Available online at www.sciencedirect.com
SCIENCE DIRECT®
Physical Therapy in Sport 7 (2006) 5–13
Physical Therapy in sport
www.elsevier.com/locate/yptsp

Original research

The effects of massage on delayed onset muscle soreness and physical performance in female collegiate athletes

Corrie A. Mancinelli *, D. Scott Davis, Leila Aboulhosn, Misty Brady, Justin Eisenhofer, Stephanie Foutty

Division of Physical Therapy, Department of Human Performance and Exercise Science, West Virginia University, Morgantown, WV 26506, USA

Received 10 June 2005; received in revised form 28 September 2005; accepted 28 October 2005

Abstract

Objective: The purpose of this study was to determine if post-exercise massage has an effect on delayed-onset muscle soreness (DOMS) and physical performance in women collegiate athletes.
Design: This study used a randomized pre-test post-test control group design.
Participants: Twenty-two NCAA Division I women basketball and volleyball players participated. On the day of predicted peak soreness, the treatment group ($n=11$) received a thigh massage using effleurage, petrissage and vibration while the control group ($n=11$) rested.
Outcome measures: Paired t-tests were used to assess differences between pre and post massage measures ($\alpha=0.05$) for vertical jump displacement, timed shuttle run, quadriceps length and pressure-pain threshold in the thigh.
Results: A significant increase (slowing) was found in shuttle run times for the control group ($p=0.0354$). There were significant changes in vertical jump displacement ($p=0.0033$), perceived soreness ($p=0.0011$) and algometer readings ($p=0.0461$) for the massage group.
Conclusions: This study supports the use of massage in women collegiate athletes for decreasing soreness and improving vertical jump.

Keywords: Pre-season training; Athletic performance; Vertical jump; Massage; Effleurage; Petrissage

1. Introduction

Athletes who engage in a sudden increase in intensity of training such as with commencement of pre-season practice often experience muscle soreness from predominantly eccentric muscle actions. Soreness begins within 24 h after exercise, peaks 48–72 h after the activity and continues for several days post-activity, hence the name delayed onset muscle soreness (DOMS) is used to describe this phenomenon (Clarkson & Sayers, 1999; Stauber, 1996). Decreased range of motion and a reduction in muscle force output by as much as 50% have been reported with DOMS (Cleak & Eston, 1992; Davies & White, 1981; Newham, Jones, & Clarkson, 1987). Muscle strength deficits may take up to 2 weeks for maximal recovery (Cleak & Eston, 1992; Newham et al., 1987).

Although much research has focused on cellular and myofibrillar disruption with eccentric exercise (Friden, Sjostrom, & Ekblom, 1983; Gibala, MacDougall, Tarnopolsky, Stauber, & Elorriaga, 1995; Stauber, Clarkson, Fritz, & Evans, 1990), less is known about the soreness that occurs following eccentric exercise-induced muscle damage. It is speculated that the sensation of soreness is caused by acute inflammation and edema (Smith, 1992). If the inflammatory response were a major contributor to DOMS, then it would seem that anti-inflammatory agents would have a role in the management of DOMS. However, anti-inflammatory drugs have shown mixed results for treating DOMS (Cheung, Hume, & Maxwell, 2003; Donnelly, Maughan, & Whiting, 1990; Hasson, Daniels, Divine, Niebuhr, Richmond and Stein, 1993; Kuipers, Keizer, Verstappen, & Costill, 1985).

In addition to anti-inflammatory agents, there have been numerous attempts to provide relief from DOMS through physical modalities used to reduce inflammation and pain.

* Corresponding author. Address: Division of Physical Therapy, West Virginia University School of Medicine, P.O. Box 9226, Morgantown, WV 26506-9226, USA. Tel.: +1 304 293 1311; fax: +1 304 293 7105.
E-mail address: cmancinelli@hsc.wvu.edu (C.A. Mancinelli).

1466-853X/$ - see front matter © 2006 Published by Elsevier Ltd.
doi:10.1016/j.ptsp.2005.10.004

Several investigators have studied the effects of cryotherapy on DOMS and found little no benefit to using this modality (Eston & Peters, 1999; Isabell, Durrant, Myrer, & Anderson, 1992; Paddon-Jones & Quigley, 1997; Yackzan, Adams, & Francis, 1984). Craig, Bradley, Walsh, Baxter, and Allen, (1990) compared the use of pulsed ultrasound for the treatment of DOMS at both low and high doses and found no significant differences between range of motion, pain ratings or pain thresholds for both ultrasound groups, a sham ultrasound group, and a control group. These authors concluded there is no convincing evidence to support the use of pulsed ultrasound for DOMS. Ciccone, Leggin, and Callamaro (1991) found that continuous ultrasound, presumably because of its heating effects, worsened DOMS. However, DOMS was attenuated when the ultrasound was combined with an anti-inflammatory agent (trolamine salicylate) for phonophoresis. The range of ultrasound treatment parameters for effectiveness in treating DOMS and influencing repair processes has yet to be fully considered. Studies of this nature are complicated by the large number of treatment variables such as ultrasound frequency and intensity parameters, size of area treated, ultrasound head size, and type of medium used to promote ultrasonic wave travel through the skin.

Electrotherapy modalities used in the management of DOMS have been shown to be equivocal. The work of Denegar, Perrin, Rogol, and Rutt (1989), Denegar & Perrin (1992) and Craig, Cunningham, Walsh, Baxter, and Allen (1996) has suggested a decrease in soreness (Craig et al., 1996; Denegar et al., 1989; Denegar & Perrin, 1992), but no effect of recovery of muscle strength with the use of transcutaneous electrical stimulation (TENS) (Denegar & Perrin, 1992). Microcurrent electrical neuromuscular stimulation (MENS) has been shown to be inconsistent, and ineffective for treating DOMS (Weber, Servedio, & Woodall, 1994).

The use of physical activity as a treatment modality for DOMS has been a longstanding suggestion by strength and conditioning specialists (Stauber, 1996). It has been postulated that the muscle pump action associated with submaximal concentric exercise will improve the symptoms and signs of DOMS following eccentric exercise (Friden, Sfakianos, & Hargens, 1986). It is not totally clear whether central neural mechanisms such as endorphin release with exercise or the psychological benefits of continued exercise play a role in decreasing muscle soreness (Armstrong, 1984). Hasson, Barnes, Hunter, and Williams (1989) reported that high speed, concentric, isokinetic exercise improved muscle torque deficits associated with DOMS. However, several investigators have reported no decrease in signs or symptoms of DOMS with concentric exercise (Donnelly, Clarkson, & Maughan, 1992; Isabell et al., 1992; Weber et al., 1994).

Coaches and trainers have advocated the use of static stretches during intense pre-season training based on the early work of Abraham (1977) and DeVries (1966) suggesting that static stretching could be used as a treatment modality for DOMS. Rodenburg, Steenbeck, Schiereck, and Barr (1994) examined the effects of pre-exercise warm-up that included stretching and post-exercise massage and found that the combination improved soreness, decreased strength loss and improved resting ROM. However, stretching cannot be distinguished from massage or pre-exercise warm-up effects in this study. More recent work calls into question the commonly held notion that stretching can alleviate DOMS, when used as a pre-exercise or post-exercise routine (Buroker & Schwane, 1989; Johansson, Lindstrom, Sundelin, & Lindstrom, 1999; Lund, Vestergaard-Poulsen, Kanstrup, & Sejrsen, 1998).

Exercise-induced muscle tissue injury leads to an influx of fluid that will result in an elevation of intramuscular pressure (Friden et al., 1986). If swelling contributes to the activation of pain receptors, then modalities that promote fluid movement away from the muscle, would be expected to result in less soreness and improved physical performance. Compression has been studied and results have been mixed, depending on the type and duration of compression used. Intermittent compression can reduce swelling and stiffness ephemerally, but it has no effect on strength deficits seen with DOMS (Chleboun et al., 1995). Kraemer, Bush, Wickham, Denegar, Gomez and Gotshalk (2001) found that constant compression via the use of a compressive sleeve reduced soreness and swelling following eccentric exercise. The compression garments used were made of a raschell fabric with 25% lycra and provided a 10 mmHg compressive force and the compression was provided for 24 h per day for 5 days post-exercise. In addition to the decrease in soreness, recovery of muscle force output and power were also hastened in this study. While this study shows promising results for the treatment of DOMS, use of compression sleeves for all extremities may not be practical during the athlete's training.

Massage like compression, may help move fluid away from involved muscles. Massage has been touted as a modality that facilitates recovery after intense exercise and can be used to enhance physical performance (Cinque, 1989; Samples, 1987). Unfortunately, these claims are anecdotal. Massage is considered to have a number of physiological and psychological benefits that may contribute to pain modulation, and tissue repair aided in part by increased circulation and lymphatic flow (Wright & Sluka, 2001). Tiidus & Shoemaker (1995) have shown that massage has no effect on blood flow to muscle. Furthermore, these investigators noted light exercise was better than massage for improving blood flow and temporarily reducing soreness. While one study showed improved lymphatic flow to the skin in humans (Mortimer, Simmons, Rexvani, Robbins, & Hopewell, 1990), muscle lymphatic flow and edema have not been shown to improve with massage (Callaghan, 1993). Despite these findings, Smith, Keating, Holbert, Spratt, McCammon and Smith (1994) found a reduction in serum creatine kinase (an indirect marker of muscle tissue damage) and soreness when massage was delivered 2 h after eccentric exercise. However, changes in creatine kinase can be highly variable and are not necessarily reflective of muscle damage (Connolly, Sayers, & McHugh, 2003). Smith et al. (1994) also showed that massage prolonged the neutrophil activity associated with inflammation and therefore may alleviate DOMS. If massage is able to diminish muscle damage and the effects of the inflammatory response, then it may be able to alter muscle soreness.

Individual massage techniques, descriptors and duration used can vary widely, thus limiting the ability to compare one massage study to another (Ernst, 1998). Classical western massage or Swedish massage is the most common form of massage used for athletes (Weerapong, Hume, & Kolt, 2005) and consists of five basic techniques known as effleurage, petrissage, tapotement, friction and vibration (Callaghan, 1993; Weerapong et al., 2005). The progression of the massage advances from distal to proximal and usually lasts between 10 and 30 min (Cafarelli & Flint, 1992; Weerapong et al., 2005). A classical massage typically begins and ends with light gliding strokes with the palm of the hand known as effleurage. The initial effleurage strokes then progress to deeper stroking known as petrissage. Petrissage involves a kneading motion or lifting, pressing or rolling of the tissues. Tapotement, friction and vibration can be added before the final effleurage strokes. Tapotement involves stimulating the tissues either with repetitive percussion strokes or tapping and is commonly used before and during competition (Weerapong et al., 2005). Friction techniques that involve circular movements with the palm or fingertips purportedly can be added for the specific purpose of reducing muscle spasm following injury (Weerapong et al., 2005). Vibration or shaking is purportedly used for reduction in muscle tone (Callaghan, 1993). However, the suggested physiologic affects of these massage techniques have not been established (Weerapong et al., 2005).

Lightfoot et al. (1997) examined the effectiveness of massage on DOMS through the use of petrissage only. The results showed that petrissage immediately following eccentric exercise did not alleviate DOMS examined 24 and 48 h later. However, the only evidence of muscle soreness was the participants' subjective report of pain. No objective measure of pain was provided. Hilbert, Sforzo, and Swensen (2003) examined the effects of effleurage, tapotement and petrissage rendered 2 h after exercise-induced injury. Soreness and mood were improved with massage, but there was no improvement in muscle peak torque production or range of motion. Several other studies have also reported a lack of improvement in muscle peak torque production following massage (Tiidus & Shoemaker, 1995; Weber et al., 1994).

Little is known about whether or not massage can enhance actual physical performance during activities such as shuttle run drills or vertical jumping ability. One would expect that a decrease in force output from muscle damage leading to DOMS as shown with various isokinetic testing devices would translate to a decrease in performance of sports specific activities; but little data exists to support this relationship. Smith & Jackson (1990) demonstrated an inverse relationship between vertical jump displacement and intensity of DOMS in football players. However, it is not clear whether or not massage could affect this physical performance decrement seen with DOMS. Drews, Kreider, Drinkard, Cotres, Lester and Somma (1990) found no effect of regular daily massages on racing performance or recovery of elite male cyclists. Hemmings, Smith, Graydon, and Dyson (2000) examined the effects of massage on repeated boxing performance. They found no difference in performance using a boxing ergometer for a group of male boxers who received a massage prior to the trial versus a group of male boxers who did not receive massage prior to the trial. To date, the effects of massage on measures of physical performance have been limited, especially in regards to women.

The purpose of this study was to determine if massage has an effect on DOMS and physical performance in Division I women college volleyball and basketball players at the start of pre-season training. We hypothesized that massage would reduce the severity of soreness and improve physical performance.

2. Methods

2.1. Experimental approach to the problem

This study used a randomized pre-test/post-test control group design. Our study population consisted of college Division I women athletes who were recruited to participate on the first day of pre-season training. Baseline measurements included height, weight, vertical jump displacement, shuttle run times, quadriceps femoris length and pressure-pain threshold using pressure algometry. Baseline measures were followed by randomization and participation in routine pre-season training as outlined by the strength and conditioning coach. Baseline measures were used to assess variance between groups and establish a baseline measure of pressure-pain threshold in all subjects. Intense strength training and drills started on the second day of practice. On the fourth day of training, when the maximal amount of soreness was expected based on the intensity of training that started on day 2, baseline measures were repeated. A 20% drop from baseline of the pressure—pain threshold measured by the algometer was used to define soreness. Subjects also reported pain perception (i.e. soreness) through the use of a visual analog scale. The experimental group received massage to each lower extremity while the control group rested. The control group was watched closely to be certain that no stretching or warm-up activity was completed during the rest period. At no time did the control group receive massage. Post-test measures of soreness rating, vertical jump displacement, shuttle run time, pressure-pain threshold and quadriceps length were then completed following the massages for the experimental group and rest for the control group.

2.2. Procedures

Following approval by the university's review board for protection of human subjects, athletes from the women's basketball and volleyball teams were recruited for participation on day 1 of pre-season training. Each athlete was asked to complete a questionnaire outlining any history of injury and activity level prior to participating in pre-season training. Inclusion criteria consisted of being an active member of the teams. Exclusion criteria included history of injury or current injury or illness that prevented full participation in routine pre-season training. Twelve basketball players and 12 volleyball players ($n=24$) qualified with a mean age of 20 years $+0.93$. All qualified subjects were then asked to sign an informed consent approved by the university's review board for the protection of human subjects.

Four stations were used for baseline, pre-treatment, and post-treatment measurements. The testing stations consisted of vertical jump displacement, speed and agility (shuttle run), length of the quadriceps muscle group, and pressure-pain threshold of the thigh.

2.3. Station one: vertical jump displacement

Vertical jump displacement was assessed using a device known as the Vertec™ (MF Athletic Co. Cranston, RI). The athlete stood directly under the Vertec™ (MF Athletic Co. Cranston, RI), with the dominant upper extremity, reaching upward with the shoulder fully flexed and elbow, wrist, and fingers extended. The horizontal bar touched by the tip of the long finger determined the highest baseline vertical reach of the athlete. The athlete was then asked to jump as high as she could without taking a step, touching the highest bar possible. Unrestricted countermovement (flexing the knees) and free arm swing were used preceding the jump based on a previous study by Davis, Briscoe, Markowski, Saville, and Taylor (2003) that demonstrated no correlation between knee flexion angle and vertical jump displacement. Vertical reach was subtracted from the jump height and the difference was used to represent vertical jump performance. Three trials were allowed for each athlete and the best vertical jump displacement was recorded.

2.4. Station two: timed shuttle run

To determine the athlete's speed and agility, two cones were placed on the floor 50 feet apart. The athlete started at a mark placed halfway between (25 feet) the two cones. The athlete was then asked to run to the first cone of her choice, touch it, run to the other cone, touch it, and return to the starting mark. The athlete began on the command of 'Ready, Go'. The run was completed twice with the best time recorded. A brief rest period was provided, allowing the women to recover between trials. The second trial began when the athlete indicated that she was ready.

2.5. Station three: quadriceps femoris length

Quadriceps femoris length was measured bilaterally by one of the study's investigators. The athlete was positioned prone on a plinth with both hips and knees extended. The examiner then passively flexed the knee, moving the athlete's heel toward the buttock until resistance or an anterior pelvic tilt of the pelvis was felt. The straight edge of a standard goniometer was then used to measure the distance from the heel to the buttock in centimeters. One measure only was taken on each side to avoid repeated stretching of the limb. Intratester reliability ($r=0.99$) was established prior to initiation of the main study.

2.6. Station four: pressure-pain threshold

Pressure-pain threshold of the anterior thigh was evaluated using pressure algometry (J Tech Medical. Salt Lake City, Utah). Intra-tester reliability with algometry has been shown to be fair to good ($r=0.67$) when it is used as a measure of pressure-pain threshold (Fischer, 1987). Each athlete was positioned supine on the plinth table. An investigator stood on either side of the table. One investigator held the tape measure from the anterior superior iliac spine to the superior pole of the patella. The other investigator marked the point halfway between the two anatomical landmarks with a skin pen. The investigator with the tape measure then took the blunt probe and placed it on the mark. The other investigator held the screen displaying the amount of pressure. After telling the subject to report when the 'pressure started to feel uncomfortable,' the investigator began applying a slow downward pressure. At the subject's response of 'There,' the measurement was recorded. The test was repeated on the opposite lower extremity using the same method. The testing order was the same for all subjects and for all sets of measurements.

The subjects were then randomized into one of two groups, massage or control, using a random number table. All subjects were instructed to avoid potential pain-relieving modalities such as analgesic medications and ice throughout the study. The subjects participated in their normal pre-season training routine as guided by their strength and conditioning coach. This included sport-specific drills, endurance training, and upper and lower extremity resistive exercises. All measures were repeated on the day that was predicted as the day of peak soreness by the strength and conditioning coach. This was day 4 of the start of pre-season training since the athletes did not begin intense training until day 2 of pre-season training. All subjects were asked to provide their perception of muscle soreness using a 10-point visual analog scale. Vertical jump displacement, shuttle run time, quadriceps femoris length and pressure-pain threshold were measured again by the same examiners who performed the baseline measures. These examiners were blinded to group assignments.

Two licensed massage therapists with 3 years of experience as general massage practitioners then completed a 17 min massage to each thigh of all subjects randomized to the treatment/massage group. The subjects were positioned in supine on one of two plinths placed approximately 3 ft apart so that the therapists could perform the massages side by side. A tape recording was played to announce the time for each therapist to change strokes. Western massage techniques of effleurage, petrissage and vibration were used as described by Tappan & Benjamin (1998). Each massage began with four minutes of effleurage consisting of 2 min of light stroking with the palm around the knee, and two minutes of light stroking over the medial thigh. Effleurage was followed by petrissage consisting of 2 min of two-handed palm kneading of the anterior thigh muscles, 2 min of two-handed thumb kneading over the medial thigh, 2 min of circular two-handed lifting of the anterior thigh, 1 min of pressing and spreading the tissues perpendicular to the long axis of the thigh, and 1 min of rolling the fingertips over the anterior thigh muscles. Two minutes of vibration was added between the petrissage techniques of circular lifting of the anterior thigh muscles and pressing and spreading the tissues. The massage then culminated with 3 min of effleurage over the anterior and medial thigh. The control group rested during this time and was prohibited from performing any exercises or stretches while the experimental group massages were performed.

Immediately following massages, subjects in both groups completed a post-treatment soreness survey, and measures of vertical jump displacement, timed shuttle run, quadriceps femoris length, and pressure-pain threshold were repeated as they were done at baseline and just prior to massage.

2.7. Statistical analyses

Baseline and pre-massage measures were compared to confirm if a decline in performance or muscle soreness existed in the subjects with training, but prior to massage. Paired *t*-tests were used to assess differences between pre and post massage measures in both groups. An alpha level of 0.05 was used for determining significance for all statistical analyses. Pre-trial variance between groups was assessed using the O'Brien test.

3. Results

Of the initial 24 volunteers, two subjects were excluded because of injuries that limited their ability to participate in normal pre-season practice. The remaining twenty-two were randomly placed into control ($n=11$) and treatment ($n=11$) groups. Only two of the participants reported having massages prior to the investigation; however, these were greater than 1 year before the present investigation. O'Brien's test of variance revealed no differences between baseline measures for the massage and control groups for height, weight, age, vertical jump, shuttle run, quadriceps length, and pressure-pain threshold ($p>0.05$).

3.1. Baseline to pre-treatment algometer measurements

Pressure-pain thresholds dropped from baseline values measured prior to intense training to measures taken after intense training began in both the control and treatment groups. Our pre-trial definition of muscle soreness was restricted to at least a 20% drop in pressure-pain thresholds. Six subjects (three from each group) did not have at least a 20% decrement in pressure-pain thresholds. They were excluded from further participation in the study because it was assumed they had minimal muscle soreness.

We found a 30% average drop (range 0–70%) for the control group from day 1 baseline testing to testing on day 4. For the experimental group, there was a 31% average drop in algometer measurements (range 0–67%) from baseline to pre-massage testing on day 4. Mean, standard deviations and results of the *t*-tests for all day 4 measures taken pre and post-massage are shown in Tables 1 and 2.

3.2. Effects of massage on perceived soreness

On day 4 testing session, the control group reported an average soreness of 5/10 both pre and post-testing. Sixty-six percent of the control group reported that they experienced the same amount of soreness pre and post-test. Seventeen percent of the subjects in the control group reported more soreness at the post-test measurement, and 17% were less sore after resting while the treatment group subjects

Table 1
Control group comparison pre and post testing on day 4 of pre-season training (* = significant)

	Pre-test mean (SD)	Post-test mean (SD)	*p*-Value
Soreness rating (0–10)	5 (2)	5 (3)	0.5911
Vertical jump (cm)	49.9 (5.7)	48.1 (5.1)	0.4275
Shuttle run (s)	7.92 (0.56)	8.22 (0.71)	0.0354*
Quadriceps flexibility left (cm)	8.3 (5)	7.7 (4.2)	0.4825
Quadriceps flexibility right (cm)	8.1 (5.5)	7.3 (5.4)	0.0669
Algometer left (lbs/in^2)	12.5 (7.2)	12.7 (6.7)	0.7867
Algometer right (lbs/in^2)	14.4 (7.5)	13.9 (6.9)	0.4850

Table 2
Treatment group comparison pre and post massage (* = significant)

	Pre-test mean (SD)	Post-test mean (SD)	p-value
Soreness rating (0–10)	5 (1)	3 (1)	0.0011*
Vertical jump (cm)	45.8 (4.7)	46.2 (3.1)	0.0033*
Shuttle run (s)	8.03 (0.59)	7.97 (0.39)	0.5522
Quadriceps flexibility left (cm)	9.3 (3.8)	8.6 (4.1)	0.1113
Quadriceps flexibility right (cm)	8.8 (3.4)	7.6 (3.7)	0.1388
Algometer left (lbs/in^2)	11.6 (6.7)	13.1 (6.8)	0.0461*
Algometer right (lbs/in^2)	11.7 (6.6)	13.0 (5.4)	0.1737

received massages. Paired *t*-tests showed there was no significant change in the control group's level of perceived muscle soreness pre and post-test ($p = 0.5911$).

The average pre-massage rating of perceived soreness in the treatment group was 5/10 and the average post-massage rating of perceived soreness was 3/10. Eighty percent of the subjects in the treatment group reported that they were less sore after massage, and 20% of the subjects in the treatment group reported the same amount of soreness after massage. Paired *t*-tests revealed a significant decrease in perceived soreness rating from pre-massage to post-massage ($p = 0.0011$) in the treatment group.

3.3. Effects of massage on vertical jump displacement

The average pre-test vertical jump displacement was 49.9 cm and the average post-test vertical jump displacement was 48.1 cm for the control group. There was no significant difference in day 4 pre-test and post-test vertical jump displacements for the control group ($p = 0.4275$). The treatment group showed a significant increase in vertical jump displacements ($p = 0.0033$) from pre-massage to post-massage with average displacement of 45.8 cm and a post-massage average of 46.2 cm.

3.4. Effects of massage on shuttle run times

A significant increase in shuttle run time was found within the control group ($p = 0.0354$) with a pre-test average of 7.92 s and a post-test average of 8.22 s. The treatment group showed no significant difference in pre-test and post-test shuttle run time ($p = 0.5522$). The average pre-test shuttle run time for the treatment group was 8.03 s with a post-test shuttle run time of 7.97 s.

3.5. Effects of massage on quadriceps femoris length

Average quadriceps femoris length increased from pre-test to post-test measures in both the treatment and control groups, but there were no significant differences found for either group. The control group showed no significant difference in pre-test and post-test quadriceps femoris measurements on both the left and the right sides ($p =$ 0.4825 and 0.0669, respectively). Pre-test measures for the control group averaged 8.3 cm on the left and 8.1 cm on the right. Post-test measures for the control group averaged 7.7 cm on the left and 7.3 cm on the right indicating that the heel was closer to the buttock or that there was an average increase in quadriceps femoris flexibility in the control group.

No significant differences were found in the pre-massage and post-massage measures for both the left and the right side in the treatment group ($p = 0.1113$ and 0.1388, respectively). Average pre-massage measures were 9.3 cm on the left and 8.8 cm on the right. Post-massage measures averaged 8.6 cm on the left and 7.6 cm on the right, indicating an average increase in quadriceps femoris flexibility for the massage group.

3.6. Effects of massage on pressure-pain threshold

No significant differences were found within the control group between pre-test and post-test algometry readings for both the left and the right sides ($p = 0.7867$ and 0.4850, respectively). The average pre-test algometry readings of pressure for the control group were 12.5 lbs/in^2 on the left and 14.4 lbs/in^2 on the right. Post-test measurements for the control group were 12.7 lbs/in^2 on the left and 13.9 lbs/in^2 on the right. A significant difference was found within the treatment group in the pre-massage and post-massage algometry readings for the left side ($p = 0.0461$). The average pre-massage reading for the left side was found to be 11.6 lbs/in^2 with an average post-massage reading of 13.1 lbs/in^2. No significant difference was found within the treatment group in the pre-massage and post-massage algometry readings for the right side ($p = 0.1737$). The average pre-massage reading for the right side was 11.7 lbs/in^2 with an average post-massage reading of 13.0 lbs/in^2.

4. Discussion

Previous investigations have looked at various therapeutic interventions aimed at alleviating DOMS. Results have been mixed and there is little consensus as to the most effective management of DOMS (Ernst, 1998).

Massage is a commonly used treatment, but little scientific evidence exists to support its use. In a recent literature review, Connolly et al. (2003) reported that no study has examined the therapeutic effects of massage with sound experimental design. Weerapong et al. (2005) in their review of the literature reported that there is no evidence that massage can improve performance, enhance recovery or prevent injury to muscle. Therefore, the present study attempted to examine the use of massage to improve performance in collegiate women athletes.

We found that massage decreased perceived soreness and increased vertical jump displacement in our sample of women collegiate athletes. We also found that massage resulted in an increase in the ability to withstand pressure before discomfort was reported for the quadriceps on one side. The control group did not have a statistically significant change for any variables tested except for shuttle run time and that actually slowed.

We attempted to objectify soreness ratings with the use of pressure algometry. Algometry ratings were lower than perceived soreness. That is, pain-pressure threshold was lower than what would be expected based on the subject's report of soreness for the massage group. It is possible that the power of suggestion may affect the soreness ratings because subjects believed that massage should help. To our knowledge, this study was the first of its kind to examine soreness associated with DOMS. Fischer (1987) reported that a decrease in pressure threshold to 3 kg is considered clinically significant and abnormal. We found a significant change in algometry measures with massage on one side only. We cannot explain why this did not occur on the opposite side. Limb dominance may have played a role in this but we did not assess dominance in our sample. Perhaps the addition of more measurement sites and other muscles would have provided more insight since soreness patterns with DOMS may vary within a given muscle (Connolly et al., 2003) and may be different for other muscles of the lower extremity.

The present investigation has several other limitations. First, it is known that DOMS is increased in non-resistance trained individuals. We could not control for the amount of resistive exercise training the athletes did prior to the start of pre-season training. This may have accounted for a large difference in soreness levels found objectively with algometry testing and that perceived by the subjects. However, we did have homogeneity between groups as evidenced by lack of significant variance for all baseline tests. Also, we did not use a specific exercise protocol known to induce DOMS, rather we relied on the training strategy of the strength and conditioning coach who was the same for both basketball and volleyball teams. Training volumes were reported to be the same. Day 4 of training was chosen by the strength and conditioning coach to be the day of greatest soreness based on what is known about DOMS. Twenty-seven percent of the subjects in each group did not reach soreness as we defined in our study. This decreased our final sample size. It is possible that the athletes who participated in this study had not reached peak soreness by the testing day.

Time was also a limiting factor in this study. While we would have liked to use massage on the entire lower extremity, the times the athletes were available for practice were restricted by NCAA rules. The massage was therefore limited to the thigh based on time allotted by the coaches. It would also have been preferred to repeat measures of assessment at more than one time interval following massages. Again, we were under constraints placed by NCAA rules. This may provide useful information in future studies of DOMS and performance.

The control group rested during the time that the treatment group received massages. This was necessary to avoid the potential interference of light exercise on DOMS. The control athletes were given attention via conversation about their workouts and the season, but no sham intervention other than the attention through conversation was provided. An attempt at sham massage with lotion is recommended for future studies.

A decrease in vertical jump with DOMS has been shown in male football players (Smith & Jackson, 1990). We too found a decrease in vertical jump performance and shuttle run times in women athletes who demonstrated a 20% or greater decrease in tolerance to deep pressure. Massage improved vertical jump displacement, but not shuttle run times. Interestingly, the control group shuttle run times slowed significantly. It is possible that not enough rest time was given between shuttle run trials as the athletes chose their own rest period between trials, rather than having a standardized duration of rest. Follow-up power analyses revealed that given the variability in our data, we would have needed a sample size greater than 11 to achieve a power of 0.8 for shuttle run times and 155 to achieve a power of 0.8 for quadriceps length testing. Our sample size was too small to comment further on the effects of massage on quadriceps length.

5. Conclusions

This study suggests that massage can alleviate soreness and improve vertical jump performance in female collegiate athletes. The study approach was novel in that an objective measure of soreness was used, massages techniques were standardized and actual measures of physical performance such as vertical jump, running speed and agility were used to assess the affects of massage on DOMS. More research is needed with a larger sample size including males to determine whether massage can have a therapeutic effect on recovery of post-exercise muscle function.

Acknowledgements

The authors thank Angela Hendershot, Jeff Markun, Rene Riffle, Carrie Smith and Amanda Stuchell for their assistance with data gathering. We also thank the coaches of the Basketball and Volleyball teams, Jim Carey and Veronica Hammersmith, their coaching staff, and the strength and conditioning staff for support provided. We thank the athletes who participated. Thanks also to Todd Adams, licensed massage therapist for providing the massages along with one of the study's investigators (SF).

Finally, the authors would like to thank Dr William Stauber for his thoughtful review of the manuscript.

References

Abraham, W. (1977). Factors in delayed onset muscle soreness. *Medicine and Science in Sports and Exercise*, *9*, 11–20.

Armstrong, R. (1984). Mechanisms of exercise-induced delayed-onset muscle soreness: A brief review. *Medicine and Science in Sports and Exercise*, *16*, 529–538.

Buroker, K. C., & Schwane, J. A. (1989). Does post-exercise static stretching alleviate delayed muscle soreness? *The Physician and Sports Medicine*, *17*(6), 65–83.

Cafarelli, E., & Flint, F. (1992). The role of massage in preparation for and recovery from exercise. *Sports Medicine*, *14*, 1–9.

Callaghan, M. J. (1993). The role of massage in the management of the athlete: A review. *British Journal of Sports Medicine*, *27*, 28–33.

Cheung, K., Hume, P., & Maxwell, L. (2003). Delayed onset muscle soreness: Treatment strategies and performance factors. *Sports Medicine*, *33*(2), 145–164.

Chleboun, G. S., Howell, J. N., Baker, H. L., Ballard, T. N., Graham, J. L., Hallman, H. L., et al. (1995). Intermittent pneumatic compression effect on eccentric exercise-induced swelling, stiffness and strength loss. *Archives of Physical Medicine and Rehabilitation*, *76*, 744–749.

Cinque, C. (1989). Massage for cyclists: The winning touch? *The Physician and Sports Medicine*, *17*(10), 167–170.

Ciccone, C., Leggin, B., & Callamaro, J. (1991). Effects of ultrasound and trolamine salicylate phonophoresis on delayed onset muscle soreness. *Physical Therapy*, *71*(9), 666–676.

Clarkson, P. M., & Sayers, S. P. (1999). Etiology of exercise-induced muscle damage. *Canadian Journal of Applied Physiology*, *24*, 234–248.

Cleak, M., & Eston, R. (1992). Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise. *British Journal of Sports Medicine*, *26*, 267–272.

Connolly, D. A., Sayers, S. P., & McHugh, M. P. (2003). Treatment and prevention of delayed onset muscle soreness. *Journal of Strength and Conditioning Research*, *17*(1), 197–208.

Craig, J., Bradley, J., Walsh, D., Baxter, D., & Allen, J. (1990). Delayed onset muscle soreness: Lack of effect of therapeutic ultrasound in humans. *Archives of Physical Medicine and Rehabilitation*, *80*, 318–323.

Craig, J., Cunningham, B., Walsh, D., Baxter, D., & Allen, J. (1996). Lack of effect of transcutaneous electrical nerve stimulation upon experimentally induced delayed onset muscle soreness in humans. *Pain*, *67*, 285–289.

Davies, C., & White, M. (1981). Muscle weakness following eccentric work in man. *Pflugers Archives*, *392*, 168–171.

Davis, D. S., Briscoe, D. A., Markowski, C. T., Saville, S., & Taylor, C. J. (2003). Physical characteristics that predict vertical jump performance in recreational male athletes. *Physical Therapy in Sports*, *4*, 167–174.

Denegar, C. R., & Perrin, D. H. (1992). Effect of transcutaneous electrical nerve stimulation, cold, and a combination treatment on pain, decreased range of motion, and strength loss associated with delayed onset muscle soreness. *Journal of Athletic Training*, *27*, 200–206.

Denegar, C. R., Perrin, D. H., Rogol, A. D., & Rutt, R. (1989). Influence of transcutaneous electrical nerve stimulation on pain, range of motion, and serum cortisol concentration in females experiencing delayed onset muscle soreness. *The Journal of Orthopaedic and Sports Physical Therapy*, *11*, 100–103.

DeVries, H. A. (1966). Quantitative electromyographic investigation of the spasm theory of muscle pain. *American Journal of Physical Medicine and Rehabilitation*, *45*, 119–134.

Donnelly, A. E., Clarkson, P. M., & Maughan, R. J. (1992). Exercise induced muscle damage: Effects of light exercise on damaged muscle. *European Journal of Applied Physiology*, *64*, 350–353.

Donnelly, A. E., Maughan, R. J., & Whiting, P. H. (1990). Effects of ibuprofen on exercise-induced muscle soreness and indices of muscle damage. *British Journal of Sports Medicine*, *24*, 191–195.

Drews, T., Kreider, R. B., Drinkard, B., Cotres, C. W., Lester, C., Somma, C. T., et al. (1990). Effects of post-event massage therapy on repeated ultra-endurance cycling. *International Journal of Sports Medicine*, *11*, 407.

Ernst, E. (1998). Does post exercise massage treatment reduce delayed onset muscle soreness? A systematic review. *British Journal of Sports Medicine*, *32*, 212–214.

Eston, R., & Peters, D. (1999). Effects of cold water immersion on the symptoms of exercise-induced muscle damage. *Journal of Sports Sciences*, *17*(3), 231–238.

Fischer, A. A. (1987). Pressure algometry over normal muscles. Standard values, validity and reproducibility of pressure threshold. *Pain*, *30*, 115–126.

Friden, J., Sfakianos, P., & Hargens, A. (1986). Muscle soreness and intramuscular fluid: Comparison between eccentric and concentric load. *Journal of Applied Physiology*, *61*, 2175–2179.

Friden, J., Sjostrom, M., & Ekblom, B. (1983). Myofibrillar damage following intense eccentric exercise in man. *International Journal of Sports Medicine*, *4*, 170–176.

Gibala, M., MacDougall, J., Tarnopolsky, M., Stauber, W., & Elorriaga, A. (1995). Changes in human skeletal muscle ultrastructure and force production after acute resistance exercise. *Journal of Applied Physiology*, *78*, 702–708.

Hasson, S., Barnes, W., Hunter, M., & Williams, J. (1989). Therapeutic effect of high speed voluntary muscle contractions on muscle soreness and muscle performance. *The Journal of Orthopaedic and Sports Physical Therapy*, *10*, 499–507.

Hasson, S., Daniels, J., Divine, J., Niebuhr, B., Richmond, S., Stein, P., et al. (1993). Effect of ibuprofen use on muscle soreness, damage, and performance: A preliminary investigation. *Medicine and Science in Sports and Exercise*, *25*, 9–17.

Hemmings, B., Smith, M., Graydon, J., & Dyson, R. (2000). Effects of massage on physiological restoration, perceived recovery and repeated sports performance. *British Journal of Sports Medicine*, *34*(2), 109–114.

Hilbert, J. E., Sforzo, G. A., & Swensen, T. (2003). The effects of massage on delayed onset muscle soreness. *British Journal of Sports Medicine*, *37*, 72–75.

Isabell, W. K., Durrant, E., Myrer, W., & Anderson, S. (1992). The effects of ice massage, ice massage with exercise and exercise on the prevention and treatment of DOMS. *Journal of Athletic Training*, *27*, 208–217.

Johansson, P. H., Lindstrom, L., Sundelin, G., & Lindstrom, B. (1999). The effects of preexercise stretching on muscular soreness, tenderness and force loss following heavy eccentric exercise. *Scandanavian Journal of Medicine and Science in Sports*, *9*(4), 219–225.

Kraemer, W., Bush, J., Wickham, R., Denegar, C., Gomez, A., Gotshalk, L., et al. (2001). Influence of compression therapy on symptoms following soft tissue injury from maximal eccentric exercise. *Journal of Orthopedic and Sports Physical Therapy*, *31*(6), 282–290.

Kuipers, H., Keizer, H., Verstappen, F. T. J., & Costill, D. L. (1985). Influence of a prostaglandin inhibiting drug on muscle soreness after eccentric work. *International Journal of Sports Medicine*, *6*, 336–339.

Lightfoot, J. T., Char, D., McDermott, J., & Goya, C. (1997). Immediate postexercise massage does not attenuate delayed onset muscle soreness. *Journal of Strength Conditioning Research*, *11*, 119–124.

Lund, H., Vestergaard-Poulsen, P., Kanstrup, I. L., & Sejrsen, P. (1998). The effect of passive stretching on delayed onset muscle soreness, and other detrimental effects following eccentric exercise. *Scandanavian Journal of Medicine and Science in Sports*, *8*(4), 216–221.

Mortimer, P. S., Simmons, R., Rexvani, M., Robbins, M., & Hopewell, J. W. (1990). The measurement of skin lymph flow by isotope clearance—reliability, reproducibility, injection dynamics and the effects of massage. *Journal of Investigative Dermatology*, *95*, 677–682.

Newham, D., Jones, D., & Clarkson, P. (1987). Repeated high-force eccentric exercise: Effects on muscle pain and damage. *Journal of Applied Physiology*, *63*, 1381–1386.

Paddon-Jones, D., & Quigley, B. (1997). Effect of cryotherapy on muscle soreness and strength following eccentric exercise. *International Journal of Sports Medicine*, *18*, 588–593.

Rodenburg, J. B., Steenbeck, D., Schiereck, P., & Barr, P. R. (1994). Warm-up, stretching and massage diminish harmful effects of eccentric exercise. *International Journal of Sports Medicine*, *15*, 414–419.

Samples, P. (1987). Does sports massage have a role in sports medicine? *The Physician and Sports Medicine*, *15*(3), 177–183.

Smith, L., Keating, M., Holbert, D., Spratt, D., McCammon, M., Smith, S., et al. (1994). The effects of athletic massage on delayed onset muscle soreness, creatine kinase, and neutrophil count: A preliminary report. *The Journal of Orthopedic and Sports Physical Therapy*, *19*, 93–98.

Smith, L. L. (1992). Causes of delayed onset muscle soreness and the impact on athletic performance: A review. *The Journal of Applied Sport Science Research*, *6*(3), 135–141.

Smith, M. E., & Jackson, C. G. R. (1990). Delayed onset muscle soreness, serum creatine kinase and creatine kinase-mb related to performance measurements in football. *Medicine and Science in Sports and Exercise*, *22*(2), S34.

Stauber, W. (1996). Delayed-onset muscle soreness and muscle pain. In J. E. Zachazewski, D. J. Magee, & W. S. Quillen (Eds.), *Athletic injuries and rehabilitation* (pp. 92–98). Philadelphia, PA: W.B. Saunders Company.

Stauber, W., Clarkson, P., Fritz, V., & Evans, W. (1990). Extracellular matrix disruption and pain after eccentric muscle action. *Journal of Applied Physiology*, *69*, 868–874.

Tappan, F. M., & Benjamin, P. (1998). *Tappan's handbook of healing massage techniques: Classic, holistic, and emerging methods* (3rd ed.). East Norwalk, CT: Appleton and Lange.

Tiidus, P. M., & Shoemaker, J. K. (1995). Effleurage massage, muscle blood flow and long-term post-exercise strength recovery. *International Journal of Sports Medicine*, *16*, 478–483.

Weber, M. D., Servedio, F., & Woodall, W. (1994). The effects of three modalities on delayed onset muscle soreness. *The Journal of Orthopaedic and Sports Physical Therapy*, *20*(5), 236–242.

Weerapong, P., Hume, P. A., & Kolt, G. S. (2005). The mechanisms of massage and effects on performance, muscle recovery and injury prevention. *Sports Medicine*, *35*(3), 235–256.

Wright, A., & Sluka, K. A. (2001). Nonpharmacological treatments for musculoskeletal pain. *The Clinical Journal of Pain*, *17*, 33–46.

Yackzan, L., Adams, C., & Francis, K. (1984). The effects of ice massage on delayed muscle soreness. *The American Journal of Sports Medicine*, *12*, 159–165.