THE EFFECT OF LOW-LEVEL LASER THERAPY ON DELAYED ONSET MUSCLE SORENESS WHEN DELIVERED PRE- AND POST- ECCENTRIC EXERCISE

A thesis submitted to the Kent State University College of Education, Health, and Human Services in partial fulfillment of the requirements for the degree of Master of Science

By

Tiffany A. Kobordo

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Delayed onset muscle soreness (DOMS) is a set of symptoms including muscle soreness and a decrease in muscle function and strength that present 24-48 hours post eccentric or unaccustomed-to exercise. Low-level laser therapy (LLLT) has been shown to be effective in attenuating DOMS symptoms. The purpose of this study was to determine the effectiveness of LLLT in the management of DOMS when delivered pre- and post- exercise protocol.

Twenty-seven male volunteers were recruited and randomly assigned into one of three groups (LLLT, sham, control). All subjects underwent an eccentric exercise protocol of their elbow flexors. Pain, muscle function, and muscle strength were assessed prior to, 24, and 48 hours after the exercise protocol. Subjects received their treatment intervention before, immediately after the exercise protocol, and 24-hours after the exercise protocol. Subjects in the sham group had identical set-up as those in the LLLT group; however they did not receive an active LLLT treatment. The control group sat quietly and did not receive treatment. There was no significant group by time interactions for pain, function, or strength. There was also no significant time main effect for function. There was a significant time main effect for pain and strength. To our knowledge, this study was the first to explore the effects of LLLT and DOMS when
delivered both pre- and post- eccentric exercise. Although LLLT was found ineffective for treating those symptoms of DOMS at our chosen parameters, previous literature has shown that LLLT has promising effects on attenuating symptoms of DOMS.
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CHAPTER I
INTRODUCTION

Delayed onset muscle soreness (DOMS) is a common phenomenon experienced by individuals of all ages, including both the elite and novice athlete. DOMS can be broadly defined as a set of symptoms within the skeletal muscle including pain, loss of strength and muscular function, and inflammation that present 24 hours after performing an unaccustomed-to or high-intensity exercise (Armstrong, 1984; Jones, Newham, & Round, 1986; Talag, 1973). Although DOMS has been linked to all types of muscle contractions, eccentric contractions have been found to elicit more intense DOMS symptoms (Clarkson, Nosaka, & Braun, 1992; Jones et al., 1986; Talag, 1973). Once these symptoms appear, they tend to intensify over the following days peaking at 48 hours and then taking 7-10 days or longer to gradually subside (Clarkson et al., 1992; Smith, 1992). Although the exact mechanism behind DOMS is unknown, it seems that muscle damage (Hough, 1902), connective tissue damage (Stauber, 1989), inflammation (Fridén, Sfakianos, & Hargens, 1986), and the efflux of enzymes into the tissues (Gulick, Kimura, Sitler, Paolone, & Kelly, 1996) may all play a role in the onset of symptoms.

Muscle function is affected during DOMS and may be due to joint range of motion decrements (Chleboun, Howell, Conaster & Giesey, 1998; Clarkson et al., 1992; Gulick et al., 1996; Nosaka & Clarkson, 1996), pain during active extension (Cleak & Eston, 1992; Gulick et al., 1996), and significant decreases in muscle strength (Alemany, Delgado-Diaz, Matthews, Davis, Kostek, 2013; Gulick et al., 1996; Nosaka & Clarkson 1996; Willoughby, Vanenk, & Taylor, 2003). The symptom of pain experienced during
DOMS is typically initially concentrated in the distal portion of the affected muscle (Armstrong, 1984; Newham, Mills, Quigley, & Edwards, 1983; MacIntyre, Reid, & McKenzie, 1995) and within 24-48 hours, the pain progressively spreads throughout the muscle belly (Newham et al., 1983). The strength decrements associated with DOMS are typically very significant and can be slow to recover. Maximal isometric strength has been shown to decline significantly when associated with DOMS (Gulick et al., 1996; Sakamoto, Maruyama, Naito, & Sinclair, 2010; Zainuddin, Sacco, Newton, & Nosaka, 2006). Zainuddin et al. (2006) noted a significant decrease in isometric strength of 8-20% over the course of four days after exercise; even after performing light concentric exercise each day to temporarily alleviate the pain associated with DOMS. Gulick et al. (1996) explored both isometric and isokinetic muscle strength and found they both decreased significantly over time, and it took approximately 72 hours to return to within 79%-90% of isokinetic baseline measures for strength. Such a long recovery time may indicate that the muscular structures damaged during exercise, such as the sarcoplasmic reticulum and connective tissue, may be slow to repair (Clarkson & Tremblay, 1988).

Traditional treatments for DOMS include cryotherapy, stretching, low-intensity exercise, and massage; however these treatments have not been proven to be absolutely effective in the management of DOMS (Torres, Ribeiro, Alberto Duarte, & Cabri, 2011; Cheung, Hume, & Maxwell, 2003). Low-level laser therapy (LLLT) is a modality that has been researched for the management of DOMS (Baroni et al., 2010; Craig, Barlas, Baxter, Walsh, & Allen, 1996; Craig, Barron, Walsh, & Baxter, 1999; Douris et al., 2006). LLLT is a type of low-power non-thermal light therapy applied to tissues in the
range of 1mW-500mW (Huang, Chen, Carroll, & Hamblin, 2009; Enwemeka et al., 2004). LLLT is used for tissue regeneration, inflammation reduction, and pain relief (Huang et al., 2009; Reddy, 2004; Borsa, Larkin, & True, 2013). LLLT has shown positive effects in the treatment of wounds (Caetano, Frade, Minatel, Santana, & Enwemeka et al., 2009; Rodriguez, 2013) osteoarthritis (Bertucci & Grey, 1995; Ozdemir, Birtane, & Kokino, 2001), tendonopathies (Bjordal, Johnson, Iversen, Aimbire, & Lopes-Martins, 2006; A. Stergioulas, Stergioula, Aarskog, Lopes-Martins, & Bjordal, 2008), neck pain (Chow, Heller, & Barnsley, 2006; Gur, Sarac, Cevik, Altindag, & Sarac, 2004; Konstantinovic et al., 2010), back pain (Basford, Sheffield, & Harmsen, 1999; M. Jovicic, Konstantinovic, Lazovic, & V. Jovicic, 2012), peripheral nerve injuries (Rochkind et al., 2007), muscle fatigue (Leal Junior et al., 2010, 2011), and strokes (Lampl et al., 2007; Zivin et al., 2009). Although the mechanism of LLLT is not fully understood, it is known that LLLT produces a photochemical effect where the absorbance of light causes a chemical change in tissues (Huang et al., 2009; Reddy, 2004).

There is limited research conducted on humans evaluating the effect of LLLT on the symptoms associated with DOMS (Baroni et al., 2010; Craig et al., 1996; Craig et al., 1999; Douris et al., 2006). This research has shown conflicting results, which may be attributed to the wide disparity of LLLT parameters and time of application (pre- or post-DOMS inducing protocol). Craig et al., (1996 & 1999) applied LLLT post DOMS protocol at a low-intensity and found LLLT to produce no significant effect on DOMS symptoms. However, another study found LLLT applied post DOMS protocol at a higher intensity than Craig et al. (1996 & 1999) significantly reduced pain at 48 hours
post protocol (Douris et al., 2006). One study also found that when applied pre-DOMS protocol, LLLT effectively attenuated the decrease in muscle force as measured through maximal voluntary contractions associated with DOMS (Baroni et al., 2010).

**Statement of Problem**

DOMS is known to occur following high-intensity activity and can have a detrimental effect on performance. This can be problematic to athletes who desire a quick recovery between bouts of activity. We currently do not know how to best treat DOMS, and typically revert to the conventional treatments such as ice, massage, and active recovery even though there have been contradictory results in the literature on the effectiveness of these treatments. LLLT is one modality that has shown some promising results in the literature as an effective treatment for symptoms of DOMS. However, the effect of LLLT incorporated both pre-and post-DOMS protocol is unknown.

**Purpose Statement**

The purpose of this study is to determine the effectiveness of LLLT in the management of DOMS symptoms when delivered both pre- and post- exercise protocol.

**Research Questions**

1. Is LLLT (applied pre-and post-DOMS protocol) effective in the treatment of DOMS?
   a. Is LLLT effective in decreasing pain associated with DOMS?
   b. Is LLLT effective in promoting a quicker restoration of muscle strength decrements associated with DOMS?
c. Is LLLT effective in promoting a quicker restoration of muscle function post-DOMS protocol as measured by the Reach Board Testing Station?

**Research Hypotheses**

1. Those receiving LLLT (applied pre-and post- DOMS inducing protocol) will experience the following positive effects:
   a. A decrease in pain associated with DOMS
   b. A quicker restoration of muscle strength decrements
   c. A quicker restoration of muscle function

**Operational Definitions**

Delayed onset muscle soreness (DOMS): A set of symptoms including pain or discomfort felt primarily within the skeletal muscle that arise 24-48 hours after performing an unaccustomed-to or high-intensity exercise, particularly one involving eccentric contractions (Talag, 1973; Jones et al., 1986; Clarkson et al., 1992).

DOMS inducing protocol: For this study, we used modified methods from Hurley, Hatfield, & Riebe (2013). Subjects performed eccentric contractions of the elbow flexor muscles to elicit DOMS. Subjects performed 5 sets of eccentric contractions using a weight that was 60% of their 1RM.

Low-level laser therapy (LLLT): A type of low-power non-thermal light therapy applied to tissues in the range of 1mW-500mW (Huang et al., 2009; Enwemeka et al., 2004).
Muscle function: Muscle function was determined by the time it took the subject to complete hitting all of the targets in the Reach Board Testing Station. The Reach Board Testing station is a custom built table with a start button and four targets that require varying amounts of elbow extension. For right arm dominant subjects, the first target is positioned 34 cm away from the start button at a 45° angle to the right, the second target is 28 cm directly in front of the start button (further from the subject), the third target is positioned 25 cm away from the start button at a 45° angle to the left, target 4 is positioned 42 cm from the start button at a 90° angle on the left. For left arm dominant subjects, the targets are aligned similarly but with target 1 starting on the left, and so on. The Reach Board Testing Station records the time taken for subjects to hit the sequence of targets in a particular order as quickly as possible in seconds.

Pain: Pain is the subjective feeling of discomfort. It was determined by the distance of the mark on the Visual Analog Scale (VAS).

Strength: Strength was determined by the amount of isometric force (in pounds) produced by the elbow flexors as measured by handheld dynamometer with the elbow in 90° of flexion.

**Assumptions**

The following assumptions were made for the purpose of this study:

1. All subjects reported honestly their health history.
2. All subjects refrained from performing any self-treatments for their DOMS symptoms including, but not limited to, the use of NSAIDS, acetaminophen, ice, massage, heat, etc. during the course of the study.
3. All subjects refrained from exercising during the course of the study.

4. All subjects provide maximum effort when performing maximum voluntary isokinetic eccentric contractions.

**Delimitations**

1. The subject population was limited to healthy physically active males over 18 years old.

2. The laser parameters administered were 250 Hz at 4 sites for 4 minutes per site for the prophylactic LLLT treatment (roughly 30J/cm² per site), and 1000 Hz delivered in a sweeping motion across the biceps and brachioradialis for 3 minutes for the post treatment. We do not know how the effects would change when using different LLLT parameters.

3. The muscle group undergoing the DOMS protocol and receiving the LLLT was limited to the elbow flexors.

**Significance of the Study**

Any individual may experience DOMS following high-intensity physical activity, which results in significant pain and muscle damage, leading to reduced muscle function. While many methods are used in an attempt to alleviate the symptoms of DOMS, no method has been consistently proven effective. It is important to discover an effective treatment for the pain and reduction in strength associated with DOMS because the alterations in muscle function could lead to an individual having to overcompensate. This overcompensation could ultimately lead to a higher risk of injury to the already weakened
musculature (Smith, 1992; Cheung et al., 2003). Determining an effective treatment of DOMS will aid athletes in high demand, low-recovery time situations could see an increase in recovery time, decreased risk of injury, and increase in muscular function.
CHAPTER II
REVIEW OF RELATED LITERATURE

Muscle Physiology

Skeletal muscle is a voluntary contractile tissue composed of both muscle and fibrous connective tissue (Saladin, 2012, p. 403). Skeletal muscle tissue contains the contractile proteins actin (thin filaments) and myosin (thick filaments) that produce muscle contractions (Saladin, 2012, p. 405). During contractions, dark A bands and light I bands alternate within the striations, with A bands bisected by lighter H bands and I bands bisected by narrow Z lines which serve as anchors for the elastic and thin filaments (Saladin, 2012, p. 406). In concentric muscle contraction, the Z lines slide closer to one another, tugging on the sarcolemma in order to accomplish shortening (Saladin, 2012, p. 407). During lengthening of a muscle, which occurs in joint extension, the Z lines separate from one another and the collagenous components resist extreme stretching in an effort to protect muscular injury (Saladin, 2012, p. 403). During eccentric contractions a muscle is lengthening as it maintains tension, while in concentric contractions the muscle is shortening while maintaining tension (Saladin, 2012, p. 422).

Anatomy of the Elbow Flexors

The muscles that produce flexion of the elbow include the brachialis, biceps brachii, and brachioradialis. The brachialis is the prime mover of the elbow and originates on the anterior distal half of the humerus and inserts on the coronoid process of the ulna (Saladin, 2012, p.350). The biceps brachii not only assists in elbow flexion but also aids in forearm supination, slight shoulder flexion, and stabilization of the head of
the humerus against the glenoid cavity (Saladin, 2012, p.350). The long head of the biceps brachii originates on the superior margin of the glenoid cavity while the short head originates on the coracoid process of the scapula (Saladin, 2012, p.350). The two heads merge into a central muscle belly and the distal tendon inserts on the radial tuberosity and the fascia of the forearm (Saladin, 2012, p.350). The brachioradialis also minimally aids in elbow flexion, as it originates on the lateral supracondylar ridge of the humerus and inserts laterally on the styloid process of the radius (Saladin, 2012, p.350). It is generally known that the biceps brachii muscle fiber composition consists mainly of type II muscle fibers (Klein, Marsh, Petrella, & Rice, 2003) which have a higher susceptibility to exercise-induced muscle damage than do type I fibers (Fridén & Lieber, 2001).

**Delayed Onset Muscle Soreness**

**Defined**

Delayed onset muscle soreness (DOMS) is broadly defined as a set of symptoms including pain or discomfort felt primarily within the skeletal muscle after performing an unaccustomed-to or high-intensity exercise (Armstrong, 1984; Jones et al., 1986; Talag, 1973). Although DOMS has been linked to any type of muscle activation, increased signs and symptoms have been linked to eccentric contractions (Clarkson et al., 1992; Jones et al., 1986; Talag, 1973). Some common signs and symptoms associated with DOMS include muscle pain, decreased range of motion (ROM), and decreased strength (Smith, 1992). Unlike transitory muscle soreness felt either during or immediately following exercise-inducing muscle damage (EIMD), DOMS symptoms typically appear
around 24 hours post-exercise, peak at 48 hours and gradually subside 7-10 days post-
activity (Clarkson et al., 1992; Smith, 1992).

Many researchers have explored DOMS inducing protocols and have found
eccentric muscle contractions to produce more damage and result in a higher severity of
DOMS symptoms than concentric muscle contractions (Armstrong, 1990; Fitzgerald,
Rothstein, Mayhew, & Lamb, 1991; Morgan & Allen, 1999; Nosaka & Newton, 2002;
Talag, 1973; Willoughby et al., 2003). In subjects performing either concentric or
eccentric quadriceps exercises, the eccentric group reported greater muscle soreness and
pain at 24 hours post exercise compared to the concentric group (Fitzgerald et al., 1991;
Willoughby et al., 2003). Those performing eccentric contractions also presented with
significantly reduced dynamic muscle strength (Willoughby et al., 2003). Morgan and
Allen (1999) concluded in their review on stretch-induced muscle damage that instability
of the sarcomeres following eccentric exercise can be a contributing factor to the severity
of symptoms.

Mechanisms of DOMS

Although the signs and symptoms of DOMS have been well established in the
literature, the mechanism that results in DOMS is currently unknown. There have been
many proposed theories in the literature to explain the mechanisms behind DOMS
(Cheung et al., 2003). The 2003 systematic review by Cheung et al. (2003) outlines the
following commonly accepted theories: muscle damage theory, connective tissue
damage theory, inflammation theory, and enzyme efflux theory.
The muscle damage theory was first introduced by Hough (1902) and purports that DOMS occurs due to structural and mechanical damage within the muscle tissue, particularly along the Z-lines, following eccentric exercise (Armstrong, 1984; Fridén, Sjöström, & Ekblom, 1981; Jones et al., 1986). This structural damage causes nociceptors in the muscle to be stimulated. This theory is supported by the observed increase in blood enzymes, such as creatine kinase (CK) following exercise, which leaks into the bloodstream following eccentric-exercise (Magal et al., 2010). Magal et al. (2010) discovered a significant increase in CK at 24 hours post-DOMS inducing protocol to the vastus lateralis. Willoughby et al. (2003) noticed significant increases in CK levels at 6, 24, and 48 hours in those who underwent eccentric exercise when compared to those who performed concentric muscle contractions. In contrast, Nosaka and Clarkson (1996) did not note any significant increase in CK levels immediately and five days after a DOMS inducing protocol of the elbow flexors and suggests that CK levels do not correlate with muscle damage parameters. Ultimately, the peak in CK levels does not always correspond to peak muscle soreness, indicating that this theory can only partially explain the mechanism of DOMS.

The connective tissue damage theory describes that the symptoms of DOMS are related to the damage done to the connective tissue surrounding the muscle fiber types. Due to the composition of fast twitch muscle fibers (Type II), they may be more susceptible to stretch-induce injury (Stauber, 1989) and consequently, may produce more muscle soreness due to excessive connective tissue strain (Hough, 1902). Research has shown significantly more myofibril damage in fast twitch muscle fibers following
eccentric exercise (Fridén et al., 1983; Jones et al., 1986; Magal et al., 2010). Similarly, Magal et al. (2010) found those with predominantly fast twitch muscle fibers experienced more pain at 48 hours post eccentric exercise-induced muscle damage.

The inflammation theory focuses on the accumulation of fluid in the injured muscle tissue and the subsequent increase in pain. Fridén et al. (1986) suggests that the increase in osmotic pressure can lead to the stimulation of mechanoreceptors and nociceptors producing pain within the injured tissue. Another argument is that within the fluid is the accumulation of macrophages that produce nerve sensitizing substances stimulating type III and IV nerve endings, resulting in pain at 24 and 48 hours (Armstrong, 1984; Smith, 1991). The noxious chemical substances that accumulate within the muscle tissue include bradykinin, 5-hydroxytryptamine, histamine, and potassium (Fock & Mense, 1976) which may bind to receptor sites on free nerve endings (Hiss & Mense, 1976) contributing to the sensation of pain (Armstrong, 1984). Kanda et al. (2013) conducted a recent study on the gastrocnemius to determine the presence of markers of muscle damage and inflammation following DOMS induction. They found mobilization of neutrophils into the blood circulation several hours after the DOMS inducing protocol, and noted that neutrophils were the most prominently present inflammatory mediators (Kanda et al., 2013).

Gulik and Kimura (1996) proposed the enzyme efflux theory which focuses on the accumulation of enzymes, specifically calcium within the damaged muscle tissue. Calcium accumulation in the damaged muscle can result due to the disruption of the sarcolemma (Armstrong, 1990). This increased amount of calcium within the muscle
tissue initiates muscle degeneration which ultimately leads to the chemical stimulation of pain nerve endings (Armstrong, 1984; Armstrong, 1990). Though many individual theories have been proposed, it is the general consensus among researchers that not one theory is solely responsible for the mechanism behind DOMS, and instead is more likely a combination of theories and events (Armstrong, 1984; Cheung et al., 2003). Further research needs to be conducted to accurately determine what causes DOMS.

**Eccentric DOMS Protocol for the Elbow Flexors**

As previously mentioned, DOMS has been associated more specifically with eccentric muscle contractions than concentric contractions (Armstrong, 1990; Fitzgerald et al., 1991; Morgan & Allen, 1999; Nosaka & Newton, 2002; Talag, 1973; Willoughby et al., 2003). DOMS symptoms are also localized to the area of the specific muscle or muscle group subjected to high-intensity eccentric exercise. One published protocol that has been found to induce DOMS symptoms in the elbow flexors over the course of 96 hours is Hurley et al. (2013). Hurley et al. (2013) first determined the subjects’ 1 RM for bicep curl on the preacher bench of their non-dominant arm. Once the 1 RM was determined, subjects performed 5 sets of preacher bench bicep curls with a weight equal to 75% of their 1 RM. During the first four sets subjects were asked to perform 10 bicep curls. During the fifth set, subjects were asked to complete as many repetitions as possible.

**DOMS Effect on Pain, Muscle Function, & Neuromuscular Control**

Due to today’s athletic demands in higher levels of competitions, many athletes have a reduced time for recovery and have to perform either in practice or competition
within 24-48 hours post high-intensity exercise. Articles investigating the time course changes of exercise-induced muscle damage found that DOMS symptoms begin to appear 24 hours post-exercise and subsequently, during this time, muscle function is greatly impaired (Clarkson et al., 1992; Cleak & Eston, 1992; Gulick et al., 1996). The DOMS symptoms contributing to overall muscle function impairment typically include: increased pain perception, inflammation, ROM decrements, and decrease in muscle strength.

The sensation of muscle soreness that accompanies DOMS can range from mild discomfort to severely debilitating pain (Armstrong, 1984). Many researchers have assessed the perceived muscle soreness associated with DOMS by using a numeric grading scale called the visual analog scale (VAS) (Anderson et al., 2013; Gulick et al., 1996; Kanda et al., 2013; Nosaka & Newton, 1996). The VAS has been validated as a reliable tool to measure human pain (Lee & Kiekchefer, 1989; Price, Mcgrath, Amir, Buckingham, 1983). In a DOMS study where pain was assessed over the course of four days in the calf musculature of healthy males, muscle soreness was present at 24 hours post-eccentric DOMS protocol, increased significantly at 48 hours and 72 hours, and then decreased slightly at 96 hours, though at 96 hours the pain remained significantly elevated above baseline (Kanda et al., 2013). These are similar to results by Nosaka and Newton who evaluated pain during palpation with a VAS scale, and who also noted increases in pain at 24 hours, though they saw a peak at day 2 post-DOMS protocol of the elbow flexors (Nosaka & Newton, 2002). Overall, perceived pain and soreness within the skeletal muscle, as measured by either the VAS or McGill Pain Questionnaire (MPQ),
has been shown to increase 24-48 hours post-exercise (Willoughby et al., 2003) and gradually subside over the course of 8-10 days (Cleak & Eston, 1992; Clarkson et al., 1992). Pain and tenderness is typically initially concentrated within the distal or myotendinous regions of muscle (Armstrong, 1984; Newham et al., 1983; MacIntyre et al., 1995) and then gradually becomes more diffuse throughout the muscle belly by 24 to 48 hours post-exercise (Newham et al., 1983).

Muscle function impairment can result from a decrease in joint ROM (Cheung et al., 2003). Previous research has shown decrements in joint range of motion to be associated with DOMS (Chleboun et al., 1998; Clarkson et al., 1992; Gulick et al., 1996; Nosaka & Clarkson, 1996). The largest decrements are associated with active range of motion (AROM) of joint extension (Gulick et al., 1996). Increases in muscle swelling or inflammation associated with DOMS has been linked to passive muscle stiffness (Chleboun et al., 1998), though results by Nosaka & Clarkson (1996), suggest inflammation may not be the cause. Nosaka & Clarkson (1996) saw a significant decrease in resting angle range of motion (RANG) of 30° immediately post DOMS inducing exercise of the elbow flexors and only began to see gradual ROM recovery after day 3, the same day in which inflammation was at its peak (at days 3-6 post-exercise). Two studies have demonstrated that subjects suffering from DOMS experience significant pain during active extension (Cleak & Eston, 1992; Gulick et al., 1996). Overall, it is unclear whether inflammation or muscle pain is the cause of ROM decrements associated with DOMS.
In addition to ROM decrements, reduced joint proprioception as well as an inaccurate estimation of the amount of force production has also been associated with DOMS (Saxton, Clarkson, & James, 1995). Saxton et al. (1995) found that participants who completed an eccentric elbow flexor protocol overestimated the amount of force produced in their experimental arm compared to their control arm; as well as overshot the reference joint angle they were supposed to match. This suggests that neuromuscular impairment may be associated with delayed onset muscle soreness (Saxton et al., 1995).

Muscle dysfunction may also result from altered recruitment patterns associated with connective tissue damage (Cheung et al., 2003). These alterations can significantly alter muscle coordination and motion (Cheung et al., 2003). Although not attributed specifically to DOMS, altered neuromuscular control has been found to result up to five days after muscle damaging eccentric exercise (Miles, Ives, & Vincent, 1997). Miles et al. (1997) ultimately found a slowing of peak velocity, alterations in temporal sequencing, and an electromechanical delay of myoelectrical activity to time of muscle contraction in the elbow flexors of ten non-weight trained females up to five days after eccentric exercise.

Significant decreases in muscle strength and function occur as a result of DOMS inducing protocols have been reported (Alemany, Delgado-Diaz, Matthews, Davis, Kostek, 2013; Gulick et al., 1996; Nosaka & Newton, 1996; Willoughby et al., 2003). Strength is greatly negatively impacted immediately post-eccentric DOMS inducing protocol (Alemany et al, 2013; Nosaka & Clarkson, 1996). Willoughby et al. (2003) observed significant dynamic muscle strength decrements of 30% in the knee extensors.
24 hours post-DOMS inducing protocol. Clarkson et al. (1992) found that isometric muscle strength and the ability to fully flex the elbow were greatly compromised in the days following DOMS induction of the elbow flexors. They also noted a shortening of the relaxed arm angle which they believe may be a result of changes in the connective tissue or abnormal build-up of calcium in the tissues (Clarkson et al., 1992). Clarkson et al. (1992) proposes a few possible explanations for this strength loss following DOMS inducing protocols including the following: structural damage of the muscle fibers, altered neural activation patterns, or the stretching of the sarcomeres which may result in a reduction of the number of cross bridges able to form. Ultimately, these decrements in muscle strength could lead to a higher risk of injury as individuals may over compensate for the weakened muscle tissue (Smith, 1992; Cheung et al., 2003).

**Common Treatment and Management Strategies for DOMS**

Various treatments for the management of DOMS are currently practiced in the clinical setting. Four commonly used treatments include cryotherapy, stretching, low-intensity exercise, and massage (Torres et al., 2011; Cheung et al., 2003). Though R.I.C.E (rest, ice, compression, and elevation) is commonly used as an initial treatment for acute injuries, aside from its temporary analgesic effect, the use of cryotherapy in the management of DOMS has shown little and inconclusive evidence in its favor (Torres et al., 2011; Cheung et al., 2003). The application of stretching pre- and/or post-exercise has been shown to be ineffective in the alleviation of DOMS, regardless of whether it was applied pre- or post-exercise (Torres et al., 2011; Cheung et al., 2003; Connolly, Sayers & McHugh, 2003). Reviews evaluating the effects of low-intensity exercise on the
alleviation of muscle soreness or restoration of muscle strength after exercise-induced muscle damage have been inconclusive (Torres et al., 2011, Cheung et al., 2003).

Out of the four treatments, massage has shown the most promising, yet still conflicting results. A meta-analysis by Torres et al. in 2011 revealed that a massage lasting 20-30 minutes has only been shown to have an alleviating effect on muscle soreness at 24 hours post exercise-inducing muscle damage, and had small clinically significant effects on strength at 1 hour (Torres et al., 2011). A more recent study by Crane et al. (2012) suggests that massage could promote a quicker recovery from exercise-induced muscle damage due to its reduction in inflammation (Crane et al. 2012), however, Anderson et al. (2013) found massage to only be effective as an acute treatment, with effects only lasting 20 minutes post-treatment (Anderson 2013).

A more recently explored DOMS treatment intervention, low-level laser has shown promise. Low-level laser has been examined in the management of DOMS on human subjects both prophylactically (Baroni et al., 2010) and in recovery (Craig et al., 1996; Craig et al., 1999; Douris, 2006; Douris, 2012). The research surrounding the use of low-level laser therapy (LLLT) is discussed in more detail below.

**Low-Level Laser Therapy**

**Defined**

LLLT is a type of low-power non-thermal light therapy applied to tissues in the range of 1mW-500mW (Huang et al., 2009; Enwemeka et al., 2004). LLLT has become much more prevalent in the clinical setting over the past 10 years and is used in the treatment of pathologies with the aim of regenerating tissues, reducing inflammation, and
relieving pain (Huang et al., 2009; Reddy, 2004; Borsa et al., 2013). LLLT has been shown to have positive effects in the treatment of wounds (Caetano et al., 2009; Rodriguez, 2013) osteoarthritis (Bertlucci & Grey, 1995; Ozdemir et al., 2001), tendinopathies (Bjordal et al., 2006; Stergioulas et al, 2008), neck pain (Chow et al., 2006; Gur et al., 2004; Konstantinovic et al., 2010), back pain (Basford et al., 1999; Jovicic et al., 2012), peripheral nerve injuries (Rochkind et al., 2007), muscle fatigue (Leal Junior et al., 2010, 2011), and strokes (Lampl et al., 2007; Zivin et al., 2009).

Although the mechanism of LLLT is not fully understood, it is known that LLLT produces a photochemical effect where the absorbance of light causes a chemical change in tissues (Huang et al., 2009; Reddy, 2004). One of the changes within the tissues is the increase in cellular ATP provided by phototherapy (Mendez, Pinheiro, Pacheco, Nascimento, & Ramalho, 2004). This increase in ATP induces more acute inflammation which promotes a quicker healing of tissues (Mendez et al., 2004), perhaps resulting in more repair at 48 hours post-exercise.

**Application of LLLT & Parameters for Musculoskeletal Treatments**

Currently there are no set LLLT parameters for treating musculoskeletal treatments such as DOMS. However, a review by Bjordal et al. (2009) suggests that for the optimal effect on acute pain LLLT should be administered at 7.5 J/cm² within the first 72 hours, which will help to reduce inflammation, and then at a dose of 2 J/cm² over the next few days to promote tissue repair. Douris et al. (2006) had untrained subjects receive LLLT at a dosage of 8 J/cm² at two treatment sites (80 sec) after they completed an eccentric DOMS protocol of the elbow flexors, and found a significant difference in
pain at 48 hours. Baroni and colleagues (2010) applied a prophylactic treatment of LLLT of 30 J/cm² for 30 seconds at six application points on the quadriceps (totaling in 180 J/cm² for the whole quadriceps) prior to an eccentric DOMS protocol of the knee extensors, and found decreased muscle damage markers (CK and lactate dehydrogenase (LDH) and a higher restoration in muscle function (maximal voluntary contraction—MVC) at 24 and 48 hours, though no significant differences were found between groups for pain. Along with dose, the intensity at which LLLT is applied is one of the greatest determinants in the amount of effect achieved (X. Liu, Zhou, T. Liu, & Yuan, 2009). Studies that have examined the effect of LLLT on DOMS applied after DOMS protocol at lower intensities have found a lack of effect (Craig et al., 1996, 1999), while other studies applying LLLT at higher intensities prophylactically have found an effect (Baroni et al., 2010). Ultimately, the best parameters and timing of LLLT to treat DOMS are currently unknown.

**LLLT Effect on Muscle Regeneration, Muscle Function, & Neurological Repair**

The effect of LLLT on skeletal muscle regeneration has been examined on animal models and has proven to be effective in promoting muscle regeneration (Assis et al., 2013; Babikova & Oron, 1993; Weiss & Oron, 1992). Weiss & Oron (1992) subjected rats to partial excisions of their gastrocnemius and applied LLLT immediately post-injury and daily for the next 5 days and examined markers of muscle regeneration for a period of 11 days (Weiss & Oron, 1992). At just 3 days post-injury the LLLT group showed significantly higher markers of muscle maturation and a significantly higher amount of young myofibrils were present at days 8 and 11, thus indicating skeletal muscle exposed
to LLLT may see an increased rate of muscle regeneration at the site of injury (Weiss & Oron, 1992).

Baroni et al. (2010) analyzed the effects of an intervention of LLLT in humans prior to a DOMS protocol. Compared to an LLLT placebo group, application of LLLT prior to a DOMS protocol increased muscle function of the quadriceps immediately, 24 hours post, and 48 hours post DOMS protocol. In this study, subjects were given an LLLT treatment of 30 J/cm² held for 30 seconds at six defined points on the anterior thigh (totaling in 180 J), prior to the DOMS inducing protocol (Baroni et al., 2010). He ultimately discovered an increase in muscle force recovery in the pre-exercise LLLT treated group when compared to the placebo LLLT treatment (Baroni et al., 2010).

To our knowledge there has not been any research evaluating LLLT on neuromuscular dysfunction associated with DOMS. However, research has shown that LLLT can effectively treat nerve crush injuries in rats (Alcântara et al., 2013), Bell’s palsy (facial nerve paralysis) symptoms in affected patients (Alayat, Elsodany, & Fiky, 2014), as well as increase proprioception in patients suffering from lower limb periostitis or shin-splints (Chang et al., 2014). Alcântara et al. (2013) found LLLT to produce axonal growth markers in crushed sciatic nerves of rats which may indicate that LLLT might aid in the growth, regeneration, or healing of injured nerves. Alayat et al. (2014) compared high intensity laser therapy and LLLT on 48 patients suffering from Bell’s palsy. Alayat et al. (2014) applied LLLT on eight points on the affected side of Bell’s palsy patient’s faces and found it to be an effective modality in facial recovery as measured by the facial disability scale and House-Brackmann scale at 3 and 6 weeks post
treatment. Chang et al. (2014) applied LLLT on the lower leg three times per day over 5 days at 1.4 J/cm in 29 patients suffering from shin-splints. Chang et al. (2014) found LLLT increased patient’s proprioception during postural stability and limits of stability tests, indicating that LLLT may have a positive effect on dynamic and static proprioception.

**LLLT Effect on Inflammation**

One rat study (Liu et al., 2009) and one human study (Douris et al., 2006) examining anti-inflammatory effects of LLLT on DOMS have showed conflicting results. Liu et al. (2009) had 72 rats undergo an eccentric exercise protocol of downhill running to induce DOMS in the gastrocnemius muscle and found that LLLT delivered at 43 J/cm\(^2\) at either 0, 18, or 42 hours post-exercise for 10 minutes significantly inhibited inflammatory cell infiltrate at 24 and 48 hours. However, Douris et al. (2006) evaluated girth measurements of the elbow flexors in humans and found non-significant differences in girth between those who received LLLT at 8 J/cm\(^2\) applied immediately post DOMS inducing protocol and on days 2 and 5 when compared to the non-treatment groups (Douris et al. 2006). Douris et al. (2006) believe their findings could be attributed to the fact that all groups in this study saw non-significant increases in girth measurements post DOMS inducing protocol.

Although not evaluating DOMS, Almeida et al. (2013) conducted a study on 48 male Wister rats that were subject to contusions of their anterior tibialis and found those who received a single LLLT intervention of 1 J/cm\(^2\), applied an hour after muscle trauma, had a significant decrease in inflammatory mediators 6 hours after muscle trauma.
(Almeida et al., 2013). These results are in line with Cressoni et al. (2008) who saw anti-inflammatory effects in the reduced number of leukocytes from LLLT when applied in three treatment areas 24 hours post surgically-induced muscular injury to the anterior tibialis of rats (Cressoni 2008). A review by Bjordal et al. (2006) discovered that 18 out of 19 studies examining the effect of LLLT on inflammation as measured by the presence of inflammatory agents found that LLLT significantly mediated the inflammatory response in a multitude of different tissue injuries (Bjordal et al., 2006).

**LLLT Effect on ROM**

Studies examining the effect of LLLT on range of motion when applied post-DOMS inducing protocols have showed no significant changes between groups receiving LLLT and placebo or control groups (Douris et al., 2006; Craig et al., 1996, 1999). In the first study by Craig et al. (1996), LLLT was applied for 12 minutes on three consecutive days, while in their second study they delivered LLLT and combined laser therapy/monochromatic light (CLILT) for 11 consecutive days (1999). Both studies by Craig et al. measured ROM three different ways: the extension angle (as measured by the range at which the elbow could be maximally straightened), the flexion angle (as measured by the maximum angle of flexion), and the resting angle (as measured by the angle of elbow flexion when the arm was hanging loosely at the subject’s side), all of which were non-significant between groups (1996, 1999). Douris et al. (2006) applied LLLT immediately, 2 days post DOMS inducing exercise, and 5 days post-exercise and also found no difference in resting ROM between groups.
LLLT Effect on Pain

Previous research has shown LLLT to be an effective treatment for relieving acute pain (Chow et al., 2006; Gur et al., 2004; Konstantinovic et al., 2010; Basford et al., 1999; Jovicic et al., 2012). Phototherapy is able to provide pain relief through its direct effect on the peripheral nerves in the treated area (Enwemeka et al., 2004; Mendez et al., 2004). Previous research indicates that LLLT has an effect on central descending inhibitory pathways and the release of endogenous opioids (Walker, 1983) such as serotonin and β-endorphins (Ferreira et al., 2005). This reduction in pain after LLLT application can also be attributed to its ability to increase blood circulation which leads to a subsequent release of pain relieving endorphins (Laakso, 1994). Douris et al. (2006) discovered that LLLT delivered immediately after a DOMS protocol of the elbow flexors significantly reduced perceived pain at 48 hours post-exercise. However, others investigating LLLT’s effect on pain perception after a DOMS inducing protocol have found no significant decrease in muscle pain (Craig et al., 1999; Craig et al. 1996, Baroni et al., 2010; Douris et al., 2012). Though Craig et al. (1996) did show a trend towards significance in tenderness and perceptions of pain in their 20-Hz LLLT group, they did not find a significant decrease in pain between groups.

LLLT Effect on DOMS (Pre- vs. Post-)

LLLT Applied Before DOMS Protocol

As previously stated, one study thus far has examined the effects of LLLT applied before an eccentric DOMS protocol. Baroni et al. (2010) had 36 healthy and recreationally active men, ages 19-35 years old, receive an LLLT treatment of 30 J/cm²
applied for 30 seconds at six defined points on the anterior quad prior to undergoing an eccentric DOMS protocol of the quadriceps musculature (Baroni et al., 2010). Muscle soreness, lactate and CK levels, and muscle function (assessed via the highest torque value of three 5 second maximal voluntary contractions) were assessed immediately, 24 hours, and 48 hours after post-eccentric exercise (Baroni et al., 2010). Results indicated subjects who received the prophylactic low-level laser treatment demonstrated lower lactate and CK levels at 24 and 48 hours, and performed higher maximal voluntary contractions immediately, 24 hours, and 48 hours post-exercise (Baroni et al., 2010). However, there were no differences in muscular soreness perception between groups as measured by the VAS.

Borsa et al. (2003), conducted a review that examined the effects of LLLT administration prior to high-intensity exercise on skeletal muscle tissue. They concluded that LLLT administered before exercise provided prophylactic and ergogenic benefits to skeletal muscle (Borsa et al., 2003). Leal Junior (2009) and colleagues had 10 professional male volleyball players undergo a muscle fatiguing protocol of the biceps brachii and found that LLLT applied immediately prior to exercise significantly decreased post-exercise levels of biochemical markers (blood lactate, CK, and C-Reative Protein (CRP) levels of skeletal muscle recovery.

**LLLT Applied After DOMS Protocol**

Craig et al. (1996, 1999) utilized combined phototherapy/low-intensity laser therapy (CLILT) and found a lack of effect of laser when applied post-DOMS protocol. Craig et al. (1996) utilized three different frequencies of CLILT delivered at a dose of
31.7 J/cm² over 12 minutes to the elbow flexors post-DOMS protocol and then measured ROM (3 different ways) and mechanical pain threshold/tenderness (via the VAS and a shortened version of the MPQ), assessing the DOMS symptoms over 3 days. They found no significant differences between groups and hypothesized it may be due to their chosen laser parameters (Craig et al., 1996). Craig et al. (1999) repeated the study delivering 4 minutes of CLILT irradiation using a GaAlAs cluster head multi-diode array (at 11 J/cm²; pulsed at 73 Hz for 4 minutes) which was applied to the distal half of the biceps after an eccentric elbow flexor protocol. Craig et al. (1999) again assessed ROM (3 different ways) and mechanical pain threshold/tenderness (via the VAS and a shortened version of the MPQ), except this time they observed these measurements over an 11-day period. The results showed those in the CLILT had a “slightly altered” time course, reporting the most pain at day 4 (Craig et al., 1999). Subjects in the CLILT also had a marginally higher degree of pain for a slightly longer duration (another 24 hours until it started to significantly decrease) than the control and placebo groups, suggesting a pro-inflammatory response from the CLILT (Craig et al., 1999). However, this pro-inflammatory response may be due to the fact that Craig et al. (1999) used CLILT instead of LLLT. CLILT uses multiple wavelengths in addition to laser and nonlaser diodes in the same unit, which may offset the benefits (Castel, Abergel, Willner, & Baumann, 1986).

Douris et al. (2006) found positive effects of applying an LLLT of 8 J/cm² immediately following completion of a DOMS protocol of the elbow flexors in five men and twenty-two women (ages 21-35). Resting arm angle and girth measurements were
taken at baseline, and in 24 hour intervals over the next 5 days, while pain, as assessed via the VAS and MPQ was taken at 24 hours post-DOMS protocol and in 24 hour intervals over the next 5 days (Douris et al., 2006). The results indicated a significant decrease in pain between groups at 48 hours post-DOMS protocol (Douris et al., 2006). Although there was a decrease in pain at 48 hours, there were no significant differences between groups in terms of girth measurements or resting arm angle (Douris et al., 2006).
CHAPTER III

METHODOLOGY

Study Design

The research design was a double-blind randomized control study. The assessor was blinded to the subjects’ group allocation and treatment prior to baseline measurements and throughout the study. The subjects in the LLLT and sham treatment groups were also blinded to if they are receiving the active LLLT treatment. Due to the nature of the control group, blinding them to treatment was not possible. The independent variables were group (LLLT, sham, control) and time (baseline, 24, 48). The dependent variables were muscle pain with movement, isometric strength, and muscle function. All treatment and measurements took place in a controlled laboratory setting.

Subject Population

Twenty-seven male subjects ages 18 and older were recruited from Kent State University and the surrounding area (see appendix A for power analysis). All subjects provided written informed consent prior to enrolling in the study. Women were excluded as it has been proposed that different phases of the menstrual cycle might alter muscle damage following high-intensity exercise (Carter, Dobridge, & Hackney, 2001). Subjects were randomly allocated via a Latin square to one of three groups: an active LLLT treatment group, a sham LLLT treatment group, and a control group who did not receive treatment.

Subjects were included if they have been free from any musculoskeletal injury of the upper extremity or trunk within three months of beginning the study. Based upon the
contraindications of the MR4® Super Pulsed Laser all were excluded if they had any of
the following: history of cancer or carcinoma, an active fever, a pacemaker, history of
Botox injections at the treatment site, a known photosensitivity, bleeding or open wounds
at the treatment site, taken oral anti-inflammatory medications 48 hours prior to the start
of the study, a recent steroid injection (within 2 weeks post) at the treatment site,
currently taking any anticoagulant medications, any tattoos over the treatment site, or if
they had any chronic musculoskeletal inflammation localized over the treatment site (see
appendix B for inclusion/exclusion checklist).

Subjects were asked to refrain from the following for the duration of the study:
any exercise involving the upper extremity, performing any self-treatments including but
not limited to: ice, massage, light exercise, stretching, and taking pain medication. Study
methods underwent review and approval from the Institutional Review Board at Kent
State University. Prior to participating in the study all subjects read and signed a
voluntary consent form (see appendix D for consent form).

**Instruments/Apparatus**

Instruments used for this study included a preacher bench, dumbbells, an LLLT
unit, a VAS scale, a handheld dynamometer, and a Reach Board Testing Station.

The preacher bench was situated so that the subject’s shoulder was positioned at
approximately 45° of shoulder flexion. The subject set up was performed by the same
researcher (TK) through visual estimation and was done individually for each subject.

LLLT was administered using the Super Pulsed Laser from Multi Radiance
Medical MR4® (Solon, Ohio). The LLLT parameters were determined by the issuing
company. Once provided with the study information, Multi Radiance Medical used the most current research to determine the best parameters to achieve the desired effect.

The VAS used was a continuous scale comprised of a horizontal 10 cm line with two verbal descriptors on each end depicting each extreme for the symptom of pain (Huskisson, 1974; Jensen, Karoly, & Braver, 1986). The left end of the line was marked as “no pain with movement” and the other as “severe pain with movement”.

Strength was assessed in pounds using a hand-held dynamometer (Lafayette Manual Muscle Test System, Model #01163, Lafayette, Indiana). The hand-held strength measurement device objectively quantifies the peak force required to break an isometric muscle contraction.

The Reach Board Testing Station was used to assess function of the elbow flexors. The Reach Board Testing station is a custom built table with a start button and four targets that require varying amounts of elbow extension (see Figure 2). For right arm dominant subjects, the first target is positioned 34 cm away from the start button at a 45° angle to the right, the second target is 28 cm directly in front of the start button (further from the subject), the third target is positioned 25 cm away from the start button at a 45° angle to the left, target 4 is positioned 42 cm from the start button at a 90° angle on the left. For left arm dominant subjects, the targets are aligned similarly but with target 1 starting on the left, and so on. The Reach Board Testing Station records the time taken for subjects to hit the sequence of targets in a particular order (see Figure 2) as quickly as possible in seconds. The order of the targets are as follows: Start to Target 1,
Target 1 to Start, Start to Target 2, Target 2 to Start, Start to Target 3, Target 3 to Start, Start to Target 4, and Target 4 to Start (see Figure 2).

**Intervention**

The active LLLT treatment group received an active treatment over three points on the elbow flexors and one over the brachial plexus. As per manufacturer provided protocol, the prophylactic LLLT treatment consisted of 250 Hz delivered at four different sites (see Figure 1 below) for 4 min per site, totaling 250 J applied to the upper arm. Post-LLLT treatment consisted of 1000 Hz delivered by scanning the diode head over the elbow flexors (see Figure 1 below) for 3 minutes.

The sham LLLT treatment group received the same treatment set-up as the active LLLT treatment group without receiving an active treatment.

The control group sat quietly for the same amount of time as the other two groups without receiving treatment.

*Figure 1.* Application Points for LLLT and Sham Treatments

*Note.* Prophylactic points indicated by red circles and post-treatment points indicated by purple circle.
**Procedures**

Data collection occurred over 3 days and is outlined below.

Consenting was completed during visit 1 (45-60 minutes). Prior to data collection subject written consent was obtained. The consenting process is described elsewhere in this protocol. Consenting occurred only on Visit 1. Then subjects were screened for eligibility. Inclusion and exclusion criteria were described earlier and are listed in appendix B. Screening occurred only during Visit 1. Anthropometric measurements of sex, height, weight, age and arm dominance were then obtained. Anthropometric measurements only occurred during Visit 1.

Baseline/Outcome measures for perceived muscle pain during active movement, muscle function, and muscle strength were obtained. All data and testing involved the subject’s non-dominant arm. A Visual Analog Scale (VAS) was used to complete perceived muscle pain during active movement. The VAS is a 10-cm horizontal line with the left end indicating “no pain with movement” and the right end labeled “severe pain with movement”. Subjects were asked to make a mark along the line to indicate their current level of pain while actively flexing and extending their non-dominant elbow (see Appendix 1). The Reach Board Testing Station was used to assess function of the elbow flexors. The subject was positioned in a caster locked chair at the Reach Board Testing Station. The subject was seated with their thoracic and lumbar spine against the back rest of the chair and with their xiphoid process in line with the top of the table. The chair was positioned at a distance from the table that provided for the tip of their second and third
fingers could reach the second target with their elbow in full extension. The subject was asked to hit the targets with the pads of their second and third finger in the following order: S1 to T1, T1 to S1, S1 to T2, T2 to S1, S1 to T3, T3 to S1, S1 to T4, and T4 to S1 (see Figure 2). Subjects were allowed to practice until they felt comfortable. Once they stated that they felt comfortable with the task, they were asked to complete the series of hitting the targets as quickly as possible by actively flexing and extending their elbow to reach the targets, all the while maintaining an upright body position. Subjects were encouraged to keep their back pressed against the back of their chair, without performing any scapular protraction. Three trials were recorded, and the average time (in seconds) was used for analysis. A handheld dynamometer was used to assess strength of the elbow flexors. Participants were seated in a height-adjustable chair at an immovable counter top. Subjects were positioned so that their elbow was at 90° of flexion and full supination. The dynamometer was then placed in the subject’s hand, with the pad facing upward. Subjects performed a maximal isometric contraction against the under surface of the countertop for 3 seconds. This was repeated for three trials and the average of the three measurements was recorded in pounds.

Following baseline measurements subjects received the pre-exercise protocol LLLT intervention (see Figure 1) immediately following the baseline measurements, the outcomes assessor (who is blinded to treatment allocation) escorted the subject to the LLLT administration room. The outcomes assessor then handed a sealed envelope with the coded group allocation to a second researcher. At this point, the outcomes assessor left the room and the second researcher delivered the assigned treatment. As mentioned
above, the intervention was administered using the MR4® Multi Radiance Therapy System which has been previously approved and used at KSU (IRB 13-336). The LLLT group received LLLT delivered at 250 Hz delivered at four different sites on the upper extremity (3 sites on the elbow flexors and 1 over the brachial plexus) at 4 minutes per site (16 minute total treatment time). The sham group received the same treatment set-up as the LLLT group but without the active treatment. The control group sat quietly for 16 minutes. All groups then sat quietly for an additional 15 minutes prior to starting the exercise protocol as per manufacturer recommendations to allow for proper LLLT absorption for the LLLT group.

Following the LLLT treatment, the subject performed the exercise protocol. The exercise protocol was a modified version of a protocol used in previous research to induce DOMS of the elbow flexors (Hurley et al., 2013). The exercise protocol included five sets of controlled dumbbell lowering on a preacher bench. This was done with the non-dominant arm holding a dumbbell with 60% of the subject’s isometric strength for elbow flexion. Following a metronome count of 3 seconds, the subject lowered the dumbbell until their elbow was fully extended. The assessor then took the weight, the subject actively returned their elbow to full flexion, and the assessor placed the weight back in their hand for them to lower to full extension again. Subjects were asked to perform 10 repetitions for the first 4 sets with 1 minute rest in between sets. If subjects were unable to complete a full set of 10 reps during any of the first 4 sets, the dumbbell weight was decreased by 5 pounds for the remainder of the current reps and for the next set. For set 5, subjects were asked to complete as many repetitions as possible. Failure to
continue was defined as when the subject could no longer complete the 3-second controlled eccentric lowering for 2 consecutive attempts. Subjects were informed to stop if they feel chest pain, shortness of breath, or experience any sort of pain.

Immediately following the exercise protocol the LLLT group received an active laser treatment of 1000 Hz delivered by scanning the diode head over the anterior arm and elbow for 3 minutes (see Figure 1). The sham group received the same set up as the LLLT group, but did not receive an active treatment. The control group sat quietly for 3 minutes. Following the immediate post LLLT intervention, subjects met with the outcomes assessor who provided them with take-home instructions (see Appendix E) and then were dismissed for the day and scheduled to return to the lab 24 hours (± 1 hour) from the conclusion of the exercise protocol.

Subjects returned to the lab 24 hours post visit 1 for visit 2 (30 minutes). All of the above outcome measures were repeated. At 24 hours post-exercise protocol LLLT intervention (see Appendix: 3) LLLT was delivered at 1000 Hz delivered by scanning the diode head over the anterior arm and elbow for three minutes. Sham group received the same treatment set-up as the LLLT group but without the active treatment. The control group sat quietly for 3 minutes.

Subjects returned to the lab 48 hours post visit 1 for visit 3 (20 minutes). All of the above outcome measures were repeated in the same order and methods as previously described.
Figure 2. Reach Board Testing Station

S= start button, T1 = target 1 button, T2 = target 2 button, T3 = target 3 button, T4 = target 4 button.

Statistical Analysis

The statistical analysis for this used a mixed-model ANOVA for group and time. To analyze strength and muscle function, we used a 3x3 group (LLLT, sham, control) by time (baseline, 24 hour, 48 hour) mixed-model ANOVA. For VAS we used a 3x3 group (LLLT, sham, control) by time (baseline, 24 hour, 48 hour) mixed-model ANOVA. Significant interactions were followed up with paired t-tests. Secondary analyses were conducted evaluating for time main effects. Any significant time main effect was followed-up using paired t-tests. For all analyses significance was set a priori to less than .05.
CHAPTER IV

RESULTS

Demographics

Demographic data for the three groups is presented in Table I. The active LLLT group was significantly taller than the sham LLLT treatment group ($F = 3.6$, $p = .04$); effect size $d = 1.24$ (CI = 0.23 – 2.26); Cohens D = .6.

Table 1. Demographic Means and Standard Deviations Among Groups.

<table>
<thead>
<tr>
<th></th>
<th>LLLT ($n = 10$)</th>
<th>Sham ($n = 8$)</th>
<th>Control ($n = 9$)</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height (cm)</strong></td>
<td>181.1 6.9</td>
<td>173.5 4.9</td>
<td>177.3 5.8</td>
<td>.04*</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>91.4 23.3</td>
<td>77.4 7.2</td>
<td>77.7 8.2</td>
<td>.10</td>
</tr>
<tr>
<td><strong>Age (yr)</strong></td>
<td>23.4 4.4</td>
<td>23.4 6.9</td>
<td>20.7 2.2</td>
<td>.39</td>
</tr>
<tr>
<td><strong>Arm Dominance</strong></td>
<td>8 right, 2 left</td>
<td>8 right, 0 left</td>
<td>9 right, 0 left</td>
<td>.17</td>
</tr>
</tbody>
</table>

Note. LLLT: Low-level laser therapy
*LLLT significantly greater than sham

Outcome Measures

There was no significant group by time interaction for pain, $F(4, 48) = .33$, $p = .85$ (see Table 2 for means and standard deviations). There was, however, a significant time main effect for pain, $F(2, 48) = 53.40$, $p < .001$. Post hoc tests showed that regardless of group, pain significantly increased from baseline to 24 hours ($p < .001$). Pain remained significantly higher at 48 hours compared to baseline ($p < .001$). Although mean group pain decreased between 24 and 48 hours, the difference was not significant ($p = .80$).
There was no significant group by time interaction for function, $(4, 48) = 1.35, p = .27$ (see Table 2 for means and standard deviations). Additionally, there was no significant time main effect for function, $F(2, 48) = .61, p = .550$. Post hoc tests showed no significant differences in function from baseline to 24 hours ($p = .62$), from baseline to 48 hours ($p = .32$), or from 24 hours to 48 hours ($p = .52$).

There was no significant group by time interaction for strength, $F(4, 48) = .13, p = .97$ (see Table 2 for means and standard deviations). There was, however, a significant time main effect for strength, $F(2, 48) = 24.40, p < .001$. Post hoc tests showed a significant decrease in strength from baseline to 24 hours ($p < .001$) and from baseline to 48 hours ($p < .001$). Decrements in strength were near significance ($p = .054$) as strength was greater at 48 hours compared to 24 hours post-exercise.
Table 2.  
*Means and Standard Deviations Among Groups.*

<table>
<thead>
<tr>
<th>Group</th>
<th>Pain Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
<th>p-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLLT (n=10)</td>
<td>0.47</td>
<td>1.26</td>
<td>0.04</td>
<td>0.11</td>
<td>0.11</td>
<td>0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sham (n=8)</td>
<td>4.93</td>
<td>2.4</td>
<td>3.9</td>
<td>1.99</td>
<td>4.28</td>
<td>2.13</td>
<td>0.85</td>
<td>&lt;0.001*#</td>
</tr>
<tr>
<td>Control (n=9)</td>
<td>4.21</td>
<td>2.41</td>
<td>3.76</td>
<td>2.35</td>
<td>4.73</td>
<td>2.72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Function Mean  | 2.64      | .49 | 2.56 | .34 | 2.81 | .39 |         |         |
| 24 hr.         | 2.70      | .46 | 2.42 | .42 | 2.76 | .21 | .27     | .55     |
| 48 hr.         | 2.63      | .45 | 2.59 | .47 | 2.52 | .28 |         |         |

| Strength Mean  | 49.01     | 10.18| 47.96 | 10.44| 45.61 | 14.01|         |         |
| 24 hr.         | 36.68     | 9.59 | 36.31 | 12.56| 31.89 | 13.07| .97     | <0.001 ‡ |
| 48 hr.         | 37.68     | 9.85 | 39.24 | 13.97| 33.70 | 12.92|         |         |

*Note.* LLLT: Low-level laser therapy.  
*Baseline significantly lower than 24 hours  
#Baseline significantly lower than 48 hours  
‡Baseline significantly higher than 24 hours  
‖Baseline significantly higher than 48 hours
CHAPTER V
DISCUSSION

The aim of this study was to determine the effectiveness of LLLT in the management of DOMS symptoms when delivered both pre- and post- exercise protocol. To our knowledge this was the first study to apply LLLT both pre- and post-eccentric exercise. Also to our knowledge, this is the first study to apply LLLT specifically over nerves to examine its effect on muscle function associated with DOMS. The results of this study showed no significant differences between those in the LLLT group, sham group, and control group in terms of pain, function, or strength throughout the 48 hour data collection period. Although we found the active LLLT group to be significantly taller than the sham LLLT treatment group, there has not been any published research showing that height affects DOMS or LLLT. Thus, we believe that the differences seen in height between our groups did not have an effect on our study.

There were no significant differences between groups for pain in this study, as measured using a VAS scale. Interestingly, the LLLT group was similar in pain ratings compared to the sham and control groups. This is similar to (Baroni et al., 2010; Craig et al., 1999) who also found no differences between groups. This differs, however, from the findings of Douris et al. (2006) who found significant reductions in pain between groups with the application of LLLT (applied at 8 J/cm² held for 80 s at 3 different sites near the musculotendinous junction of the biceps brachii, totaling 24 J delivered to biceps brachii). Interesting to note, however, is that the LLLT group’s pain peaked at 24 hours post exercise and then began to decline, while the control group’s pain was still
increasing after 24 hours. This could possibly be attributed to LLLT speeding up the healing process through more acute inflammation (Mendez et al., 2004).

As expected, there were significant time main effects for pain between baseline and 24 hours post-exercise protocol. This is similar to the findings of other studies, where VAS score was higher for all groups at 24 hours and 48 hours post-exercise compared to baseline (Craig et al., 1990; Douris et al., 2006). Researchers have found that pain significantly increases from baseline post eccentric exercises (Alemany et al., 2013; Craig et al., 1990; Douris et al., 2006; Fitzgerald et al., 1991).

It is possible that we may have missed significant differences occurring outside of the 48 hour post-exercise time frame. However, Douris et al. (2006) measured pain up to 5 days post exercise, but only saw a significant decrease in pain at 48 hours in those who received LLLT immediately post exercise compared to the placebo and control groups.

In this study, muscle function, which also had components of neuromuscular function assessment, was assessed using the Reach Board Testing Station- an exploratory measure for DOMS. The Reach Board Testing Station is a custom built table that has been used in Parkinson’s studies (Seidler, Alberts, & Stelmach, 2001; Seidler, Alberts, & Stelmach, 2002; Seidler et al., 2010). This testing station combines components of neuromuscular function of the elbow joint including ROM, neuromuscular control, and speed of muscle contractions. ROM decrements are commonly associated with DOMS (Chleboun et al., 1998; Clarkson et al., 1992; Gulick et al., 1996; Nosaka & Clarkson, 1996), with the largest decrements shown in AROM during the extension of a joint (Gulick et al., 1996). In this study, we treated the neural plexus that innervates the elbow flexors, however
there were no significant differences between groups, or within groups over time in terms of muscle function during the course of this study. However, those in the LLLT group stayed pretty consistent from baseline throughout the 48 hour time period as far as the time it took subjects to complete the testing station. This may indicate that LLLT has some type of positive effect on muscle function. It is important to consider, however, that our outcome measure may not have been sensitive enough to fully capture the differences between groups as the Reach Board Testing Station was initially designed to test neuromuscular control in Parkinson’s patients. So, perhaps it was too easy for the healthy subjects in this study as they could handle the pain it took to perform the test for the short period of time. Future research should look into other methods of measuring muscle function with neuromuscular components in those suffering from DOMS.

The Reach Board Testing Station may also have been too easy as the only target at the testing station that required full elbow extension was T2 (see Figure 2). Although there have been studies that demonstrate those suffering from DOMS experience significant pain during active extension (Cleak & Eston, 1992; Gulick et al., 1996), it is unclear at what point during active extension that pain is most severe. Cleak & Eston (1992) propose that pain with active lengthening of the muscle tissue may be due to the excitation of free nerve endings located at the musculotendinous junctions. It is unknown that if the Reach Board Testing Station had required increased active elbow extension, if resultant pain would have contributed to a decrease in muscle function. Additionally, to our knowledge, there is no evidence that the timing of muscle contractions and lengthening is altered with DOMS, just that subjects experience painful (Cleak & Eston,
1992; Gulick et al., 1996) and reduced ROM (Chleboun et al., 1998; Clarkson et al., 1992; Gulick et al., 1996; Nosaka & Clarkson, 1996).

Studies have shown that strength decrements associated with DOMS occur immediately post exercise (Alemany et al., 2013; Baroni et al., 2010) and are slow to recover over the following days (Gulick et al., 1996; Clarkson et al., 1992). Our time main effect for strength reflects this slow recovery time and showed that, on average, all three groups experienced slight attenuation of muscle strength at 48 hours post-exercise. Weiss & Oron (1992) who made excisions to the gastrocnemius of rats found that it wasn’t until day 3, or 72 hours after LLLT application, that there was significant muscle regeneration in the LLLT group. And so it is possible that the generation of young myofibrils may take up to 72 hours to appear in damaged muscle tissue. Similar to other researchers (Baroni et al., 2010; Willoughby et al., 2003) we chose to collect data out to 48 hours post-exercise, so we do not know if significant differences in strength would have been observed between groups past 48 hours. However, significant differences in muscle strength between LLLT and control groups have been found in previous research at 48 hours post-exercise (Baroni et al., 2010).

High-intensity exercise, such as higher repetitions, could potentially lead to more intense DOMS symptoms or to more of a delay in the peaking of DOMS symptoms, thus slowing the recovery (Draganidis et al., 2013). And so, another possible reason why no significant group by time interaction was observed could be due to the fact that prophylactic LLLT administration can lead to higher repetitions during exercise (Leal Junior et al., 2009) and therefore treating an individual with LLLT prior to exercise has
the potential to lead to more muscle damage. Leal Junior et al. (2009) found that an active LED laser treatment (41.7 J administered in 30 seconds total irradiation) administered prior to an exercise protocol increased the number of biceps brachii contractions by 12.9%. For this study, we did not have a set amount of weight training volume (repetitions and weight lifted) and did not record the total volume of weight lifted, instead subjects performed eccentric contractions until failure, similar to Douris et al. (2006). So we are unable to compare the total amount of work done between groups.

Baroni et al. (2010) found a significant effect of LLLT on muscle strength (as measured by maximal voluntary contractions) at 24 and 48 hours post exercise when applied prophylactically (30 J for 30 seconds at 6 different sites- 180 J for the quadriceps musculature). However, Baroni et al. (2010) had a set volume of exercise performed by each subject. Each subject performed 5 sets of 15 maximal eccentric quadriceps contractions at a constant velocity with a 30 second rest in between sets. And so, the difference in effectiveness of the LLLT between our study and Baroni et al. (2010) may have been due to volume differences.

**Limitations**

There are a few limitations associated with this study. The first limitation is that we used only males between the ages of 18 and 40 years of age in the surrounding Kent State area. Although we did not find any group differences in males, it is unknown how females would respond to our intervention. Another limitation of this study is the limited monitoring of subjects activity outside of data collection.
There is currently no evidence as to the most appropriate parameters for LLLT as this was the first time LLLT was applied both prophylactically and as a post-exercise treatment, the most beneficial parameters are currently unknown.

**Recommendations & Future Research**

This study looked at the effectiveness of LLLT on pain, muscle strength, and muscle function in males delivered pre- and post-eccentric exercise over the course of 48 hours post-exercise. Although significant differences over time were observed for all groups in terms of pain and muscle strength decrements, this study did not find a significant effect between groups. This suggests that LLLT delivered pre- and post-eccentric exercise using our parameters on males in our age range is ineffective in alleviating those symptoms of DOMS. Future research should explore the effect of different pre- and post-exercise LLLT parameters in other populations. Additionally, it may be beneficial for future studies to use a set volume of exercise to account for any prophylactic effects of LLLT to better determine differences between groups. Future studies should also look at the effect of LLLT delivered prophylactically and post-exercise for additional functional measures. The effect of LLLT combined with another treatment for DOMS is still unknown. Clinicians usually don’t just use one method to treat pathologies, and we still do not know the effect of LLLT on DOMS when combined with cryotherapy, stretching, low-intensity exercise, or massage. Future studies should examine the effect of LLLT when combined with other common treatments for DOMS symptoms.
Conclusion

This study was, to our knowledge, the first to explore the effects of LLLT on DOMS when delivered both pre- and post-eccentric exercise. Our results found that LLLT delivered pre- and post-eccentric exercise was ineffective in terms of treating pain, muscle strength, or muscle function (as measured by speed of muscle contractions and lengthening) associated with DOMS. Although LLLT was found ineffective for treating those symptoms of DOMS at our chosen parameters, previous literature has shown that LLLT has promising effects on attenuating symptoms of DOMS.
APPENDICES
APPENDIX A

SAMPLE SIZE CALCULATION
Appendix A

Sample Size Calculation

Sample size estimation was determined using data from “Low-level laser therapy before eccentric exercise reduced muscle damage markers in humans” by Baroni et al. (2010). The estimation was determined using the visual analog scale (VAS) outcome measure at baseline and 24-hours post eccentric exercise protocol. The effect size for the published VAS data was Cohen’s $d = 1.4$. With an effect size of $d=1.4$, and an alpha of $\alpha = 0.05$ and beta of $\beta = 0.80$, the estimated number of subjects needed per group for our study is 9; 27 total. Assuming a 20% attrition rate, the total number of subjects expected to be recruited are 33; 11 per group.
APPENDIX B

CHECKLIST OF INCLUSION/EXCLUSION CRITERIA
## Appendix B

**Checklist of Inclusion/Exclusion Criteria**

<table>
<thead>
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<th>INCLUSION</th>
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</tr>
</thead>
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<tr>
<td>Older than 18</td>
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<td>Musculoskeletal injury free for past 3 months</td>
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<table>
<thead>
<tr>
<th>EXCLUSION</th>
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<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performed upper extremity workout within last 7 days</td>
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</tr>
<tr>
<td>History of cancer or carcinoma</td>
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<td></td>
</tr>
<tr>
<td>Fever</td>
<td></td>
<td></td>
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<tr>
<td>Pacemaker</td>
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<tr>
<td>History of Botox injections at the treatment site</td>
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<td></td>
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<td>Known photosensitivity</td>
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<td></td>
</tr>
<tr>
<td>Bleeding or open wound at treatment site</td>
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</tr>
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<td>Oral anti-inflammatory medication (taken within 48 hours)</td>
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<td></td>
</tr>
<tr>
<td>Steroid injections at treatment site (within 2 weeks)</td>
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<td></td>
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<tr>
<td>Currently taking any anticoagulant medications</td>
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<tr>
<td>Tattoos over treatment site</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chronic musculoskeletal inflammation localized over treatment site</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C

VAS

Place a mark on the line below to indicate your level of pain during active bending and straightening of your elbow.

No pain with movement  Severe pain with movement
APPENDIX D

CONSENT FORM
Appendix D

Consent Form

Study Title: Effect of Low-Level Laser Therapy on Delayed Onset Muscle Soreness

Principal Investigator: Lisa Chinn, PhD, AT Co-Investigator: Tiffany Kobordo, AT

You are being invited to participate in a research study. This consent form will provide you with information on the research project, what you will need to do, and the associated risks and benefits of the research. Your participation is voluntary. Please read this form carefully. It is important that you ask questions and fully understand the research in order to make an informed decision. You will receive a copy of this document to take with you.

Purpose:
The purpose of this study is to determine the effectiveness of low-level laser therapy (LLLT) in the management of delayed-onset muscle soreness (DOMS) symptoms when delivered both pre- and post- exercise protocol. Specifically, we will be looking at the effect of LLLT delivered to the musculature used in elbow flexion. We will be inducing delayed onset muscle soreness to your elbow flexors and measuring your perceived pain, strength, and muscle function.

Participants:
You are being asked to participate because you have reported that you have not sustained an injury to the upper extremity within the past 6 months.

Procedures:
During this study you will be asked to report to the MACC Annex on the campus of Kent State University for a total 3 visits. The total amount of time required is estimated to be about 2.5 hours over 3 consecutive days. A description of each visit is below:

Visit 1: (80 minutes – 95 minutes)
Consenting & Screening (only done Study Visit 1): If you agree to participate, you will sign this consent form before any study related procedures take place. Before you can start the study, there will be a screening period to check for your eligibility for the study. If you are eligible to participate you will begin the study procedures as outlined below.

Measurements and Procedures: The first step is to take a complete set of baseline measurements. The measurements that will be taken, in order, are: 1.) your perceived pain, 2.) muscle function, and 3.) muscle strength. You will be asked to use your non-dominant arm for all three measurements.
Measurement 1: Perceived pain
To measure this, you will be provided a visual scale. The scale consists of a 10cm line. You will be asked to place a vertical line or X along the line to represent your current level of pain while actively flexing and extending your elbow.

Measurement 2: Muscle function
To measure this, you will be asked to sit upright at a table and complete a series of touching 5 buttons in a particular order as quick as possible. You will be allowed to practice this task until you feel comfortable and then perform a total of three recorded timed trials.

Measurement 3: Muscle strength
To measure this, you will be asked to flex your elbow against manual resistance for 3 seconds at 90 degrees of elbow flexion. You will be asked to complete this task for a total of three times.

Treatment 1: Prior to the exercise protocol, you will receive either a low-level laser treatment, a sham treatment, or sit quietly for 16 minutes. Your treatment assignment is randomized, and the investigator will be blinded (ie, will not know what treatment you will be receiving). We will treat 4 different sites on your anterior arm. Each point will be treated at 4 minutes per site. You will be asked to wear tinted glasses during both treatments. After a 15 minute wait period you will then complete the exercise protocol as described below.

Exercise Protocol: This protocol lasts approximately 15 minutes and will include 5 sets of controlled single-arm dumbbell lowering on a preacher bench. This will be done with your non-dominant arm holding a dumbbell with 60% of your isometric strength for elbow flexion (as determined during the baseline measurements for strength). Following a metronome count of 3 seconds, you will lower the dumbbell until your elbow is fully extended. The assessor will then take the weight, you will actively return your elbow to full flexion, and the assessor will place the weight back in your hand. You will be asked to perform 10 repetitions for the first 4 sets with 1 minute rest in between sets. For the last set (set 5) you will be asked to complete as many repetitions as possible. This will be defined as when you can no longer complete the 3-second controlled eccentric lowering for 2 consecutive attempts.

NOTE: During the exercise protocol, you may stop at any time. If you experience any pain or shortness of breath you should stop and tell the research study staff.

Treatment 2: Immediately following the exercise protocol, you will receive either a low-level laser treatment, a sham treatment, or sit quietly for 3 minutes. If you are in the low-level laser treatment group we will deliver an active treatment by scanning the treatment head over your anterior upper arm and elbow. If you are in the sham treatment group, you will receive the same set up and the machine will appear to be delivering treatment,
however no active treatment will be delivered. If you are in the control group, you will sit quietly for those 3 minutes.

This will end Study Visit 1/3. You will be asked to return for Study Visit 2/3 in about 24 hours.

**Study Visit 2: (30 minutes).**

**Measurements:** Upon returning to the laboratory, the three measurements will be repeated: perceived pain (Measurement 1), muscle function (Measurement 2), and muscle strength (Measurement 3).

**Treatment 3:** After the measurements, you will receive either a low-level laser treatment, a sham treatment, or sit quietly for 3 minutes. This treatment will be identical to treatment 2 described above.

That will end Study Visit 2/3. You will be asked to return for Study Visit 3/3 about 24 hours after Study Visit 2/3.

**Study Visit 3: (20 minutes)**

**Measurements:** Upon returning to the laboratory, the three measurements will be repeated: perceived pain (Measurement 1), muscle function (Measurement 2), and muscle strength (Measurement 3).

This will end Study Visit 3 and will conclude the study.

**Benefits:**

This research will not benefit you directly. However, your participation in this study will help us to better understand if LLLT is a worthwhile intervention for muscle recovery when delivered pre- and post-exercise.

**Risks and Discomforts:**

There are minimal risks associated with this study. However you may encounter:

- Likely risk you may experience moderate muscle soreness during and/or after the exercise protocol.

- Likely risk that you may feel some discomfort during the measurements.

The low-level laser has been suggested to cause an increase in abnormal cell growth in those previously diagnosed with cancer. Furthermore, if there are suspicious lesions, or areas of what appear to be abnormal growth on the skin, use of the low-level laser should be avoided. While the low-level laser has not been shown to increase the risk for cancer, it has been suggested that treating suspicious lesions, if cancerous, may exacerbate them. In addition, staring into the laser directly may permanently damage your retina, so you
will be given tinted glasses to wear during treatment. It is also important not to apply the laser over the neck, chest, or genitals. For this project, we will only be treating the elbow and upper arm. Also, we will not be able to treat areas of active bleeding. Be sure all wounds are clean and sanitized before performing any portion of this study. If you feel sick or feverish prior to the testing procedures please let the Primary Investigator know so that you can be rescheduled. Treatment will be administered and supervised by a trained individual.

Medical treatment by the University Health Center is provided only to currently registered students. Please be advised that for all other injuries, emergency services will be called for those occurring on the Kent State University campus. You or your medical insurance will be billed for this service. No other medical treatment or financial compensation for injury from participation in this research project is available.

Privacy and Confidentiality:

No identifying information will be collected. Your signed consent form will be kept separate from your study data, and responses will not be linked to you. Your study related information will be kept confidential within the limits of the law. Any identifying information will be kept in a secure location and only the researchers will have access to the data. Research participants will not be identified in any publication or presentation of research results; only aggregate data will be used.

Your research information may, in certain circumstances, be disclosed to the Institutional Review Board (IRB) which oversees research at Kent State University, or to certain federal agencies. Confidentiality may not be maintained if you indicate that you may do harm to yourself or others.

Voluntary Participation:

Taking part in this research study is entirely up to you. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. You will be informed of any new, relevant information that may affect your health, welfare, or willingness to continue your study participation.

Termination:
You may choose to withdraw from this study at any time.

Compensation:
To compensate for your time, you will receive $10 upon completion of data collection.

Contact Information:
If you have any questions or concerns about this research you may contact Lisa Chinn at 330-672-2841 or lchinn@kent.edu. This project has been approved by the Kent State University Institutional Review Board. If you have any questions about your rights as a
research participant or complaints about the research, you may call the IRB at 330.672.2704.

**Consent Statement and Signature**
I have read this consent form and have had the opportunity to have my questions answered to my satisfaction. I voluntarily agree to participate in this study. I understand that a copy of this consent will be provided to me for future reference.

________________________________________  ____________________  
Participant Signature                        Date
APPENDIX E

TAKE-HOME INSTRUCTIONS
Appendix E

Take-Home Instructions

DOMS & LASER STUDY
Next Visits & Take-Home Instructions

Thank you for your participation in this study! We will see you again at the following days/times:

Visit 2: ______________________________

Visit 3: ______________________________

A.) Please do not perform any self-treatments until the end of Visit 3. These include but are not limited to the following:
   a. Ice
   b. Massage
   c. Light exercise
   d. Stretching
   e. Pain medication (Tylenol, Ibuprofen, Advil, etc.)

B.) Please use your non-dominant arm throughout the day as normally as possible.
APPENDIX F

ADDITIONAL RESULTS
Appendix F

Additional Results

Figure 3. Muscle Pain: Relationship between Groups and Time
Mean pain values as measured by the VAS (cm) depicting the amount of pain during active bending and straightening of the non-dominant elbow. No significant differences were found between groups. There was a significant increase in pain from baseline to 24 hours and baseline to 48 hours for all groups.

Note. LLLT: Low-level laser therapy. VAS: Visual analog scale.
Figure 4. Muscle Function: Relationship between Groups and Time
Mean muscle function values as measured by the Reach Board Testing Station (sec) depicting the speed of active muscle contraction and lengthening of the non-dominant elbow. No significant differences were found between groups. No significant differences were observed over time for all groups.

Note. LLLT: Low-level laser therapy.
Figure 5. Muscle Strength: Relationship between Groups and Time

Mean muscle strength values as measured by the handheld-dynamometer (lbs.) depicting the amount of isometric elbow flexor strength of the non-dominant elbow. No significant differences were found between groups. All groups significantly decreased in strength from baseline to 24 hours and from baseline to 48 hours.

Note. LLLT: Low-level laser therapy.
REFERENCES


regeneration and prevents fibrosis in rat tibialis anterior muscle after cryolesion.  


