recorded at pre-MVC, immediately after the conditioning MVC, and then every 1 minute thereafter until the 5-minute point, followed by 1 more stimulation at the 10-minute point during each of CON and PAP sessions.

**Subjects**

Nine male subjects (26.7 ± 4.4 year, 175.1 ± 4.5 cm, 68.7 ± 7.2 kg; mean ± SD) with no history of orthopedic or neuromuscular disorders volunteered for this study. All the subjects were recreationally active but had not taken part in regular weight training for at least 1 year. The subjects were fully informed of the procedures used, the possible risks, and the purpose of the study. Written informed consent was obtained from all subjects prior to the investigation. This study was approved by the ethical committee of the Faculty of Sport Sciences at Waseda University and was consistent with their requirement for human experimentation.

**Experimental Set-Up**

Subjects were seated on an isokinetic dynamometer (CON- TREX, CMV AG, Switzerland) with their right knee fully extended. The right foot was tightly fixed to the dynamometer’s footplate, and the right thigh was also firmly secured by a strap to the dynamometer’s bench. The rotation axes of the ankle and the footplate were aligned as closely as possible. The subject performed maximal isometric and isokinetic concentric plantarflexion contractions. In isometric contraction, the ankle was fixed at 0° (neutral position; the sole of the foot at right angles to the tibia axis). In concentric contractions, the range of motion of the ankle was between −20° (dorsiflexion) and 35° (plantarflexion). Subjects were completely relaxed at −20° and then asked to exert the maximal plantarflexion torque until the angle of the ankle reached 35°. The angular velocity of the dynamometer was set at 180°/second. The selection of this velocity was for the purpose of elucidating muscle behavior in a ballistic countermovement jumping exercise in which the ankle joint typically rotates at or near this angular velocity (a result from a preliminary experiment).

**EMG Recordings**

Surface electromyography (EMG) signals were obtained from the medial and lateral gastrocnemius (MG and LG), soleus (SOL), and tibialis anterior (TA) muscles by pre-amplified bipolar surface electrodes (1 × 10 mm, 10-mm interelectrode distance) with band-pass filtering between 20 and 450 Hz (The Bagnoli 8 EMG System, DELSYS, Boston, Massachusetts, U.S.A.). The reference electrode was placed over the left lateral malleolus for all EMG measurements. The torque and EMG data were simultaneously and continuously stored on the hard disk of a personal computer for later analysis using a 16-bit analogue-to-digital converter (PowerLab/16SP, ADInstrument, Australia) with a sampling frequency of 2 kHz.

**Electrical Stimulation**

To evoke triceps surae twitches and the maximal compound motor action potential (M-wave), the posterior tibial nerve was stimulated percutaneously in the popliteal fossa using the cathode (11 mm in diameter). The anode (4 × 5 cm) was placed over the ventral aspect of the thigh, just proximal to the patella. Single rectangular pulses of 500 μs duration were delivered from a high-voltage stimulator (SEN-3301, Nihon Koden, Japan) with a specially modified isolator (SS-1963, Nihon Koden, Japan). Supramaximal stimulus intensity was determined prior to the experiment by increasing the voltage until the M-wave amplitude and the corresponding torque reached a plateau at 0 degrees. Stimulus intensity was then set
30% above maximum for the experimental measures. All electrically induced contractions were elicited at an ankle angle of 0°.

**Procedure**

At the familiarization session, subjects were asked to perform several sets of 3 submaximal and maximal concentric plantarflexion contractions. The primary purpose of this session was to familiarize the subjects with concentric actions on the dynamometer. Each set was separated by approximately 30 seconds of rest to minimize any possible fatigue by this familiarization procedure.

For the experimental sessions, after the familiarization session, subjects rested for approximately 20 minutes during the placement of the stimulating and recording electrodes. This elapsed time was sufficient for potentiating effect by the familiarizing contractions to disappear (11,21). The experimental session consisted of a CON condition (no 6-second MVC to induce PAP) and an MVC condition (6-second MVC to induce PAP). Subjects performed each session in a random order. Before performing the conditioning MVC, we recorded the responses to a single twitch (Pre-before) 3 maximal concentric contractions, followed 5 seconds later by a single twitch (Pre-after; Figure 1). The last stimulation was used to examine the possible potentiating effect by a set of 3 maximal concentric contractions. After these control recordings, subjects performed the conditioning 6-second MVC in the MVC condition. In both CON and MVC conditions, the tests that consisted of 1 twitch and 3 maximal isokinetic concentric contractions were carried out during the recovery interval in the following sequence: immediately (5 seconds) after the MVC, and then every 1 minute thereafter until the 5-minute point, followed by 1 more stimulation at the 10-minute point (Figure 1). The stimulation prior to the concentric contractions was used to quantify the magnitude of PAP during the dynamic contractions. A 15-minute rest was provided between the end of each session and the beginning of the next one.

**Measurements**

The peak twitch torque and the peak-to-peak amplitude of the M-wave of MG, LG, and SOL muscles were calculated from the evoked twitch torque and EMG data. With regard to the dynamic contractions, the data from the trial in which the peak torque was highest among 3 contractions per each set were adopted for analysis. The peak torque and the associated root mean square EMG values (RMS-EMG) of MG, LG, SOL, and TA muscles were calculated. RMS-EMG was computed over a 200-ms period around the maximal torque (i.e., 100 ms before and 100 ms after the peak torque). Relative changes in peak twitch torque, M-wave amplitude, voluntary concentric torque, and RMS-EMG values were obtained according to the following formula: Pre-after or Post-MVC value/Pre-before value × 100 (%). For the conditioning MVC, the values of average torque and corresponding RMS-EMG of all muscles were calculated for the first and last 1-second period.

The repeatability of the peak torque of maximal voluntary isokinetic concentric contraction and twitch contraction was investigated in our preliminary study. The ICC values were 0.78 ± 0.10 and 0.85 ± 0.06 for voluntary concentric peak torque and twitch peak torque, respectively.

**Statistics**

For all parameters of twitch and voluntary concentric contractions, separate 2-way analyses of variance (ANOVA with time) or repeated measures were used. Additional 1-way ANOVAs with post hoc test (Dunnett and paired t-test with Bonferroni corrections) were performed when appropriate. To compare the values between the first and last periods during MVC, paired t-tests were used for torque and RMS-EMG data. The
significance level for all comparisons was set at $p < 0.05$. Unless stated otherwise, the data are expressed as means ± SD in the text and displayed as mean ± SE in figures.

RESULTS

Twitch Responses

At $\text{Pre}_{\text{before}}$, no significant difference was found in the parameters between the 2 conditions (CON and PAP), indicating that a 15-minute recovery time was sufficient for restoration of twitch from potentiation. For the twitch torque, the 2-way ANOVA revealed that the condition $\times$ time interaction was significant. Further analyses showed that in both conditions peak twitch torque after a set of 3 maximal concentric plantarflexion ($\text{Pre}_{\text{before}}$) was significantly potentiated (130.5 ± 14.0% in MVC and 128.6 ± 15.5% in CON condition, respectively), indicating that 3 concentric torque exertions induce PAP. In the MVC condition, twitch torque was significantly enhanced to 178.6 ± 18.8% of the control value ($\text{Pre}_{\text{before}}$) immediately after the MVC ($p < 0.05$, observed power = 0.98). The degree of PAP was maximal immediately after the MVC, declined over time, and returned to the $\text{Pre}_{\text{before}}$ value within 10 minutes (Figure 2). The PAP in the MVC condition was significant from Post0 to Post5, whereas no significance was found at Post10. For the CON condition, twitch torques were
Figure 4 demonstrates that the EMG condition interaction. Further analysis showed that the M-wave amplitude of all muscles, there was no significant main effect of the time or condition, nor was there a time \times condition interaction.

**Isokinetic Peak Torque**

The 2-way ANOVA revealed that there was a significant time \times condition interaction. Further analysis showed that peak torque during isokinetic concentric contractions significantly increased from the control value (Pre-\text{baseline}) at Post1, Post2, and Post3 in the MVC condition (\(p < 0.05\), observed power = 0.78–0.90), whereas no significant difference was found over time in the CON condition (\(p > 0.05\); Figure 3). Moreover, there were significant differences in peak torque between the 2 conditions at Post1, Post2, and Post3 (\(p < 0.05\)). Figure 4 demonstrates that the EMG activity of MG muscle was significantly depressed only immediately after the MVC (\(p < 0.05\), observed power = 0.88) and that EMG activities of LG, SOL, and TA muscles remained unchanged over time.

**Torque and EMG Activities During Conditioning MVC**

During the conditioning MVC, the average torque of the last 1-second period was significantly reduced compared with that of the first 1-second period (\(p < 0.05\), observed power = 0.80; Figure 5). The corresponding EMG activity of the MG muscle was significantly lower during the last period (\(p < 0.05\), observed power = 0.76), whereas there was no significant difference between the 2 periods in the EMG activities of LG, SOL, and TA muscles.

**DISCUSSION**

The main findings of this study were that (a) the potentiation of twitch torque was maximal immediately after the conditioning MVC and decreased over time until finally it disappeared at 10 minutes of recovery, whereas the voluntary isokinetic concentric torque was potentiated at 1 minute after the MVC and maintained only to 3 minutes post-MVC, and (b) the M-wave amplitude of twitch responses of all muscles was unchanged between the conditions and over time, whereas the EMG activity of the MG during voluntary concentric contraction immediately after the MVC was significantly depressed. These results imply that PAP induced by 6-second MVC improved maximal voluntary dynamic performance in the absence of fatigue when proper recovery time is given after MVC.

In the present study, the twitch torque for evaluating the magnitude of PAP was maximally potentiated immediately after the conditioning MVC, whereas potentiation occurred 1 minute after the conditioning MVC for voluntary concentric contractions. Our result is in agreement with those of Baudry and Duchateau (1) who have reported that the maximal potentiation of the rate of torque development during voluntary isometric ballistic contractions at sub-maximal intensity (10, 20, 50, and 75% MVC) was observed 1 minute after a 6-second conditioning MVC, under the existence of PAP evaluated by twitch responses. These results support previous reports that showed the increase in maximal vertical jump height after strong conditioning contractions (3,6,22). In contrast, it has been shown that there was no significant increase in jump height after high-load resistance exercise (13,14,19). These discrepancies could be partly attributed to the time when voluntary contractions were performed because the delay of onset of the potentiation in voluntary contractions is probably explained by the coexistence of the dual effects of the conditioning MVC (i.e., PAP and fatigue) (2,5). Therefore, when effects of PAP on voluntary contractions are examined, we must consider the dilemma that a brief recovery interval between the end of the conditioning contraction to induce PAP and the beginning of the performance can maximize both the PAP and fatigue effects and that potentiation effects may be lost if the recovery interval is too long (18).

With regard to the fatigue by the conditioning contraction, for example, during sustaining MVC some high-threshold motor units cease to discharge within seconds (9), suggesting a possibility that the 6-second conditioning MVC in the present study elicits fatigue and the subsequent impairment of dynamic performance immediately after the MVC. Indeed, we observed the significant decrease in the EMG activity of MG muscle during the MVC (Figure 5), without changes in the MG M-wave amplitude after the MVC, implying presence of the central fatigue (4,17). This fatigue would also have contributed to counteract the effect of PAP on maximal voluntary concentric torque immediately after the conditioning MVC in this study. However, at fourth- and fifth-minute post-MVC, there was no significant enhancement in voluntary concentric torque. A longer recovery interval may reduce PAP effects and fatigue on voluntary contractions. Collectively, a shorter or longer recovery interval could have a potentiating effect of a less than optimal recovery interval. Thus, it is important to set the optimal recovery interval. Thus, it is important to set the
optimal recovery interval between the end of the conditioning contraction and the start of the subsequent performance when a strategy for exploiting PAP in the voluntary dynamic performance is considered.

Several previous studies have reported, within moderate recovery interval, the lack of the high-load conditioning contraction effect on the subsequent dynamic performance such as jump height and peak power (8,13). One major reason other than the recovery interval is the intensity of the conditioning contraction. For example, Jensen and Ebben (13) used a set of 5RM squats as the conditioning contraction. The magnitude of PAP depends on the intensity of the conditioning contraction; a 10-second contraction of less than 75% MVC elicits little PAP (21). Although the intensity of 5RM may be greater than 75% MVC, it is unclear whether the PAP existed when the jump height was measured in the previous studies because none of them have tested the presence of PAP by twitch responses. Thus, it is possible that submaximal contractions could not evoke sufficient phosphorylation of myosin regulatory light chain to enhance jump performance. Indeed, in this study, although the twitch torque after a series of maximal voluntary concentric contractions (Pre-PAP) was also potentiated (Figure 2), significant enhancement of concentric peak torque was not observed in the CON session. Additionally, in the PAP session, the performance was not enhanced 4 to 5 minutes after the MVC at a time twitch torque is still potentiated. These results suggest that sufficiently greater PAP may be required to enhance voluntary dynamic performance.

In the present study maximal isokinetic concentric contraction at 180 degrees/second was adopted as the protocols for the voluntary dynamic performance. Because the nature of isokinetic actions is different from that of isotonic actions, it may be difficult to directly apply the results to movements in sports and training, but the enhancement of dynamic joint torque as observed in this study should positively affect sport performance that is also produced by joint movements.

In conclusion, the present study revealed that a 6-second maximal voluntary isometric contraction significantly enhanced maximal isokinetic torque development performed 1 to 3 minutes after the isometric contraction. The findings suggest that PAP could be a mechanism that can improve following voluntary dynamic performance within a proper recovery interval.

**Practical Applications**

The findings obtained here suggest that PAP induced by high-intensity contractions can improve following voluntary dynamic performance within a proper recovery interval. Based on these findings, we recommend including PAP during warm-up procedures for sports activities. Although submaximal contractions have so far been used as warm-up procedures to reduce fatigue, there is a possibility that short-time, high-intensity contractions can be a more effective procedure for warm-up in high-power activities. For example, isometric rack-squat exercise before vertical jump could be a simple way to elicit the PAP state prior to sports performance. However, it should be noted that the positive performance-enhancing effect lasts only for a few minutes. The use of PAP protocol could result in no advantageous effect immediately after the high-load resistance exercise, and the recovery interval of more than 4 minutes also cannot positively affect the following dynamic performance. To improve practical use of the current study, future studies should examine multijoint movements typically observed in various sports along with more substantial stimulus than a 6-second isometric MVC to induce sufficient PAP.

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**References**


