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ORIGINAL ARTICLE

Effect of intensity and duration of conditioning protocol on post-activation potentiation and changes in H-reflex

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Abstract

The force enhancement of muscle twitch contraction after a maximal voluntary contraction (MVC) has been defined as post-activation potentiation. However, the effects of post-activation potentiation on ballistic movements have not been studied extensively, or the underlying neurophysiologycal mechanism. In the current study, we examined post-activation potentiation and spinal H-reflex excitability in the soleus muscle. Mechanical power during explosive ballistic plantar flexions was measured in 14 males before and after 5 s, 4 min, and 10 min of isometric conditioning (EPF_{pre}, EPF_{5s}, EPF_{4min}, EPF_{10min}, respectively). Four sessions corresponding to four different protocols of isometric conditioning were conducted. The protocols were different in the intensity (10% vs. 100% of MVC) and duration (7 vs. 10 s) of the isometric conditioning. The results showed a significant enhancement in mechanical power in EPF_{4min} compared with EPF_{pre}, only when the isometric conditioning was performed at 100% of MVC for 10 s. No significant changes were observed in the H-related parameters (e.g amplitude, threshold, H/M ratio) after the isometric conditioning. Our results show that to obtain a post-activation potentiation during explosive ballistic movements, the intensity and duration of the isometric conditioning must be controlled. Moreover, the improvement in mechanical power is not related to spinal H-reflex excitability.

Keywords: *Post-activation potentiation, plantar flexion, H-reflex*

Introduction

The force enhancement of muscle twitch contraction after a conditioning tetanus or maximal voluntary contraction has been referred to as post-tetanic potentiation and post-activation potentiation, respectively (Binder-MacLeod, Dean, & Ding, 2002; Gossen & Sale, 2000; Hamada, Sale, & MacDougall, 2000a; Tillin & Bishop, 2009). Although there is evidence of potentiation in twitch responses, the effect on short-term voluntary explosive movements has yet to be determined. Some studies support the existence of potentiation in explosive activations of large (Baker, 2003; Chiu et al., 2003; Gourgoullis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003; Gullich & Schmidtbleicher, 1996; Young, Jenner, & Griffiths, 1998) and small muscle groups (Baudry & Duchateau, 2007a, 2007b). However, other studies did not find post-activation potentiation during voluntary movements (Ebben, Jensen, & Blackard, 2000; Gossen & Sale, 2000; Hrysomallis & Kidgell, 2001). These discrepancies might be due to the different protocols used in these studies. Such parameters as characteristics of the participants (e.g. muscle fibre-type distribution, training experience, strength), features of the conditioning contractions (e.g. type of contraction, intensity, duration, rest between sets, time of measurement of potentiating activity), characteristics of the muscles assessed (e.g. muscle fibre-type distribution, muscular architecture), and duration of muscle activation demanded after conditioning differ across the studies.

Although the neurophysiology of post-tetanic potentiation and post-activation potentiation has not been extensively investigated, two processes have been proposed to explain these phenomena (Hodgson, Docherty, & Robbins, 2005). The first is an increase in Ca^{2+} sensitivity of the myofilaments (Metzger et al., 1989) that could lead to a twitch

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potentiation, increase in muscle isometric twitch force and rate of force development, or a decrease in the time to peak twitch force (O'Leary, Hope, & Sale, 1997). The second is a reflex potentiation that leads to an enhancement in the muscle response to an afferent neural volley. This reflex potentiation has been investigated using the Hoffmann reflex (H-reflex) technique. The H-reflex provides a measure of the efficacy of synaptic transmission between Ia afferent fibres and alpha motoneurons resulting from changes in spinal excitability (Capaday, 1997). Gullich and Schmidtbleicher (1996) were the first to attempt to relate changes in the H-reflex to post-activation potentiation. They reported an increase in the maximal amplitude of the H wave in the soleus muscle after isometric maximal voluntary contraction (MVC). Previous studies using a more detailed methodology for the H-reflex technique have reported a modulation of this parameter after different sets of conditioning contractions (Folland, Wakamatsu, & Fimland, 2008; Trimble & Harp, 1998). However, in a recent study Hodgson and colleagues (Hodgson, Docherty, & Zehr, 2008) reported post-activation potentiation during isometric explosive plantar flexion actions without reflex potentiation. Thus, the exact role of spinal excitability in post-activation potentiation is unclear.

The aims of the current study were to examine the effect of the duration and intensity of the conditioning isometric contraction on the post-activation potentiation of a ballistic movement, and to determine whether the post-activation potentiation in a ballistic movement is related to changes in the H-reflex.

The durations of the conditioning isometric contraction used in the current study (7 and 10 s) were selected based on previous studies that showed the greatest post-activation potentiation at 5 and 10 s of maximum contraction (Baudry & Duchateau, 2007a; Hamada et al., 2000a, b; O'Leary et al., 1997; Vandervoort, Quinlan, & McComas, 1983). For the intensity of the conditioning isometric contraction, we compared 10% and 100% of MVC. The 10% of MVC was selected since it has been shown that isometric contractions less than 25% of MVC do not lead to a conditioning effect (Requena, Gapeyeva, Garcia, Ereline, & Pääsuke, 2008), while 100% of MVC was used since high intensities of MVC (>75%) are required to achieve potentiation (Vandervoort et al., 1983).

Methods

Participants

Fourteen males volunteered to participate in the study (mean age 22.3 years, $s = 3.6$; height 1.75 m, $s = 0.05$; weight 74.6 kg, $s = 7.2$). The participants were students in the Faculty of Sport Sciences, all of whom had experience of weight training and were familiar with the experimental procedures. They were informed of all procedures and signed a written informed consent consistent with the policies of the Ethics Committee of the University of A Coruña.

Procedures

The participants took part in four different experimental sessions. The study was conducted over 6 weeks with the sessions separated by 1 week. In each session, the participant began with a standardized warm-up that consisted of 5 min of slow running and two series of 15 repetitions of ankle plantar flexions on a soleus machine (Biotech, Brazil) performed simultaneously with both legs. The participant sat in the soleus machine with the metatarsus of each foot on fixed supports and the heels on two wooden wedges. The position was standardized with knee flexion fixed to 90°. Flexion was measured with a manual Jamar goniometer. These plantar flexions were performed without any load added to the machine and the participant was required to perform all repetitions with a medium velocity through the full range of movement.

After the warm-up, the participant performed three explosive plantar flexions (EPF_{pre}) with both ankles simultaneously, with 5 s rest between them. After 10 min of resting in the same sitting position, the participant was asked to perform a conditioning pre-activation protocol consisting of a soleus isometric contraction. At 5 s, 4 min, and 10 min after the pre-activation protocol, the participant was required to perform another three blocks of three explosive plantar flexions (EPF_{5s}, EPF_{4min}, and EPF_{10min}).

Four test sessions were conducted corresponding to the four different pre-activation protocols. These protocols were different in the intensity and duration of the soleus isometric contraction as follows: 7 s of submaximal voluntary contraction (SVC7), 10 s of submaximal voluntary contraction (SVC10), 7 s of maximal voluntary contraction (MVC7), and 10 s of maximal voluntary contraction (MVC10). The submaximal contraction intensity was set to 10% of MVC and the participants were informed of the force exerted to control the intensity of their contraction via visual feedback. The order of the sessions was counterbalanced.

Mechanical recording

The power output during the explosive plantar flexion was recorded using a linear encoder connected to the soleus machine (MuscleLab, Bosco Systems, Norway). The cable of the encoder was attached to the load to measure its position with an accuracy of less than 0.075 mm. The encoder's method of functioning enabled the cable to move in the vertical direction, sending the position of the load to an interface connected to a computer. Then, customized software allowed us to calculate velocity, force, and power. Signals were sampled at a frequency of 100 Hz. During the isomentric contractions, a force sensor was attached in line to a chain connected to the soleus machine to display the force feedback. The chain was removed for the explosive contractions. The repetition with the highest power exerted by the participant in each block of plantar flexion (EPF_{pre}, EPF_{5s}, EPF_{4min}, and EPF_{10min}) was selected for statistical analysis.

Complementary experiment

The participants performed a further session using the MVC10 protocol of soleus pre-activations, since only this protocol led to a post-activation pattern. In this session after the warm-up described previously, neuromuscular parameters were recorded before the MVC10 and 5 s, 4 min, and 10 min after the MVC10. During recording, the participant maintained the same position as during the isometric contraction. The participant did not perform plantar flexions. The neuromuscular parameters recorded for the H-reflex were the maximum H and M amplitudes, H and M thresholds, and recruitment curves.

Neuromuscular parameters

Electromyography (EMG) activity was recorded from the soleus and anterior tibialis muscles using bipolar surface electrodes (inter-electrode distance = 2 cm). On the soleus, the electrodes were placed vertically in the mid-dorsal line approximately 4 cm distal to the point where the two heads of the gastrocnemius join the Achilles tendon. On the tibialis anterior, the electrodes were placed on the thickest part of the muscle belly. The reference electrode was positioned above the lateral malleolus. The amplified EMG signal was filtered (band-pass, 30 Hz to 1 kHz), sampled at 2 kHz, and stored on a PC for off-line analysis.

The H-reflex was evoked by stimulating the posterior tibia through a bipolar felt pad with an adjustable Velcro® strap (Digitimer, UK). The surface-stimulating electrode consists of two 8-mm felt pads in a stainless steel holder. The spacing between the tips is 25 mm. The bipolar felt pad was positioned in the popliteal fossa and connected to a constant-current stimulator (model DS7AH, Digitimer, UK). The reference electrode was positioned above the lateral malleolus. Recruitment curves were assessed by averaging two responses at each stimulus intensity. The interval between stimuli was 5 s. The stimulus intensity was increased in steps of 0.05 mA starting below H threshold and gradually increasing to maximal H wave amplitude (H_{max}). The stimulus intensity was then increased in steps of 2 mA up to supramaximal intensity to measure the maximal motor response (M_{max}) (Pérez, Lundbye-Jensen, & Nielsen, 2007). The ascending limb of each recruitment curve was fitted using a general least squares model of a custom three-parameter sigmoid function (equation 1) (Klimstra & Zehr, 2008):

$$H(s) = H_{max}/1 + em(s50 - s) \quad (1)$$

where H_{max} is the upper limit of the curve, m is the slope parameter of the function, s50 is the stimulus at 50% of the H_{max} value, and H(s) is the H-reflex amplitude at a given stimulus value (s). The maximal H amplitude (H_{max}) and M amplitude (M_{max}) were obtained from the previous sigmoided curve fit, since this procedure has been suggested to be the most realiable (Klimstra & Zehr, 2008). The ratio H_{max}/M_{max} was also calculated.

Statistical analysis

Standard statistical methods were used for the calculation of the mean and standard deviation (*s*). For the main experiment, three-way repeated-measures analyses of variance (ANOVAs) were performed for power with duration (7 and 10 s), intensity (submaximal voluntary contraction, SVC; maximal voluntary contraction, MVC), and time (EPF_{pre}, EPF_{5s}, EPF_{4min}, and EPF_{10min}) as main factors.

For the complementary experiment, a one-way repeated-measures ANOVA was performed with time (EPF_{pre}, EPF_{5s}, EPF_{4min}, and EPF_{10min}) as the main factor. The variables analysed were H_{max}, M_{max}, H_{max}/M_{max} ratio, H threshold, and M threshold.

Post hoc analyses were conducted using a *t*-test with Bonferroni corrections. Statistical significance was set at $P \leq 0.05$. None of the data violated the assumption of normality.

Results

Mechanical measurements

The analysis of power (Figure 1) showed a significant effect of time ($F_{3,11} = 5.065$, $P = 0.019$) and a significant duration × intensity × time interaction ($F_{3,11} = 5.632$, $P = 0.014$). *Post hoc* analysis showed that in SVC7 the power at EPF_{5s} was significantly lower compared with EPF_{4min} ($P < 0.01$). The power at EPF_{5s} was significantly higher in MVC7 than SVC7 ($P < 0.01$). Only in MVC10 did the power

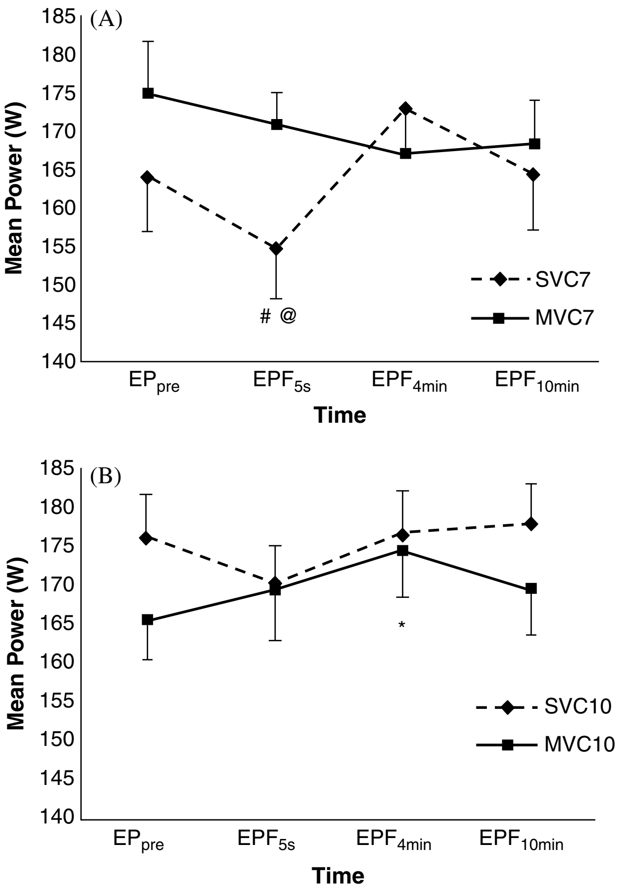

Figure 1. Changes in mean power (MP) before (EPF_{pre}) and 5 s (EPF_{5s}), 4 min (EPF_{4min}), and 10 min (EPF_{10min}) after 7 s of submaximal (SVC7) and maximal voluntary contraction (MVC7) (A), and 10 s of submaximal (SVC10) and maximal voluntary contraction (MVC10) (B). Values are mean ± standard error. *Significantly different from EPF_{pre}. #Significantly different from EPF_{4min}. @Significantly different from MVC7.

increase significantly with EPF_{4min} compared with EPF_{pre} ($P = 0.049$). Table I summarizes the remaining mechanical parameters.

Neuromuscular parameters

Statistical analysis revealed no changes in the recruitment curve or in the other neuromuscular parameters. Table II summarizes the mean values of the neuromuscular parameters across the different recording times.

Discussion

The novel approach of this study was to compare the effect of the intensity and duration of isometric contractions of the soleus muscle on posterior ballistic plantar flexions. Our results show that a maximal isometric contraction performed for 10 s leads to a post-activation potentiation resulting in a power enhancement during ballistic plantar flexions.

Effect of duration of the contraction

Our results show that 10 s of maximal isometric contraction of the soleus muscle leads to an increase in the power of the posterior plantar flexions compared with plantar flexions performed before the isometric contraction. However, this enhancement in power was not observed when the duration of isometric contraction was 7 s. In human muscle, there is general consensus that twitch potentiation is maximal immediately after a brief (5–10 s) isometric MVC conditioning (Baudry & Duchateau, 2004; Hamada et al., 2000a, b; Requena et al., 2008). Nevertheless, Vandervoort et al. (1983) showed that twitch potentiation of the dorsiflexor and platar flexor muscles was greater with 10 s than with 1 or 3 s of isometric MVC. A possible explanation for the difference in results at 10 and 7 s of MVC could be due to the close relationship between fatigue and post-activation (Behm, Button, Barbour, Butt, & Young, 2004; Sale, 2002). Tillin and Bishop (2009) have proposed that although isometric conditioning contraction induces central fatigue, it could activate peripheral mechanisms of post-activation potentiation such as phosphorylation of myosin regulatory light chains. On the other hand, the action assessed in the present study involved mainly activation of the soleus muscle. This muscle is usually considered "slow", since it has a higher proportion of ftype I than type II fibres (Galea, 2001). Vandervoort et al. (1983) showed that a muscle with a higher

Table I. Mechanical variables in 7 s submaximal voluntary preactivation (SVC7), 10 s submaximal voluntary preactivation (SVC10), protocol with 7 s maximal isometric voluntary contraction (MVC7), and protocol with 10 s isometric maximal voluntary contraction (MVC10) (mean ± s)

	Movement time (s)				Movement displacement (cm)				Maximum isometric force (N)
	EPF_{pre}	EPF_{5s}	EPF_{4min}	EPF_{10min}	EPF_{pre}	EPF_{5s}	EPF_{4min}	EPF_{10min}	
SVC7	0.29 ± 0.02	0.29 ± 0.04	0.28 ± 0.05	0.29 ± 0.03	29.34 ± 4.25	28.00 ± 3.24	29.44 ± 5.33	29.64 ± 3.73	
SVC10	0.30 ± 0.04	0.28 ± 0.03	0.29 ± 0.03	0.30 ± 0.04	32.43 ± 4.51	29.79 ± 4.09	31.44 ± 4.07	32.09 ± 4.14	
MVC7	0.29 ± 0.03	0.29 ± 0.03	0.28 ± 0.03	0.28 ± 0.26	30.75 ± 3.94	30.16 ± 3.82	29.44 ± 4.77	29.55 ± 5.05	1207.35 ± 174.17
MVC10	0.27 ± 0.02	0.27 ± 0.02	0.27 ± 0.02	0.27 ± 0.02	27.64 ± 3.79	27.58 ± 4.26	28.11 ± 4.19	27.61 ± 3.66	1219.61 ± 228.89

Note: EPF_{pre} = explosive plantar flexions before pre-activation; EPF_{5s} = explosive plantar flexions 5 s after pre-activation; EPF_{4min} = explosive plantar flexions 4 min after pre-activation; EPF_{10min} = explosive plantar flexions 10 min. after pre-activation.

Table II. Neuromuscular parameters in 7 s submaximal voluntary pre-activation (SVC7), 10 s submaximal voluntary pre-activation (SVC10), protocol with 7 s maximal isometric voluntary contraction (MVC7), and protocol with 10 s isometric maximal voluntary contraction (MVC10) (mean ± s)

	EPF_{pre}		EPF_{5s}		EPF_{4min}		EPF_{10min}	
	Absolute (mV)	Sigmoidal	Absolute (mV)	Sigmoidal	Absolute (mV)	Sigmoidal	Absolute (mV)	Sigmoidal
M_{max}	6.23 ± 1.91	98.00 ± 3.39	6.10 ± 1.69	94.27 ± 14.68	6.07 ± 1.97	95.97 ± 12.86	6.21 ± 1.92	96.15 ± 6.01
H_{max}	3.52 ± 1.60	55.61 ± 19.05	3.39 ± 1.46	56.49 ± 20.54	3.51 ± 1.57	55.28 ± 20.84	3.51 ± 1.87	56.60 ± 21.70
Ratio H_{max}/M_{max}	0.56 ± 0.22		0.56 ± 0.2		0.57 ± 0.18		0.56 ± 0.21	
SM	5.98 ± 3.76		5.73 ± 3.10		5.72 ± 2.39		4.97 ± 2.04	
SH	15.55 ± 10.15		13.17 ± 11.89		14.48 ± 8.57		14.80 ± 13.32	
S ratio H/M	0.66 ± 0.75		0.72 ± 0.67		0.54 ± 0.44		1.86 ± 4.07	
MTh (mA)	243.4 ± 6.62		245.2 ± 6.32		254.1 ± 7.49		248.0 ± 7.93	
HTh (mA)	79.8 ± 2.69		78.2 ± 2.62		78.0 ± 2.31		74.0 ± 1.98	

Note: The parameters of interest are reported as absolute and estimated (sigmoidal function) values. SM = slope M wave; SH = slope H reflex; S ratio = slope ratio of M wave and H reflex; MTh = M wave threshold; HTh = H reflex threshold.

percentage of type II than type I fibres, such as the gastrocnemius, has a greater post-tetanic twitch potentiation than the soleus muscle. In this study, MVC longer than 10 s reduced its potentiating effects in the dorsiflexor muscles, but not the plantar flexors. Thus, in our study 10 s of MVC produced more potentiating local effects than 7 s as a result of the low fatigability of the soleus muscle.

An alternative explanation for the post-activation potentiation observed after the MCV10s conditioning is the type of movement in which the post-activation potentiation was recorded. French and colleagues (French, Kraemer, & Cooke, 2003) reported greater potentiation in movements with less than 250 ms of muscle activation (e.g. drop jump) than a movement with a longer duration of activation (countermovement jump). In our study, mean time of displacement ranged between 268 and 299 s, so it is likely that explosive plantar flexion was sensitive enough for post-activation potentiation.

Effects of intensity contraction

The lack of post-activation potentiation in the submaximal conditioning protocols is in line with previous studies (Van Cutsem & Duchateau, 2005; Requena et al., 2008). Van Cutsem and Duchateau (2005) showed that the performance of dorsiflexion ballistic contraction after a sustained submaximum contraction (~25% of MVC) was lower than after a period of rest. These authors suggested that a sustained submaximum contraction led to a decrease in the instantaneous discharge rate of motor units during a posterior ballistic contraction, negatively affecting the maximal rate of the muscle contraction. It is unlikely that this could explain the diminution in power during the plantar flexions immediately after submaximal preactivation, because it was only significant in SVC7. The low level of isometric contraction (10% of MVC) and the slow properties of the soleus muscle make this explanation unlikely. Further studies are required to replicate and verify this depletion in power after submaximal contraction in the soleus muscle.

An explanation could be the non-recruitment of fast motor units during the submaximal conditions. Hamada et al. (2000b) found that muscles with shorter twitch contraction and a higher percentage of type II fibres exhibit greater post-activation potentiation. This argument was employed by Requena et al. (2008) to explain the absence of twitch peak torque potentiation in the knee extensors after 7 s of submaximal (25% of MVC) voluntary isometric contraction.

Lack of H-reflex changes

Our results did not show any change in the H-reflex and related parameters, even when post-activation potentiation was observed. Hence, the effect of isometric contraction conditioning on the improvement of explosive plantar flexions does not appear to be related to changes in the H-reflex. This result contrasts with previous studies (Folland et al., 2008; Gullich & Schmidtbleicher, 1996; Trimble & Harp, 1998) that reported changes in spinal excitability after different types of conditioning contractions. The different methodology used to induce post-activation potentiation could account for the different results in our study. Moreover, most of these studies did not actually incorporate measures of post-activation potentiation and inferred that post-activation potentiation had occurred.

Our results are in line with those of Hodgson et al. (2008), who observed an increase in the twitch torque and rate of force during voluntary isometric plantar flexion after maximal contractions without any changes in the H-reflex amplitude. They concluded that post-activation potentiation might result in a minor increase in the rate of voluntary isometric force production that is unrelated to neural excitability. Although we used a ballistic plantar flexion action compared with the isometric contraction used by Hogdson et al., our results support this hypothesis of independence and extend it to ballistic movements. However, further studies using a winder range of electrophysiological measures are required to exclude the contribution of the nervous system in post-activation potentiation.

In conclusion, our results show that isometric contractions of the soleus can lead to a post-activation potentiation in this muscle during explosive ballistic plantar flexions. The presence of post-activation potentiation depends on the intensity and duration of the isometric contraction and is not related to changes in spinal excitability.

References

Baker, D. (2003). Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. *Journal of Strength and Conditioning Research*, *17*, 493–497

Baudry, S., & Duchateau, J. (2004). Postactivation potentiation in human muscle is not related to the type of maximal conditioning contraction. *Muscle and Nerve*, *30*, 328–336.

Baudry, S., & Duchateau, J. (2007a). Postactivation potentiation in a human muscle: Effect on the rate of torque development of tetanic and voluntary isometric contractions. *Journal of Applied Physiology*, *102*, 1394–1401.

Baudry, S., & Duchateau., J. (2007b). Postactivation potentiation in a human muscle: Effect on the load–velocity relation of tetanic and voluntary shortening contractions. *Journal of Applied Physiology*, *103*, 1318–1325.

Behm, D. G., Button, D. C., Barbour, G., Butt, J. C., & Young, W. B. (2004). Conflicting effects of fatigue and potentiation on voluntary force. *Journal of Strength and Conditioning Research*, *18*, 365–372

Binder-MacLeod, S. A., Dean, J. C., & Ding, J. (2002). Electrical stimulation factors in potentiation of human quadriceps femoris. *Muscle and Nerve*, *25*, 271–279.

Capaday, C. (1997). Neurophysiological methods for studies of the motor system in freely moving human subjects. *Journal of Neuroscience Methods*, *74*, 201–218.

Chiu, L. Z., Fry, A. C., Weiss, L. W., Schilling, B. K., Brown, L. E., & Smith, S. L. (2003). Postactivation potentiation response in athletic and recreationally trained individuals. *Journal of Strength and Conditioning Research*, *17*, 671–677.

Damiano, D. L., Martellotta, T. L., Sullivan, D. J., Granata, K. P., & Abel, M. F. (2000). Muscle force production and functional performance in spastic cerebral palsy: Relationship of cocontraction. *Archives of Physical Medicine and Rehabilitation*, *81*, 895–900

Ebben, W. P., Jensen, R. L., & Blackard, D. O. (2000). Electromyographic and kinetic analysis of complex training variables. *Journal of Strength and Conditioning Research*, *14*, 451–456

Folland, J. P., Wakamatsu, T., & Fimland, M. S. (2008). The influence of maximal isometric activity on twitch and H-reflex potentiation, and quadriceps femoris performance. *European Journal of Applied Physiology*, *104*, 739–748.

French, D. N., Kraemer, W. J., & Cooke, C. B. (2003). Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *European Journal of Applied Physiology*, *17*, 678–685.

Galea, V. (2001). Electrical characteristics of human ankle dorsi- and plantar-flexor muscles: Comparative responses during fatiguing stimulation and recovery. *European Journal of Applied Physiology*, *85*, 130–140.

Gossen, E. R., & Sale, D. G. (2000). Effect of postactivation potentiation on dynamic knee extension performance. *European Journal of Applied Physiology*, *83*, 524–530.

Gourgoulis, V., Aggeloussis, N., Kasimatis, P., Mavromatis, G., & Garas, A. (2003). Effect of a submaximal half-squats warm-up program on vertical jumping ability. *Journal of Strength and Conditioning Research*, *17*, 342–344.

Gullich, A., & Schmidtbleicher, D. (1996). MVC-induced short-term potentiation of explosive force. *New Studies in Athletics*, *11*, 67–81.

Hamada, T., Sale, D. G., & MacDougall, J. D. (2000a). Postactivation potentiation in endurance-trained male athletes. *Medicine and Science in Sports and Exercise*, *32*, 403–411.

Hamada, T., Sale, D. G., MacDougall, J. D., & Tarnopolsky, M. A. (2000b). Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *Journal of Applied Physiology*, *88*, 2131–2137.

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-activation potentiation: Underlying physiology and implications for motor performance. *Sports Medicine*, *35*, 585–595.

Hodgson, M., Docherty, D., & Zehr, E. P. (2008). Postactivation potentiation of force is independent of H-reflex excitability. *International Journal of Sports Physiology and Performance*, *3*, 219–231.

Hrysomallis, C., & Kidgell, D. (2001). Effect of heavy dynamic resistive exercise on acute upper-body power. *Journal of Strength and Conditioning Research*, *15*, 426–430.

Klimstra, M., & Zehr, E. P. (2008). A sigmoid function is the best fit for the ascending limb of the Hoffmann reflex recruitment curve. *Experimental Brain Research*, *186*, 93–105.

Metzger, J. M., Greaser, M. L., & Moss, R. L. (1989). Variations in cross-bridge attachment rate and tension with phosphorylation of myosin in mammalian skinned skeletal muscle fibers. Implications for twitch potentiation in intact muscle. *The Journal of General Physiology*, *93*, 855–883.

O'Leary, D., Hope, K., & Sale, D. G. (1997). Posttetanic potentiation of human dorsiflexors. *Journal of Applied Physiology*, *83*, 2131–2138.

Pérez, M. A., Lundbye-Jensen, J., & Nielsen, J. B. (2007). Task-specific depression of the soleus H-reflex after co-contraction training of antagonistic ankle muscles. *Journal of Neurophysiology*, *98*, 3677–3687.

Requena, B., Gapeyeva, H., García, I., Ereline, J., & Pääsuke, M. (2008). Twitch potentiation after voluntary versus electrically induced isometric contractions in human knee extensor muscles. *European Journal of Applied Physiology*, *104*, 463–472.

Sale, D. (2002). Postactivation potentiation: Role in human performance. *Exercise and Sport Sciences Reviews*, *30*, 138–143.

Tillin, N. A., & Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Medicine*, *39*, 147–166.

Trimble, M. H., & Harp, S. S. (1998). Postexercise potentiation of the H-reflex in humans. *Medicine and Science in Sports and Exercise*, *30*, 933–941.

Van Cutsem, M., & Duchateau, J. (2005). Preceding muscle activity influences motor unit discharge and rate of torque development during ballistic contractions in humans. *Journal of Physiology*, *562*, 635–644.

Vandervoort, A. A., Quinlan, J., & McComas, A. J. (1983). Twitch potentiation after voluntary contraction. *Experimental Neurology*, *81*, 141–152.

Young, W. B., Jenner, A., & Griffiths, K. (1998). Acute enhancement of power performance from heavy load squats. *Journal of Strength and Conditioning Research*, *12*, 82–84.