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EFFECTS OF DEEP HEAT AS A PREVENTATIVE MECHANISM ON DELAYED ONSET MUSCLE SORENESS

T. BROCK SYMONS,[1] JODY L. CLASEY,[1] DAVID R. GATER,[2] AND JAMES W. YATES[1]

[1]*Department of Kinesiology and Health Promotion, University of Kentucky, Lexington, Kentucky 40506;*
[2]*Department of Physical Medicine & Rehabilitation, University of Michigan, Ann Arbor, Michigan 48109.*

ABSTRACT. Symons, T.B., J.L. Clasey, D.R. Gater, and J.W. Yates. Effects of deep heat as a preventative mechanism on delayed onset muscle soreness. *J. Strength Cond. Res. 18(1):155–161. 2004.*—The effects of increased muscle temperature via continuous ultrasound prior to a maximal bout of eccentric exercise were investigated on the symptoms of delayed onset muscle soreness (DOMS) of the elbow flexors. Perceived muscle soreness, upper arm circumferences, range of motion (ROM), and isometric and isokinetic strength were measured over 7 days on 14 college-aged men ($n = 6$) and women ($n = 8$). Ten minutes of continuous ultrasound (ULT) or sham-ultrasound (CON) were administered. Muscle temperature was measured in the biceps brachii of both arms. Muscle temperature increased by 1.79° ± 0.49° C (mean ± SD) in the experimental arm of the ULT group. Muscle soreness was induced by a single bout of 50 maximal eccentric contractions. The ULT group did not differ significantly ($p < 0.05$) from the CON group with respect to perceived muscle soreness, upper arm circumference, ROM, and isometric and isokinetic strength. In conclusion, increased muscle temperature failed to provide significant prophylactic effects on the symptoms of DOMS.

KEY WORDS. muscle soreness, eccentric exercise, ultrasound, DOMS prevention

INTRODUCTION

Delayed muscle soreness is a common phenomenon that can occur in all individuals regardless of their physical fitness level, from the individual trying resistance training for the first time to the highly trained distance runner. All will experience the soreness and stiffness that is associated with unaccustomed or eccentric exercise. Additionally, this phenomenon has the potential to reoccur throughout one's lifetime because there is no known mechanism to completely prevent delayed onset muscle soreness (DOMS).

DOMS is defined as the sensation of discomfort or pain in skeletal muscles that occurs following any unaccustomed exercise. The soreness normally increases in intensity during the first 24 hours and peaks between 24 and 72 hours post-exercise. DOMS then decreases and is typically eliminated by 5 to 7 days post-exercise (2). One bout of intense eccentric exercise results in substantial damage to the muscle fiber. Ultrastructural damage occurs in the form of sarcomere disruption (z-line streaming) (25); t-tubule impairment (22); sarcoplasmic reticulum disruption (1); and myofibril protein degradation and disorganization (calpain acting on desmin, α-actinin and vimentin) (9, 22). Furthermore, there is increased collagen breakdown following eccentric exercise indicative of connective tissue damage (6). Following the ultrastructural damage and if the damage is extensive enough, parts of or whole muscle fibers will die (25). Breakdown of the dead and dying cells causes a local inflammatory response coupled with tissue edema and the stimulation of nerve endings resulting in muscle soreness (4, 25).

To date, the only proven mechanism to diminish the effects of DOMS is eccentric exercise itself. The repeated-bout effect reduces the amount of muscle damage, the time required to repair the muscle damage, and the concentration of blood born biochemical markers of muscle damage (8). However, this only reduces the symptoms of DOMS in subsequent bouts of eccentric exercise following the initial bout that causes an individual to experience the full symptoms of DOMS. Therefore, it cannot be deemed a true preventative mechanism. The majority of research has focused on post-eccentric exercise treatments (5, 7, 16, 20, 24) with very little success. However, limited research has been directed towards a preventative mechanism for reducing the symptoms of DOMS. A few studies have examined the effects of warm-up exercise on the symptoms of DOMS (13, 18, 23). Johanson et al. (13) found pre-exercise static stretching had no preventative effect on muscle soreness, tenderness, and force loss following heavy eccentric exercise. McClusky and Pascoe (18) suggested that the mechanism responsible for reducing DOMS and serum creatine kinase activity with prior cycling (warm-up) might be temperature related. Their research supports the idea that increased muscle temperature decreases perceived soreness following eccentric exercise. Nosaka and Clarkson (23) indicated that muscle damage was less severe when a warm-up of arm flexion and extension against minimal force was performed prior to eccentric exercise. The authors noted that the effects of increased muscle temperature as a result of the warm-up exercise might play a role in better preparing the muscle for damage-inducing exercise (23).

Because ultrastructural damage to the connective and muscle tissue initiates DOMS and previous studies advocate the possible benefits of increased muscle temperature, the notion of utilizing the therapeutic beneficial effects of temperature on tissue (increased metabolic effect, blood flow and elasticity of both muscle and connective tissue) is appealing. Our approach was to examine the effects of a passive warm-up produced by an ultrasound unit rather than a traditional active warm-up. It is clear that the active component of the warm-up in the previously mentioned studies (18, 23) may have contributed to reducing the symptoms of DOMS in addition to the temperature increase. However, we wished to examine the effects of temperature alone, and previous research has demonstrated that similar temperatures found in active warm-up (12) can be achieved using ultrasound (11). Ultrasound is an ideal agent to elevate muscle temperature because of its ability to heat deep muscle tissue without heating or burning the superficial muscle tissue or structures. It has been demonstrated that dense connective tissue, composed predominately of collagen fibers, becomes more extensible as its temperature is increased (15). Additionally, it has been suggested that increasing muscle temperature reduces muscle viscosity (29) and results in smoother muscle contractions (28, 29) by increasing the amount of elongation that can occur without rupture, and potentially offering some protection against strain injury in warmed muscles.

It was hypothesized that increasing the temperature of the muscle and connective tissue would increase the viscoelastic properties of these tissues and, therefore, attenuate the damaging effects of maximal eccentric exercise on the elbow flexors. The purpose of this research investigation was to determine the preventative effects of increased muscle temperature via continuous ultrasound prior to a maximal effort eccentric exercise bout on the symptoms of DOMS.

METHODS

Experimental Approach to the Problem

A controlled trial design was used for this study. We hypothesized that increased muscle and connective tissue temperature would increase the elastic properties of these tissues and, therefore, better prepare these tissues for the damaging effects of maximal eccentric exercise on the elbow flexors. Subjects were randomly assigned to an ultrasound or control group. Ten minutes of ultrasound was administered to the ultrasound group to increase tissue temperature; the control group received sham-ultrasound. Mean perceived muscle soreness, upper arm circumference, range of motion, and eccentric, isometric, and concentric strength were calculated on Day 2, Day 4, and Day 7 post-eccentric exercise for both groups and compared for between-subjects and within-subjects effects.

Subjects

Fourteen (6 men and 8 women) healthy college-aged volunteers participated as subjects (mean age 25 ± 3 years; mean height 172 ± 10 cm; mean mass 71 ± 17 kg). A signed informed consent document was required from each subject before participating in the study. The subjects had not participated in any studies involving eccentric exercise in the last 6 months and had not participated in resistance training of the elbow flexors for 30 days prior to the start of the study. Additionally, all subjects were asked to refrain from any new or strenuous physical activity for 7 days prior to and at any time during the study. The study was approved by the Institutional Review Board of the University of Kentucky, Lexington, Kentucky.

Protocol

All subjects participated in 4 sessions with criterion measures being evaluated 4 times throughout the course of the study. Each subject underwent a familiarization session on a computer-interfaced dynamometer (Biodex Medical Systems, Inc., B-2000, Shirley, NY) prior to assessment. Individual adjustments to the dynamometer chair and dynamometer were recorded for each subject. Baseline criterion measures of perceived muscle soreness, upper arm circumferences, range of motion (ROM), isometric and isokinetic (concentric and eccentric) strength of the experimental arm were measured on Day 0. Following the completion of perceived muscle soreness, ROM, and upper arm circumference measurements, 10 minutes of continuous ultrasound (ultrasound group) or sham-ultrasound (control group) was administered. Muscle temperature was then measured in the biceps brachii of both the experimental arm and nonexperimental arm (baseline muscle temperature) of the subject. Immediately following the completion of the ultrasound or sham-ultrasound, baseline strength measurements of isometric and isokinetic strength were obtained in the experimental arm. Muscle soreness was then induced in the experimental arm by the performance of 50 maximal-effort eccentric contractions ($-120^\circ \cdot s^{-1}$) of the elbow flexors. Selection of dominant and nondominant arm and ultrasound group (ULT) and control group (CON) was randomized for all subjects. The subjects returned on Days 2, 4, and 7 for repeated testing.

Treatment and Muscle Temperature

Treatment was performed on each subject while seated in the dynamometer chair. Ultrasound gel (Aquasonic 100, Parker Laboratories, Inc., Orange, NJ) was applied to the upper arm of the experimental arm. The Forte 400 Combo (Chattanooga Group, Inc., Hixson, TN) ultrasound unit was used for all treatments and sham-procedures. The ultrasound treatment was administered in a continuous mode for 10 minutes at a frequency of 1 MHz and an intensity of 1.5 W per cm^2. The sound applicator was moved at approximately 4 cm per second over a 5- by 12-cm area covering the distal portion of the upper arm. Calibration of the ultrasound unit was performed prior to the start of testing in accordance with the manufacturer's specifications. The sham-treatment consisted of one 10-minute continuous treatment with the ultrasound unit turned off.

Prior to the completion of the treatment, the subject's nonexperimental arm was scrubbed and cleaned with 70% isopropyl alcohol. A sterilized hypodermic needle probe thermistor (Physitek MT-23/3 and MT-26/4, Physitemp Instruments, Clifton, NJ) was inserted into the anterior aspect of the biceps brachii to a depth of ~2.5 cm. The thermistor was coupled to a monitor (HH-25TC, Omega Engineering, Inc., Stamford, CT) that gave a digital readout of muscle temperature in increments of 0.1 degrees Celsius. At the completion of the treatment, the experimental arm was cleaned of ultrasound gel and scrubbed with 70% isopropyl alcohol. Muscle temperature was then measured at a depth of ~2.5 cm in the experimental arm. According to the manufacturer, the accuracy of the temperature reading for the thermistor and the monitor was within ±0.1° C for both devices. All thermistors were calibrated according to the manufacturer's specifications prior to the start of the experiment and were found to be highly accurate and within manufacturer's specifications.

Soreness Inducing Exercise

Muscle soreness was induced in the experimental arm of the subject by a single bout of 50 maximal effort eccentric contractions of the elbow flexors at a velocity of $-120^\circ \cdot s^{-1}$. The subject resisted the computer-interfaced dynamometer as it forcibly extended the elbow flexors, causing the muscles to perform an eccentric (lengthening) action. The arm was immediately returned to its starting position (fully flexed) by the experimenter to ensure that the subject performed only eccentric actions.

Criterion Measures

Criterion measures of perceived soreness, upper arm circumference, ROM, and isometric and isokinetic strength were measured on Day 0 and again on Days 2, 4, and 7.

Perceived soreness was scored on a 100-mm visual analog scale (VSA) ranging from 0 to 4. The ratings were: 0 (complete absence of pain), and, 4 (extremely sore with noticeable pain and stiffness and the muscle and arm are difficult to use). Each subject was asked to place a mark on the scale indicative of his or her level of perceived biceps soreness. The use of a VAS for recording subject's level of perceived soreness or pain has been found to be reliable and valid (26) and is a commonly used measurement tool (23).

Upper arm circumference measurements were taken at 3 distances (40, 70, and 100 mm) from the elbow joint (line between the medial and lateral epicondyles) using an anthropometric tape measure. The distances were marked with semi-permanent ink to ensure repeatability throughout the study. All measurements were obtained by the same experimenter, with the exception of one subject for whom a certified physiotherapist measured all 3 sites on each measurement day. The reliability of the upper arm circumference measures was determined for each site by testing 6 subjects and re-testing them on a later date. The reliability scores for the 40, 70 and 100 mm sites were $R = 0.95$, $R = 0.97$, and $R = 0.97$, respectively.

A mechanical goniometer was used to measure the flexion and extension angle of the elbow joint as the subject stood. Anatomical reference points were marked in semi-permanent ink to ensure proper placement of the goniometer each day. The anatomical references were the lateral epicondyle of the humerus, the lateral midline of the humerus, and the lateral midline of the radial head and the styloid process. The elbow joint angle was measured in 2 positions. Relaxed arm angle was designated as the angle of the elbow as the arm hung relaxed at the subject's side. Flexed arm angle was designated as the angle of the elbow as the subject attempted to fully flex his or her elbow while keeping the elbow at their side as their hand remained in the natural position. All measurements were obtained by the same experimenter, with the exception of one subject for whom a certified physiotherapist measured all 3 sites on each measurement day. Additionally, the reliability of both the ROM measures was determined by testing 6 subjects and re-testing them on a later date. The test-retest reliability for relaxed arm angle was $R = 0.91$ and for flexed arm angle $R = 0.91$.

Isometric and isokinetic strength was measured on a computer-interfaced dynamometer. Isometric strength was measured at an elbow angle of 90°. The subject performed two 3-second maximal isometric contractions (MVC) with a 30-second rest between the contractions. The average of the 2 trials was recorded as the subject's isometric strength score. Isokinetic strength was measured at the angular velocities of −120 and −30 (eccentric) and 30, 120, and $300°\cdot s^{-1}$ (concentric). Each subject was allowed 2 warm-up contractions at each angular velocity, if desired, and then performed 3 measured trials at each angular velocity without a pause between contractions. The maximal contraction force at each angular velocity was determined by taking the torque value at an arm angle of 140° for each of the 3 maximal contractions, and then averaging the 3 torques. The order of the speed and type of contraction was randomized between subjects; however, the order of the speed and type of contraction performed by the subject was maintained for each subsequent measurement day.

Statistical Analyses

Statistical analysis was performed using Statistica (StatSoft, Tulsa, OK), SPSS 9.0 (SPSS Inc., Chicago, IL), and Microsoft Excel (Microsoft, Seattle, WA). Changes in criterion measures were analyzed using 2 × 4 repeated-measures analysis of variance (ANOVA). Reliability of the upper arm circumferences and ROM measurements were determined by test-retest correlation analysis. Statistical significance was set at $p \leq 0.05$.

RESULTS

All ULT and CON subjects demonstrated a statistically significant DOMS effect. The ULT group was not significantly different from the CON group regarding the criterion measures of perceived muscle soreness, upper arm circumference, ROM, isometric strength, and isokinetic strength. However, statistically significant differences were obtained in all criterion measures across the 4 periods (Day 0, 2, 4, and 7). There was no interaction between the 2 treatments (ULT and CON) and time for any criterion measures.

Muscle Temperature. Internal muscle temperature increased by 1.79° C ± 0.49° C ($p < 0.01$) in the experimental arm of the ULT group at the completion of the ultrasound treatment, producing a mean muscle temperature of 37.50° C ± 0.36° C. Mean muscle temperature in the nonexperimental arm of the ULT group was 35.71° C ± 0.71° C. Mean muscle temperature in the experimental arm of the CON group at the completion of the sham-ultrasound was 34.04° C ± 1.04° C, compared to 35.20° C ± 1.03° C in the nonexperimental arm.

Muscle Soreness. Muscle soreness increased significantly and then decreased over time for both groups ($p < 0.01$). Peak muscle soreness occurred 2 days after exercise and gradually subsided to no perceived muscle soreness (0.0 ± 0.0 mm) for the ULT group and to very little pain for the CON group (4.3 ± 6.5 mm) by Day 7. The ULT group reported less muscle soreness on Days 2, 4, and 7 compared to the CON group, but the difference was not significant ($p = 0.149$) for any of the days at the 95% confidence level (Figure 1).

Upper Arm Circumference. Upper arm circumference measured at 40 mm, 70 mm, and 100 mm were significantly different from Day 0 for both the ULT and CON groups. There were no differences between the ULT and CON groups at any of the 3 measurement sites. Changes in circumference were smaller for the ULT group on Days 2, 4, and 7, but did not reach significance. The greatest change in circumference occurred on Day 4 at all 3 measurement sites for both groups.

Range of Motion. Relaxed arm angle decreased significantly over time for both test groups ($p < 0.01$) as shown in Figure 2. The CON group had a trend towards greater decreases in relaxed arm angle when compared to the ULT group at 2, 4, and 7 days after exercise, which approached statistical significance ($p = 0.05016$), suggesting the ULT group had greater elbow extension and ap-

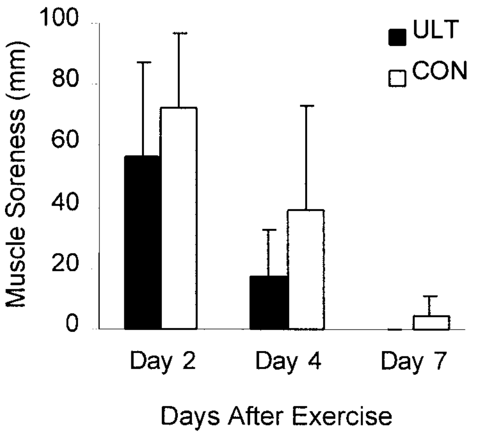

Figure 1. Changes in perceived muscle soreness for Day 2, Day 4, and Day 7 post-eccentric exercise showing the mean and standard deviation. Changes were significant over time ($p < 0.01$).

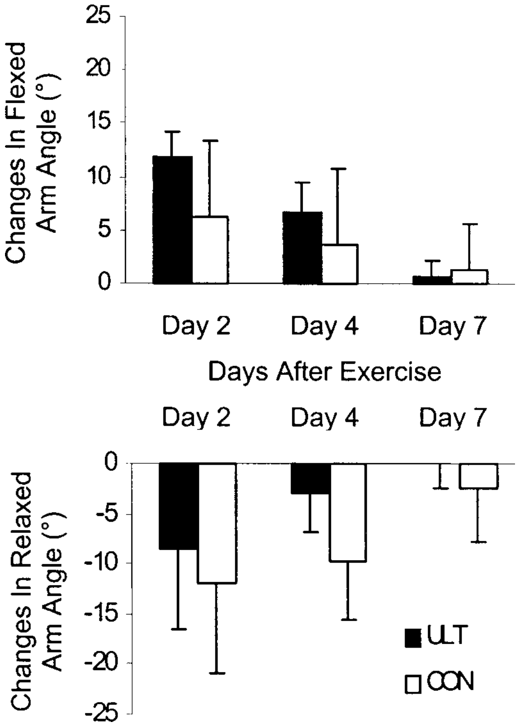

Figure 2. Changes in flexed and relaxed arm angle for Day 2, Day 4, and Day 7 post-eccentric exercise showing the mean and standard deviation. Changes were significant over time ($p < 0.01$).

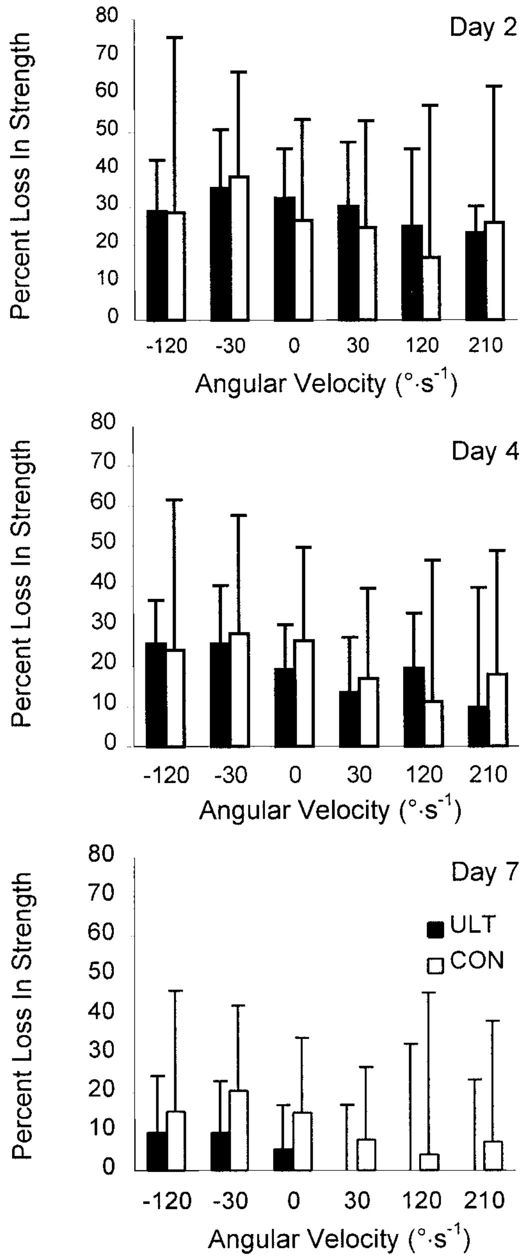

Figure 3. Percent loss (% Day 0) in eccentric strength at -30 and $-120°\cdot s^{-1}$, isometric strength at $0°\cdot s^{-1}$, and concentric strength at 30, 120, and $210°\cdot s^{-1}$ for Day 2, Day 4, and Day 7 (showing percent loss and standard deviation). Changes in strength were significant over time for Day 2, Day 4, and Day 7 ($p < 0.01$).

peared to recover faster. Flexed arm angle measures (Figure 2) were also significant over time as the flexed arm angle increased for both groups ($p = 0.01$), with the ULT group demonstrating greater changes in flexed arm angle. Although there was no significant difference between the 2 groups, the CON group had smaller changes in flexed arm angle and appeared to have greater elbow flexion than the ULT group.

Isometric Strength. A significant decrease in isometric strength was found over time for both groups ($p < 0.01$). The ULT group did not differ significantly from the CON group at any time during the measurement days (Figure 3). By the seventh day postexercise, the ULT group had recovered 94.68 ± 11.30% of their baseline (Day 0) isometric strength, while the CON group had only recovered 85.31 ± 19.35%.

Isokinetic Strength. Both groups experienced a significant decrease in eccentric strength at both -30 and $-120°\cdot s^{-1}$ (Figure 3) over time ($p < 0.01$). The 2 groups did not differ significantly at any point during the 4 measurement days at either angular velocities. The ULT group demonstrated a smaller change in eccentric strength at $-30°\cdot s^{-1}$, but the changes were minimal. Both groups failed to return to baseline values (Day 0) by Day 7 for either eccentric angular velocity.

As shown in Figure 3, both the ULT and CON group experienced significant decreases in concentric strength at all 3 angular velocities (30, 120 and $210°\cdot s^{-1}$) over time ($p < 0.01$, $p < 0.05$ and $p = 0.01$, respectively). No difference was found between the 2 groups at any concentric angular velocity on any of the measurement days. By Day 7, the strength loss demonstrated by the ULT group for all 3 concentric velocities was not significantly different from the baseline values and the CON group remained significantly below baseline values.

DISCUSSION

Increasing muscle temperature using ultrasound failed to significantly reduce the effects of DOMS in the ULT group as demonstrated by the outcome measures. Perceived soreness, isometric and isokinetic strength, upper arm swelling and ROM did not differ between groups. However, the ULT group did show a trend ($p = 0.149$) towards lower perceived muscle soreness and increased resting arm angles ($p = 0.05016$). In addition, while there were no statistical differences between the groups for isokinetic strength due to the rather large standard deviations, the ULT group did recover concentric strength to the baseline values while the CON group remained impaired. These data suggest that ultrasound had some impact on the recovery of strength. Power analyses on all the criterion measures confirmed that considerably more subjects were required to achieve 80% power for demonstrating statistically significant differences, with numbers ranging from 12 to 1571 subjects per group.

The ULT group failed to reach the desired increase (~3.5° C) in muscle temperature after receiving 10 minutes of continuous ultrasound at a frequency and intensity of 1.0 MHz and 1.5 W per cm^2, respectively. Using the prescribed protocol, muscle temperature was 1.79° C ± 0.49° C higher in the ULT group compared to the control arm. The rationale for selecting the chosen ultrasound protocol was based on the belief that it would raise muscle temperature to a higher level. The frequency of 1.0 MHz was selected for its ability to deep heat the muscle as opposed to the frequency of 3.0 MHz, which loses more energy in the superficial structures (due to greater attenuation by the tissue). The intensity of 1.5 W per cm^2 was chosen because intensities of 1.0 to 2.0 W per cm^2 of continuous ultrasound lasting 5 to 10 minutes are required to increase tissue temperature into the therapeutic range of 40° C to 45° C (19). The results of Draper and coworkers (11) indicate that 10 minutes of continuous ultrasound at a frequency of 1 MHz and at intensities of 1.5 and 2.0 W per cm^2 increased muscle temperature at a depth of 2.5 cm by ~3.5° C and ~4.0° C, respectively, and at a depth of 5.0 cm by ~3.0° C and ~3.5° C, respectively. The inability to attain the same temperature increase of ~3.5° C in the present study could be due to slightly different methodology, the use of a different brand of ultrasound unit, differences between the triceps surae and the biceps brachii, or any combination of these conditions. Despite efforts to reproduce the exact movement speed of the transducer head and to approximate a similar size treatment area specified by Draper et al. (11), the muscle temperature did not increase to expected levels. Draper et al. (11) inserted the temperature probe prior to the ultrasound, whereas in the present study the temperature probe was inserted immediately after the ultrasound. It is possible that the interaction of the temperature probe with the ultrasound in the study by Draper et al. (11) localized the heating of the tissue around the probe, thereby yielding results different from the present study. However, this difference should not account for the large difference in muscle temperature when it is generally accepted that the ultrasound protocol used was sufficient to reach the desired increase of ~3.5° C (7, 13). Prior to data collection, the above protocol was administered in a single subject and produced a 3.0° C increase in the biceps brachii. However, the ability to reproduce the equivalent increases in muscle temperature required to alter the viscoelastic properties of connective or muscle tissue (or both) was not achieved throughout the course of the study. Further study is needed to find a reliable method of deep heating the muscle on a consistent basis and to a consistent temperature, which might attenuate the symptoms of DOMS.

The ULT group reported less muscle soreness on Days 2, 4, and 7 than the CON group. These findings are similar to the findings of McClusky and Pascoe's (18) that support the idea that increased muscle temperature from prior cycling decreases perceived soreness following eccentric exercise. This reduced muscle soreness may be the result of increased muscle temperature altering the viscoelastic properties of the connective tissue or the muscle tissue (or both) making them less susceptible to damage caused by eccentric exercise. The majority of the evidence supports the belief that the delayed soreness observed is most likely caused by mechanical damage to the muscle fiber (2, 3, 14, 21) or the connective tissue (6, 30), or both. Safran and coworkers (28) believe that elevated muscle temperature results in the reduction of the viscoelastic properties of muscle and the increased extensibility offers some protection against strain injury in warm muscles (27, 28, 31). Therefore, the slight increase in muscle temperature achieved in our study may have altered the viscoelastic properties of the connective or muscle tissue resulting in lower perceived muscle scores for the ULT group.

Differences between groups for the variable of relaxed arm angle resulted in a *p*-value of 0.05016, suggesting that increased muscle temperature in the distal portion of the elbow flexors may prepare the musculotendinous junction, the connective tissue, the muscle tissue, or any combination of these elements of the elbow flexors for eccentric exercise. Strickler et al. (31) stated that the extensibility of the musculotendinous unit was increased by passive warming and the possibility of it sustaining a strain injury was decreased. Safran et al. (27) concluded that physiologic warming, using isometric preconditioning to elevate muscle temperature on average by 1.0° C, was beneficial in preventing muscle injury by increasing the length and force to failure of the muscle and by increasing the elasticity of the muscle-tendon region. Therefore, it is probable that the relaxed arm angle was greater in the ULT group as a result of the ~1.79° C increase in muscle temperature and that significant results might have occurred had the temperature increases been larger.

Flexed arm angle produced a surprising outcome with the ULT group demonstrating greater changes in flexed arm angle. One would expect the group subjected to the treatment to demonstrate smaller changes than the nontreatment group or at least the 2 groups would be similar or equal. However, it appears that increased muscle temperature had an inverse effect on the variable of flexed arm angle.

Increased muscle temperature had no effect on upper arm circumference. The ULT group had marginally lower swelling than the CON group. The results in the present study are similar to those found in studies when examining the effects of eccentric exercise on upper arm circumference measures (8, 10).

The large reductions in isometric strength 2 days after eccentric exercise were similar to the findings of others (10, 23). Nosaka and Clarkson (23) had their subjects perform a passive warm-up by moving their elbow joint from an extended position to a flexed position with minimal force against a lever arm of an isokinetic device in *Experiment 2.* By the second day post-eccentric exercise, there was no significant difference in isometric strength between the arm that performed the warm-up in addition to the eccentric exercise and the arm that performed eccentric exercise only (23), similar to the present findings. However, by the fourth day post-eccentric exercise, a significant difference had occurred with the warm-up arm demonstrating less isometric strength loss than the eccentric-only arm. This trend was obscured in the present study, although variability was large.

In contrast, in their *Experiment 1* Nosaka and Clarkson (23) had their subjects perform a more vigorous dynamic exercise consisting of 100 repetitions of isokinetic concentric contractions at an angular velocity of 1.05 rads^{-1} immediately before eccentric exercise. Isometric strength loss was significantly less in the arm that performed the 100 isokinetic concentric contractions prior to the eccentric exercise when compared to the armed that performed eccentric-exercise only (23). Therefore, the concentric-eccentric arm recovered force at a significantly faster rate during the first 5 days post-eccentric exercise (23). Nosaka and Clarkson (23) concluded that the isokinetic exercise appeared to serve as a warm-up, better preparing the muscle to respond to the stress induced by eccentric exercise. They further suggested that muscle temperature increased during both the 100 isokinetic contractions and the minimal force extension to flexion warm-up, causing the connective or muscle tissue viscosity to be reduced as Shellock and Prentice (29) had proposed, and increasing muscle tissue elasticity as Safran et al. (28) had proposed, thus making the muscle fiber better prepared for eccentric exercise. Unfortunately, Nosaka and Clarkson (23) did not measure muscle temperature; therefore it is impossible to determine if the differences between their study and the present study are due to differences in muscle temperature or some other factor.

Changes in eccentric and concentric strength were similar for both the ULT and CON groups at all angular velocities tested. The failure to see decreased isokinetic strength loss for the ULT group may be related to lack of experimental control and the diverse subject population used. The failure to match or pair the subjects into 2 groups could have contributed to the large standard deviations. On the other hand, having the subjects act as his or her own control would likely have also increased the chances for obtaining significant results.

In conclusion, increasing muscle temperature by 1.79° C ± 0.49° C, resulting in a mean muscle temperature of 37.50° C ± 0.36° C, failed to provide any significant prophylactic effect on the symptoms of DOMS. This causes one to question whether the viscoelastic properties of the connective or muscle tissue (or both) were altered sufficiently to produce the desired effect. Further research is required to find a reliable method of deep heating the connective and muscle tissue and to determine whether or not a large temperature increase would attenuate the symptoms of DOMS.

PRACTICAL APPLICATIONS

Due to the reoccurring nature of DOMS and its ability to occur in all individuals despite their fitness level when performing unaccustomed or strenuous activity, a preventative mechanism would be extremely advantageous. Because so many activities contain an eccentric component (e.g., walking, jogging, jumping, and weightlifting) a practitioner is bound to come across DOMS throughout one's career. Conventional approaches such as: stretching prior (13) and post-eccentric (17) exercise, microcurrent treatment (5), electrical stimulation (7), massage (16), hyperbaric oxygen therapy (20), and postexercise ultrasound (24) fail to produce satisfactory results in decreasing the symptoms of DOMS. Conversely, the reduction in the symptoms of DOMS through active warm-up and the possible role of increased tissue temperature (18, 23) may be beneficial. If the same results can be achieved using a passive warm-up (a very simple and nontaxing approach) as opposed to performing an energy expending active warm-up (cycling at 40% of maximal power output) this may be more appealing to athletes and lay individuals when performing unaccustomed or strenuous activities. It is true that not all athletes or lay individuals will have access to an ultrasound unit; therefore, it is necessary to further explore the role of increased tissue temperature by examining the effects of passive heat through exothermic pads, heat lamps, and other heating modalities alone and in conjunction with various active warm-ups. Furthermore, with the increased belief that eccentric-only exercise may help to attenuate the effects of sarcopenia (loss of muscle mass) and the accompanying loss in voluntary strength in the elderly (32), it would appear that preparing skeletal muscle prior to eccentric training would be extremely beneficial.

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Address correspondence to Dr. James W. Yates, jwyate1@uky.edu.