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The effect of intermittent pneumatic compression on the management of pain associated with delayed onset muscle soreness

Ashley Kay Lindahl
University of Northern Iowa

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THE EFFECT OF INTERMITTENT PNEUMATIC COMPRESSION ON THE MANAGEMENT OF PAIN ASSOCIATED WITH DELAYED ONSET MUSCLE SORENESS

An Abstract of a Thesis
Submitted
in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Ashley Kay Lindahl
University of Northern Iowa
July 2016
ABSTRACT

Context: Intermittent pneumatic compression is used for the recovery of active individuals following intense exercise with little research to support its use. This study evaluates the effectiveness of intermittent pneumatic compression on musculoskeletal pain associated with DOMS among healthy college age population. Objective: Evaluate the efficacy of intermittent pneumatic compression, compared to a placebo, in the prevention of pain associated with delayed onset muscle soreness. Design: Experimental, Repeated Measure Design. Participants: Thirty healthy college-age volunteers (15 male: 21.5 ± 2.3 yrs, 179.3 ± 9.9 cm, 91.4 ± 26.4 kg; 15; female: 20.4 ± 1.5 yrs, 168.9 ± 6.9 cm, 69.1 ± 12.4 kg). Methods: Participants were induced with delayed onset muscle soreness in the elbow flexors of their non-dominant arm. Participants were randomly assigned to two groups: intermittent pneumatic compression treatment or placebo. Participants received treatment for 30 minutes immediately after completing the DOMS protocol. Main Outcome Measures: Pain reported using the Numeric Rating Scale (NRS). Results: A 2x3 factorial ANOVA revealed a significant interaction (F(2,56)=3.5, p=0.037), therefore simple effects were calculated. The primary question was the effect of the intervention on pain and not the effect of time on pain. Thus, only differences between the experimental groups were considered. Independent t-tests indicated that there were no differences in reported pain between the intermittent pneumatic compression (treatment) group and the placebo group immediately (t(28)=-0.68, p=0.50) post-treatment, at 24 hours (t(28)=-1.4, p=0.18) or at 48 hours (t(28)=0.68, p=0.50). Conclusion: Intermittent pneumatic compression was not effective at preventing pain associated with DOMS when
applied immediately after exercise for 30 minutes. Therefore, clinicians should choose a different intervention when attempting to prevent the pain associated with DOMS.
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ONSET MUSCLE SORENESS

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Ashley Kay Lindahl
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July, 2016
This Study by: Ashley Kay Lindahl

Entitled: THE EFFECTS OF INTERMITTENT PNEUMATIC COMPRESSION ON THE MANAGEMENT OF PAIN ASSOCIATED WITH DELAYED ONSET MUSCLE SORENESS

Has been approved as meeting the thesis requirement for the

Degree of Master of Science in Athletic Training

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Date ____________________________
Dr. Peter J. Neibert, Thesis Committee Member

Date ____________________________
Dr. Kavita Dhanwada, Dean, Graduate College
DEDICATION

This thesis is dedicated to my family: my parents, Deb and Lee Lindahl, siblings and in-laws: Lisa, Saben, Ross, Kelly, Nicole, Brad, Cody and Mikayla and my nieces and nephews: William, Kennedy, Fayth, Emma and Grayson. Your continued motivation and support, as well as the examples you have set for me with your own lives is a constant reminder of what is possible. You inspire me daily.
ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to Dr. Todd Evans who served as my committee chair, for his persistent work and guidance in helping me to accomplish my academic goals. I would also like to thank Dr. Kelli Snyder and Dr. Peter Neibert for serving on my committee and offering advice throughout this journey, and Aaron Krejci for joining me in the data collection process. I truly could not have accomplished this feat without all of you.
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INTRODUCTION

According to the Institute of Medicine (2011), pain is defined as “an unpleasant physical, sensory and emotional experience associated with actual or potential tissue damage, as well as an unpleasant and, therefore, also an emotional experience.” However, pain is often thought of as being abstract, and for this reason, McCaffery (1968) described pain as being “whatever the experiencing person says it is, existing whenever the experiencing person says it does.” Painful conditions effect an estimated 100 million Americans, annually costing over $600 billion in medical bills, lost productivity, and wages (Institute of Medicine, 2011). The most frequent reason why people seek medical care is pain, making up 80% of all physician visits (Gatchel, Peng, Peters, Fuchs, & Turk, 2007).

The importance of reducing pain is multi-faceted. When left untreated, pain can have detrimental physical and psychological effects (Gordon et al., 2010; Li, 2015; Nelson & Churilla, 2015; Shakoor, Furmanov, Nelson, Li, & Block, 2008). Shakoor et al. (2008) found a direct correlation between changes in pain and changes in muscle strength and proprioception. Pain also has the ability to interfere with daily activities, contributing to the reasons why patients seek medical attention for the presence of pain (Wilson, 2014). One way that pain prohibits function is through the ability of pain to cause a fear of movement. The fear avoidance model exhibits this relationship between pain and the ability to function (Nelson & Churilla, 2015). Hypervigilance of pain has the potential to cause avoidance of painful activities which leads to disuse, disability, dysfunction, and ultimately a reduction in participation (World Health Organization; WHO, 2002).
In addition to physical disturbances, pain has the ability to impact mental health (Byrne, Twist & Eston, 2004; Nelson & Churilla, 2015; Shakoor et al., 2008). Although a direct link for pain causing depression has not been established, depression, anxiety and suicidal thoughts often coexist with chronic pain (Li, 2015). There is a positive correlation between patients with multiple pain symptoms and the development of depression. This is known as the pain-depression syndrome, and acknowledges the frequent coexistence of both conditions, their ability to exacerbate one another and the presence of their overlapping biological mechanisms.

One condition that consistently causes pain is delayed onset muscle soreness (DOMS; Cleak & Eston, 1992; Proske & Morgan, 2001; Weerakkody, Whitehead, Canny, Gregory, & Proske, 2001). DOMS is a condition which occurs in the days following unaccustomed eccentric exercise and is marked by pain, stiffness, swelling and strength loss (Cleak & Eston, 1992; Proske & Morgan, 2001; Weerakkody et al., 2001). Symptoms of DOMS are not apparent immediately after exercise, but occur around 24 hours after exercise, and can last as long as nine days (Cleak & Eston, 1992). Although there are many hypotheses, the precise cause for this phenomenon known as DOMS remains a mystery, requiring more research.

Current treatment for DOMS include medication such as non-steroidal anti-inflammatories (NSAID), activities such as a “cool down” or exercise, and modalities such as ultrasound, electric stimulation, hydrotherapy and massage. However, the use of these interventions have been shown to have limited effectiveness in their ability to attenuate the symptoms of DOMS (Barnett, 2006; Cheung, Hume & Maxwell, 2003;
Of these treatments, massage is one modality that shows significant promise in its ability to reduce pain in the days following eccentric exercise (Ernst, 1998; Frey Law et al., 2008; Mancinelli et al., 2006; Nelson, 2013). When used immediately after exercise, massage has been shown to prevent severe pain (Crawford et al., 2014; Frey Law et al., 2008; Mancinelli et al., 2006). However, it remains unknown why this treatment is effective.

Another modality, which has recently gained popularity and is believed to have effects similar to massage, is intermittent pneumatic compression (IPC; Normatec™, Newton Center, MA). IPC is commonly used for recovery after intense exercise, especially by those in the athletic population. These devices uses air pumped through a nylon sleeve that encompasses the involved limb to compress and knead the tissue progressively from distal to proximal (Normatec™, Newton Center, MA; Sands, McNeal, Murray & Stone, 2015; Waller, Caine & Morris, 2005). Previous research on the effectiveness of IPC shows mixed results when used as a recovery modality to prevent DOMS. Hanson, Stetter, Li and Thomas (2013), Sands et al. (2015) and Waller, Caine and Morris (2005) in their respective studies, all found this modality to be more effective than passive recovery in preventing DOMS. However, Chlebourn et al. (1995) did not find this to be true, and Cochrane, Booker, Mundel and Barnes (2013) found mixed results. While the presence of IPC machines are common in many facilities for the purpose of recovery, limited research has been conducted to assess the effectiveness of this modality’s ability to prevent the effects of DOMS, especially pain. The purpose of
this study was to discover the effects of intermittent pneumatic compression on the pain associated with delayed onset muscle soreness.
METHODS

Research Design

An experimental, placebo controlled design incorporating both quantitative and qualitative data was used for this study. The independent variable was the use of an intermittent pneumatic compression modality or placebo treatment, while the dependent variable was the pain reported by participants using the Numeric Rating Scale (NRS).

Research Participants

Participants were selected from a convenient sample of athletic training students at a Midwestern university. Thirty healthy volunteers (15 male: 21.5 ± 2.3 yrs, 179.3 ± 9.9 cm, 91.4 ± 26.4 kg; 15 female: 20.4 ± 1.5 yrs, 168.9 ± 6.9 cm, 69.1 ± 12.4 kg; table 1) were recruited to participate in this study, and randomly assigned to either the treatment or placebo group (treatment group: 20.7 ± 2.2 yrs, 175 ± 10.2 cm, 84.6 ± 27.2 kg control group: 21.1 ± 1.8 yrs, 173 ± 10.2 cm, 75.9 ± 18.4 kg; ).

Participants were recruited in person during a regularly scheduled class. During recruitment, participants were provided a description of the study. Included in the description were risks associated with participation, along with inclusion and exclusion criteria. Inclusion criteria included: 18-30 years of age and having no identified health issues. Exclusion criteria included: pregnancy, history of rhabdomyolysis, infections of the skin or joint of the arm, cardiac disease, cardiac pace maker or other implants, surgery/injury to the arm in the last six months, history of severe adverse exercise response, sensitivity to compression, history of embolism or clotting, and indication the
he/she cannot complete elbow movements. Participants were informed that for the duration of the study they would be asked not to engage in analgesic treatments (i.e. massage, ice, exercise, stretch, pain medication, other pain relieving modalities, etc.) and to avoid exercise (i.e. weight lifting, cardio, etc.). Students who were interested in participating in the study were asked to leave their contact information for the researcher. Participants were then contacted to schedule the three sessions.

**Instruments**

**Normatec™ Compression Sleeves**

The intermittent pneumatic compression was provided by the Normatec™ Compression Sleeves (Normatec™, Newton Center, MA; Figure 3). This sleeve, made of nylon, is placed around, and extends the entire length of the limb. Chambers in the sleeve inflate beginning distally and progressing proximal, and this cycle is repeated for the duration of the treatment. Parameters were set to the manufacturers recommended settings for recovery after exercise. For the purpose of maintaining consistency and control of this study, the treatment parameters were set at level 7 for 30 minutes.

**Numeric Rating Scale**

Participants’ pain was measured using the Numeric Rating Scale (NRS). The NRS is a Likert scale that is used to measure subjective pain ranging from 0, meaning no pain to 10, meaning worst imaginable pain. Evidence of validity for the NRS has been established through several studies including Bijur, Latimer, and Gallagher (2003) as well as Lara-Munoz, Ponce de Leon, Feinstein, Puente, and Wells (2004; Appendix C).
Health History Form

Participants completed a health history form to identify inclusion and exclusion criteria, including information pertaining to their physical activity level, current health status, and demographics including height, weight, age, and gender. Participants who had a current health or injury issue were asked to elaborate on the condition (Appendix C).

Post-Compression Intervention Questions

At the conclusion of each individual’s data collection, participants completed questions pertaining to the compression sleeve and the effect that they felt it had on their recovery (Appendix C).

Procedures

IRB approval for this study was attained prior to the start of recruitment. Data collection occurred over three sessions, 24 hours apart. The first session consisted of informed consent, health history, DOMS inducing procedures and subjective pain measurement. Upon arrival, participants were asked to thoroughly read the informed consent and provide their signature, printed name and date. Following the informed consent, participant completed a health history questionnaire to ensure their eligibility for the study based on inclusion and exclusion criteria. Once deemed eligible, participants then began the DOMS inducing procedure.

Participants’ non-dominant arm were used for data collection. Participants were seated with a decline board placed on their upper thighs to support their arm and prevent hyperextension of the elbow (Figure 1).
Figure 1. Participant Position with Decline Board

Next, participants’ one repetition maximum (1RM) was determined by having participants perform one bicep curl using dumbbells, increasing in weight by 2.27 kg (5lbs) until the participant could no longer complete the motion for one repetition.
Once 1RM was established, the DOMS inducing protocol began with the starting weight for exercise being the participant’s 1RM increased by 2.27 kg (5lbs). Participants began the exercises in full elbow flexion with the forearm supinated (Figure 2). The researcher then placed the weight in the participant’s hand. The participant then lowered the weight into full elbow extension to the researcher’s count of five. The weight was then removed from the participant’s hand, while they remained in full elbow extension. The researcher then passively moved the participants arm back into flexion. This was repeated for ten repetitions, followed by one minute of rest. This procedure was repeated for five sets. Once the participant was fatigued to the point where they were unable to lower the weight to the count of five, the weight was reduced by 2.27 kg (5lbs) and the repetitions continued at that weight for the remainder of the sets.

Immediately after the completion of five sets of ten repetitions, either the intermittent pneumatic compression or the placebo treatment was administered, depending on the participant’s predetermined placement into either the treatment or placebo group. Group placement was determined systematically by order of participation and gender to ensure equal numbers of males and females in each group. Each participant was placed in a recumbent position on a treatment table with a bolster.
supporting their back for comfort. The intermittent compression sleeve was placed on the involved arm and secured with the attached Velcro.

For those in the treatment group, the sleeve was attached to the Normatec™ modality and turned on to the recommended intensity of seven (Normatec™; Figure 3). A

Figure 2: Starting Position for Eccentric Exercise
timer was set for 30 minutes. Participants were allowed to use their phone or other devices at this time, but were asked to remain stationary.

*Figure 3:* Positioning for IPC Treatment
For those assigned to the placebo group, the intermittent pneumatic compression sleeve was left unattached to the Normatec™ modality (Figure 4). However, the Normatec™ was turned on to the recommended settings with an intensity of seven to create the illusion of treatment being administered, although the sleeve did not fill with air as in the treatment group. A timer was set for 30 minutes.

Figure 4: Positioning for Placebo Treatment
Following the treatment, or placebo treatment, participants were again placed in the exercise position as seen in Figure 1. Participants were given a 2.27 kg (5lb) weight and asked to complete three bicep curls by extending their elbow and lowering the weight to the researchers count of five, then flexing their elbow to lift it at their own pace. After the completion of three curls, participants were asked to rate their pain by circling the number on an NRS that best represented their pain while performing the bicep curls. After the completion of this step, participants were reminded not to participate in exercise or pain relieving treatments or take any pain medications for the remainder of the study. This concluded the first session of data collection. This session took no longer than 50 minutes.

The second session occurred 24 hours following the first. Participants were asked to complete three bicep curls with 2.27 kg (5lbs), lowering the weight to the count of five, and then raising it at their own pace, as described previously. This was done using the same positioning as seen in Figure 1. Following the completion of three bicep curls, participants were asked to complete a NRS, as previously described, for the pain they felt while completing the curls. This concluded session 2. Session 2 took no longer than five minutes to complete.

The third and final session occurred 24 hours after session two, and 48 hours after session one. Participants completed three bicep curls and a NRS, as described in session two. Participants were then asked to complete two short questions in regards to their perception of the effectiveness of the intermittent pneumatic compression modality.
Participants were given an opportunity to ask any questions or express any concerns that they had in regards to the study at this time. This concluded the study.

Data Analysis

Descriptive summaries were calculated for the participants’ demographics. The pain data was analyzed using SPSS statistical software Version 22.0 (IBM, Armonk, NY). The level of significance was set at p<.05 for all inferential statistics. A 2 (experimental vs. control) x 3 (baseline, 24 hrs post, 48 hrs post) factorial ANOVA was calculated to compare pain levels of the control and the experimental group at the designated intervals. Independent t-tests were used for the post-hoc analysis to determine if there were differences between the conditions at each of the three data collection points. Qualitative responses were grouped into like-answers and assessed by the researcher.
RESULTS

The 2 x 3 factorial ANOVA revealed a significant interaction (F(2,56)=3.5, p=0.037). Therefore simple effects were calculated. The primary question was the effect of the interventions on pain and not the effect of time on pain. Thus, only differences between the experimental groups were considered. The independent t-tests indicated that there were no differences in reported pain between the treatment group and the placebo group immediately (t(28)=1.2, p=0.23), at 24 hours (t(28)=−1.4, p=0.18), or 48 hours (t(28)=−0.68, p=0.50) post-treatment (Table 3, Figure 5).

Table 1.

Participant Demographics

<table>
<thead>
<tr>
<th>Group</th>
<th>Sex</th>
<th>Age (yrs)</th>
<th>Standard Deviation (±)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>IPC*</td>
<td>8</td>
<td>7</td>
<td>20.7</td>
</tr>
<tr>
<td>Control</td>
<td>7</td>
<td>8</td>
<td>21.1</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>15</td>
<td>21.1</td>
</tr>
</tbody>
</table>

*Intermittent Pneumatic Compression

When asked if the treatment impacted their pain, 10/30 (eight from the treatment group and two from the control group) participants indicated that they felt the compression sleeve impacted their pain and one participant in the experimental group reported that the treatment had increased his/her pain. Because all of the participants’
comments were simple and lacked detail, their responses were reduced into two nominal categories (yes or no) regarding the opinion of the effectiveness of the treatment they received (Table 2).

Table 2.

*Treatment Effectiveness in the Reduction of Pain (Qualitative Questionnaire)*

<table>
<thead>
<tr>
<th>Group</th>
<th>Yes</th>
<th>No</th>
<th>I don’t know</th>
<th>Increased Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPC*</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Placebo</td>
<td>2</td>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>18</td>
<td>1</td>
<td>1</td>
</tr>
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*Intermittent Pneumatic Compression*

Table 3.

*NRS Mean Score and Standard Deviation by Group*

<table>
<thead>
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<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPC*</td>
<td>15</td>
<td>3.07</td>
<td>1.624</td>
</tr>
<tr>
<td>Control</td>
<td>15</td>
<td>2.33</td>
<td>1.676</td>
</tr>
<tr>
<td>Day 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPC</td>
<td>15</td>
<td>2.73</td>
<td>1.907</td>
</tr>
<tr>
<td>Control</td>
<td>15</td>
<td>3.67</td>
<td>1.799</td>
</tr>
<tr>
<td>Day 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPC</td>
<td>15</td>
<td>3.167</td>
<td>1.9055</td>
</tr>
<tr>
<td>Control</td>
<td>15</td>
<td>3.600</td>
<td>1.5492</td>
</tr>
</tbody>
</table>

*Intermittent Pneumatic Compression*
Figure 5. Mean Pain Scores by Condition and Day
DISCUSSION

Intermittent pneumatic compression is a modality commonly used to aid recovery after intense exercise. However, research on its preventative efficacy is limited. The results of this study indicate that 30 minutes of IPC applied immediately after exercise, did not prevent DOMS pain, when compared to a placebo treatment. This study represents level 2 evidence based on the Oxford CEBM (Phillips et al., 1998).

These results are in contrast to those of a similar study by Waller et al. (2005) in which participants underwent three different treatments, each lasting one hour, after a progressive shuttle run known to induce DOMS. Treatments consisted of rest, low pressure IPC and high pressure IPC. Immediately after the treatment, and at 24 and 48 hours post-exercise, participants were asked to rate their soreness level. Mean soreness levels were significantly lower with both low and high pressure treatment, however high pressure IPC showed the greatest improvement at all three times. Variation in findings could be due to muscles involved: upper body versus lower body, DOMS inducing procedure or a difference in wording. Although the words are often interchanged, participants in the study by Waller et al. (2005) were asked to rate “soreness,” while those in our study were asked to rate their “pain.” Varying interpretations of the word used could have led to the contradicting results of the studies. Another factor that may contribute to contradicting results between studies is the language used to describe the sensation of pain to the participants. Participants in this study were asked to rate their “pain,” while other previous studies used “soreness” ratings (Waller et al., 2005).
Although it is unknown why, one of the few treatment modalities that has consistently been supported through research to relieve the symptoms of DOMS is massage (Crawford et al., 2014; Frey Law et al., 2008; Mancinelli et al., 2006). In a study conducted by Mancinelli et al. (2006), NCAA Division I basketball and volleyball players were recruited on the day when their soreness was predicted to reach its peak during pre-season training. Participants were randomly assigned to receive either massage, applied by licensed massage therapists, or the control group, which consisted of rest. Immediately following the treatment, participants were asked to rate their pain. Those in the treatment group reported lower perceived pain than those in the control group. However, pain was not assessed after this time, therefore this study did not truly assess the effect on DOMS, since DOMS is known to begin 24 hours after exercise (Chlebourn et al., 1995).

In a similar study by Frey Law et al. (2008), participants underwent one of three treatments: quiet rest, superficial light stroking, or deep tissue massage. All treatments occurred between 24 and 48 hours after the first session where DOMS was induced. Immediately following the randomly assigned treatment, pain was assessed using a visual analog scale (VAS) under three different conditions: at rest and during a stretch. The authors concluded that both superficial touch and deep tissue massage are able to reduce pain due to DOMS. Additionally, deep tissue massage was able to reduce pain to a significantly greater degree than superficial touch.

Both of the aforementioned studies support the use of massage as a means to alleviate the pain of DOMS. However, both of these studies involved the use of treatment
in the days following exercise, after DOMS had already set in, whereas our study attempted to take a preventative approach. Through publishing an updated version of the Quality Improvement Guidelines in 2005, the American Pain Society placed an emphasis on prevention of pain whenever possible instead of waiting for it to occur to begin treatment (Gordon et al., 2005). The importance of pain prevention guided this study to determine the efficacy of IPC as a preventative measure.

Micklewright (2009) studied the effects of massage as a means to prevention of soreness by having participants receive the treatment immediately after exercise. A series of eccentric bicep exercises known to induce DOMS were completed by the participants on their non-dominant elbow flexors. Immediately following, participants in the experimental group received a massage known as soft-tissue release, while those in the control group did not. Pain ratings via a VAS were taken immediately after the cessation of treatment and at 24 and 48 hours post-intervention. Results of the study showed no discernable decrease in pain for those who received massage, over those who did not. Interestingly, those in the treatment group reported slightly more pain in the mid-arm when compared to those in the control group. Micklewright attributed this to the aggressive nature of the massage used. Overall, this study concluded that massage used immediately after exercise does not improve soreness ratings, and may actually increase pain immediately following treatment. This study involved methods very similar to ours, with the substitution of massage in place of IPC, and showed similar results to our findings.
Similar to Micklewright’s (2009) results, the findings of the current study show an increase in pain immediately after IPC treatment when compared to the placebo group. Specifically, those who received the IPC treatment immediately after exercise reported an increase in pain ratings directly after treatment, compared to those who received the placebo. These findings support the proposed similarities between IPC and massage when used as a preventative means to recovery.

The current findings are different from those of Sands et al. (2015). In their study, participants’ pain was measured using pressure-to-pain threshold after a 15 minute treatment with IPC, which followed exercise. These exact procedures were repeated later that same day. Their results showed that those in the treatment group required more pressure to elicit pain than those in the control group. In their study, IPC was able to reduce muscle tenderness elicited by pressure, immediately after treatment and later in that same day.

However, these measures do not represent IPCs effect on preventing DOMS, since pain related to this condition is known to begin at 24 hours and not immediately following exercise (Chleboun et al., 1995; Cleak & Eston, 1992; Proske & Morgan, 2001; Weerakkody et al., 2001). The current findings raised the question, not only does the use of this modality not help alleviate the pain occurring with DOMS, but it may actually increase immediate pain when used directly after exercise.

Although pain was worse immediately following treatment for those in the IPC group, participants saw slight improvement at 24 hours. However, at 48 hours- when pain is traditionally reported to be at its peak (Chleboun et al., 1995; Cleak & Eston, 1992;
Proske & Morgan, 2001), those both in the treatment group as well as the control group reported similar pain ratings. Although pain at 24 and 48 hours was slightly lower for those in the experimental group than for those in the placebo group, the difference was not statistically significant. For this reason, we conclude IPC to be ineffective in preventing pain associated with DOMS. This refutes our hypothesis that IPC would prevent pain associated with DOMS.

There are several clinical implications that can be derived from this study. First, it addresses the current practices and treatment modalities and their ability to accomplish what is promoted by the manufacturer. As medical practitioners, it is important to understand the effects of the interventions that we apply to patients, and eliminate unnecessary and ineffective treatments (Pellegrino, 1986). Not only was IPC ineffective in preventing DOMS pain, the results suggest that this modality may actually increase the amount of pain felt immediately after treatment. With little evidence to suggest that IPC prevents the pain associated with DOMS, its use should be questioned considering the risk of increased pain immediately following its application. This study provides external evidence on which health care practitioners can make their decision of whether to apply IPC to patients immediately after exercise.

Since massage has consistently been found to decrease pain with DOMS after the pain has occurred (Mancinelli et al., 2006; Frey Law et al., 2008; Nelson, 2013; Moraska, 2005; Ernst, 1998), this method is the standard to which other treatments should be compared when determining in their ability to relieve DOMS symptoms. According to
our results, IPC used immediately after exercise is not as effective as massage in relieving pain.

**Limitations**

There are several limitations to consider when interpreting the results of this study. First, although they were frequently reminded, we were unable to account for participants engaging in pain relieving techniques or addition forms of exercise for the three-day duration of our study. Also, since pain can only be measured subjectively, we relied on the honesty of each participant when reporting pain. Additionally, we were not able to account for participants’ familiarity with the IPC device. Although we attempted to blind the participants as much as possible, some individuals in the control group stated that they knew they were not receiving the treatment because the sleeve did not inflate.

Another limitation was the omission of an NRS score before the DOMS inducing procedures. Although, participants completed a health history questionnaire on which they all indicated having no pain in their arms, determining the exact change in pain from baseline to immediately post exercise and then at 24 hours was not possible. Furthermore, the IPC treatment was only applied to the elbow flexors in this study. The effects of this modality may be different for preventing DOMS in other muscle groups.

The timing of the pain assessment and the treatment application for the current study can be viewed as a limitation as well. First, pain was only assessed immediately after DOMS inducing exercise and at 24 and 48 hours post-exercise. We did not assess the effect that this treatment has on pain after 48 hours post-exercise. Additionally, prevention of pain was the main objective of this study. Treatment of pain with IPC once
it had already occurred was not assessed. The impact of additional IPC treatments after exercise and after the DOMS pain was present was not addressed. Finally, other signs or symptoms common with DOMS, such as reduced function and motion, were not assessed.

**Recommendations**

Future research should assess factors such as duration and intensity of IPC as well as multiple treatments to reveal their effect on pain with DOMS. It may also be beneficial to extend the time in which data is collected to see if IPC used preventatively has the ability to decrease the duration of pain as a symptom of DOMS. Future research could also investigate the ability of IPC to alleviate pain while it is being applied, to assess its ability to be an effective palliative treatment while it is running.

This studied suggests that IPC, applied for 30 minutes immediately after exercise, is not effective in preventing DOMS pain. Although more research is needed to determine if alternate protocols are effective, this protocol cannot be recommended.
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APPENDIX A

EXTENDED RATIONALE AND PURPOSE
Statement of the Problem

The use of compression is thought to decrease the effects of DOMS, however, little research has been done to support the use of intermittent pneumatic compression immediately after completing an exhaustive exercise on patient’s pain as reported 24 to 48 hours post-exercise. The purpose of this study was to examine the effects of intermittent pneumatic compression, used preventatively, on the perceived pain associated with delayed onset muscle soreness in healthy college students.

Research Question

This study attempted to answer the following:

1. What effect does intermittent pneumatic compression, used preventatively, have on the subjectively reported pain level of DOMS when compared with the placebo treatment?

Experimental Hypothesis

This study was guided by the following hypothesis:

1. Intermittent pneumatic compression, used preventatively, will cause a larger decrease in pain when compared to the placebo treatment.

Significance of the Study

One of the symptoms reported in patients experiencing DOMS is pain (Cleak & Eston, 1992; Weerakkody, Whitehead, Canny, Gregory, & Proske, 2001). Pain has been shown to be a factor in the decreased ability of an individual to function (Gordon et al.,
Dysfunction may lead to an increased risk of injury in patients participating in athletics. Therefore, decreasing pain may lead to a decrease in injury risk in patients in the days following exhaustive eccentric activities. One modality that has been shown to decrease pain with DOMS is massage (Barnett, 2006; Howatson & van Someren, 2008; O’Connor & Hurley, 2003; Torres, Ribeiro, Duarte & Cabri, 2012). Intermittent pneumatic compression has been used after exercise to aid in recovery and is advertised to temporarily relieve muscle aches and pains in a way similar to massage (Normatec™, Newton Center, MA). However, research has been minimal and the evidence is insufficient to support the use of intermittent pneumatic compression for the prevention of DOMS pain. The research of intermittent pneumatic compression in regards to pain management with DOMS will be beneficial to clinicians by providing for them evidence on its efficacy to assist them in making clinical decisions about its use.

**Delimitations**

The following delimitations guided this study:

1. All participants were healthy college age students.
2. Participants completed a fatiguing biceps workout that has been proven to cause DOMS. Those in the experimental group underwent a treatment with intermittent pneumatic compression while those in the control group received a placebo treatment.
3. Intermittent pneumatic compression treatment parameters were pre-decided and consistent for all participants in the experimental group.

Limitations

The following limitations were present during this study:

1. Participants were not randomly selected and were comprised of a convenience sample.
2. We were not able to control for training prior to participation in this study.
3. Although pain scales are the most effective resource to objectify pain, we were not able to account for false feedback given by the subjects.
4. We were not able to control for practitioner error when reading or using equipment.

Assumptions

This study was conducted under the following assumptions:

1. Participants were honest when reporting pain.
2. Participants gave maximal effort during the fatiguing exercise.
3. Participants did not participate in other methods of recovery while participating in this research study.
Definition of Terms

- **Delayed Onset Muscle Soreness (DOMS):** A commonly occurring myogenic condition, which develops following strenuous eccentric exercise (O’Connor & Hurley, 2003).

- **Eccentric exercise:** The contracting muscle is forcibly lengthened to slow or stop a movement (Proske & Morgan, 2001).

- **Intermittent compression:** A post-exercise recovery modality which does not require muscle tone to create appropriate pressure to increase venous and lymphatic return and reduce swelling (Cochrane, Booker, Mundel & Barnes, 2013).
APPENDIX B

EXTENDED LITERATURE REVIEW
Introduction

Pain is the primary reason for patients to seek medical care, affecting an estimated 100 million Americans (Institute of Medicine, 2011). This number represents 23% of adults living in the United States, which is greater than those affected by heart disease, diabetes and cancer combined (Gatchel, Peng, Peters, Fuchs & Turk, 2007; Institute of Medicine, 2011). The prevalence of pain is not only expensive, costing the nation $635 billion annually in medical expenses and lost wages (Institute of Medicine, 2011), it is also harmful to patients in multiple ways (Gordon et al., 2005; McNeill, Sherwood, Starck & Thompson, 1998).

When left untreated, pain can have an effect both physically and psychologically (Nelson & Churilla, 2015). Pain interferes with many daily activities and decreases a person’s functioning, mobility, dexterity and stamina (Wells, Pasero & McCaffery, 2006; WHO, 2002). In some individuals, the presence of pain can cause and extreme and progressive fear of activity (Nelson & Churilla, 2015). Additionally, pain often occurs simultaneous to depression, and the two conditions exacerbate one another (Li, 2015). Patients experiencing prolonged pain are more likely to become depressed, anxious and have suicidal thoughts (Wells et al., 2006).

The adverse effects that pain can have on a person physically and psychologically, as well as the monetary cost of treatment demonstrates the necessity of effective pain assessment and treatment in health care. In recent years, the World Health Organization as well as the Institute of Medicine have produced documents emphasizing the importance of health care providers understanding the effects of pain on patients and
standardizing the assessment and management of pain (Institute of Medicine, 2011; WHO, 2002).

Current treatment options for the management of painful conditions include medications such as opioids and non-steroidal anti-inflammatories (NSAIDS) as well as a wide array of modalities thought to relief pain. While opioids and NSAIDS have been shown to be effective in pain management, their positive effects do not come without risk. Additionally, modalities can be expensive and lack efficacy. More research is needed to find effective and money saving ways to relief pain. Pain assessment can be done in several ways, but self-reported pain is the most effective and accurate method to record a patient’s pain level (Wells et al., 2006). One pain intensity rating scale that has shown to be reliable and effective is the eleven point Numeric Rating Scale (NRS), which allows patients to circle their pain level (Ferreira-Valente, Pais-Ribeiro & Jensen, 2011).

One common condition that causes pain is delayed onset muscle soreness (DOMS) which occurs after strenuous bout of exercise that involves eccentric loading (Cleak & Eston, 1992; Proske & Morgan, 2001; Weerakkody et al., 2001). While the exact cause for the pain is unknown, it is widely reported that the pain of this condition peaks between 24 and 48 hours after exercise and tapers off in the days following its peak (Chlebourn et al., 1995).

Many modalities and medications are used in an attempt to decrease the pain of DOMS. One of the modalities that has gained prevalence is intermittent pneumatic compression (IPC). IPC uses pressure from progressively inflating chambers of a sleeve that encompasses the limb to displace edema and provide a massage-like kneading of the
tissue (Starkey, 2004; Normatec™). Traditionally, this modality has been used for the treatment of edema, lymphedema (often due to cancer and cancer treatments) and the prevention of deep vein thrombosis (Starkey, 2004). In addition to its use for the treatment of these conditions, IPC has increased in prevalence for muscle recovery. However, limited research is available for the efficacy of its use.

Pain is a common condition that can have a devastative effect on the lives of those experiencing it. One condition that causes pain is DOMS. Treatments for the pain associated with DOMS vary greatly and require more research. The purpose of this literature review is to discuss pain, the importance of pain assessment and relief, function and the effect of pain on function, DOMS, its effects and current treatments, and intermittent pneumatic compression.

Pain

Pain has been documented as the primary reason why patients seek medical care, with painful conditions currently affecting as much as 60% of the U.S. population (Schappert & Nelson, 1999). Complaints of pain are the reason for over 80% of all doctor visits (Gatchel et al., 2007). Wilson (2014) suggests that pain interference, or the amount that a person is bothered by pain, can be the most prominent and motivating reason for patients to seek medical care. Pain can affect many aspects of a person’s life, including both physical and emotional functioning (Li, 2015; Williamson & Hoggart, 2005; Wilson, 2014).
The definition of pain involves the unpleasant physical, emotional and sensory experience that accompanies potential or actual tissue damage, which can in turn cause an adverse emotional experience (Glowacki, 2015). However, it has also been defined as simply as being “whatever the experiencing person says it is, existing whenever the experiencing person says it does (McCaffery, 1968).”

Importance of Pain Relief

The importance of pain relief has gained increasing attention and has become an important aspect of health care. Williamson and Hoggart (2005) emphasized the importance of pain management by referring to it as the fifth vital sign, requiring frequent assessment, to ensure patient satisfaction. The importance of pain relief is also emphasized by Hertel and Denegar (1998) on their Hierarchy of Rehabilitation Goals pyramid, on which “control pain” is on the base of the 5 tiers. Being placed at the foundation of the pyramid emphasizes the necessity of controlling pain before other steps can be taken in the rehabilitation process. Without the relief of pain, other components of rehabilitation may not proceed.

The importance of pain relief can also be observed by looking at the use of pain relievers, both over-the-counter and prescription, and the amount of money that is spent on them. As reported in 2011, treatment of painful conditions cost society $261 to $300 billion annually in the United States alone. Of that, $16.4 billion dollars are spent on pharmaceutical pain relievers (Gaskin & Richard, 2011). Most analgesics can be classified as either opioid or non-opioid, such as non-steroidal anti-inflammatory drugs
(NSAIDS) and acetaminophen (Wells et al., 2006). Both classifications have their benefits, however, both also have risks that can be detrimental to health and healing.

**Treatments for Pain Relief**

Opioids are commonly used in the treatment of acute pain for their strong analgesic affect, however it is not without cost. The most concerning side effects for opioids include hypotension and respiratory distress, although these effects were found to be present in 5 and 1 percent respectively. However, less detrimental effects such as nausea, vomiting, unnecessary sedation, pruritis and urinary retention were noted in anywhere from 2 to 25 percent of users. One in every four people using opioid pain relievers will experience these unwanted side-effects to some degree (Wells et al., 2006). Another factor consider when using opioid drugs is the risk of addiction. Although the risk of developing a dependence is low, addiction is a concern held by many patients undergoing treatment for pain.

Although the risk for developing a dependence and the side effects are considered to be less problematic, non-opioids such as NSAIDS and acetaminophen are not used without risk. NSAIDS are the most commonly recommended class of medication for musculoskeletal conditions (Halverson, 1999). However, their use is not without risk. The most common side effects of NSAIDS are gastrointestinal issues such as nausea, ulcers and gastrointestinal bleeding (Hertel, 1997). Those who use NSAIDS are three times more likely to develop gastrointestinal bleeding than non-users (Halverson, 1999). Although these symptoms are most often associated with long term use, they can also be
seen with short term use (Hertel, 1997). Additionally, the use of NSAIDS may increase healing time in those with acute inflammation and may lead to greater hematoma. Chronic use of these types of medication may also lead to kidney failure and liver damage (Cheung, Hume & Maxwell, 2003).

Another factor to consider when consuming NSAIDS for musculoskeletal conditions is their effect on healing. The use of this class of drug can be used effectively for heterotopic ossification (unwanted bone growth), however, it may impede bone healing when dealing with fracture and stress fracture- delaying complete union by as much as two months (Dabners & Mullis, 2004). Additionally, the use of NSAIDS have been shown to be detrimental to long-term tendon and ligament healing in animal studies (Hertel, 1997; Su & O’Connor, 2013). However, it should be noted that the effects of these drugs on animals may be different than that of humans due to the difference in dosage and metabolism.

Although decreasing pain may be the reason for the majority of doctor visits, it is important to acknowledge that a decrease in reported pain does not necessarily mean that complete healing has occurred. Although NSAIDS can reduce pain-causing inflammation, for many conditions, the use of NSAIDS are palliative in nature and do not treat the cause of the pain, but merely the symptoms. This is true for the treatment of DOMS, since the condition is not thought to be caused by inflammation, as will be discussed later in this paper. Inflammation is indeed a desired response, as it may have an integral role in muscle adaptation and repair (Barnett, 2006).
Increasing in popularity is the use of modalities for the treatment of pain. A modality is the application of some form of energy to the body which elicits an involuntary response (Starkey, 2004). One of the main benefits of these non-drug treatment techniques, like modalities, is the minimal safety issues and adverse effects that are associated with them (Wells et al., 2006). With the decreased negative effects, patients are beginning to choose these treatments with increasing regularity. According to one study, nonpharmacological treatments were used by 40% of patients, with a greater satisfaction and superior patient outcomes (Gordon et al., 2010).

One non-pharmaceutical treatment that has been shown to reduce pain is massage. In a review done by Keeratitanont, Jensenb, Chatchawanc and Auvichayapata (2015), the effects of traditional Thai massage were examined in relation to its ability to moderate pain. Six articles were included in which pre to post treatment pain reductions were evaluated. Their results showed reductions in pain varying between 25-80%, with decreases in perceived muscle tension and anxiety as well as improvement in disability and flexibility. The proposed mechanism for how massage is able to reduce pain is by altering the physiological process (Wells et al., 2006). One way in which it may accomplish this is via the stimulation of large diameter fibers, which may reduce pain signals to the brain, also known as the gate theory. Another potential reason for its effectiveness is through a reduction of muscle tension, which is believed to contribute to the transmission of pain signals. Similar to massage, is the relatively new treatment option of intermittent pneumatic compression, which will be discussed in greater depth later in this paper.
Gaining popularity in healthcare is the use of a multi-modal approach to pain management. This approach includes the use of opioid and non-opioid analgesics as well as non-pharmacological practices for the relief of pain. Non-pharmacological practices can include treatments such as massage, modalities and psychological techniques, among other things. A multi-modal approach is recommended whenever possible due to its ability to provide better outcome and patient satisfaction (Gordon et al., 2005; Gordon et al., 2010; Glowacki, 2015; McNeill et al., 1998; Wells et al., 2006), as well as its ability to decrease adverse effects via the decreased need for excessive medication (Wells et al., 2006). The use of a multi-modal approach is necessary for increased satisfaction of patients in the management of their pain. However, more research is needed on non-pharmaceutical interventions for pain to be sure of their efficacy.

In addition to a multi-modal approach, the implementation of prevention of pain used in conjunction with the treatment of pain once it has occurred has gained importance. In 1995, the American Pain Society published Quality Improvement Guidelines for the treatment of pain (Gordon et al., 2005). In their publication, they emphasized the need for the prompt recognition and treatment of pain. In 2005, however, an updated version of the guidelines was published with the addition of an emphasis not only on treatment, but on the importance of preventing pain whenever possible. In one study by Cepeda, Africano, Polo, Alcala and Carr (2003), seven hundred adult patients were evaluated on their pain intensity after surgery and the decrease necessary for it to be meaningful to them. Pain was recorded before treatment with opioid drugs as well as every 10 minutes after administration. Results showed that those who had a more intense
baseline pain rating were less likely to experience pain relief, showing that the more pain is prevented, the greater the chances of notable pain relief (Cepeda et al., 2003).

In a similar study by Jensen, Martin and Cheung (2005) that addressed pain relief, it was noted that pain can have an effect on a person’s satisfaction with the care they received. In this study, operative patients rated their pain early in the postoperative (pre-recovery) phase, and again in the post-recovery phase, with both phases lasting four hours in total. Those who had greater decreases in pain reported greater satisfaction with their care. Although the complete absence of pain is ideal, it is not necessary for patients to be satisfied with their pain relief. In Jensen et al.’s (2005) previously mentioned study, none of the patients were completely pain free at any point of the four hours during which they were assessed. Despite still having pain, 49% of patients still reported being “very satisfied” with their pain relief.

Reporting Pain

Although complete absence of pain is not necessary for patient satisfaction, a significant decrease in pain is necessary. Once common way to compare pre-treatment and post-treatment pain and monitor progress is to use percentage of reduction of pain (Williamson & Hoggart, 2005). This is calculated by finding the difference between pre and post treatment pain ratings and dividing it by the pretreatment intensity. It is then multiplied by 100 to be expressed as a percentage of change. According to different authors, there is a wide range of percentages that are considered to be statistically significant. A clinically important change in pain is defined as being ‘much improved’ or
‘very much improved’, and relates to a 33-50% decrease in pain by most standards
(Cepeda et al., 2003; Farrar, Portenoy, Berlin, Kinman & Strom, 2000; Gordon et al.,
2005; Williamson & Hoggart, 2005).

According to Wells et al. (2006), self-reported pain is the most accurate method
for assessment, since a lack of physiological and pain-indicating behaviors does not
indicate an absence of pain. Several techniques exist for the self-reported rating of pain.
The most common of these include the Numeric Rating Scale (NRS), Visual Analog
Scale (VAS), Verbal Rating Scale (VRS) and Faces Pain Scale-Revised (FPS-R)
(Ferreira-Valente et al., 2011; Williamson & Hoggart, 2005). Through research, all test
have been shown to be reliable, valid and responsive to changes in pain intensity.
However, the NRS was shown to be the most responsive, closely followed by the VAS.
Similarly, the NRS and VAS were similar in sensitivity, with the NRS again, being
slightly superior (Ferreira-Valente et al., 2011). Williamson and Hoggart (2005) also
suggest that, while the NRS and VAS are both appropriate for clinical use, the NRS may
be more useful for pain assessment, audit and research. For these reasons, the NRS is one
of the most commonly used tools for assessing pain.

The NRS is most commonly administered as an 11 point scale on which the
endpoints represent the two extremes of pain. On the far left side of the scale is “0” or the
complete absence of pain, with the far right side being “10”, representing the worst
imaginable pain (Williamson & Hoggart, 2005). However, it can also be represented in a
21 or 101 point scale. It can be administered graphically, allowing the patient to circle his
or her rating along the line, or verbally. For research purposes, the NRS provides interval
level data useful for parametric analysis (Ferreira-Valente et al., 2011; Williamson & Hoggart, 2005).

Psychological Effects of Pain

There are several reasons why pain relief has gained attention in health care. Pain not only affects the patient physically, but also emotionally (Glowacki, 2015; Williamson & Hoggart, 2005; Wilson, 2014). Gordon et al. (2010) describes the Brief Pain Inventory, which separated life interferences due to pain into two different dimensions: interference with affect, such as mood and enjoyment, and interference with activity such as walking, working and general activity. These two dimensions are also broken down into smaller categories that evaluate how pain interferes with the function and well-being of patients.

Although pain is rarely caused by psychological factors, they are often associated with each other. Pain is often linked with fear and anxiety (Williamson & Hoggart, 2005), and those who spend less time in pain show less distress (Gordon et al., 2010). Ultimately, if left inadequately treated, persistent pain can lead to the development of depression (Li, 2015; Williamson & Hoggart, 2005). The presence of pain and depression as a comorbidity is labeled as the pain-depression syndrome (Li, 2015). Although it has been reviewed extensively, the mechanism for their frequent co-existence remains unclear. It is hypothesized that the frequency of their comorbidity may be due to their separate, but overlapping neuroplasticity. Pain and depression share similar treatment techniques and biological mechanisms, and often intensify each other. Those with
chronic pain, as well as those with multiple pain symptoms have increased odds for depression (Li, 2015).

Pain may not only lead to depression, it may also lead to a decrease in activity level. According to the fear avoidance model (FAM), an individual can interpret pain in two different ways, leading to coping with either avoidance or confrontation. Those who cope with confrontation view pain as temporary and a minor setback. Conversely, those who show avoidance catastrophize their pain by focusing on the painful sensation. This focus leads to a fear of pain and avoidance of painful activities which can spiral into disuse, deconditioning and disability. In regards to the FAM, this condition is known as kinesiophobia, or “an excessive, irrational, and debilitating fear of physical movement and activity resulting from a feeling of vulnerability to painful injury or reinjury” (Nelson & Churilla, 2015). For this reason, it is important that pain be prevented whenever possible, in order to maintain an active lifestyle and maintain participation.

**Function**

In order to maintain a healthy and active lifestyle, it is imperative that a person’s function is not limited by pain. Again, pain can interfere with activities such as walking, working and general every day activity (Gordon et al., 2010). This interference can also be described as distress, or the degree to which a person is bothered by pain. It is interference caused by pain with movement that often limits a person’s activity and may ultimately lead to disability and reduced participation (Wilson, 2014). When recorded on a pain scale such as the NRS, a rating of four or less is typically necessary for pain to
have a minimal impact on daily activities and overall function (Jensen, Martin & Cheung, 2005). The importance of the relationship between pain and function is emphasized in the American Pain Society; Quality Improvement Guidelines which were updated in 2005 to include the assessment of whether or not a patient’s pain is controlled to a degree enough that it facilitates function and he or she is satisfied with their quality of life (Gordon et al., 2005).

Dysfunction was defined by the World Health Organization (WHO, 2002) as “an impairment of an individual’s physical functioning, mobility, dexterity or stamina.” Impairments, or perceptions of impairments, of any of these factors can have a devastating effect on an individual’s quality of life and enjoyment. Similarly, disability, a form of dysfunction, can be conceptualized in three different ways, according to Nagi’s Disablement Model, originating in the 1960s (Jette, 2006; WHO, 2002). Within the medical model, disability is seen as a characteristic of the person, caused by disease, trauma or other health conditions. In this model, some type of intervention is necessary to correct or compensate for the disability within the person (Jette, 2006). Contradictory to this model, is the social model for disability. This model removes the responsibility from the person and places it solely on society, requiring accommodation by society for created an unaccommodating environment for individuals experiencing a disability (WHO, 2002). A third model, the biopsychosocial model, combines both the medical and the social model to say that disability is a consequence of biological, personal and social forces (Jette, 2006).
International Classification of Functioning

In 1980, the WHO published the International Classification of Functioning (ICF) for the first time, and since then have continued to add to and improve upon it (WHO, 2002). The purpose of the ICF is to provide a common language for health and function (Jette, 2006). The implementation of the ICF takes the focus off of disability, and concentrates on function and what a person is able to do (WHO, 2002). Previously, a person deemed “disabled” was placed into a separate category from those seen as “healthy”. The two categories were viewed as being completely separate, with no overlap. However, with the introduction of the ICF, “disability” is seen as something that is experienced by the majority of humans to some degree throughout their life. “Disability” is a part of the human experience. With the ICF, functioning, or what a person is able to do, is measured instead of what they are unable to accomplish. It is able to measure function, no matter what the reason for the impairment may be.

The goal of the WHO when developing the ICF was the same as its goal as an organization as a whole. They aim to include everyone in their mission to achieve a life where each person is able to use each opportunity to its fullest potential (WHO, 2002). They hope to achieve this by focusing on a person’s function and its impact on their individual quality of life. The ICF focuses on a patients’ ability to function in a standard environment as well as how well they are able to function in their usual environment (WHO, 2002). With the publication of the ICF, the WHO has attempted to draw more attention to function and a patient’s perceptions of his or her function in their environment.
With the increased focus on function brought on by the implementation of the ICF, more questions surfaced about the impact of other factors on function. For example, the impact that pain has on a person’s ability to function. Shakoor et al. (2008) attempted to answer this question using patients with osteoarthritis (OA). In their study, thirty-eight patients with OA were recruited, their baseline pain, strength and proprioceptive function were assessed, and they were given at home exercises. Eight weeks later, their pain, strength and proprioceptive function were again assessed. The results of this study showed a direct inverse correlation between pain and strength, as well as between pain and proprioceptive acuity. While the authors attribute the increase in strength to a decrease in pain, they cannot be sure of the same relationship with pain and proprioception. It is unknown at this time if a decrease in pain causes an increase in proprioceptive quality or if the decrease in proprioceptive acuity is responsible for the pain within the joint.

In terms of strength, however, three previous studies using OA patients showed similar results, with a relationship between pain reduction and quadriceps strength. Additionally, they reported that a temporary decrease in pain improved maximum voluntary contraction of a muscle as well as decreased abnormal involuntary muscle contraction. In all studies, a temporary decrease in pain was clearly in correlation with an increase in maximal muscle contraction and strength (Shakoor et al., 2008).

Controlling pain is prominent part of the foundation of Hertel and Denegar’s (1998) Hierarchy of Rehabilitation Goals. On the fourth level of the pyramid, is the goal of “restore control of complex functional movements,” and on the fifth and final level is
“return to functional activities.” The placement of functional components of rehab being placed on the fourth and fifth level of the pyramid show the importance that other factors, such as pain, range of motion and strength (which are placed lower on the pyramid) have on functional movements. The return of range of motion and strength, along with a decrease in pain is necessary before the end goal of “return to functional activities” can be accomplished.

Not only do conventional musculoskeletal injuries such as fractures, strains and sprains result in dysfunction, the muscle damage that accompanies delayed onset muscle soreness (DOMS) also causes dysfunction that requires several days for complete recovery to occur (Choi, 2014). The study by Shakoor et al. (2008) suggested that pain plays a large role in strength loss and may potentially contribute to decreased proprioception. Cheung et al. (2003), in their review of DOMS and its impact on performance, concluded that decreased range of motion, decreased strength and muscle recruitment patterns were all present in people experiencing DOMS. They also reported a decreased ability for individuals to function within their normal abilities, which they described as functional limitations. These aforementioned conditions, along with an altered strength tension relationship between agonist and antagonist muscle groups may cause an increased risk for injury (Cheung et al., 2003).

The importance of function as well as the effect that dysfunction can have on a person cannot be overlooked. The ability of one to accomplish tasks in an effective and pain-free way is the ultimate goal of most rehabilitating persons (Hertel & Denegar, 1998). Without the ability to function, and the ability to function without pain, quality of
life is decreased and can lead to greater psychological issues (WHO, 2002). As previously mentioned, on painful condition that has the ability to cause dysfunction is DOMS.

**Delayed Onset Muscle Soreness**

Delayed onset muscle soreness (DOMS) is a highly disputed phenomenon that dates back as far as 1902 with a documented case in which soreness was noted in a middle finger in the hours following rhythmic exercise (O’Connor & Hurley, 2003). Although there are still several questions surrounding it, some consistencies have been established and supported with thorough research. It is described as soreness and dysfunction of the muscles due to exercise induced muscle damage (Choi, 2014). However, unlike other muscle injuries, this exercise induced muscle damage is not apparent during exercise, or even immediately after (Proske & Morgan, 2001). DOMS is most notable hours to days after an individual engages in movements that he or she is unaccustomed to (Lieber & Friden, 2002).

This condition can effect anyone, including those in the athletic community due to their constant changes and increases in training. However, it is not specific to athletes. It is also a condition which is caused by activities that people engage in on a daily basis (Choi, 2014). Researchers agree that DOMS is present only after eccentric exercise, also known as the controlled stretching of the muscle under tension. This is often seen during the lowering or return phase of lifting, as well as downhill walking and other activities that require the slowing of a movement (Choi, 2014). Proske and Morgan (2001) explain
DOMS as the contracting of the muscle to control gravity. A simplified definition for
DOMS can be stated as a muscular condition that occurs only when individuals engage in
eccentric exercise that is more aggressive or differing in nature from the movements that
an individual is accustomed to (O’Connor & Hurley, 2003).

Research has found that fast twitch muscle fibers are more susceptible to the
damage that occurs during eccentric activity when compared to slow twitch fibers
(McHugh, Connolly, Eston & Gleim, 1999; Proske & Morgan, 2001). This is believed to
be due to the higher rate of fatigue that type 2, or fast twitch, muscle fibers are
susceptible to (Lieber & Friden, 2002). Other explanations for why these fibers are more
likely to be effected, as much as three times more likely than slow twitch fibers (McHugh
et al., 1999), include their lower recruitment threshold, their lack of oxidative threshold,
and as a result of their short fiber length (Proske & Morgan, 2001).

Effect of DOMS

Unlike conventional injuries where pain and dysfunction are apparent almost
immediately, signs and symptoms of DOMS present themselves in the days following the
activity. This condition begins to become apparent around 24 to 48 hours after finishing
the workout, and peaks between 24 to 72 hours (O’Connor & Hurley, 2003). Although,
Valle et al. (2013) reported symptoms as early as 6 to 12 hours after exercise. Although
many authors state the peak of DOMS averaging anywhere between 24 and 96 hours
(Cleak & Eston, 1992; Proske & Morgan, 2001; Yu, Liu, Carlsson, Thornell & Stal,
2013), there remains an inconsistency in current research as to how long the effects may
last. Mancinelli, et al. (2006) concluded that deficits were apparent for as long as two weeks, while O’Connor and Hurley (2003) offer a more conservative approach to the effects of DOMS, believing that individuals are back to normal, and the effect of the condition are no longer prevalent within 5 to 7 days.

Patients who suffer from DOMS typically experience no pain during rest. While lying in bed the morning after a workout, there are no signs of muscle injury (Weerakkody et al., 2001). However, the signs, symptoms and functions that are effected by DOMS begin to become apparent as soon as the individual attempts to move. These effects include strength loss, decrease in range of motion (Cleak & Eston, 1992; Lieber & Friden, 2002), swelling (Cleak & Eston, 1992; Yu et al., 2013), change in optimal muscle length (Choi, 2014), soreness (Cleak & Eston, 1992; Proske & Morgan, 2001; Weerakkody et al., 2001), pain (Cleak & Eston, 1992; Lieber & Friden, 2002; Weerakkody et al., 2001), and dysfunction (Cheung et al., 2003; Choi, 2014).

Loss of strength after eccentric exercise was one of the outcomes measured in a study performed by Cleak and Eston (1992) in which 26 female participants underwent a DOMS inducing exercise for the elbow flexors and subsequently underwent strength measurements, among other measures, every 24 hours for 11 days. Isometric strength was tested in the same position in which the exercise was performed with three maximal contractions. The results of the study showed a significant reduction in strength after exercise, with the greatest deficit occurring at 24 hours, and a 20% decrease in strength remaining at 11 days when the study concluded. Similarly, in a review of several studies, Cheung et al. (2003) concluded that strength loss is most apparent while performing
eccentric exercises, although there were also strength deficits noted during concentric and isometric contractions. Another finding that is consistent across several studies was the recovery of concentric and isometric strength within four days, while eccentric strength required an average of 8-10 days for complete recovery.

In addition to loss of strength, Cleak and Eston (1992) examined the effect that eccentric exercise of the elbow flexors has on the resting angle of the elbow to identify how DOMS effects the length of the muscle. In the same study previously mentioned, they found that starting immediately after the exercise, and continuing for 10 days, the resting angle of the elbow was significantly reduced when compared to the contralateral control arm. Unlike strength, however, the greatest decrease was found on day four post-exercise, suggesting that the temporary strength loss and muscle shortening have different causes. Cheung et al. (2003), in their review, noted statistically significant reductions in ankle, knee, and hip joint range of motion in participants across several studies following eccentric exercise. They attributed this decrease in range of motion to an increase in swelling within the muscle that occurs simultaneously with the loss of motion.

Yu et al. (2013) examined biopsies of healthy males’ soleus muscles at 2-3 days and again at 7-8 days post eccentric exercise in an attempt to establish if there is a correlation between sarcolemma integrity, muscle fiber swelling, and the timing of these occurrences with DOMS. The results of their study showed a 24% increase in muscle fiber size at 7-8 days as compared to 2-3 days. However, measures in between these days were not taken so it is not clear from their study when the peak of swelling occurred.
Although, it was apparent that the peak of swelling is not congruent with the peak of soreness, as will be discussed more in depth later in this paper.

In Cleak and Eston’s research (1992), swelling of the exercised muscle was measured every 24 hours for 11 days. Their results concluded that swelling peaked on day four and slowly dissipated until it returned to the pre-exercise level on day 10. Their findings agree with those found by Yu et al. (2013) in that there is no correlation between swelling and soreness in relation to the timing of their peak in other DOMS symptoms. However, they did find a correlation between the peak of both swelling and decreased range of motion, leading them to believe swelling may be a possible cause for the lack of motion.

Another sign of DOMS, although seldom referenced in research, is the idea of a change in the optimal muscle length. In both Choi’s (2014) and Proske and Morgan’s (2001) respective reviews of events following eccentric exercise, they describe a shift of the length at which the muscle is able to generate the maximum amount of isometric force to that of a longer length. Proske and Morgan (2001) attribute this change to the overextension of some sarcomeres in the muscle, which do not re-interdigitate causing surrounding sarcomeres to become shortened. This would in turn require the muscle to be stretched further than pre-exercise lengths to be able to acquire comparable tension. In short, the optimal muscle length for maximum force will be longer after exercise than it had been prior. According to Choi (2014), the amount of shift of the optimal length is a reliable measure for the amount of muscular damage induced by the eccentric exercise.
One of the main effects that DOMS has is pain and soreness, which are often described interchangeably. The pain is not apparent at rest, but is elicited with motion and palpation (Weerakkody et al., 2001). In the days following an unaccustomed to or intense eccentric workout, pain is apparent in many activities of daily living - activities that do not normally cause pain, such as simply getting out of bed. Although many would describe it as a satisfying pain, often times it can seem almost debilitating in dealing with even the simplest of tasks. However, this pain is unlike the pain that is experienced with other injuries. Similar to other muscle injury, pain is elicited with the stretching and contracting of the affected muscle (Lieber & Friden, 2002), as well as when pressure is being applied (Weerakkody et al., 2001). Conversely, the major difference between DOMS pain and pain associated with other muscular injuries is that with DOMS there is no pain when the involved muscles are at rest. There are no symptoms that are apparent when an individual with DOMS is sitting motionless. This realization that soreness does not persist at rest has led some to believe that the pain and soreness associated with the days following eccentric exercise is brought on by stimuli that differs from that which is associated with other injuries (Weerakkody et al., 2001).

Cleak and Eston (1992) used separate measures for pain/soreness and tenderness at 24 hour intervals for 11 days following eccentric exercise. Soreness was recorded by the participant using a visual analog scale, on which subjects moved a sliding indicator to rate their level of pain from zero to ten when their elbow was actively extended. Their results showed a dramatic increase in soreness at the 24 hour data collection, and the peak of soreness was recorded on day three. By the eighth day after exercise, the majority of
individuals recorded an absence of pain with active elbow extension. Tenderness was recorded in those same individuals using a myometer, where participants indicated when the sensation of pressure from the myometer changed to that of discomfort (Cleak & Eston, 1992). The force at the precise moment that discomfort was stated was recorded. Results showed a significant increase in tenderness in the mid-belly of the muscle as well as at the distal musculotendinous junction, with the peak of soreness occurring on day two, and was eliminated by day seven. Conversely, no increase in tenderness was noted at the proximal musculotendinous junction at any point throughout the study. Surprisingly, there was no notable correlation between pain/soreness and tenderness and the reported timeline for their peak. This finding leads to the belief that they are caused by different, though possibly related mechanisms. Also interesting to note is the lack of relationship of the peak of soreness and pain, at three days, and that of strength loss, which occurs at 24 hours post-exercise (Cleak & Eston, 1992).

Another symptom of DOMS, in addition to pain, tenderness and soreness is dysfunction. The combination of some of the effects of DOMS, such as strength loss and decreased range of motion, can collectively make up the dysfunction that occurs following eccentric exercise. Dysfunction after exercise can be short term (e.g. the fatigue and loss of strength immediately following exercise) or more long term, as seen in DOMS where days are required to completely recover (Choi, 2014). In addition to strength loss and a decrease in range of motion, Cheung et al. (2003) proposed abnormal electromyographical patterns as a contributing factor to the functional impairment that occurs. When injury occurs to a muscle, such as that during eccentric exercise, it may
lead to a change in recruitment and activation patterns of the muscle. This change in recruitment has the ability to effect the coordination of muscles and movements, as well as cause a delay in the recruitment of muscles. Proske and Morgan (2001) also proposed the possibility that the damage done to muscles during eccentric exercise (as explained in detail later in this paper) could progress into more significant tears due to the demands of the muscles during competitive events.

Cheung et al. (2003) also focused on the individuals’ perceptions of their impairments and how that perception effected their ability to perform and function at their desired level. When an individual experiencing DOMS feels they are not functioning at his/her pre-DOMS levels and perceives their limitations to be effecting their performance, they may be increasing their risk of injury (Cheung et al., 2003). This perception of dysfunction, in addition to the previously mentioned altered recruitment pattern, delay in muscle recruitment, and possibility of increased tearing of muscle fibers may increase an athletes’ risk of injury during this period.

Additional factors that may lead to an increased risk for injury include a lack of cushioning due to decreased range of motion, compensatory recruitment of other muscles, and strength ratio of agonist and antagonist muscles (Cheung et al., 2013). While engaging in running, jumping and plyometric activities, the muscles act as cushions for the joints to slow the movement. When there is a decrease in range of motion, as seen with DOMS, these joints are unable to absorb the forces, causing other joints and structures to endure those forces. This compensation causes unaccustomed strain on those other structures, increasing the risk of injury. Similarly, when the muscle
undergoes the damage of exercise, it is unable to handle its usual load. This causes the force usually recruited from the injured muscle to come from other muscles, or from portions of that same muscle which were less effected by the exercise, placing increased stresses where they are unaccustomed. Finally, altered muscle function may cause an imbalance in the ratio of antagonist to agonist muscle action. All of these effects may lead to a possible increase in risk of injury in people experiencing DOMS. While the pain that accompanies DOMS may not be intense enough to warrant the removal of athletes from participation in athletic activity, it does pose a threat to their abilities and ultimately increase their risk for injury (Cheung et al., 2003).

The presence of DOMS may not only be detrimental because of its likelihood to increase injury risk. Howatson and van Someren (2008) suggest that in some individuals, it may reduce adherence to an exercise program due to its ability to reduce performance in subsequent exercise sessions. It may also reduce desire to exercise due to pain with motion in the days following eccentric exercise. This is similar to the aforementioned fear of movement (kinesiophobia) and pain catastrophizing as discussed in the pain section of this paper (Nelson & Churilla, 2015; Wilson, 2014).

**DOMS Theories**

While the majority of researchers can agree on the definition and effects that DOMS has on the body, there remains a controversy over the cause for the pain, swelling and dysfunction that occurs in the days following unaccustomed eccentric exercise. While no clear physiological cause has been accepted as the reason for DOMS, several
theories have been suggested. Through extensive research, a timeline for the effects of DOMS has been established, as well as what muscle fibers are effected, and the effect that this has on individuals. However, there remains uncertainty as to why these events occur.

Several theories are centered on the idea that the swelling and inflammation of intracellular fibers caused by eccentric exercise is the cause for the soreness and stiffness felt in muscles in the days following the unaccustomed activity. The cause for this swelling, however, is under dispute. One of the theories reported by Yu et al. (2013) proposed that the stress that is placed on the muscle during the eccentric contraction causes the cell membrane in the muscle to become disrupted. This disruption causes proteins within the muscular network to be broken apart and a disorganization and sometimes complete tearing of Z-bands. These disruptions cause necrosis of fibers as well as a rush of inflammation to the muscles, which in turn aggravate the surrounding nerves, causing pain.

Additionally, both active and passive movement alter the already disrupted structures causing an increase in intramuscular pressure which causes the feeling that is described as soreness. However, in their attempt to provide data to support this hypothesis, Yu et al. (2013) disproved this theory that DOMS is caused by muscle fiber swelling when they discovered that the greatest increase in muscle fiber size and inflammation is seen at 7-8 days after exercise, while the greatest feelings of soreness reported at 2-3 days.
In an attempt to identify inflammation as the cause for the pain that accompanies DOMS, the effects of anti-inflammatory medications have been studied on their ability to reduce pain in the days that follow eccentric exercise. The overwhelming consensus was that the use of anti-inflammatory medication was not helpful in reducing pain in subjects when compared to a placebo (Hertel, 1997). These results agree with other research which concludes that, although inflammation is present, it is not responsible for the pain.

Similarly, Cleak and Eston (1992) studied the many effects of DOMS and their correlation to each other in the days following exhaustive eccentric exercise of the elbow flexors. These results also demonstrated no relationship between swelling and soreness rating, suggesting, as Yu et al. (2013) had, that the pain associated with DOMS is not due to the swelling of muscle fibers. Instead, they proposed the pain to be caused by mechanical damage to connective tissue, especially that of the musculotendinous junction. However, in Cheung et al.’s (2003) review of DOMS and its’ treatments, they credited the increased inflammation, especially within the myontendinous junction and perimuscular connective tissue, as the reason for decreased range of motion and stiffness.

Another commonly investigated cause of DOMS involves the disruption of sarcomeres, the contractile unit of the muscle. The theory of over-stretched or “popped” sarcomeres is consistent over several works. Weerakkody et al. (2001) describe this theory simply as the stretching of an actively contracting muscle that causes an unequal length change in only some of the sarcomeres. Sarcomere disruption is involved in many theories for DOMS in varying degrees.
In a review of exercise induced muscle damage prevention and treatment, Howatson and van Someren (2008) simplify the description of “popped” sarcomeres as a non-uniform lengthening of sarcomeres which prevents the sarcomeres from overlapping with other myofilaments. As a result, passive structures such as desmin, synemin and titin undergo more tension, causing them to “pop” and causes Z-band streaming. Desmin, synemin and titin help to hold the structures of Z-bands, as well as Z-band themselves together (Proske & Morgan, 2001). When these structures are placed under excessive tension from eccentric contractions, Z-band streaming occurs causing a decrease in a muscles ability to generate force and is believed to contribute to the dysfunction of DOMS (Howatson & van Someren, 2008).

Proske and Morgan’s (2001) explanation for DOMS portrays damage to sarcomeres as the main cause. Evidence suggests that during eccentric contractions, sarcomeres and half-sarcomeres become over extended and remain longer than those that were not damaged. In the case of half-sarcomeres, one half will become over stretched while the other will become shortened with contraction. This is thought to be caused by elastic element that extends for the length of the sarcomere and is hypothesized to have some part in muscles’ active length-tension relationship and contribute to the pain and dysfunction of the DOMS phenomenon, although the specifics of it have yet to be discovered.

This theory of “popped” sarcomeres and Z-band disruption is consistent across several publications and is currently believed to play at least a partial role in the loss of strength and passive muscle length in the days following eccentric exercise, although
more research is needed to fully explain it (Choi, 2014; Howatson & van Someren, 2008; Lieber & Friden, 2002; McHugh et al., 1999; Proske & Morgan, 2001; Weerakkody et al., 2001; Yu et al., 2013). Cleak and Eston (1992) proposed the idea that an excessive influx of Ca\(^{2+}\) due to damage done to the sarcoplasmic reticulum during exercise could be a possible explanation for the shortening of the muscle and decreased ROM. Other explanations for the pathology of DOMS involve the combination of multiple theories. Both Howatson and van Someren (2008) and Proske and Morgan (2001) propose the combination of both mechanical damage and the influx of either Ca\(^{2+}\) or inflammation resulting from that damage as the cause. According to Howatson and van Someren (2008) and Choi (2014), the “popped” sarcomeres and Z-band streaming may cause damage to the membrane of the muscle, or sarcolemma, which causes an influx of Ca\(^{2+}\) which causes a cascade of events which ultimately ends in fiber necrosis and then rebuilding in the days following.

Similarly, Proske and Morgan (2001) reported that it is a combination of an influx of Ca\(^{2+}\) and inflammation after the mechanical damage that accounts for the soreness. The overstretching of sarcomeres causes inflammation in the damaged muscle, which brings in inflammation’s chemical mediators such as macrophages, monocytes and prostaglandins which stimulate local pain receptors, accounting for the pain that accompanies DOMS. As stated previously, research has not supported inflammation as the main factor contributing to the symptoms of DOMS, but it may play a role in it.

In addition to these theories on the sometimes debilitating effects of DOMS, there are also several other theories that necessitate further research. Other chemicals that have
been named as being involved in DOMS include lactic acid and creatine kinase (CK). However, lactic acid build-up has since been shown to have no effect on DOMS since it has been proven to dissipate within one hour of exercise, and thus is no longer thought to be a cause of the soreness (Nelson, 2013). Although there is an increase in CK levels within the muscle in the days following exercise, there is no correlation between the timing of peak pain and peak CK levels, leading researchers to believe that it is not responsible for the soreness of DOMS (Lieber & Friden, 2002).

Another proposed reason for DOMS includes the idea of an alteration or even failure of the excitation-contraction (E-C) coupling process (Proske & Morgan, 2001). In short, the E-C coupling process involves the relationship between the electrical action potential that triggers a muscle contraction and the actual mechanical contraction of the muscle. McHugh et al. (1999) address this alteration as being due to the difference in calcium present after exercise induced muscle damage and the role of calcium in the E-C coupling process. However, Choi (2014) declared the E-C coupling process not to be responsible for the effects of DOMS due to its inability to explain the shift in the length-tension relationship within the muscle and the increase in passive tension that is seen with muscle damage caused by eccentric exercise.

While the definitive reasoning for why DOMS occurs remains unknown, many theories have been ruled out, such as lactic acid build-up. Several theories are still thought to be possible causes including swelling of intracellular fibers, “popped” sarcomeres and connective tissue disruption, Ca^{2+}, and inflammation. More research is
needed in order to find a conclusive reason or series of events that causes this phenomenon.

**DOMS Treatments**

The debate over the cause of DOMS has led to a gap in uniformity of the treatments that are applied and recommended by those treating patients with DOMS. Several studies on the effects of different treatments for DOMS focus on physiological and objective measures. However, in accordance with the purpose of this study, the following review of treatments effects will focus primarily on pain and soreness. Treatments can be applied in a variety of time frames, from before the eccentric exercises take place, during the exercises, or in the hours and days following the workout. Prophylactic treatments, or those done before the exercise, can include easing into activity and non-steroidal anti-inflammatories (NSAIDs) administered prior to exercise.

Perhaps the most effective way to reduce the severity of the symptoms of DOMS is to ease into activity. It has been shown that subsequent exercise sessions following the first of its kind have greatly reduced symptoms when compared to the first session (Howatson & van Someren, 2008; Nosaka & Aoki, 2011). This is known as the repeated bouts effect. Unaccustomed exercise that may have caused impairment and pain the first time, will have reduced affects after subsequent sessions. This is true even when several weeks separate the bouts, with little or no exercise in between. Less muscle damage and a decreased time to recovery is seen following the primary bout of exercise. The exact
mechanism for this decrease in symptoms is unknown. However, it is thought to be a combination of neural, mechanical and cellular adaptations.

The most effective prophylactic treatment for DOMS is to slowly increase intensity of workouts so as to allow the body time to adjust to the demands that exercise place on the body. However, often times this is not an option for competitive athletes. An alternative method of treatment that can be applied prior to workouts is the ingestion of NSAIDs. Studies have been done by several researchers in which all had similar results. Anti-inflammatories administered prior to an eccentric intense workout were not found to decrease pain, soreness, tenderness, or damage to muscles in the days following the exercise (Barnett, 2006; Cheung et al., 2003; Hertel, 1997; Howatson & van Someren, 2008). Additionally, research suggested that anti-inflammatories may be harmful when taken before or during the experience of DOMS. Other studies suggest that frequent use of NSAIDs may decrease the muscle’s ability to repair itself and have detrimental effects on adaptation to training (Barnett, 2006). Additionally, overuse of NSAIDs can increase the risk of stomach ulcers, kidney failure and liver damage (Cheung et al., 2003). Research does not support the use of NSAIDs taken prophylactically or after exercise for the treatment of DOMS.

One of the few methods of proposed recovery that occurs while the athlete is actively exercising is the use of compression garments worn on the exercising muscle groups. There are several hypothesized reasons for a possible decrease in damage to muscles. Researchers observed that the involved leg underwent a decreased range of motion at the hip and knee as compared to the control side, without a decrease in stride
length. Additionally, there is a decrease in the oscillation of the muscles that are covered by the compression sleeve, which is proposed to reduce the amount of mechanical stress that is placed on the tissue. A third reason involves the direct compression of the muscles as well as venous and lymphatic return and thermal changes when wearing compression garments. Authors attribute the decrease in muscle damage while wearing the sleeves to these factors, or a combination of several of them (Valle et al., 2013).

Several studies have examined participants wearing compression garments while exercising, after exercising, or both during and after exercise to see if it can aid in recovery. Cipriani, Yu and Lyssanova (2014) studied the effects of wearing a compression shirt during and after cycling and the benefits of it on post-ride recovery as perceived by the cyclist. The cyclists reported a perceived positive influence of the shirt on recovery. However, pain specifically was not addressed, and the outcome measures used have not been validated. Beliard et al. (2015) also concluded in a review of literature on the use of compression garments during exercise, that while it cannot be fully confirmed, there is a trend leaning toward the use of compression garments to decrease the effects of soreness.

Similarly, Duffield, Cannon and King (2008) reported lower perceived muscle soreness 24 hours post exercise in participants undergoing high intensity spring and plyometric exercises. However, they believe this to be caused by the placebo effect, and not the result of physiological changes brought on by wearing such garments. Kraemer et al. (2001) found a decrease in DOMS when participants wore compression sleeves continuously after completing eccentric exercise by promoting faster recovery of function.
and speeding the healing process. Although these studies somewhat support the use of compression garments while exercising, Duffield et al. (2008) found no benefit in wearing them. More research is needed in this area to find the exact cause or causes for the improvement in pain associated with DOMS when athletes wear compression garments.

After exercise, recovery methods can be separated into two groups: modalities and activities. For the purpose of this paper, “modality” will be defined as an intervention that is applied to the body involving the transfer of energy (Starkey, 2004), while activities will include movements that are done by the participants themselves in an attempt to attenuate or prevent the pain and soreness from DOMS. Common modalities used include electrotherapy, ultrasound, cryotherapy, and massage, and activities include stretching, cooldown, and exercise.

While there are a few regimens that are commonly practiced before or during a workout to combat the effects of DOMS, many of the treatments available are used in the days after eccentric exercise to decrease its effects. In a systematic review published by O’Connor and Hurley (2003), many of the modalities commonly used were reviewed to find the effectiveness in their ability to treat DOMS. The review included modalities such as ultrasound and TENS, as well as other types of electrical stimulation. While some of the research studies that were considered in the review supported the use of these modalities, the results of the search concluded that none of the mentioned modalities were effective in reducing pain, loss of range of motion, or loss of strength in individuals with DOMS.
Similarly, in a review of literature by Barnett (2006), no effect on pain was found when electromyostimulation was applied to damaged muscles when compared to those not treated with TENS. Howatson and van Someren (2008) and Cheung et al. (2003) both found mixed results on the effect of electrotherapeutic modalities on pain following eccentric exercise. The combination of the results of these studies support that electrotherapy is not a consistently reliable modality for the treatment of pain associated with DOMS.

Hydrotherapy for the treatment of DOMS commonly includes cold water immersion, or the combination of both hot and cold water in succession of one another. Cold water immersion is thought to reduce the inflammatory process during the acute stage of muscle trauma (Howatson & van Someren, 2008). However, many authors agree in their review of DOMS treatments that cold water immersion is not successful in reducing soreness ratings, and in some cases may even increase muscle pain (Barnett, 2006; Howatson & van Someren, 2008; O’Connor & Hurley, 2003; Torres et al., 2012). Additionally, aggressively cooling the muscles after exercise may decrease the effects of the training by delaying the adaptive process that allows for improvement (Barnett, 2006). Less research has been done on the effectiveness of contrast therapy, however the limited research that is available does not support the use of it for the purpose of reducing the soreness of DOMS.

In addition to these treatments, there are several other methods that do not require the use of modalities to reduce the effects of DOMS. Mancinelli et al. (2006) studied the effects of massage on the soreness that accompanies this condition. The results of this
study concluded that there are benefits to massage after an intense workout. These benefits included decreased soreness and an increased ability to tolerate pressure when compared to the control group. Many authors agree in their review of literature that although massage may not reduce all effects of DOMS, it does have a pain relieving effect (Barnett, 2006; Howatson & van Someren, 2008; O’Connor & Hurley, 2003; Torres et al., 2012).

The precise cause for the reduction of pain with massage is unknown. However, part of the effects are believed to be due to psychological reasons where massage reduced anxiety and worry. It may also reduce the secretion of cortisol, the stress hormone, and increase the secretion of serotonin and dopamine. All of these psychological changes are thought to decrease the perception of pain (Nelson, 2013). In the previously mentioned study, Mancinelli et al. (2006) hypothesized that the use of massage increased the time frame in which neutrophils were active, which plays a large role in inflammation. This prolonging of neutrophil activity could be the reason why they found that massage was effective. Another hypothesized reason why massage may be effective is the belief that it may help to move fluid and inflammation away from the site of the injured muscle, decreasing the damage (Ernst, 1998; Mancinelli et al., 2006; Tiidus, 1997). Frey Law et al. (2008) suggests that massage can cause an anti-nociceptor response, essentially sending more enjoyable stimulus to the brain to decrease the perception of pain. Although more research is needed to find the precise cause for why it is so, it is well established that massage decreases the pain of DOMS.
Stretching is theorized to decrease the symptoms of DOMS by either relieving the muscle spasms or by forcing the dispersion of edema that is caused by the damage done to the tissue (Cheung et al., 2003). However, several studies have been conducted surrounding the topic, and the results do not support the hypothesis that stretching is able to offer relief (Barnett, 2006; Cheung et al., 2003; Howatson & van Someren, 2008; O’Connor & Hurley, 2003; Torres et al., 2012). Regardless of whether the stretching occurs before or after exercise, no reduction of soreness was observed (Cheung et al., 2003; Torres et al., 2012). In some cases, static stretching was even shown to significantly increase soreness in participants who completed eccentric exercises (Cheung et al., 2003).

Another commonly used treatment, especially in team sports is the use of a “cool down” session after practices and games. These post-exercise cool down sessions can include a number of things, however, a study done by Dawson, Gow, Modra, Bishop and Stewart (2005) included the elements of jogging and stretching as well as a muscle shake down that was performed by a partner. Their results showed that athletes partaking in this short session after games showed a decrease in soreness when compared to a control group. These effects were shown to hold true at both 24 and 48 hours after the end of the game. However, these effects were not great enough to conclude that a post-game recovery session significantly reduced the effects of DOMS to a greater extent than next day recovery. Sufficient evidence is not available to make definite conclusions on the effectiveness of a post-activity cooldown on the effects of DOMS.
One of the most effective post-exercise treatments for alleviating soreness is more exercise (Cheung et al., 2003). However, the relief brought on by exercise is temporary and lasts only for as long as the exercise is happening, and soreness resumes soon after it is completed (Cheung et al., 2003; O’Connor & Hurley, 2003; Torres et al., 2012). The proposed reasons for this temporary relief include the breakup of adhesions in the damaged muscle, increased blood flow which aids in the removal of noxious waste, and an increase in endorphin release during activity (Cheung et al., 2003).

One of the newer, and minimally researched treatment modalities available for the treatment of DOMS is known as intermittent pneumatic compression (IPC). This modality uses the pressure from air compressing from distal to proximal on the involved extremity. The theory behind the use of this modality is that the compression will reduce swelling, remove waste, increase blood flow and reduce muscle soreness (Cochrane et al., 2013).

**Intermittent Pneumatic Compression**

Intermittent pneumatic compression (IPC) is a modality which is traditionally used to promote the venous and lymphatic return from extremities (Starkey, 2004). To use this modality, a nylon sleeve is placed around the involved limb, covering it from its most distal point to its proximal attachment to the trunk of the body. The sleeve consists of several chambers which inflate starting distally and progressing to the most proximal portion. This cycle repeats for the duration of the treatment. Pressure can be adjusted to customize the treatment for each individual patient, and usually ranges from 35mm Hg to
100 mm Hg depending on the extremity and treatment goals. However, it is generally
recommended that pressure not exceed 60-70 mm Hg due to increased reports of
ischemic skin damage at pressures exceeding that (Feldman et al., 2012). The duration of
a treatment can last anywhere from 20 minutes to multiple hours and can be repeated
several times a day if desired (Starkey, 2004).

Current Uses and Theories

Traditionally, IPC is used for the treatment of edema (both post-traumatic and
postsurgical), lymphedema (often caused by cancer or cancer treatments), venous stasis
ulcers and for the prevention of deep vein thrombosis (although the presence of a deep
vein thrombosis is contraindicated; Feldman et al., 2012; Starkey, 2004). The proposed
treatment effects of IPC for these conditions occur via several principles. The mechanical
pressure from the sleeves in a gradient fashion push the fluid away from the extremity
and back towards the heart (Starkey, 2004). Additionally, by compressing the area, fluid
is displaced and spread out over a larger area. When it is confined to one area, the ducts
become overwhelmed and are unable to absorb all of the matter necessary. However,
when edema is spread out over a larger area, more ducts are recruited for the uptake of
fluid and solid matter that is present in the fluid.

Pain reduction with IPC is thought to occur secondary to the aforementioned
removal of edema. Reducing the amount of edema allows for the return of normal range
of motion and function. Additionally, by reducing vascular clogging, arterial supply
increases which in turn increases delivery of oxygen and other nutrients to the tissues,
reducing ischemic pain (Starkey, 2004). The combination of these effects are thought to have the potential to decrease pain.

In addition to edema removal for lymphatic diseases and post-traumatic swelling, IPC is often used for recovery after intense bouts of exercise (Chleboun et al., 1995; Cochrane et al., 2013; Hanson, Stetter & Thomas, 2013; Sands, McNeal, Murray & Stone, 2015; Waller, Caine & Morris, 2005). According to the instruction manual put out by Normatec™, one of the leading manufacturers for IPC devices, the benefits of using this modality are similar to that of massage (Normatec™, Newton Center, MA). The use of their product is advertised as a “Recovery System” which can provide “temporary relief of minor muscle aches and pains” and “can also temporarily increase circulation in the area being massaged.”

With the use of the Normatec™ Recovery System, nylon sleeve are placed on the involved limb, and chambers fill sequentially from distal to proximal, as with other IPC modalities. However, the creators of Normatec™ describe this action as being similar to a kneading or stroking that moves the extrastitial fluid proximally, similar to that which is thought to occur during a massage. As stated previously, massage has been shown to be an effective treatment in providing significant relief for pain after eccentric exercise. If IPC is thought to have similar effects to that of massage, it may be effective in reducing soreness.

There has always been an emphasis on recovery by competitive athletes and their sports medicine staff (Hanson et al., 2013). One modality that has increased in popularity
for the purpose of recovery is IPC. Although IPC machines are seen in many clinics, gyms and athletic training facilities, few studies have been conducted on this modalities ability to decrease the effects of DOMS, and specifically pain associated with DOMS.

**Previous Research**

Research that has been conducted often assessed the ability of IPC to aid in the immediate recovery after exercise. One study conducted by Hanson et al. (2013) involved the use of IPC used immediately following an anaerobic Wingate cycling test. Participants were randomly assigned to one of three groups. Those in the first group underwent 20 minutes of IPC, while those in group two participated in an active cooldown, and a third group underwent a passive recovery for the designated time. Immediately after undergoing the designated treatment, participants blood lactate concentrations were taken and compared to both pre-treatment levels and between group levels. Results of this study indicated that IPC was more effective than passive recovery in reducing blood lactate concentration. IPC also had a similar effect on blood lactate levels when compared to active recovery, but no significant difference was noted (Hanson et al., 2013).

In a similar study conducted by Sands et al. (2015), elite athletes were examined to discover the effects of IPC on short-term pressure-to-pain threshold (PPT). Participants underwent their normal morning training session, followed by a pre-treatment PPT assessment. Those in the experimental group then underwent IPC treatment while those in the control group sat with the sleeves on, without any inflation, both lasting 15 minutes. Immediately after the treatment, PPT was again taken, as well as a delayed PPT
assessment following a second workout in the afternoon of that same day. Results of the study showed that more pressure was required to elicit a painful response in participants who had undergone the IPC treatment, when compared to those in the control group, both immediately after treatment and at the delayed PPT assessment. Although both studies, done by Hanson et al. (2013) and Sands et al. (2015) showed improvement in participant who used the IPC over those who did not receive the treatment, no measures were taken at 24 or 48 hours when DOMS is prevalent.

Other studies have looked at the effects that IPC has in the days following intense exercise. One such study conducted by Chleboun et al. (1995) consisted of six treatments with IPC, beginning the day of exercise and continuing for five consecutive days. The experiment examined the ability of multiple IPC treatments to decrease soreness, swelling, stiffness and strength in the exercised muscle. Results suggested that IPC is effective in temporarily decreasing swelling and stiffness caused by exercise. However, no effect of compression on strength was observed when compared to the control group. Additionally, soreness was not compared between the treatment and control groups, but is consistent with other literature in showing a peak in soreness on day two with a slow tapering following the second day (Chleboun et al., 1995).

Cochrane et al. (2013), in their study of the effect of IPC on muscle recovery, had participants perform eccentric exercises immediately followed by either IPC therapy or rest with no compression. IPC treatment also occurred at 24, 48 and 72 hours. Two weeks later, participants returned for the opposite treatment on their contralateral leg. Measures taken included blood creatine kinase level, single leg vertical jump height and peak
power, and isometric, concentric and eccentric muscular performance using an isokinetic dynamometer. All measures were assessed pre and post exercise, as well as at 24, 48 and 72 hours. Results of the study showed an ability for IPC treatment to attenuate muscle function assessed as strength loss, however, no different was seen between groups with the vertical jump or creatine kinase levels.

In a similar study, Waller et al. (2005) had participants complete shuttle runs on three separate occasions, all at least three days apart. Those in the first group then immediately underwent low pressure IPC for an hour, while a second group had high pressure IPC and a third rested with no compression for an hour. Following each session, participants were asked to complete a soreness diagram on which they circled the body part affected and rated the soreness on a scale from 1-10. Significant reductions in soreness were seen in those both in the high and low pressure group, while the greatest improvement was seen in those in the high pressure group. This was true for assessment at 1, 24 and 48 hours post exercise.

Although the body of evidence is insufficient to draw conclusive results about the effects of IPC and its ability to attenuate muscle recovery after workouts, previous research has found it to have positive effects. Variations in treatment duration, timing after a workout and pressure can account for some of the inconsistencies among research. More studies are needed to conclude the effects and limitations of IPC as well as to define treatment guidelines.
APPENDIX C

EXTENDED METHODS
Appendix C1. Informed Consent

UNIVERSITY OF NORTHERN IOWA
HUMAN PARTICIPANTS REVIEW
INFORMED CONSENT

Title: The Effect Intermittent Compression & Therapeutic Tape on Delayed Onset Muscle Soreness

Name of Investigators: Ashley Lindahl, Aaron Krejci, Dr. Todd Evans, Dr. Kelli Snyder

Invitation to Participate: You are invited to participate in a research project conducted through the University of Northern Iowa. The University requires that you give your signed agreement before participate in this project. The following information is provided to help you make an informed decision about whether or not to participate.

Nature and Purpose: We are investigating the effects of an inflatable arm sleeve and therapeutic taping on delayed onset muscle soreness (DOMS) that occurs after intense excise. You have been invited to participate in this study because you are between the ages 18-30, healthy, and physically active. If you volunteer to participation in this study, you will be asked to do the following:

1. **Day 1:** There are four steps parts to the first session. On Day 1, you will be asked to:
   i. Fill out a health history questionnaire to assure your safety for this study.
   ii. Perform three bicep curls with a 5lbs, then mark a line to show your pain level.
   iii. Under our supervision and directions, perform bicep curls slowly until your arm is completely fatigued.
      - This will involve performing a total of 5 sets of 10 repetitions of curls.
      - Beginning with your 1 rep max weight, each rep will include you slowly lowering the weight for a count of five seconds.
      - Between each set you will have 1 minute of rest.
      - If at any time you are unable to perform the slow-motion lowering with the weight, the weight will be decreased by 5lbs until you are able to complete the motion for five seconds.
      - After the 5th and final set, then mark a line to show your pain level.
   iv. After the arm curls, wear an inflatable compression sleeve to your arm for 30 minutes.
      - (Total Day1 time: *Approximately 1 hour*)

2. **Day 2:** You will return to our lab the next day to complete a pain survey. (Time: *Approximately 5 minutes*)

3. **Day 3:** There are three steps to the third session. (Time: *Approximately 25 minutes*)
   i. We will first ask you to complete the pain survey again
   ii. If your arm is still sore, we will ask you to perform 3 sets of arm curls, for 3 repetitions in each set, with little or no weight, while wearing one of three taping conditions. The three tape conditions include two different tape applications and one condition with no tape. The tape applications will include strips pf tape applied over your biceps region.
      You be asked to rate you pain after each of the sets of arm curls.
   iii. Finally, we will ask a few questions regarding your opinion of the tape and compression sleeve.
Appendix C1. Informed Consent (Continued).

**Important requirements for you to consider:**

- Participation in our study will make your bicep muscle sore; probably for 3 – 5 days.
- We anticipate that your participation will take approximately 1.5 hours over the three sessions.
- You might not be able to participate if you have (or had): heart issues, rhabdomyolysis, sensitivity to therapeutic tape, negative response to weight lifting, recent arm injury/surgery, open wound on your arm(s), or a skin infection on your arm. We will perform a history screening before you begin to determine your eligibility.
- We are also asking that you
  1. Do not exercise between the Day 1 and Day 3 session.
  2. Do not use any other pain relieving techniques such as:
     - Pain relieving medications such as ibuprofen or aspirin
     - Applying hot or cold packs to the affected area for the duration of this study
- We may withdraw you from this research if your eligibility status changes during the study (e.g. Illness, begin additional weight lifting, take pain medication, etc.)

**Discomfort and Risks:**

- You will experience mild to moderate pain/soreness from the bicep curl protocol. This biceps pain may be uncomfortable and may be similar to discomfort you may feel after beginning a new physical activity/exercise. This pain is often described as achy, tender, or annoying.
- There are treatments used in this study which utilize therapeutic tape. If you are sensitive to tape or other adhesives on your skin, you might develop redness on your skin after the treatment.
- The compression treatment and tape treatments should not be uncomfortable or painful AND you can discontinue your participation at any time.
- If your health status requires further medical consultation, the researcher is obligated to refer you to the appropriate physician. If you do become sore, the researcher and university are not obligated to provide you with any other treatment. Any costs for injuries or other medical attention are solely your responsibility.

**Benefits and Compensation:** Although your participation may be of no direct benefit, you will be entered in a drawing to win 1 of 4 $20 pre-paid VISA cards (there will be 20 participants). At the end of the study, all of the participants’ identifying codes will placed in a hat. The last participant of the study will draw four codes out of the hat. The primary investigator will then match the codes with the participant’s information and notify them of their winnings by email or phone. If you do not complete the entire session, you will still be eligible for the drawing.

**Confidentiality:** Information obtained which could identify you will be kept confidential. The summarized findings with no identifying information may be published in an academic journal or presented at a scholarly conference.

**Right to Refuse or Withdraw:**

Your participation is completely voluntary. You are free to withdraw from participation at any time or to choose not to participate at all, and by doing so, you will not be penalized or lose benefits to which you are otherwise entitled.
Appendix C1. Informed Consent (Continued).

Questions: If you have any questions or concerns about your rights as a research participant related to this study or the study itself, now or in the future, please contact Ashley Lindahl (319-354-0941), Aaron Krejci [(507) 440-6958, krechtia@uni.edu] or Todd Evans [(319)273-6152 todd.evans@uni.edu]. You can also contact the office of the IRB Administrator, University of Northern Iowa, at 319-273-6148, for answers to questions about rights of research participants and the participant review process.

Agreement: Include the following statement:

I am fully aware of the nature and extent of my participation in this project as stated above and the possible risks arising from it. I hereby agree to participate in this project. I acknowledge that I have received a copy of this consent statement. I am 18 years of age or older.

(Signature of participant) __________________________  (Date)

(Printed name of participant)

(Signature of investigator) __________________________  (Date)

(Signature of instructor/advisor) __________________________  (Date)
Appendix C2. Health History Questionnaire.

Participant Number: __________

Health History Form

PLEASE DO NOT PUT YOUR NAME ON THIS PAPER

Ht. ___ feet ___ inches  Wt. ___ pounds  Age: ___  Gender: M  F

1. Does the statement below best describe your physical activity level?  Yes  No
   I engage in moderate-intensity aerobic physical activity for a minimum of 30
   minutes a day, 5 days a week or a vigorous intensity aerobic activity for a
   minimum of 20 minutes a day, 3 days a week.

2. Are you currently participating in a weight training program?  Yes  No

3. Do you incorporate bicep curls in your workout?  Yes  No

4. Are you sensitive or allergic to therapeutic tape of other types of adhesives?  For
   example: do you get a rash or itchy skin from tape or band aids?  Yes  No

5. Have you ever had a severe adverse effect when weight lifting? (More severe than
   soreness)  Yes  No

6. Have you ever been diagnosed with Malignancy, rhabdomyolysis, infection of the
   skin or joint, or a cardiac disease?  Yes  No

7. Have you had an injury or surgery to your upper extremity in the past 6 months?
   (ie. shoulder, elbow, arm, wrist, hand)  Yes  No

8. Do you currently have any other injury or condition that limits your activity level?  
   Yes  No

9. Do you currently have pain in your arms?  Yes  No
Appendix C2. Health History Questionnaire (Continued).

If you answered “YES”, to any questions, or you are unsure about any of your answers, you will be asked for more detail to help us determine if it is safe for you to participate in our study.
Appendix C3. Post-Compression Intervention Questions

Participant Number:___________
Arm (R or L):_______________

Post-Compression Intervention Questions
1. Do you feel as if the compression sleeve impacted the pain you felt from the arm curls?
2. Do you have any comments or questions about the compression device?
Appendix C4. Numeric Pain Rating Scale

Participant Number: ______________
Arm (R or L): ______________

Please circle or “X” the number on the scale that represents the intensity of the pain you experience at this time.

NO PAIN                                                                 WORST PAIN
POSSIBLE
APPENDIX D

ADDITIONAL MATERIAL
Appendix D: Classroom Recruiting Script

(*Instructors will not be present)

Hello Everyone,

For those that don’t know me, my name is ____. I’m an athletic training master’s student here at UNI and I am here to invite you to participate in my research study.

I am studying the effects of different modalities on pain; specifically, the effects of a new type of compression sleeve and different types of taping techniques. You might have seen these being used already in the athletic training room.

If you participate in my study it will involve 3 sessions with me in the athletic training research lab.

1. Day 1: On the first day, probably a Sunday, I will ask you to:
   a. Complete a series of arm curls to the point of nearly exhausting your biceps. The purpose of these curls is to induce delayed onset muscle soreness; you’ve probably heard it called DOMS. This is what you feel a few days after you begin working out and you are very sore for the next several days. So if you participate, I will be asking you to give yourself DOMS to your biceps.
   b. Complete a pain scale several times
   c. Wear the inflatable arm sleeve for 30 minutes before you leave the lab.
2. On Day 2, I will ask you to return to the lab to repeat the pain scale.
3. On Day 3, I will ask you to complete the pain scale again. If your arm is still sore, I will then apply three different taping techniques to your arm, ask you to perform 3 curls with 5 lbs while wearing the tape, then rate your pain for each technique.
4. Your total approximate time commitment over the three session is 1.5 hours.

Please note, if you agree to participate:
- You will be asked not to participate in any exercise including weight lifting and cardio activity during the duration of this study, approximately 3 days.
- You will also be asked not to use any other pain relieving techniques. This could include taking pain relieving medications such as ibuprofen or aspirin as well as applying hot or cold packs to the affected area for the duration of this study.

If you are interested in participating, please write your name, number and email address on the paper I distributed and I will contact you to set up the first session.

Thank you!
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