Effect of Aerobic Recovery Intensity on Delayed-Onset Muscle Soreness and Strength

James J. Tufano, Lee E. Brown, Jared W. Coburn, Kavin K.W. Tsang, Vanessa L. Cazas, and Joe W. LaPorta

Department of Kinesiology, Center for Sport Performance, California State University, Fullerton, California

Abstract

Tufano, JJ, Brown, LE, Coburn, JW, Tsang, KKW, Cazas, VL, and LaPorta, JW. Effect of aerobic recovery intensity on delayed-onset muscle soreness and strength. *J Strength Cond Res* 26(10): 2777–2782, 2012—Because of the performance decrements associated with delayed-onset muscle soreness (DOMS), a treatment to alleviate its symptoms is of great interest. The purpose of this study was to investigate the effect of low vs. moderate-intensity aerobic recovery on DOMS and strength. Twenty-six women (22.11 ± 2.49 years; 60.33 ± 8.37 kg; and 163.83 ± 7.29 cm) were split into 3 different groups and performed a DOMS-inducing protocol of 60 eccentric actions of the knee extensors followed by 1 of three 20-minute recovery interventions: moderate-intensity cycling ($n = 10$), low-intensity cycling (LIC; $n = 10$), or seated rest (CON; $n = 6$) after the eccentric protocol. Pain scale (PS), isometric strength (ISO), and dynamic strength (PT) were recorded before (PRE), immediately post (IP), 24- (24h), 48- (48h), 72- (72h), and 96- (96h) hours after exercise. For PT, PRE, 48h, 72h, and 96h were significantly ($p < 0.05$) greater than IP values but not different from 24h. For PS, IP (4.83 ± 0.36) was greater than that for all other time periods, whereas 24h (2.91 ± 0.42), 48h (2.62 ± 0.53), and 72h (1.97 ± 0.49) were all greater than PRE (0.44 ± 0.19) values. Also, 24h and 48h were not different but were both greater than 72h and 96h (1.13 ± 0.32), whereas 72h was >96h. For ISO, neither CON nor LIC showed any significant difference across time. Moderate-intensity cycling showed no difference between PRE (189.88 ± 40.68), IP (193.75 ± 47.24), 24h (186.52 ± 53.55), or 48h (195.36 ± 55.06), but 72h (210.05 ± 53.57) and 96h (207.78 ± 59.99) were significantly >24h. The 72h was also greater than IP. Therefore, moderate-intensity aerobic recovery may be suggested after eccentric muscle actions.

Key Words performance, isometric, cycling

Address correspondence to Lee E. Brown, leebrown@fullerton.edu.

26(10)/2777–2782

Journal of Strength and Conditioning Research

Introduction

Unaccustomed exercise, primarily involving large quantities of eccentric muscle actions, induces muscle damage across a variety of populations (12,20,24,25,26,27,29), including athletes (9). This unaccustomed stress results in what is commonly known as delayed-onset muscle soreness (DOMS). Namely, DOMS is associated with pain, discomfort, and a decrease in performance. Because of the performance decrements associated with DOMS, a treatment to alleviate its symptoms is of great interest to athletes, and coaches alike.

Coaches and researchers have implemented a variety of strategies in an attempt to alleviate DOMS. Passive recovery strategies abound in the literature. Some examples are nutritional interventions (6,8,31,37), therapeutic modalities such as ice (13), heat (3,5,13,17,30), and massage (15,19,38), electrical stimulation (5), anti-inflammatory drugs (10,11,13), and stretching (13). Additionally, active recovery has also been considered during the search for effective treatment strategies. Active recovery methods include light resistance training (39), high-intensity resistance training (28), aquatic exercise (32), warm-up and cool-down (18), whole-body vibration (1,2), and low-intensity aerobic exercise (9). However, many of these demonstrate conflicting outcomes.

Although there is an abundance of research on passive recovery strategies, research on active recovery is lacking. The proposed rationale for the majority of the aforementioned active recovery interventions is that blood flow is acutely increased in the treated area (9). As a result of this increased blood flow, more waste is taken away from the injured site, and more nutrients are delivered, accelerating repair and remodeling (9). With even more blood flow, it may be possible to speed up recovery. Eliciting greater blood flow via exercise that elevates HR may encourage greater healing. Among active recoveries, aerobic exercise seems to be the most appropriate treatment strategy because it increases blood flow without causing more muscle damage that may occur with higher intensity exercises.

However, to our knowledge, few, if any, studies have investigated the acute effect of different intensities of aerobic activity on DOMS and strength. A recovery treatment that demonstrates an acute recovery may be further investigated to determine the chronic effect of that treatment. Therefore, the purpose of this study was to investigate the acute effect of low vs. moderate-intensity aerobic recovery on DOMS and peak torque.

Methods

Experimental Approach to the Problem

This between-groups study examined the effect of 2 different intensities of aerobic activity on DOMS and strength. The subjects performed a DOMS-inducing protocol on day 1 followed by 1 of 3 recovery interventions: moderate-intensity cycling (MIC), low-intensity cycling (LIC), or rest (CON). Delayed-onset muscle soreness and strength were recorded immediately post (IP), 24- (24h), 48- (48h), 72- (72h), and 96- (96h) hours after the DOMS-inducing eccentric protocol and compared with baseline (PRE) measures.

Subjects

Twenty-six women were randomly assigned to 1 of 3 groups: MIC; $n = 10$ (21.80 ± 2.66 years, 162.4 ± 8.17 cm, 57.32 ± 9.90 kg, ISO; 197.84 ± 36.36 $N \cdot m^{-1}$, and PT240; 96.41 ± 9.87 $N \cdot m^{-1}$), LIC; $n = 10$ (22.40 ± 2.91 years, 163.35 ± 7.56 cm, 60.46 ± 5.34 kg, ISO; 189.88 ± 40.68 $N \cdot m^{-1}$, and PT240; 89.13 ± 14.80 $N \cdot m^{-1}$), or CON; $n = 6$ (22.17 ± 1.94 years, 167.00 ± 6.04 cm, 65.12 ± 9.48 kg, ISO; 217.77 ± 34.70 $N \cdot m^{-1}$, and PT240; 89.28 ± 13.91 $N \cdot m^{-1}$). All the subjects received, read, and signed a University institutional review board–approved informed consent before participation. No subjects had incurred any recent musculoskeletal injury that may have affected their performance. All the subjects were familiar with and had experienced DOMS before. The subjects were instructed to refrain from any physical activity outside of the investigation and to sustain their normal diet and daily activities (going to school, driving to work, etc.) for the duration of the study. Additionally, they were instructed to avoid any stretching, ice, heat, antiinflammatory drugs, or any other type of recovery for the extent of the study. The only methodological difference between groups was the recovery intervention. Baseline (PRE) anthropometrics, isometric, and dynamic strength were not different between groups, minimizing within-group variance.

Procedures

For baseline testing (PRE), the subjects reported to the laboratory, informed consent forms were signed, their mass was measured using a digital scale (Model # ES200L, Ohaus, Pine Brook, NJ, USA), and their height using a wall-mounted stadiometer (Seca Stadiometer, Ontario, Canada). Resting HR was taken after the subjects were seated for approximately 5 minutes. Baseline measurements included the following: pain scale (PS), peak isometric torque of the right quadriceps at 60° of knee flexion (full extension = 0°) (ISO), and peak torque of the right quadriceps at $240° \cdot s^{-1}$ (PT). After the PS measurement, the subjects were seated on a cycle ergometer while wearing an HR monitor (Polar FT1, Kempele, Finland). They cycled at 80 rpm for 5 minutes, and the work rate was adjusted until the HR met the requirements of their assigned group. The CON subjects cycled at approximately 50 W. This served as a warm-up before ISO and PT testing and also as a trial for the investigators to determine the load at which each subject would cycle during their recovery intervention.

Within 1 week of PRE, the subjects reported back to the laboratory for 5 consecutive experimental trial days (days 1–5). On day 1, they completed a 5-minute cycle warm-up at 50 W at a self-selected cadence. Next, they performed the DOMS-inducing protocol, underwent testing again, and participated in their appropriate recovery intervention. On days 2–5, the subjects reported back to the laboratory at the same time as day 1 and performed the same tests.

Recovery Intervention

The MIC and LIC groups performed 20 minutes of cycling at 80 rpm (16) on a stationary cycle ergometer (Monark 838E, Varberg, Sweden) after testing on day 1. Resistance during the recovery intervention was adjusted to match the desired HR. The MIC group cycled at 70% age-predicted maximum HR reserve, while the LIC group cycled at 30% age-predicted maximum HR reserve. The CON group was seated on the cycle ergometer for 20 minutes without pedaling with the pedals parallel and the right foot in front.

Pain Scale

The participants rated their quadriceps pain on a scale of 0–10, adapted from McHugh and Tetro (0 = no pain to 10 = extremely intense pain) (21).

Isometric and Dynamic Strength Testing

The subjects were seated on a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) with the body stabilized by straps over the thighs, waist, and chest and the right lateral epicondyle of the femur aligned with the axis of rotation. Once in position, peak isometric

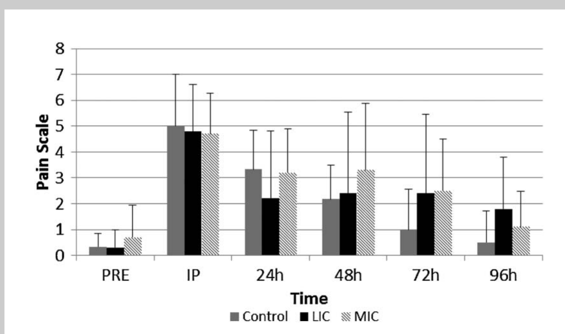

Figure 1. Pain scale at preexercise protocol (PRE), immediately postprotocol (IP), 24 (24h), 48 (48h), 72 (72h), and 96 (96h) hours postprotocol. No significant differences between groups.

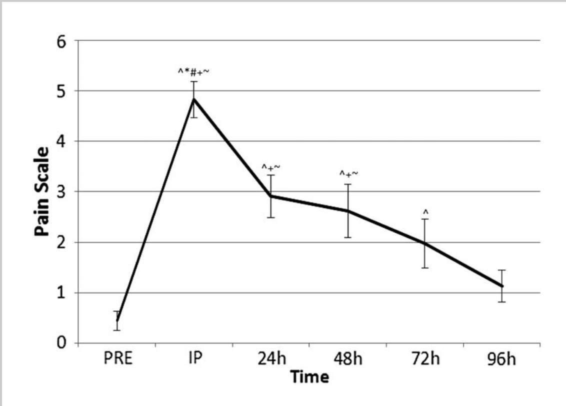

Figure 2. Pain scale collapsed across groups at preexercise protocol (PRE), immediately postprotocol (IP), 24 (24h), 48 (48h), 72 (72h), and 96 (96h) hours postprotocol. ^ IP, 24h, 48h, and 72h significantly greater than PRE. *IP significantly >24h. #IP significantly >48h. +IP, 24h, and 48h significantly >72h. ~IP, 24h, and 48h significantly >96h.

torque of the right quadriceps was assessed at 60° of knee flexion or dynamic peak torque of the quadriceps at 240°·s^{-1}, in random order. For the isometric test, three 6-second maximal isometric actions of the knee extensors were performed, separated by 2 minutes of rest (4). Two minutes of rest was also given between the isometric and dynamic trials. Dynamic trials were performed with the range of motion set to 10° of knee extension and 90° of knee flexion. The subjects performed 6 maximal concentric reciprocal repetitions of the knee extensors and flexors. They did not receive any visual feedback but were verbally encouraged throughout the duration of testing.

Eccentric Protocol

The subjects were securely positioned at 90° knee flexion for unilateral knee extension and flexion of the right leg on the dynamometer. They performed 6 sets of 10 maximal

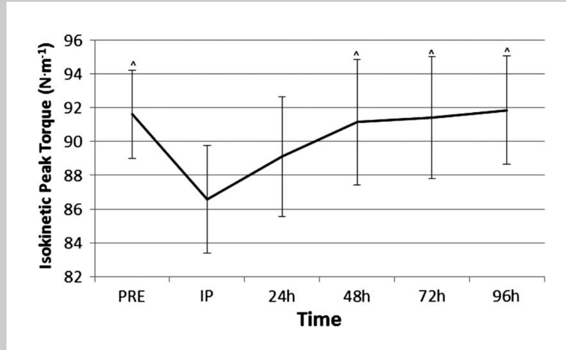

Figure 4. Dynamic peak torque at 240°·s^{-1} collapsed across groups at preexercise protocol (PRE), immediately postprotocol (IP), 24 (24h), 48 (48h), 72 (72h), and 96 (96h) hours postprotocol. ^ Significantly greater than IP.

eccentric actions of the right knee extensors at 60°·s^{-1} (1) with the range of motion set to 10° of knee extension and 90° of flexion with the dynamometer in continuous passive mode. They returned to the extended position passively between each eccentric action of the knee extensors. One minute of rest was allotted between sets.

Statistical Analyses

Three 3 × 6 (group × time) mixed-factor analyses of variance (ANOVAs) were used to analyze PS, ISO, and PT using SPSS Version 20 (Statistical Package for Social Sciences, Chicago, IL, USA). An a-priori alpha level of 0.05 was considered statistically significant.

Results

Pain scale demonstrated no interaction (Figure 1), but there was a main effect for time (effect size = 0.51). Immediately postexercise value was greater than all other time periods' values, whereas 24h, 48h, and 72h were all significantly greater than PRE. Values of 24h and 48h were not different

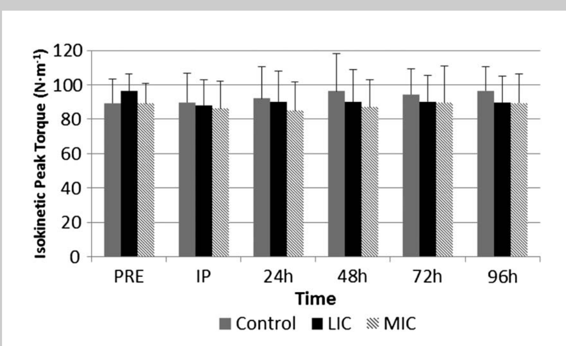

Figure 3. Dynamic peak torque at 240°·s^{-1} at preexercise protocol (PRE), immediately postprotocol (IP), 24 (24h), 48 (48h), 72 (72h), and 96 (96h) hours postprotocol. No significant differences between groups.

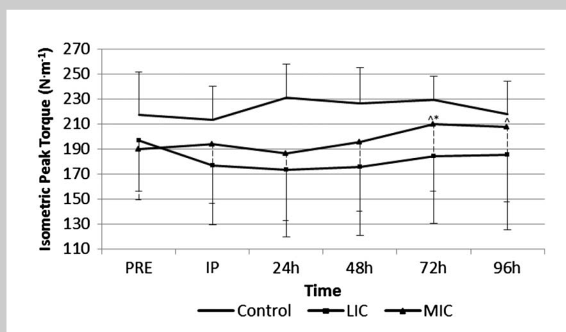

Figure 5. Isometric quadriceps peak torque at 60° of knee flexion at preexercise protocol (PRE), immediately postprotocol (IP), 24 (24h), 48 (48h), 72 (72h), and 96 (96h) hours postprotocol. ^72h and 96h significantly >24h. *72h significantly greater than IP.

from each other but were both greater than those of 72h and 96h, whereas 72h was also >96h (Figure 2).

Dynamic strength demonstrated no interaction (Figure 3), but there was a main effect for time (effect size = 0.11). The PRE was significantly greater than IP but was not different from 24h, 48h, 72h, or 96h, whereas 48h, 72h, and 96h were also significantly greater than IP but were not different from 24h (Figure 4).

The ISO demonstrated a significant time × group interaction (effect size = 0.15). This was followed up with three 1 × 6 ANOVAs for each group. The CON and LIC showed no significant differences across time. The MIC showed no difference between PRE, IP, 24h, or 48h, but 72h and 96h were significantly >24h, whereas 72h was also greater than IP (Figure 5).

Discussion

Unaccustomed bouts of eccentric exercise often result in DOMS. Because of the performance decrements associated with DOMS, a treatment to alleviate its symptoms is of great interest to athletes, coaches, and researchers. The purpose of this study was to investigate the effect of different aerobic recovery intensities on DOMS and strength. Our results showed that DOMS significantly increased immediately after eccentric exercise and remained elevated for 3 days, whereas dynamic strength decreased immediately after and returned to baseline 2 days later. Additionally, isometric strength remained constant in the CON and LIC groups, but it increased 3 days after in the MIC group. It is possible that despite inducing muscle soreness, the MIC group gained isometric strength throughout the week as a result of cycling at a greater intensity, which resulted in increased blood flow to the muscles, aiding in the removal of waste products and the delivery of nutrients. Also, the MIC, coupled with a short-term training effect (daily testing), may be partially responsible for the increase in isometric strength seen in the MIC group.

The subjects in our study reported the greatest soreness immediately after exercise. Similar to other studies, soreness subsided 24–48 hours after exercise, but it was still significantly greater than that at baseline (6,13,34). Despite prior familiarization with the PS, the increase in soreness immediately postexercise may have been misconstrued by the subjects because of the intense effort of the eccentric protocol. Nonetheless, soreness was significantly greater than baseline at 24- and 48 hours postexercise, indicating that the protocol sufficiently induced DOMS.

The immediate decline in dynamic strength in our study mimics the results of Close et al. (6), where dynamic torque returned to baseline 48 hours after exercise. This can be explained by the findings of Nguyen et al. (23), which elucidate that DOMS and muscle performance are not always comparable and can return to baseline at different times. Further, Close et al. also showed that concentric and eccentric strength recovered from eccentric exercise at different rates (6). This may explain why, in our study, isometric and dynamic strength were not affected by eccentric exercise in the same way.

The MIC group did not exhibit a decrease in isometric strength; rather, they exhibited an increase 3–4 days after eccentric exercise. This may be explained by an increase of muscle perfusion during the MIC intervention, possibly aiding in the removal of waste products and in the deliverance of nutrients. Davis et al. (9) reported a decrease in soreness over time as a result of increasing the HR during interset rest periods (and, in turn, an entire resistance training session) when compared with resting during interset rest periods. They speculated that elevating the HR before each set of exercise enhanced muscle perfusion, accelerated H+ release, and increased nutrient delivery, accelerating tissue repair. Metabolic byproducts from high-intensity exercise can be detrimental to subsequent performance (22,35). One consequence of high-intensity exercise is H+ ions from lactate, which can disrupt contractile mechanisms of skeletal muscle (22). Removing lactate and its resultant H^+ can be accelerated by increasing skeletal muscle blood flow (22). In our study, the MIC may have experienced greater levels of metabolic byproduct removal compared with that in the CON and LIC groups as a result of their elevated HR and increased cardiac output (16,33).

To further examine the effects of blood flow on muscle recovery, 2 studies noted that blood flow restriction significantly reduced the amount of repetitions completed during resistance exercise when compared with a normal blood flow condition (35,36). Additionally, Hannie et al. (14) observed enhanced dynamic strength recovery after a fatiguing bench-press exercise by performing aerobic exercise between sets. They observed no change in isometric strength, although improvements were made in dynamic strength after recovery, whereas our study showed improvements in isometric strength and no change in dynamic strength after recovery. Although the data from Hannie et al.'s study (14) and our study are incongruous, the discrepancies may be attributed to the difference in exercise and recovery protocols. In contrast to our study, they used an upper-body multijoint exercise, whereas our study used a single joint lower-extremity exercise. Conclusively, reduced blood flow impairs skeletal muscle performance (35,36), whereas the active recovery in our study demonstrated enhanced isometric strength at 72- and 96-hour recovery (14).

Increased blood flow to the muscles, by itself, may not fully explain the increase in isometric torque experienced by our MIC group. An increase in isometric strength in the MIC group may also possibly be explained by a short-term training effect. In a study conducted by Brown and Whitehurst (4), the subjects performed 3 sets of 8 reciprocal isokinetic knee extensions and flexions, on 2 occasions within in 1 week. Their results indicated that the subjects experienced a velocity-specific increase in rate-of-velocity-development without an accompanying increase in strength.

To further investigate the effect of short-term training on dynamic performance, Coburn et al. conducted a similar study but increased training volume to 4 sets of 10 and increased the frequency to 3 days (7). Contrary to Brown and Whitehurst's results (4), their results showed an increase in strength. Therefore, the increase in strength observed by Coburn et al. (7) may be explained by the increase of volume during training, compared with that of Brown and Whitehurst (4). In our study, the subjects performed 3 maximal isometric and 6 maximal dynamic muscle actions per day, for a total of 6 days. These testing procedures resulted in volumes equaling 18 maximal isometric actions and 36 maximal dynamic extensions of the quadriceps over approximately 1 week which, when combined with greater intensity aerobic activity, may have been sufficient to elicit a short-term training effect. Although neither of the aforementioned studies investigated isometric strength, it may be postulated that isometric training, when combined with MIC, might produce similar short-term increases because of specificity of training.

Practical Applications

Enhanced blood perfusion during moderate-intensity aerobic recovery, in conjunction with a short-term training effect, may enhance isometric strength after DOMS. Therefore, moderate intensity aerobic activity is suggested as a recovery method after multiple eccentric muscular actions. Further research should be conducted to determine the chronic effects of moderate-intensity aerobic recovery after resistance training.

References

1. Aminian-Far, A, Hadian, M, Olyaei, G, Talebian, S, and Bakhtiary, A. Whole-body vibration and the prevention and treatment of delayed-onset muscle soreness. *J Athl Train* 46: 43–49, 2011.
2. Bakhtiary, AH, Safavi-Farokhi, Z, and Aminian-Far, A. Influence of vibration on delayed onset of muscle soreness following eccentric exercise. *Br J Sports Med* 41: 145–148, 2007.
3. Brock Symons, T, Clasey, JL, Gater, DR, and Yates, JW. Effects of deep heat as a preventative mechanism on delayed onset muscle soreness. *J Strength Cond Res* 18: 155–161, 2004.
4. Brown, LE and Whitehurst, M. The effect of short-term isokinetic training on force and rate of velocity development. *J Strength Cond Res* 17: 88–94, 2003.
5. Butterfield, DL, Draper, DO, Ricard, MD, Myrer, JW, Schulthies, SS, and Durrant, E. The effects of high-volt pulsed current electrical stimulation on delayed-onset muscle soreness. *J Athl Train* 32: 15–20, 1997.
6. Close, GL, Ashton, T, Cable, T, Doran, D, Noyes, C, McArdle, F, and MacLaren, DP. Effects of dietary carbohydrate on delayed onset muscle soreness and reactive oxygen species after contraction induced muscle damage. *Br J Sports Med* 39: 948–953, 2005.
7. Coburn, JW, Housh, TJ, Malek, MH, Weir, JP, Cramer, JT, Beck, TW, and Johnson, GO. Neuromuscular responses to three days of velocity-specific isokinetic training. *J Strength Cond Res* 20: 892–898, 2006.
8. Cooke, MB, Rybalka, E, Williams, AD, Cribb, PJ, and Hayes, A. Creatine supplementation enhances muscle force recovery after eccentrically-induced muscle damage in healthy individuals. *J Int Soc Sports Nutr* 6: 13, 2009.
9. Davis, WJ, Wood, DT, Andrews, RG, Elkind, LM, and Davis, WB. Elimination of delayed-onset muscle soreness by pre-resistance cardioacceleration before each set. *J Strength Cond Res* 22: 212–225, 2008.
10. Donnelly, AE, Maughan, RJ, and Whiting, PH. Effects of ibuprofen on exercise-induced muscle soreness and indices of muscle damage. *Br J Sports Med* 24: 191–195, 1990.
11. Donnelly, AE, McCormick, K, Maughan, RJ, Whiting, PH, and Clarkson, PM. Effects of a non-steroidal anti-inflammatory drug on delayed onset muscle soreness and indices of damage. *Br J Sports Med* 22: 35–38, 1988.
12. Francis, K and Hoobler, T. Delayed onset muscle soreness and decreased isokinetic strength. *J Strength Cond Res* 2: 20–23, 1988.
13. Gulick, DT, Kimura, IF, Sitler, M, Paolone, A, and Kelly, JD. Various treatment techniques on signs and symptoms of delayed onset muscle soreness. *J Athl Train* 31: 145–152, 1996.
14. Hannie, PQ, Hunter, GR, Kekes-Szabo, T, Nicholson, C, and Harrison, PC. The effects of recovery on force production, blood lactate, and work performed during bench press exercise. *J Strength Cond Res* 9: 8–12, 1995.
15. Hilbert, JE, Sforzo, GA, and Swensen, T. The effects of massage on delayed onset muscle soreness. *Br J Sports Med* 37: 72–75, 2003.
16. Kang, JIE, Walker, H, Hebert, M, Wendell, M, and Hoffman, JR. Influence of contraction frequency on cardiovascular responses during the upper and lower body exercise. *Res Sports Med* 12: 251–264, 2004.
17. Kuligowski, LA, Lephart, SM, Giannantonio, FP, and Blanc, RO. Effect of whirlpool therapy on the signs and symptoms of delayed-onset muscle soreness. *J Athl Train* 33: 222–228, 1998.
18. Law, RY and Herbert, RD. Warm-up reduces delayed onset muscle soreness but cool-down does not: A randomised controlled trial. *Aust J Physiother* 53: 91–95, 2007.
19. Lightfoot, JT, Char, D, McDermott, J, and Goya, C. Immediate postexercise massage does not attenuate delayed onset muscle soreness. *J Strength Cond Res* 11: 119–124, 1997.
20. Marginson, V, Rowlands, AV, Gleeson, NP, and Eston, RG. Comparison of the symptoms of exercise-induced muscle damage after an initial and repeated bout of plyometric exercise in men and boys. *J Appl Physiol* 99: 1174–1181, 2005.
21. McHugh, MP and Tetro, DT. Changes in the relationship between joint angle and torque production associated with the repeated bout effect. *J Sports Sci* 21: 927–932, 2003.
22. Neric, FB, Beam, WC, Brown, LE, and Wiersma, LD. Comparison of swim recovery and muscle stimulation on lactate removal after sprint swimming. *J Strength Cond Res* 23: 2560–2567, 2009.
23. Nguyen, D, Brown, LE, Coburn, JW, Judelson, DA, Eurich, AD, Khamoui, AV, and Uribe, BP. Effect of delayed-onset muscle soreness on elbow flexion strength and rate of velocity development. *J Strength Cond Res* 23: 1282–1286, 2009.
24. Nosaka, K, Newton, M, and Sacco, P. Delayed-onset muscle soreness does not reflect the magnitude of eccentric exercise-induced muscle damage. *Scand J Med Sci Sports* 12: 337–346, 2002.
25. Pettitt, RW, Udermann, BE, Reineke, DM, Wright, GA, Battista, RA, Mayer, JM, and Murray, SR. Time-course of delayed onset muscle soreness evoked by three intensities of lumbar eccentric exercise. *Athl Training Sports Health Care* 2: 171–176, 2010.
26. Pullinen, T, Mero, A, Huttunen, P, Pakarinen, A, and Komi, PV. Hormonal responses to a resistance exercise performed under the influence of delayed onset muscle soreness. *J Strength Cond Res* 16: 383–389, 2002.

27. Pullinen, T, Mero, A, Huttunen, P, Pakarinen, A, and Komi, PV. Resistance exercise-induced hormonal response under the influence of delayed onset muscle soreness in men and boys. *Scand J Med Sci Sports* 21: 184–194, 2011.
28. Sakamoto, A, Maruyama, T, Naito, H, and Sinclair, PJ. Acute effects of high-intensity dumbbell exercise after isokinetic eccentric damage: Interaction between altered pain perception and fatigue on static and dynamic muscle performance. *J Strength Cond Res* 24: 2042–2049, 2010.
29. Soctt, KE, Rozenek, R, Russo, AC, Crussemeyer, JA, and Lacourse, MG. Effects of delayed onset muscle soreness on selected physiological responses to submaximal running. *J Strength Cond Res* 17: 652–658, 2003.
30. Stay, JC, Richard, MD, Draper, DO, Schulthies, SS, and Durrant, E. Pulsed ultrasound fails to diminish delayed-onset muscle soreness symptoms. *J Athl Train* 33: 341–346, 1998.
31. Stock, MS, Young, JC, Golding, LA, Kruskall, LJ, Tandy, RD, Conway-Klaassen, JM, and Beck, TW. The effects of adding leucine to pre and postexercise carbohydrate beverages on acute muscle recovery from resistance training. *J Strength Cond Res* 24: 2211–2219, 2010.
32. Takahashi, J, Ishihara, K, and Aoki, J. Effect of aqua exercise on recovery of lower limb muscles after downhill running. *J Sports Sci* 24: 835–842, 2006.
33. Temfemo, A, Carling, C, and Ahmaidi, S. Relationship between power output, lactate, skin temperature, and muscle activity during brief repeated exercises with increasing intensity. *J Strength Cond Res* 25: 915–921, 2011.
34. Vaile, JM, Gill, ND, and Blazevich, AJ. The effect of contrast water therapy on symptoms of delayed onset muscle soreness. *J Strength Cond Res* 21: 697–702, 2007.
35. Wernbom, M, Augustsson, J, and Thomee, R. Effects of vascular occlusion on muscular endurance in dynamic knee extension exercise at different submaximal loads. *J Strength Cond Res* 20: 372–377, 2006.
36. Wernbom, M, Järrebring, R, Andreasson, MA, and Augustsson, J. Acute effects of blood flow restriction on muscle activity and endurance during fatiguing dynamic knee extensions at low load. *J Strength Cond Res* 23: 2389–2395, 2009.
37. White, JP, Wilson, JM, Austin, KG, Greer, BK, St John, N, and Panton, LB. Effect of carbohydrate–protein supplement timing on acute exercise-induced muscle damage. *J Int Soc Sports Nutr* 5: 5, 2008.
38. Zainuddin, Z, Newton, M, Sacco, P, and Nosaka, K. Effects of massage on delayed-onset muscle soreness, swelling, and recovery of muscle function. *J Athl Train* 40: 174–180, 2005.
39. Zainuddin, Z, Sacco, P, Newton, M, and Nosaka, K. Light concentric exercise has a temporarily analgesic effect on delayed-onset muscle soreness, but no effect on recovery from eccentric exercise. *Appl Physiol Nutr Metab* 31: 126–134, 2006.