Journal of Strength and Conditioning Research, 2007, 21(3), 837–840

Intermittent Exercise as a Conditioning Activity to Induce Postactivation Potentiation

Mauro A.B. Batista,[3,4] Carlos Ugrinowitsch,[1] Hamilton Roschel,[3,4] Renato Lotufo,[5] Mark D. Ricard,[2] and Valmor A.A. Tricoli[1]

[1]Department of Sport, School of Physical Education and Sport, University of São Paulo, São Paulo, SP, Brazil; [2]Exercise Science Research Laboratories, Department of Kinesiology, University of Texas at Arlington, Arlington, Texas 76019; [3]School of Physical Education and Sport, University of São Paulo, São Paulo, SP, Brazil; [4]Paulista University, São Paulo, SP, Brazil; [5]Institute of Physical Evaluation of Sport, São Paulo, SP, Brazil.

Abstract. Batista, M.A.B., C. Ugrinowitsch, H. Roschel, R. Lotufo, M.D. Ricard, and V.A.A. Tricoli. Intermittent exercise as a conditioning activity to induce postactivation potentiation. *J. Strength Cond. Res. 21(3):837–840. 2007.*—Postactivation potentiation (PAP) is defined as a short-term increase in voluntary muscle activation following a previous conditioning activity (CA). Controversy about PAP is mostly attributed to the characteristics of the CA and the training status of the subjects. While some studies have found that PAP can be induced by series of 5–10 second maximal voluntary isometric contractions or near maximal dynamic contractions (e.g., 3–5 repetition maximum), others have failed to do so. On the other hand, some studies suggest that intermittent contractions can also induce PAP. However, even though PAP was observed, its duration was not taken into account, leaving ground for further investigations. The purpose of this study was threefold: (a) to verify if PAP can progressively enhance performance of voluntary actions throughout a set of intermittent contractions; (b) to verify PAP duration when induced by an intermittent contractions protocol; and (c) to verify if PAP effects were reproducible in different sessions when induced by intermittent contractions. Ten physically active men, not engaged in strength training, underwent 5 randomized experimental sessions, during which they performed a set of 10 unilateral knee extensions (KE) (1 every 30 seconds) at $60°\cdot s^{-1}$ in an isokinetic dynamometer. Peak torque was evaluated over the 10 unilateral KE and at the randomized intervals of 4, 6, 8, 10, and 12 minutes post CA. Peak torque was potentiated 1.3 ($\pm$0.79) N·m per unilateral KE, and the potentiation effect persisted for 12 minutes after the last contraction. These findings were reproduced in all 5 experimental sessions. Thus, intermittent conditioning activities seem to be an effective way to produce PAP. However, these activities should be tested in a more real world situation to verify the applicability as a warm-up routine.

Key Words. torque, leg extension, force enhancement, isokinetic, force-velocity

Introduction

Force production is modulated by muscle contractile history. A previous muscle contraction may acutely decrease or increase force production in a subsequent motor activity (1). Force depression after a previous muscle contraction is known as fatigue while force enhancement is defined as postactivation potentiation (PAP) (20, 22). This phenomenon is usually associated with mechanisms within the muscle, even though neural factors cannot be ruled out when considering voluntary muscle actions (11, 22, 25, 27). Any previous muscle activity can trigger both PAP and fatigue mechanisms. Thus, the performance enhancement depends on the prevalence of PAP mechanisms over fatigue mechanisms, which is modulated by the characteristics of the previous muscle activity (10, 20).

As a consequence, a great effort has been made in finding a proper conditioning activity (CA) protocol to induce PAP. Most studies have used either single or multiple sets of 5- to 10-second duration maximal voluntary isometric contractions (MVIC) or submaximal isoinertial contractions (3–5 repetition maximum [RM]) (3, 4, 7–9, 11, 17, 23). The prevalence of PAP has been consistently shown when performance is measured involuntarily through electrical stimulation (1, 2, 13, 24, 30). Although results are still controversial, several studies have also demonstrated PAP through voluntary contractions (4, 7, 11, 19), while others have failed to do so (3, 5, 8, 15, 17, 19). Many factors have been used to explain the lack of PAP, however, its absence has mostly been attributed to the prevalence of fatigue induced by CA. In light of these arguments, a CA protocol must be able to avoid fatigue while inducing PAP.

In an interesting approach, Hughes et al. (14) tested PAP during intermittent muscle contractions after a single 10-second MVIC used as CA and observed that the contractions themselves produced PAP despite the CA (compared to control group). These results suggest that intermittent contractions can be used as CA. However, these authors did not test the duration of PAP effects after a set of intermittent contractions. The duration of such effect is of great importance to indicate if intermittent protocols are adequate to warm athletes up and, therefore, increase sports performance.

Therefore, the aim of this study was threefold: (a) to test an intermittent muscle contraction protocol as CA in producing a cumulative effect of PAP between consecutive contractions; (b) to test the duration of PAP in different time intervals; and (c) to test reproducibility of PAP occurrence across testing days.

Methods

Experimental Approach to the Problem

To test the occurrence of a cumulative effect of PAP within a set of intermittent contractions used as CA, physically active subjects had concentric knee extension peak torque (KE) assessed every contraction during a CA protocol, composed of a set of 10 intermittent knee extensions on an isokinetic dynamometer. In order to assess duration of PAP, KE performance was randomly measured at 5 different time intervals (each interval in a separate experimental session). This approach also served as a reproducibility test for PAP occurrence.

This study was a 5 × 6 crossover factorial design where all subjects were exposed to all levels of the experimental factors. The first factor was the testing day (first, second, third, fourth, and fifth), and the second factor was the time of data acquisition (baseline, and 4, 6, 8, 10, and 12 minutes after the conditioning activity).

In order to investigate the occurrence and the reliability of such phenomenon, a well-controlled environment is mandatory. Our set-up was able to reduce the effects of other variables on PAP occurrence, allowing a better comprehension of the efficiency of the CA protocol. However, this may not be the more adequate strategy if one is considering practical feasibility.

Subjects

Ten healthy, physically active men (age: 25.1 ± 2.6 years; weight: 79.8 ± 6.4 kg; height: 181.5 ± 7.6 cm), not involved in any kind of strength training, voluntarily participated in this study. All subjects were informed of the purpose and possible risks associated with the experimental protocol prior to signing an informed consent form approved by the institutional review board. All subjects were free of any musculoskeletal problems in the lower limbs. They were instructed to abstain from any exhausting exercise for 48 hours prior to testing. Because previous studies have reported that highly trained subjects are more able to experiment PAP (4, 9, 11), we decided to test strength untrained subjects. We believed PAP induced in untrained subjects would give more reliance to the suggested protocol.

Procedures

Subjects reported to the laboratory on 6 different occasions. At the first visit they were familiarized with the apparatus and the experimental procedures. In the following 5 sessions, subjects were tested. Experimental sessions were held 1 week apart to avoid fatigue and training effects. Prior to every testing and familiarization session, subjects performed a standardized warm-up consisting of 5 minutes of submaximal cycling (70–80 rpm) followed by light stretching leg exercises. Immediately after, subjects were securely seated in the isokinetic dynamometer (REV 9000; Technogym, Seattle, WA). The dominant leg was secured to the lever arm at the inferior border of the lateral maleolus. Subjects' settings on the dynamometer were recorded to guarantee the same position between testing sessions. Range of motion was defined from 90° of knee flexion to 0° of knee extension (leg parallel to the ground). Gravity correction was performed through standard procedure. After the set-up, subjects completed a specific warm-up routine performing 2 maximal sets of 5 knee extensions at $180°\cdot s^{-1}$, separated by a 2-minute rest period.

For the CA protocol, the subjects were asked to perform 10 maximal knee extensions at $60°\cdot s^{-1}$, one every 30 seconds. They were instructed to perform all knee extensions as fast and hard as possible throughout full range of motion. Subjects were provided with visual feedback and standardized verbal encouragement. The same researcher conducted all experimental sessions.

Peak torque was recorded on each repetition to verify if there was a potentiation effect throughout the set. This procedure was repeated in all testing sessions to verify if peak torque potentiation was a reproducible phenomenon.

The duration of the potentiation effect was measured at 5 time intervals (4, 6, 8, 10, and 12 minutes), through 3 consecutive knee extensions at $60°\cdot s^{-1}$, one interval per testing session. This procedure was adopted because the previous posttest interval could potentiate the next one. The highest peak torque was considered for further analysis. The order of the posttest intervals was randomized for each subject. The peak torque of the first contraction in the conditioning set of each experimental session was used as the baseline value.

We utilized an isokinetic dynamometer to assess torque produced during each contraction (during CA protocol), and also post CA voluntary activity because of the greater accuracy of its torque measurements.

Statistical Analyses

Instead of using a regular repeated measures analysis of variance (ANOVA), a random coefficient growth curve model was used to assess the potentiation effect within a CA set, and between sets on the testing sessions (18, 28). In this case, random coefficient growth curve models are more efficient to detect the potentiation effects within and between sets because they do not deal with interactions. Instead, this analysis identified if baseline peak torque values were different across testing sessions, if peak torque increased during the conditioning activity, and if this increment was consistent across testing sessions. Then, linear contrasts were used to compare baseline values and rate of change in peak force within a set and between sessions. In addition, random coefficients growth curve models decrease the probability of type I error occurrence compared with regular repeated measures ANOVA. The power of the test was 0.82.

The duration of the potentiation effect was tested with a linear mixed model. Subjects were considered as random effects and testing day and time of posttest measurement as fixed effects. A post hoc Tukey adjustment was used for multiple comparison purposes. Significance level was set at $p \leq 0.05$ for both analyses.

Reliability (intraclass correlation coefficient) of torque measurements was assessed for the first and last repetition of the CA protocol across test days. Intraclass correlation coefficient r was 0.97 and 0.95 for the first and last repetition, respectively.

Effect sizes (ES) were estimated for peak torque increment from the first to the tenth contraction of the CA and from the first to the average of the fourth, sixth, eighth, tenth, and twelfth minute peak torque increment, giving a better perspective of the magnitude of peak torque increments during the CA and after it.

Results

The linear models adjusted to the data showed an average increase of 1.3 N·m (±0.79) from previous to subsequent contractions, along the 10 intermittent knee extensions (Figure 1). The slope of the torque increment, between repetitions, was not significantly different across days ($p < 0.05$).

Peak torque measured in the first contraction of the conditioning activity was not different between sessions. For this reason, the peak torque of the first contraction in the set was used as the baseline value. This value was compared with the highest peak torque achieved in the posttest intervals. Peak torque increased significantly from baseline to posttest (4, 6, 8, 10, and 12 minutes after CA). The magnitude of torque improvement was not different between time intervals. In other words, peak torque potentiation was maintained up to 12 minutes after conditioning activity. Figure 2 summarizes this information.

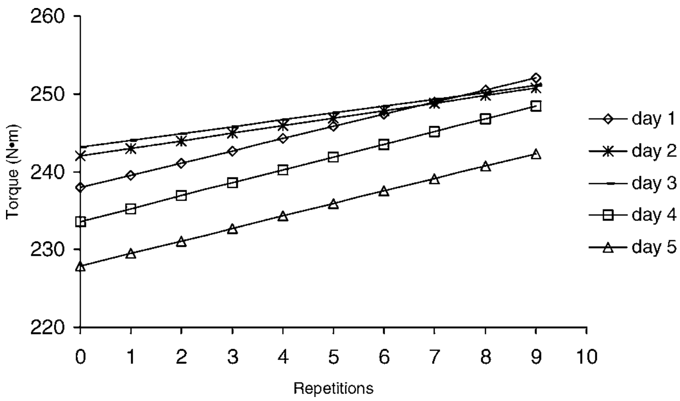

FIGURE 1. Adjusted growth curve models of the potentiation effect throughout a set of 10 isokinetic knee extensions at 60°·s⁻¹.

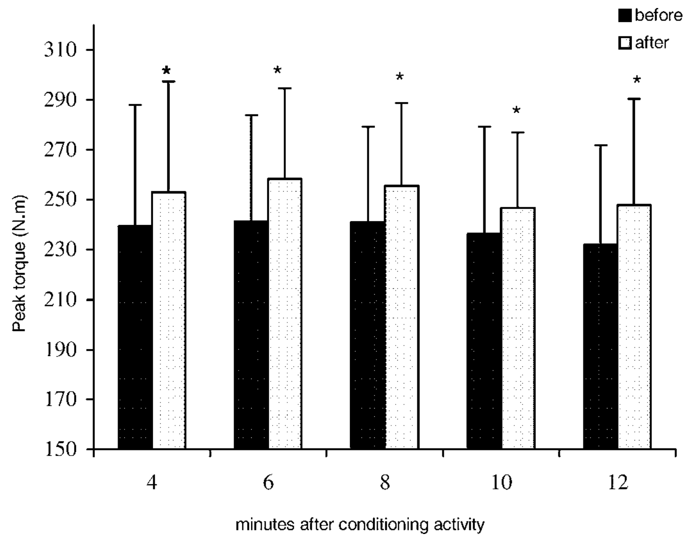

FIGURE 2. Knee extension peak torque before (first contraction of the conditioning activity [CA]) and after the conditioning activity (4, 6, 8, 10, and 12 minutes after CA). *indicates pretest to posttest difference ($p < 0.05$).

Average ES from the first to the tenth contraction of the CA was 1.0. Two subjects presented negative ES (−0.19 and −0.48) and were classified as nonresponders. The remaining subjects had positive ES (1.17) and were all classified as responders.

DISCUSSION

The major and novel finding of this study is that a CA protocol consisting of intermittent muscle contractions is able to progressively produce peak torque potentiation between contractions. This effect lasts up to 12 minutes after the last contraction. Another important finding is that the proposed CA protocol is reproducible across testing days.

This is the first study to show a progressive peak torque potentiation throughout an intermittent protocol of CA. However, other studies have also observed the same effect of PAP on different performance parameters using intermittent contractions. Hughes et al. (14) showed peak velocity potentiation during a set of 8 knee extensions (one every 30 seconds). In the same way, Gossen and Sale (8) found peak velocity potentiation during knee extensions (20-second intervals). In addition to that, Güllich and Schmidtbleicher (11) demonstrated jumping peak height potentiation throughout a set of 8 consecutive (20-second interval) counter movement maximal jumps. Once performance enhancement is only observed when PAP mechanisms prevail over fatigue mechanisms, it seems reasonable to assume that during the intermittent protocols (of the studies mentioned above) fatigue never prevails over PAP, since performance increased contraction after contraction. In addition, we believe that this staircase effect, induced by intermittent protocols, is associated with 2 primary conditions: (a) use of high-intensity short-duration contractions and (b) recovery intervals between consecutive contractions.

Using high-intensity contractions allows the activation of high threshold motor units composed of type II fibers. Postactivation potentiation is reported to be greater in type II than type I fibers because the type II fibers undergo greater myosin light chain phosphorylation (MLCP), which is thought to be the primary mechanism supporting force potentiation (13, 26, 30). In addition to MLCP, an increased neuromuscular excitation at the spinal cord level may also induce PAP. This increased excitability has been demonstrated through augmented H-reflex amplitude after a voluntary conditioning activity (11, 16, 29). However, the occurrence of this event seems to be related to muscle stimulations greater than 100 Hz (29), which seems to be the case in high-intensity muscle contractions (21).

In addition to contraction intensity, its duration also seems to be important. Longer contractions, as usually seen in the literature, may induce higher fatigue levels. In this situation, fatigue might overcome potentiation and PAP is not observed immediately after CA. Gossen and Sale (8) used a single 10-second MVIC conditioning activity and observed peak velocity depression during knee extensions performed immediately after CA (8). In accordance with that, Jensen and Ebben (15) found decrement in jumping performance 10 seconds after 5 RM squats, suggesting that fatigue may be prevailing at this time (15). However, after 4 minutes of recovery, the authors observed a trend toward increase. Additional evidence is that H-reflex is decreased right after 5-second MVIC plantar flexion, increasing from base values around 3 minutes of recovery (6). These data support the idea that longer contractions may require longer recovery intervals in order for fatigue to dissipate. In our study, the contractions lasted 1.5 seconds (60°·s⁻¹ for a 90° range of motion); therefore, the staircase effect observed suggests that such duration was not long enough to elicit high levels of fatigue.

The rationale for the use of intermittent protocols seems not to be the work-to-rest ratio, but the absolute duration of the contractions and the rest intervals themselves (11). Short duration contractions would not allow fatigue to build up during contractions, while still promoting PAP (20). Moreover, the rest interval would allow muscle recovery, enhancing the prevalence of PAP over fatigue.

It is interesting to notice that the efficiency of a CA can also be related to the duration of the PAP effect, since it is closely connected to its practical implications. To the best of our knowledge, this is the first study to show that PAP induced by intermittent protocol has a short-term duration effect. In our study, PAP effects were observed in all tested intervals (i.e., up to 12 minutes past CA). However, it cannot be ruled out that our effect may have lasted longer than 12 minutes, since other studies (that did not use intermittent protocols) reported durations around 20 minutes (4, 11).

The staircase effect observed in our study (peak torque potentiation between contractions) was reproducible across testing days. Baseline values were not different across testing days and the rate of peak torque increment was also not different between testing sessions. It means that torque produced in the first contraction of CA was similar from test day to test day. In addition, the rate of torque increment from repetition to repetition (during CA) was consistent across days. Hughes et al. (14) observed a similar effect for KE peak velocity (reproducibility across test days), however, using different loads every testing session. Güllich and Schmidtbleicher (11) observed high reproducibility between sets, although the tests were carried out in the same day. Moreover, since in our study baseline and rate of torque improvement did not change across testing days, familiarization was able to stabilize performance and minimize learning and training effects. It can also be highlighted that, in our study, reproducibility was demonstrated in untrained subjects, which are less susceptible to PAP (4, 9, 11, 12). These data also support the ability of intermittent protocol to be used as an efficient CA.

In conclusion, our study showed the effectiveness of an intermittent protocol to induce PAP. However, it should be emphasized that we used single joint movement in our design. Thus, it is important to point out that other studies, investigating the effect of intermittent protocols on sport-related motor tasks, are necessary in order to draw more task-specific conclusions.

Practical Applications

The use of strength exercises as warm-up routines for sport events that depend on strength and power is widely spread. The rationale for such an approach relies on the PAP effect produced by previous conditioning activity (i.e., strength exercises). As of today, it is difficult to determine the best conditioning activity protocol in order to induce PAP. Our study shows that intermittent protocols may be an interesting alternative compared to MVIC and submaximal isoinertial protocols because they produced increased torque output throughout the conditioning activity, and this effect was maintained for up to 12 minutes. Moreover, this effect was highly reproducible across testing days. It should be highlighted that the intermittent protocol did not produce any torque decrement after the conditioning activity as observed in other studies. Even though our study was carried out in an isokinetic dynamometer, the results should not be attributed to the device employed, but to the CA protocol itself (high-intensity, short-duration intermittent exercise), since our data are in accordance with studies in literature that have used similar CA protocols and more real life situations (11, 14). Albeit our data are consistent, the same effects on sport-specific tasks using a nonlaboratorial set-up, such as one would find in the real world, remain to be shown.

References

1. Abbate, F., A.J. Sargeant, P.W. Verdijk, and A. De Haan. Effects of high-frequency initial pulses and posttetanic potentiation on power output of skeletal muscle. *J. Appl. Physiol.* 88:35–40. 2000.
2. Baudry, S., and J. Duchateau. Postactivation potentiation in human muscle is not related to the type of maximal conditioning contraction. *Muscle Nerve* 30:328–336. 2004.
3. Behm, D.G., D.C. Button, G. Barbour, J.C. Butt, and W.B. Young. Conflicting effects of fatigue and potentiation on voluntary force. *J. Strength Cond. Res.* 18:365–372. 2004.
4. Chiu, L.Z., A.C. Fry, L.W. Weiss, B.K. Schilling, L.E. Brown, and S.L. Smith. Postactivation potentiation response in athletic and recreationally trained individuals. *J. Strength Cond. Res.* 17:671–677. 2003.
5. Ebben, W., R. Jensen, and D. Blackard. Electromyographic and kinetic analysis of complex training variables. *J. Strength Cond. Res.* 14:451–456. 2000.
6. Enoka, R.M., R.S. Hutton, and E. Eldred. Changes in excitability of tendon tap and Hoffmann reflexes following voluntary contractions. *Electroencephalogr. Clin. Neurophysiol.* 48:664–672. 1980.
7. French, D.N., W.J. Kraemer, and C.B. Cooke. Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *J. Strength Cond. Res.* 17:678–685. 2003.
8. Gossen, E.R., and D.S. Sale. Effect of postactivation potentiation on dynamic knee extension performance. *Eur. J. Appl. Physiol.* 83:524–530. 2000.
9. Gourgoulis, V., N. Anggeloussis, P. Kasimatis, G. Mavromatis, and A. Garas. Effect of a submaximal half-squats warm-up program on vertical jumping ability. *J. Strength Cond. Res.* 17:342–344. 2003.
10. Grange, R.W., and M.E. Houston. Simultaneous potentiation and fatigue in quadriceps after 60-second maximal voluntary isometric contraction. *J. Appl. Physiol.* 70:726–731. 1991.
11. Güllich, A., and D. Schmidtbleicher. MVC-induced short-term potentiation of explosive force. *N. Stud. Athl.* 11:67–81. 1996.
12. Hamada, T., D.G. Sale, and J.D. MacDougall. Postactivation potentiation in endurance-trained male athletes. *Med. Sci. Sports Exerc.* 32:403–411. 2000.
13. Hamada, T., D.G. Sale, J.D. MacDougall, and M.A. Tarnopolsky. Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *J. Appl. Physiol.* 8:2131–2137. 2000.
14. Hughes, S., E. Gossen, and D. Sale. Effect of postactivation potentiation on dynamic knee extension performance [Abstract]. *Can. J. Appl. Physiol.* 26:486. 2001.
15. Jensen, R.L., and W.P. Ebben. Kinetic analysis of complex training rest interval effect on vertical jump performance. *J. Strength Cond. Res.* 17: 345–349. 2003.
16. Kitago, T., R. Mazzocchio, G. Liuzzi, and L.G. Cohen. Modulation of H-reflex excitability by tetanic stimulation. *Clin. Neurophysiol.* 115:858–861. 2004.
17. Koch, A.J., H.S. O'Bryant, M.E. Stone, K. Sanborn, C. Proulx, J. Hruby, E. Shannonhouse, R. Boros, and M.H. Stone. Effect of warm-up on the standing broad jump in trained and untrained men and women. *J. Strength Cond. Res.* 17:710–714. 2003.
18. Littell, R.C., G.A. Miliken, W.W. Stroup, and R.D. Wolfinger. *SAS System for Mixed Models.* Cary: SAS Institute, 1996.
19. Radcliffe, J.C., and J.L. Radcliffe. Effects of different warm-up protocols on peak power output during a single response jump task. *Med. Sci. Sports Exerc.* 28:s189. 1996.
20. Rassier, D.E., and B.R. Macintosh. Coexistence of potentiation and fatigue in skeletal muscle. *Braz. J. Med. Biol. Res.* 33:499–508. 2000.
21. Sale, D.G. Influence of exercise and training on motor unit activation. *Exerc. Sport Sci. Rev.* 15:95–151. 1987.
22. Sale, D.G. Postactivation potentiation: Role in human performance. *Exerc. Sport Sci. Rev.* 30:138–143. 2002.
23. Sánchez, B.R., M.Z. Díaz, I.C. Ríos, P.P. Puche, and M.M. Marín. Efecto de la inducción de la potenciación postetánica muscular sobre los factores de rendimiento en un gesto dinámico del tren superior. *Apunts: Educ. Fís. Dep.* 73:78–85. 2003.
24. Skurvydas, A., K. Vasiliauskas, N. Lagunaviciene, and A. Stanislovaitis. Muscle fatigue and post-tetanic potentiation in boys and adult men when performing jumping exercises of maximal intensity. *Educ. Phys. Train.* 4(37):40–45. 2000.
25. Suzuki, S., K. Kaiya, S. Watanabe, and R.S. Hutton. Contraction-induced potentiation of human motor unit discharge and surface EMG activity. *Med. Sci. Sports Exerc.* 20:391–395. 1988.
26. Sweeney, H.L., B.F. Bowman, and J.T. Stull. Myosin light chain phosphorylation in vertebrate striated muscle: Regulation and function. *Am. J. Physiol.* 264:C1085–C1095. 1993.
27. Trimble, M.H., and S.S. Harp. Postexercise potentiation of the H-reflex in humans. *Med. Sci. Sports Exerc.* 30:933–941. 1998.
28. Ugrinowitsch, C., G.W. Fellingham, and M.D. Ricard. Limitations of ordinary least squares models in analyzing repeated measures data. *Med. Sci. Sports Exerc.* 36:2144–2148. 2004.
29. Van Boxtel, A. Differential effects of low-frequency depression, vibration-induced inhibition, and posttetanic potentiation on H-reflexes and tendon jerks in the human soleus muscle. *J. Neurophysiol.* 55:551–568. 1986.
30. Vandervoort, A.A., J. Quinlan, and A.J. McComas. Twitch potentiation after voluntary contraction. *Exp. Neurol.* 81:141–152. 1983.

Address correspondence to Dr. Mark D. Ricard, ricard@uta.edu.