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NEUROMUSCULAR ELECTRICAL STIMULATION IN COMPARISON TO HEAT THERAPY AS A MODALITY AFTER EXERCISE-INDUCED MUSCLE FATIGUE

By

Diana Dzasezeva

THESIS

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NEUROMUSCULAR ELECTRICAL STIMULATION IN COMPARISON TO HEAT THERAPY AS A MODALITY AFTER EXERCISE-INDUCED MUSCLE FATIGUE

This thesis by Diana Dzasezeva is recommended for approval by the student's Thesis Committee and Department Head in the Department of Health and Human Performance and by the Dean of Graduate Studies and Research.

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ABSTRACT

NEUROMUSCULAR ELECTRICAL STIMULATION IN COMPARISON TO HEAT THERAPY AS A MODALITY AFTER EXERCISE-INDUCED MUSCLE FATIGUE

By

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Increasing blood flow to exercised areas expedites metabolite removal, aiding quicker recovery and preventing injury during return to exercise. However, the effectiveness of different recovery modalities remains unclear. The purpose of the study is to evaluate the efficacy of neuromuscular electrical stimulation (NMES) and heat therapy (HT) as recovery modalities after inducing fatigue with maximal exercise in active individuals. The study involved 56 participants who performed a fatiguing exercise before the intervention. They then either rested (control group) or received one of three treatments: HT, NMES, or NMES+HT for 15 minutes. Afterward, they performed another bout of fatiguing exercise. Outcomes included ground reaction force (GRFz) and ratings of perceived exertion (RPE) immediately after fatiguing exercise. An ANCOVA was used to control for pre-test values as a covariate. No statistically significant effect x time or intervention were observed after controlling for peak total GRFz (pre) at $p=0.16$. RPE scores also did not reveal any statistical significance ($p>0.05$). Results showed that pre-test GRFz values (mean ± SD) were 2248.7 ± 788.19 for the control group, 2526.52 ± 703.65 for HT, 2368.86 ± 837.72 for NMES, and 2196.39 ± 560.62 for NMES+HT. Post-test values were 2051.76 ± 783.67 for the control group, 2434.29 ± 839.67 for HT, 2400.82 ± 737.62 for NMES, and 2269.94 ± 699.23 for NMES+HT. Despite the lack of statistical significance, NMES and/or HT showed potential for enhancing recovery compared to the control group, particularly in peak GRFz, indicating a potential increase in recovery efficacy for improved performance and injury prevention.

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2024

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CHAPTER ONE: INTRODUCTION

THIS THESIS FOLLOWS THE FORMAT PRESCRIBED BY THE APA STYLE MANUAL AND THE DEPARTMENT OF HEALTH AND HUMAN PERFORMANCE.

Muscular fatigue is associated with prolonged impairment in muscle strength and power, delayed muscle refueling, microvascular dysfunction, and mitochondrial dysfunction (Kim, Monroe, Gavin, & Roseguini, 2020a; Malone, Blake, & Caulfield, 2014). The capacity for an athlete to execute and recuperate from high-intensity exercise is essential for success, as inadequate recovery can limit sporting performance and may result in tissue injury or over-training syndrome (Barnett, 2006; Higgins, Heazlewood, & Climstein, 2011). Muscular fatigue is specifically associated with a buildup of metabolites in the muscle (lactate, inorganic phosphate ions, and H+ ions) and tissue inflammation (Wan, Qin, Wang, Sun, & Liu, 2017). Therefore, it is important to increase blood flow to the area and to allow for metabolite removal (González-Alonso et al., 1999). The ability to accelerate the recovery rate is critical for both athletic and general populations to improve physical capacity (Pournot et al., 2011). Modes that could be used to increase blood flow to post-exercise fatigued muscles are neuromuscular electrical stimulation (NMES) and heat therapy (HT).

Neuromuscular and muscular electrical stimulation (NMES and EMS) involves the use of electrical impulses to induce muscle contractions by stimulating neurons through the skin's surface. This process simulates an action potential from the central nervous system, resulting in muscular contractions. Neuromuscular electrical stimulation can be utilized with or without functional movement and has long been used to prevent muscle atrophy and to strengthen muscles in those

experiencing immobility (Hainaut & Duchateau, 1992). Dr. Yakov Kots, a Russian scientist, experimented with NMES to understand its potential for exercise utilization (Ward & Shkuratova, 2002). Prior to this, EMS was already well established in rehabilitation settings for pain relief and addressing muscular tightness. Dr. Kots discovered that by increasing the intensity of the electrical current and configuring the machine to specific settings like 2,500 Hz wave frequency, modulation at 50 bursts/s, a pulse duration of 200μs, and an inter-burst interval of 10 minutes, he could elicit electrically evoked contractions and potentially increase muscular strength (Avila, Brasileiro, & Salvini, 2008). Currently, many European training facilities offer both whole-body suits equipped with electrodes or sensors and separate transcutaneous electrical nerve stimulation (TENS) units. This setup allows individuals to receive electrical stimulation across multiple muscle groups using the whole-body suit, while also providing the option for targeted stimulation on specific areas of the body using the separate TENS units. This combined approach enables individuals to achieve the intensity equivalent to a 60-minute strength training session in just 20 minutes (Seyri & Maffiuletti, 2011). It has been suggested that NMES can effectively increase strength and power in athletic populations without interfering with sports-specific training (Maffiuletti, 2010; J. K. Malone, Coughlan, Crowe, Gissane, & Caulfield, 2012). According to the muscle pump theory, skeletal muscle contractions constrict intramuscular veins, delivering kinetic energy and facilitating blood return to the heart (Miller, Pegelow, Jacques, & Dempsey, 2005). Therefore, similarly, low-frequency NMES creates a series of involuntary muscular contractions that increase blood flow through the muscle pump theory (Broderick, Breathnach, Condon, Masterson, & ÓLaighin, 2013). Removing metabolites like lactate and inorganic phosphate via NMES may reduce fatigue symptoms.

Regular exposure to HT has been used in patient care for medicinal purposes, including

the treatment of skeletal muscle disorders (Kim et al., 2020a). New studies show that HT could promote angiogenesis, anabolism, mitochondrial biogenesis, and glucose homeostasis, which increase overall energy metabolism in medical patients and athletes (Akasaki et al., 2006; Chung et al., 2008; A. Goto et al., 2015; K. Goto et al., 2003; Hafen et al., 2019; Hafen, Preece, Sorensen, Hancock, & Hyldahl, 2018; Harris, Blackstone, Ju, Venema, & Venema, 2003; Hesketh et al., 2019; Hoekstra, Bishop, Faulkner, Bailey, & Leicht, 2018; Ives et al., 2012; Katsumasa et al., 2005; Kobayashi et al., 2005; Kuhlenhoelter et al., 2016; Liu & Brooks, 2012). Heat therapy also stimulates corticotropin-releasing hormone to cause vasodilation in human skin, as well as promotes endothelial nitric oxide (eNOS), which is another enzyme that leads to vasodilation and potentially metabolite removal, while enhancing the flow of leukocytes and cytokines to the damaged tissue synthase (K. Goto et al., 2003; Harris et al., 2003). Heat therapy also increases oxygen uptake and accelerates tissue healing, as well as the protein catabolic rate (Boucher & Carpentier, 1993). Both NMES and HT have the potential to provide an innovative solution to enhance post-exercise recovery in athletic populations, potentially helping to prevent overtraining syndrome, reduces injury risks, enhances physical capacity, and improves overall quality of life.

Purpose Statement

The objective of this study was to assess the efficacy of neuromuscular electrical stimulation (NMES) alone, heat therapy (HT) alone, and NMES + HT as recovery interventions, compared to a control condition, following maximal fatigue-inducing exercise in active individuals. The student investigator hypothesized that both NMES + HT would improve skeletal muscle recovery rates, with HT anticipated to have a more pronounced effect compared to NMES.

CHAPTER TWO: LITERATURE REVIEW

NMES for Strength Enhancement

The majority of proposed clinical research on electrical stimulation, including NMES, suggests that NMES can enhance muscle strength, increase range of motion (ROM), and prevent muscle atrophy (Cullen, Casazza, & Davis, 2021). Strength training at higher intensities, that may be difficult to achieve voluntarily, may be facilitated by NMES (Enoka, Amiridis, & Duchateau, 2020; Kramer, Lindsay, Magee, Wall, & Mendryk, 1984; Okuma, Bergquist, Hong, Chan, & Collins, 2013). This capability of NMES to induce more intense muscular contractions is due to enhanced muscle recruitment. Unlike voluntary contraction (VC), which contracts according to the theory of Henneman's size principle, NMES recruits slow and fast muscle fibers at the same rate as it involves the electrical stimulation of muscle and/or nerve cells to trigger muscle contractions. The electrical current first activates the nerves, as their excitability threshold is lower than that of muscle fibers. Surface electrodes are used to apply the electrical stimulus over the motor point of the muscle through the skin (Paillard, 2008). Small motor units are made up of slow-twitch fatigue-resistant fibers, whereas large motor units are made up of fast-twitch, highly fatiguing fibers. As a result, muscle fatigue appears earlier with NMES than with VC for a given intensity and duration of stimulation (Dehail, Duclos, & Barat, 2008). In addition, NMES is only capable of stimulating muscles on the direct superficial area that it is placed; therefore, it does not recruit synergetic or stabilizing muscles as VC does. Similarly, NMES induces higher levels of cytoplasmic acidification compared to VC, suggesting increased muscular fatigue and the possibility of greater muscular adaptations (Chudinova, Nadezhdina, & Ivanov, 2012).

As a prominent technique, NMES has the potential to significantly enhance muscular

development and performance. Fillipovich and colleagues (2011) conducted a systematic review of approximately 200 studies, selecting 89 trials that met specific criteria, including subject age (<35 years), electrical stimulation type (percutaneous stimulation), and study duration (>7 days). The study categorized subjects into three groups based on their level of fitness (untrained, trained, and elite athletes) and the types of electrical stimulation methods used (local, whole-body, and combination). The primary aim was to identify the preconditions for generating a stimulus above the training threshold with electrical stimulation. This activates strength adaptations and provides guidelines for implementing electrical stimulation effectively in strength training, particularly in high-performance sports. The analysis found a significant relationship ($p<0.05$) between a stimulation intensity of ≥50% maximum voluntary contraction (MVC; 63.2 ± 19.8%) and significant strength adaptations ($p<0.05$). To achieve this level of MVC, specific guidelines were identified for combining training regimens with relevant stimulation parameters to systematically develop various strength abilities such as maximal strength, speed strength, jumping and sprinting ability, and power (Filipovic, Kleinöder, Dörmann, & Mester, 2011). The incorporation of NMES into resistance training has been found to be effective in promoting muscular adaptations (Kemmler et al., 2016). In this study, the authors compared the effects of traditional training, which involved a combination of resistance exercises and endurance exercises performed twice a week, with training that also included NMES (Kemmler et al., 2018).The study included 30 post-menopausal women with experience in physical training who were divided into a control group (n = 15) and an NMES group (n = 15). The participants underwent a 14-week program, with the NMES group performing additional 20-minute sessions of NMES training. Resting metabolic rate (RMR) remained stable in the NMES group (-0.1 +/- 4.8 kcal/h) but decreased in the control group (3+/-5.2 kcal/h, $p<0.05$). Significant reductions in the sum of skinfolds (28.6%) and waist

circumference (22.3%) were observed in the NMES group, while both parameters increased in the control group ($p = 0.001$). Furthermore, isometric strength of trunk extensors and leg extensors significantly improved in the NMES group compared to the control group (9.9% vs. 6.4%, $p<0.05$; 9.6% vs. -4.5%, $p<0.05$, respectively). These findings suggest that NMES training can effectively enhance strength, maintain lean body mass, and improve metabolic fitness outcomes, making it a promising alternative for post-menopausal women.

Consequently, the authors proposed that this innovative exercise technology could be a viable alternative for individuals seeking to enhance functional and morphological adaptations obtained from resistance training (Evangelista et al., 2019; Kemmler, Schliffka, Mayhew, & von Stengel, 2010). In conclusion, the integration of NMES into resistance training has shown promising results in enhancing muscular adaptations, metabolic fitness outcomes, and strength adaptations, making it a valuable and effective alternative for individuals seeking to improve their physical capabilities and overall fitness levels.

Physically Active Population and NMES

Elite athletes have a superior fitness level; therefore, athletes would have different parameters and training regimens compared to the general and untrained population (Steinacker, Wang, Lormes, Reißnecker, & Liu, 2002). Regardless of the already high-level strength of elite athletes, NMES interventions showed an increase in muscular strength (Filipovic et al., 2016).As an example, Deley et al. (2011) examined the effects of a six-week combined NMES and gymnastic training program on muscle strength and vertical jump performance in prepubertal gymnasts. Sixteen young (12.4 ± 1.2 years) female gymnasts participated in the study, with eight assigned to the NMES group and the remaining eight assigned to a control group (training only in gymnastics). The NMES group received knee extensor muscle stimulation three times a week

during the first three weeks and once a week during the last three weeks, while both groups underwent similar gymnastics training five to six times a week. The results showed that after the initial three weeks of NMES training, there were significant increases in maximal voluntary torque (+40.0 ± 10.0%, +35.3 ± 11.8%, and +50.6 ± 7.7% for -60°, +60°, and +240° per second, respectively; $p<0.05$). Additionally, improvements were observed in squat jump, reactivity tests, and specific jump performances (+20.9 ± 8.3%, +20.4 ± 26.2%, and +14.9 ± 17.2%, respectively; $p<0.05$). After six weeks of NMES training, improvements were observed in the counter-movement jump (CMJ) (+10.1 ± 10.0%, $p < 0.05$). Notably, the enhancements in jump ability were still maintained one month after the conclusion of the NMES training program. This study demonstrates that a six-week NMES program, combined with regular gymnastic training, resulted in improvements in knee extensor muscle strength and both nonspecific and specific jump performances among prepubertal gymnasts (Deley, Cometti, Fatnassi, Paizis, & Babault, 2011). The authors also described that, due to the prolonged amount of practice gymnasts have, it would be beneficial to use additional tools to support and increase muscular strength and power output by performing specific gymnastic movements and jumps. The study found significant differences ($p<0.05$) between the control and experimental groups (Deley et al., 2011; Gondin, Guette, Ballay, & Martin, 2005)

Similarly to Deley and colleagues (2011), a study conducted by Babault and colleagues (2007) examined the impact on ($n = 25$) elite rugby players that underwent a 12-week NMES training protocol, which involved the placement of NMES on the knee extensor, plantar flexor, and gluteus muscles three times a week. After the 12th week, there were significant improvements in the −120°·s-1 maximal eccentric torque, 120 and 240°·s-1 maximal concentric torque ($p<0.05$), as well as squat strength (+15.0 ± 8.0%; $p<0.001$), squat jump (+10.0 ± 9.5%; $p<0.01$), and drop jump

from a 40-cm height (+6.6 ± 6.1%; $p<0.05$). Nonetheless, NMES had no effect on their specialized abilities, such as scrummaging and running (Babault, Cometti, Maffiuletti, & Deley, 2011). These findings suggest that NMES training can have a substantial long-term impact on the muscle strength and power of professional athletes.

On the other hand, Willoughby and Simpson (1998) investigated the impact of NMES on knee extensor strength and vertical jump performance during weightlifting exercises. Female college track and field athletes (n = 20) were randomly assigned to one of three groups: weight-training-only, NMES-only, or weight-training + NMES. Athletes trained three times per week at 85% of their 1- repetition maximum (RM), performing three sets of 8–10 reps, while the NMES group received stimulation three times per week. The three experimental groups showed significant differences ($p<0.05$) compared to the control group in both strength and vertical jump. Furthermore, the weight-training and NMES groups demonstrated significant superiority over the weight-training-only and NMES groups. These findings suggest that combining NMES with dynamic contractions is more effective than using NMES alone or weight training alone in enhancing knee extensor strength and vertical jump performance in female track and field athletes (Willoughby & Simpson, 1998). In addition, Maffiuletti and colleagues (2002) also found that combining NMES with plyometric training can enhance the vertical jump ability of volleyball players. The objective of this study was to examine the impact of a 4-week NMES training program on the vertical jump performance of volleyball players (n = 12). Each NMES adaptation was conducted three times per week for about 34 minutes in total, involving stimulations of the knee extensor and plantar flexor muscles. No significant changes were observed in squat jump (SJ) and counter-movement jump (CMJ) performance following NMES training. However, the mean height and mean power maintained during 15 seconds of consecutive CMJs significantly increased

by approximately 4% ($p<0.05$). Furthermore, 10-days after the conclusion of NMES training, there was a significant improvement in jump height for both single jumps (SJ +6.5%, CMJ +5.4%) compared to baseline ($p<0.05$). These findings suggest that when utilizing NMES resistance training to enhance vertical jump ability, incorporating sport-specific workouts after NMES can optimize the central nervous system's control over neuromuscular properties (Maffiuletti, Dugnani, Folz, Di Pierno, & Mauro, 2002). However, some studies did not show any significant difference ($p<0.05$) comparing experimental and control groups. As an example, Dehail and his colleagues (2008) concluded that, in terms of strength improvements, it provided no greater advantages compared to conventional strength training techniques. However, researchers also mentioned that there is not enough data to determine the concrete benefits of NMES (Dehail et al., 2008). According to Seyri and Maffiuletti (2011), short-term NMES training did not produce any noticeable effects on muscle strength, vertical jump performance, or power. However, the analysis revealed that a stimulation duration of 10-15 minutes of treatments, 2-3 sessions per week for 3-4 weeks is adequate to bring about improvements in speed and strength, as well as in jumping and sprinting capabilities (Seyri & Maffiuletti, 2011). Consequently, the length of some studies did not allow for enough time to properly develop any strength adaptations, particularly for elite athletes who practice continuously and do not exhibit the same levels of muscular growth and development as beginners, leaving less room for improvement.

NMES as a Recovery Modality

Muscular fatigue is associated with impairments in muscle strength and power, which could be detrimental in competitive sports. Inadequate recovery after short-term, high-intensity bouts of exercise can be a limiting factor to optimal athletic performance, leading to tissue injury or over-training syndrome (Barnett, 2006; Higgins et al., 2011). As a result, it is critical for athletic

populations to enhance exercise recovery in order to increase performance restoration prior to continued physical activity (Pournot et al., 2011). Previous literature indicates that NMES can be used effectively for increasing indices of both strength and power in athletic populations. NMES is also associated with analgesic effects and muscle hypotrophy (Lake, 1992). However, fewer studies have examined the effects of NMES as a recovery intervention to enhance sporting performance. Neric and colleagues (2009) conducted a repeated measures study to compare swim recovery and NMES in reducing blood lactate levels after sprint swimming. Competitive swimmers (n = 30) participated in the study and completed three testing sessions with different recovery treatments: passive resting recovery, submaximal swimming recovery, and electrical muscle stimulation. Electrical muscle stimulation was set to a biphasic waveform with an amplitude of 35 mA and settings ranging from low frequency (2 Hz) to high frequency (70 Hz). The findings demonstrated a significant ($p<0.05$) relationship between the recovery period and the clearance of blood lactate (mmol/L). Employing NMES resulted in reduced blood lactate levels (3.12 ± 1.41 mmol·L−1) following a 20-minute recovery period when compared to passive rest (4.11 ± 1.35 mmol·L−1) (Neric, Beam, Brown, & Wiersma, 2009). A similar study conducted by Seo and colleagues (2011) examined the effect of electrical stimulation on blood lactate levels after inducing anaerobic muscle fatigue in Taekwondo athletes. The study included 24-competitive male athletes who were divided into three groups: the NMES group (n = 8), the massage group (n = 8), and the control group (n = 8). Anaerobic muscle fatigue was induced using a Wingate ergometer. Participants were instructed to sit on the ergometer, place their feet on the fixed pedals, and maintain a 75-degree inclination of their body angle with a 10-degree angle between the handle of the bicycle ergometer and their elbow during the initial posture for measurement. The NMES group received neuromuscular electrical stimulation (NMES) with specific parameters, including a

carrier frequency of 4 kHz, a pulse duration of 125 μs, and a current intensity set to the minimum visible contraction of the rectus femoris muscle. Results revealed significant differences ($p<0.05$) between the NMES group and the control group, concluding that NMES improved the recovery of muscle fatigue induced by anaerobic exercise in Taekwondo athletes (Seo, Kim, Choi, Kwon, & Shin, 2011). Similarly, Warren and colleagues (2011) focused on a decrease in blood lactate levels using three recovery methods: NMES, passive, and active recovery. Integrating (n = 7) NCAA Division II collegiate baseball pitchers who participated in all three methods. NMES was set to a biphasic symmetrical waveform, and the pulse width was 250μs. The frequency started at 9 Hz and automatically decreased every 2 minutes. The first 2 minutes were at 9 Hz, the following 2 minutes were at 8 Hz, and the last 2 minutes were at 7 Hz. The study found that blood lactate levels significantly decreased after using the NMES recovery method ($p<0.05$), while no significant changes were observed with passive recovery ($p<0.5$) or active recovery ($p<0.05$). These results suggest that NMES is an effective recovery method for pitchers between innings (Warren, Brown, Landers, & Stahura, 2011). Additionally, Bieuzen and colleagues (2014) also investigated the effect of low-frequency NMES and whether it accelerated the recovery rate as compared to passive and active recovery. Scientists measured the blood lactate, pH, bicarbonate concentrations, heart rate, respiratory gas exchange, and tissue saturation index of gastrocnemius muscle to determine the effect of a recovery technique. They recruited a group of highly trained female handball players (n = 14) to undergo two Yo-Yo Intermittent Recovery Tests (YYIR2), with a 15-minute recovery period in between. Participants were then randomly assigned to one of three recovery methods: NMES, active recovery, or passive recovery. The impulse duration of NMES was set to vary between 25μs and 250μs, with a frequency of 250 Hz. Results revealed that low-frequency NMES demonstrated a significant improvement in performance during the second YYIR2 compared to

passive recovery (-1.8%). Additionally, NMES led to faster restoration of resting blood lactate (86%), pH (11%), and bicarbonate concentrations (3%) compared to passive recover (Bieuzen, Borne, Toussaint, & Hausswirth, 2014). Pecho and colleagues (2018) examined the effect of low-frequency NMES on repeated-sprint performance compared to active and passive recovery in amateur soccer players. They recruited male amateur soccer players (n = 11) who completed two repeated-sprint events separated by a 15-minute recovery period. Executed seven maximal sprints covering a distance of 34.2 meters, each including changes of direction, followed by 25 seconds of active recovery involving jogging. NMES was set to a frequency of 250 Hz, and the impulse duration modulated from 25 to 250 μs. Results showed that the mean sprint time significantly increased between the first and the second repeated-sprint ability test after NMES (from 6.45 ± 0.25 s to 6.54 ± 0.27 s; $p<0.05$), suggesting that NMES can be useful during recovery for enhancing performance. There seems to be good evidence to show that NMES can have a positive blood lactate-lowering effect compared with passive recovery (Pecho, Šiska, Ščibrany, & Zemková, 2018).

Heat Therapy

Local heat modalities are often used with musculoskeletal conditions related to pain, increased tissue stiffness, and reduced range of motion. Local HT allows an individual to heat the body part, interchanging body core temperature (Kim, Monroe, Gavin, & Roseguini, 2020b). The application of heat stimulates thermoreceptors, which then send messages proximally to the dorsal horn in the brain. These thermoreceptors initiate signals that can block the processing of pain signals, also known as nociception, in the lumbar dorsal fascia and spinal cord (Placzek & Boyce, 2006). For instance, Nadler and colleagues (2002) demonstrated the effect of HT on nociceptors. Scientists recruiting individuals with acute, non-specific lower back pain (LBP) were randomly

divided into three groups: heat wrap therapy for 8 hours daily (n = 113), acetaminophen (n = 113), ibuprofen (n = 106), oral placebo (n = 20), or unheated back wrap (n = 19). All three groups experienced pain relief, but the heat wrap therapy exhibited significantly greater pain relief compared to acetaminophen or ibuprofen throughout a two-day treatment period ($p<0.001$ for all) as well as a two-day follow-up period ($p<0.001$ for all). HT also promoted a significant reduction in muscle stiffness ($p<0.05$) (Nadler et al., 2002). Another study by Nadler and colleagues (2003) demonstrated similar results where participants were divided into the following groups: heat-wrap (n = 95), oral ibuprofen (n = 12), oral placebo (n = 96), and unheated back wrap (n = 16). The results showed that the heat wrap therapy provided significantly greater pain relief compared to the oral placebo on the first day ($p<0.001$). This difference in pain relief continued throughout the two-day follow-up period ($p<0.001$). Furthermore, improvements in muscle stiffness and lateral trunk flexibility were evident, with the heat wrap group displaying significantly greater enhancements compared to the oral placebo group (Nadler et al., 2003).

Heat therapy has been shown to promote angiogenesis, which is beneficial for exercise tolerance in such conditions as peripheral artery disease, chronic heart failure, and chronic obstructive pulmonary disease (Kuhlenhoelter et al., 2016). While investigating the impact of local HT on skeletal muscle capillarization in humans, Kuhlenhoelter and colleagues (2016) conducted a study where they exposed healthy young adults to HT (n = 43) compared to a control group (n = 12). In the skeletal muscle, researchers illustrated increased mRNA expression of vascular endothelial growth factor (VEGF), angiopoietin 2 (ANGPT2), chemokines CCL2 and CX3CL1, platelet factor-4 (PF4), and various heat shock proteins (HSPs) compared to the control group. However, it did not have an impact on the levels of CX3CL1, transcription factor FOXO-1, and platelet factor-4 (PF4). These findings indicate HT may have the potential to stimulate the

expression of factors associated with the growth of capillaries in human skeletal muscle (Kuhlenhoelter et al., 2016). Similar research was conducted by Hesketh and colleagues (2019), comparing the effects of local HT and moderate-intensity continuous training (MICT) on various factors in skeletal muscle. Twenty sedentary males underwent either six weeks of local HT (n = 10) or MICT (n = 10). Both HT and MICT resulted in significant increases in capillary density (PHT: 21%, MICT: 12%), capillary-fiber perimeter exchange index (PHT: 15%, MICT: 12%), and endothelial-specific eNOS content (PHT: 8%, MICT: 12%) ($p<0.05$) (Hesketh et al., 2019). Therefore, it enhances the delivery of oxygen and nutrients, aiding in muscle repair and recovery following intense physical activity. Similarly, in wound healing, improved capillary density around the injured area can bolster blood flow, which is essential for tissue repair.

Another effect of HT is its ability to promote better blood circulation, which is important for damaged tissue. Heat activates transient receptor potential vanilloid 1 and ankyrin 1 (TRPV1) and (TRPA1), which are, respectively, non-selective cation channels recognized for their specific involvement in pain and nociceptive signaling. TRPV1 and TRPV4 receptors, as well as nociceptors, leads to an increase in blood flow to a damaged area (Petrofsky et al., 2013). The initial response to heat is facilitated by sensory nerves that release substance P and calcitonin gene-related peptide, resulting in enhanced circulation. Following the initial response, vascular endothelial cells begin producing nitric oxide, which is responsible for sustaining the circulation's response to heat. This increase in circulation plays a crucial role in safeguarding the tissues from heat and aiding in the repair of damaged tissue (Jerrold Petrofsky et al., 2013). In a study designed by Petrofsky and colleagues (2007), the objective was to compare the effects of global heat versus using local heat to determine the greater blood flow influx. The study involved the recruitment of 29 healthy participants, who were either incubated in a warm room or received local HT through a

heat lamp. Results indicated a significant blood flow increase with both HT treatments ($p<0.05$) (Petrofsky et al., 2007). Later, Petrofsky and colleagues (2009) examined the effect of moist heat and dry heat on skin blood flow. A total of 10 healthy participants were enrolled by the researchers, where subjects' blood flow was measured using a laser Doppler flow meter. The results of the experiments using a dry heat pack (commercially available chemical 42°C cell dry heat source), a moist hydrocollator pack (72.8°C) separated from the skin by eight layers of towels, and a whirlpool at 40°C revealed that moist heat induced significantly higher skin blood flow compared to dry heat (approximately 500% greater) ($p<0.01$) (Petrofsky et al., 2009).

Conclusion

Both NMES and HT have been widely implemented as medicinal modalities with the potential to promote and expedite the muscle recovery process. NMES has the potential to boost performance and reduce blood lactate levels, coupled with HT capacity to enhance blood circulation, manage inflammation, and alleviate pain. One common advantage they share is their ability to enhance blood circulation, which plays a pivotal role in delivering essential oxygen and nutrients to muscles while aiding in the removal of metabolic waste products, thus expediting the recovery process. Additionally, HT has the capacity to assist in managing inflammation. HT promotes the release of anti-inflammatory cytokines and reduces the activity of pro-inflammatory molecules, contributing significantly to tissue healing. Another noteworthy aspect is the versatility and accessibility of these modalities, making them practical choices for recovery across various settings, ranging from sports rehabilitation centers to home use. However, despite their extensive use, the effects of combining these modalities have yet to be investigated. Research examining the efficacy of HT as a post-recovery modality has been limited, leaving the extent of its impact on muscle recovery following exercise-induced damage unknown. This study aims to fill these gaps

by exploring the effects of NMES and HT on muscle recovery rate through assessments of ground reaction Fz (GRFz) force output and rate of perceived exertion (RPE). It is hypothesized that HT will exert a more significant positive influence on skeletal muscle recovery rate compared to NMES.

CHAPTER THREE: METHODS

This randomized control trial involved 56 participants, encompassing both male and female recreational to professional athletes. All participants were required to meet regular physical fitness guidelines for American Adults HHS (2018). Therefore, the exclusion criteria were as follows: individuals who engage in less than 150 minutes of moderate-intensity aerobic activity or less than 75 minutes of vigorous-intensity aerobic activity per week. Participants who did not engage in any form of muscle-strengthening activity involving major muscle groups on at least two days per week. Additionally, individuals were excluded from the study if they had a pacemaker, were currently pregnant, could not grip a barbell due to arthritis or hand injury, or had any orthopedic, neuromuscular, or cardiovascular health issues within six months of data collection. All eligible participants were fully informed of all procedures related to the study and were required to complete a written informed consent before participating. Lastly, participants completed and passed the Physical Activity Readiness Questionnaire (PAR-Q+) form that assesses the presence of risk factors during moderate physical activity and evaluates medical history and the severity of any existing illnesses (Thomas, Goodman, & Burr, 2011). All individuals were familiarized with the fatigue protocol. The aim of this familiarization process was to minimize any misunderstanding about the test, particularly concerning the technique.

The study was approved by the Northern Michigan University Institutional Review Board (HS23-1373). Data collection for each participant took place over one visit to the laboratory, lasting about 40 minutes. Participants were instructed to abstain from exercise for 24 hours and to refrain from consuming caffeine for three hours prior to participating in the study. Participants

were asked to wear shorts and comfortable athletic clothing. Participants were randomly assigned to one of four different experimental groups, including NMES (Fig. 1), HT (Fig. 2), NMES + HT (Fig. 3), and a control group, passive recovery (PR) (Fig. 4). Each participant performed a pre-test, a fatigue protocol, and a post-tests.

Pre-test

For the pre-test, participants were instructed to perform maximal isometric contractions in the high hang pull position with a clean grip and knee angle fixed at 45 degrees. Participants were asked to exert maximum force by pulling up on the barbell for a duration of 30 seconds, and were verbally encouraged and instructed to pull as fast and as hard as possible. The participant's hands were fixed to the bar using lifting straps (Implus LLC, NC, USA) to prevent hand movement and to ensure maximum effort could be given without the limitation of handgrip fatigue (Bailey, Sato, Alexander, Chiang, & H. Stone, 2013). AMTI (Advanced Mechanical Technology, Watertown, MA, 2023) force plates were placed beneath the participant to measure GRFz force output. Additionally, participants were asked to report their RPE immediately after completing the exercise bout. Following the pre-test, each group was given a one-minute period to arrange their assigned intervention setup and assume a comfortable seated position.

NMES Intervention

Participants were instructed to be seated comfortably in a chair with knees at 90-degrees and feet flat on the floor. The NMES was applied to the vastus medialis (VM) and rectus femoris (RF). These muscles were chosen due to their properties as powerful knee extensors. The intervention was administered by placing two 5x3-inch adhesive electrodes at 80% of the line running from the anterior superior iliac spine to the superior pole of the patella of the right leg. The NMES (Balego EMS Digital Neuromuscular NMES Stimulator, Minneapolis, MN, USA) operated

at a frequency of 4 Hz, with a phase duration of 250 μs, a contraction time of 4-seconds (inclusive of 1-second ramp-up/-down time), and an 8-second rest period in between (Malone et al., 2014).The entire recovery protocol spanned 15 minutes, during which time the NMES group received the targeted treatment.

Heat Therapy Intervention

The treatment involved the application of 15x24-inch hydrocollator moist heat packs, each incubated at a consistent temperature of 78°C. These packs were carefully placed in microfiber covers and applied to the right leg, with focused placement over the VM and RF muscles, for a duration of 15 minutes. To ensure maximum comfort and safety, a towel was placed between the skin and the microfiber cover to prevent the occurrence of burns or any other form of discomfort that might have arisen from the treatment.

NMES and HT Intervention

The NMES and HT group followed the same recovery protocol settings, but receiving both recovery modalities simultaneously. The NMES modality was performed under the same terms and conditions using 4Hz frequencies, 250 μs, a contraction time of 4 seconds (inclusive of 1-second ramp-up/-down time), and an 8-second rest period in between (Malone et al., 2014). A heat pack was placed over the electrodes for 15 minutes.

Passive Recovery Intervention

The control group was not provided with any modality and passively recovered for 15 minutes while in a seated position, ensuring a comfortable position in the chair. This served as a baseline comparison for the experimental groups receiving either NMES, HT, or a combination of both treatments.

Post-test

Following a one-minute rest, participants repeated the fatigue protocol, performing a 30-second maximal isometric contraction in the high hang pull position with knees at 45 degrees. During both pre- and post-fatigue protocols, peak and average GRF were analyzed.

Statistical Analysis

A two-step statistical analysis approach was employed to assess the effects of different recovery modalities on recovery rates. Firstly, a one-way ANOVA followed by a Bonferroni post hoc test was conducted to evaluate significant differences in baseline data among the four groups (NMES, HT, NMES+HT, and passive recovery) and to check for assumptions of the independent effect of the covariate. Subsequently, an analysis of covariance (ANCOVA) was performed to investigate the effect of the covariate peak total GRFz (pre) on the recovery rates. This step was crucial in controlling for the influence of pre-existing conditions on post-recovery outcomes, ensuring that any differences observed among the recovery modalities were not solely due to variations in participants' initial states. The statistical analyses were conducted using G*Power software, with significance set at $p < 0.05$ for all analyses.

Control group designs: SDIR

The Standard Deviation Individual Response (SDIR) is a measure used to quantify the difference in variability between the intervention groups and the control group. It is used to assess how much the standard deviation of the changes observed in the intervention groups differs from that of the control group. We calculated it by utilizing this formula: SDIR=\sqrt{(SD_{exp}^2 - SD_{con}^2)}. Where (SD_{exp}^2 \) is the variance (standard deviation squared) of the changes observed in the intervention group. (SD_{con}^2 \) is the variance (standard deviation squared) of the changes observed in the control group. The magnitude of correlation was qualitatively assessed

according to Hopkins as follows: trivial $r<0.1$, small $0.1<r<0.3$, moderate $0.3<r<0.5$, large $0.5<r<0.7$, very large 0.7 (Hopkins, Marshall, Batterham, & Hanin, 2009). For all analyses, the significance level was set at 5% ($p<0.05$). All data were analyzed using IBM SPSS Statistics 29.0 for Windows (SPSS, Inc., Chicago, IL).

Figure 1: NMES Recovery Protocol

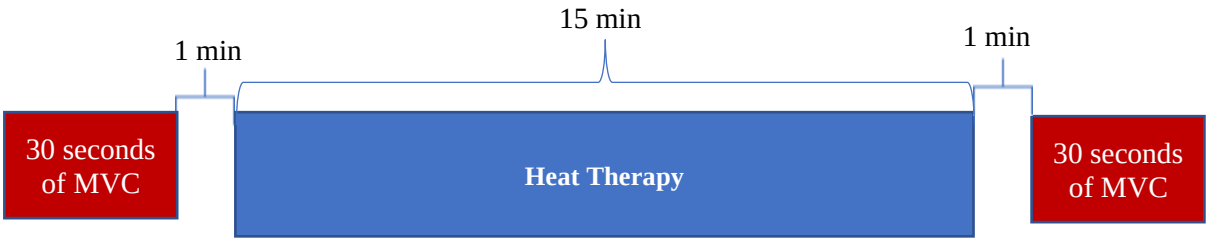


Figure 2: HT Recovery Protocol

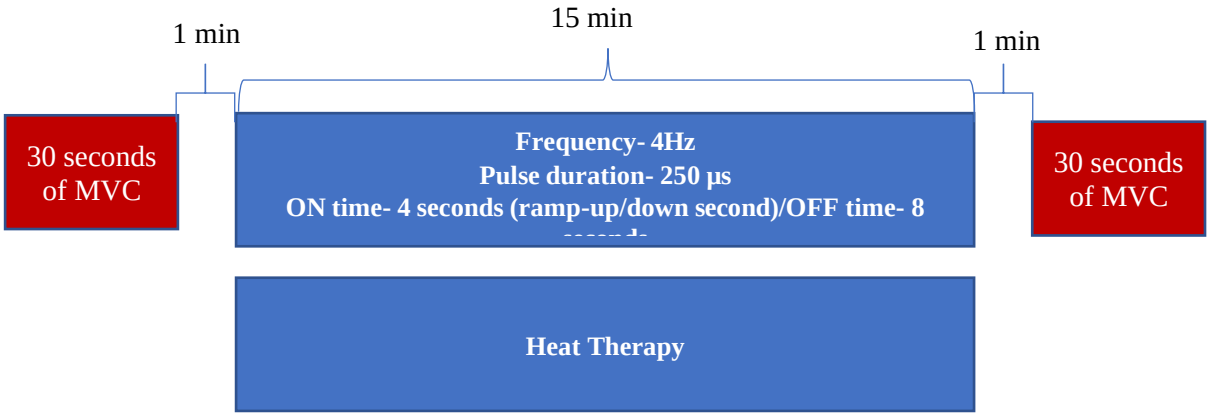


Figure 3: NMES and HT Recovery Protocol

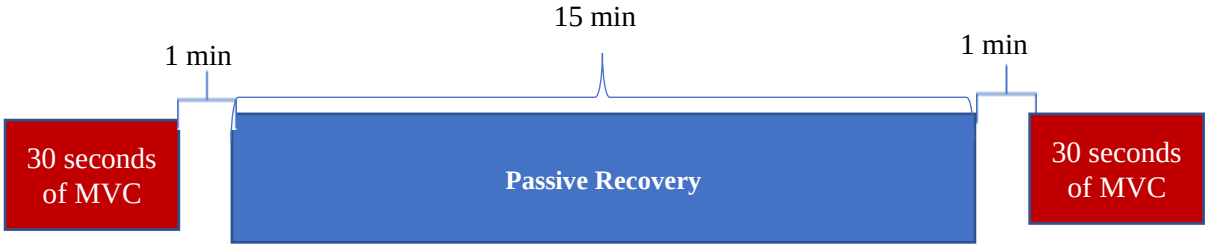
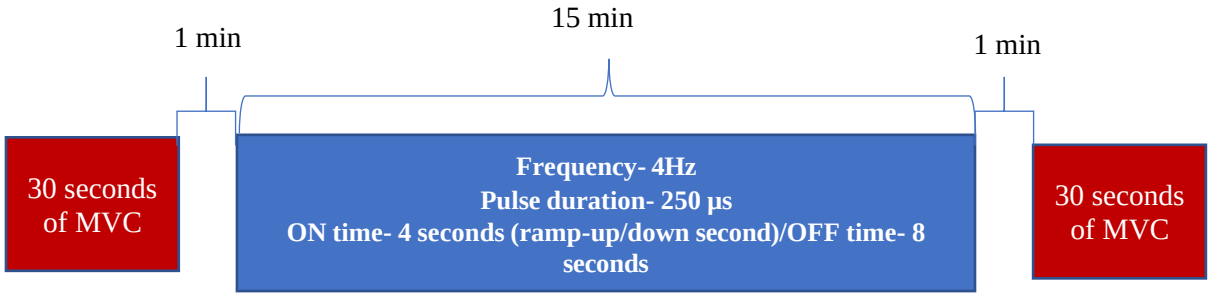


Figure 4: Passive Recovery (Control) Protocol



CHAPTER FOUR: RESULTS

The research sample consisted of 56 participants, predominantly male (n=32). On average, participants were 23 years old, with a standard deviation of 3.8 years. The average height was 173.4 centimeters, and the average weight was 78 kilograms, with standard deviations of 9.4 centimeters and 15.9 kilograms, respectively. Table 1 breaks down these characteristics by recovery intervention groups and a control group, allowing for a direct comparison of participant characteristics within each subgroup.

Table 1. Descriptive statistics of participants by group groups: Control, HT, NMES, and NMES + HT

Group (n)	Age (years)	Height (cm)	Weight (kg)	Female (n(%))	Male (n(%))
Control (14)	23 ± 3.5	171.16 ± 6.89	73.89 ± 12.98	7 (50%)	7 (50%)
HT (14)	22 ± 4.4	176.36 ± 9.13	84.41 ± 15.02	4 (29%)	10 (71%)
NMES (14)	23 ± 3.6	174.50 ± 12.92	79.23 ± 22.42	5 (36%)	9 (64%)
NMES+HT (14)	23 ± 4.2	171.41 ± 7.48	74.64 ± 9.66	8 (57%)	6 (43%)

HT-heat therapy, NMES- neuromuscular electrical stimulation.

Performance parameters

Table 2 displays the changes in performance parameters observed before and after the intervention across different groups. Pre-test peak GRFz did not exhibit statistically significant differences between the groups ($F(3, 52) = 0.564$, $p = 0.641$, 95% CI). Furthermore, all assumptions required for ANCOVA were satisfied. Three was a statistically significant effect of the covariate, pre-test peak GRFz, on peak GRFz post-test scores ($F(1, 51) = 213.911$, $p < .001$). After controlling for pre-test peak GRFz, there was no difference in post-test peak GRFz between the four recovery modalities ($F(3,51) = 1.79$, $p = 0.16$).

Table 2. Pre and post-intervention mean and standard deviation of peak total GRFz across four groups: control, HT, NMES, AND NMES + HT

Group (n)	Pre-Intervention (N)	Post-Intervention (N)
Control (14)	2248.7 ± 788.19	2051.76 ± 783.67
HT (14)	2526.52 ± 703.65	2434.29 ± 839.67
NMES (14)	2368.86 ± 837.72	2400.82 ± 737.62
NMES+HT (14)	.39 ± 560.62	2269.94 ± 699.23

HT-heat therapy, NMES- neuromuscular electrical stimulation, GRFz- vertical ground reaction force

Heterogeneity of treatment response

The SDIR values for the change in peak total GRFz for the control, HT, NMES, and HT+NMES intervention groups were 199.9N, 482.7N, 231.1N, and 365N, respectively. Standardizing the SDIR values to all participants' baseline Peak Total GRFz values resulted in a value of 0.61 for the HT group, 0.16 for the NMES group, and 0.42 for the NMES+HT group, respectively, indicating that there was a large, small, and moderate to response heterogeneity for participants in the intervention groups, respectively.

Perceptual measures

Table 3 presents the RPE scores before and after the intervention for each group. While there were fluctuations in RPE scores within each group, indicating variations in perceived exertion levels, statistical analysis did not reveal significant differences ($p > 0.05$) between pre- and post-intervention RPE scores across the groups.

Table 3: Comparison of pre- and post-exercise Borg's scale across different intervention groups

Group (n)	RPE (pre)	RPE (post)
Control (14)	15.57 ± 2.71	15.36 ± 3.05
HT (14)	15.57 ± 1.99	15.29 ± 1.73
NMES (14)	12.66 ± 3.18	14.21 ± 3.33
NMES+HT (14)	15.64 ± 2.76	15.07 ± 3.29

HT-heat therapy, NMES- neuromuscular electrical stimulation, RPE- ratings of perceived exertion

CHAPTER FIVE: DISCUSSION

The aim of the study was to determine the effects of NMES, HT, or NMES + HT on muscle recovery following a maximal isometric hang-high-pull fatigue protocol. Vertical GRFz and RPE were used to assess fatigue following the recovery protocol. The findings suggest initial peak GRFz values did not differ among the intervention groups, implying participants did not defer in fatigue levels pre-intervention. Furthermore, even after adjusting for the baseline values, the selected recovery modalities did not yield statistically significant differences in the post-intervention outcomes to suggest one modality was superior to another. Our findings suggest factors beyond the chosen interventions may have influenced the observed changes in peak total GRFz scores. Moreover, exploring the heterogeneity of treatment responses revealed interesting insights into how participants in each intervention group reacted differently to the protocols when accounting for variability in the control group. The variation in responses, as indicated by the SDIR values, suggests that individual characteristics and other unaccounted factors may have influenced the efficacy of the interventions. For instance, participants in the HT group exhibited a wide range of responses, indicating considerable diversity in how they reacted to the intervention. On the other hand, participants in the NMES group showed more uniform outcomes, with smaller variations observed among individuals. The combined NMES+HT group displayed a moderate-to-large range of responses, suggesting a mix of reactions to the combined intervention.

Our findings align with and expand upon previous research, which has often produced conflicting results regarding the efficacy of NMES or HT. For example, Martínez-Gómez and colleagues (2022) explored recovery strategies post-high-intensity functional training (HIFT)

sessions in CrossFit athletes, comparing low-intensity peddling exercise, NMES, and total rest. They assessed perceptual (RPE), physiological (blood lactate and muscle oxygen saturation), and performance (CMJ and drop jump) indicators of recovery. Martínez-Gómez used similar NMES settings to our study, with a current of 5 Hz, a pulse duration of 300 μs, and a 15-minute resting interval, also employing RPE as a fatigue indicator. Despite a significant interaction effect for RPE, post hoc analysis did not show significant differences between conditions. There was a near-significant trend indicating lower RPE with NMES compared to control right after a 15-minute recovery, suggesting that while NMES may improve perceived recovery, it does not significantly enhance physiological recovery metrics or performance outcomes. This study supports our observation that NMES does not significantly influence fatigue recovery as measured by performance and perceptional indicators (Martínez-Gómez, Valenzuela, Lucia, & Barranco-Gil, 2022).

Similarly, Malone and colleagues (2012) examined the immediate effects of NMES on physical, perceptual, and performance indicators in trained male triathletes. Participants performed six 30-second Wingate tests followed by a 30-minute recovery intervention: passive, active (cycling), or NMES. While blood lactate decreased faster with active recovery, there were no significant performance differences between interventions. Similar to our study, Malone et al. utilized a 30-second fatiguing exercise, and despite doubling the recovery phase, NMES did not enhance the recovery rate. This study highlights that NMES did not outperform traditional methods in enhancing short-term recovery or improving subsequent performance, which aligns with our findings (Malone et al., 2012).

Consistent with our investigation, preceding studies utilized low frequencies and brief resting intervals, yielding non-significant disparities. This implies that NMES efficacy may

necessitate extended application periods. For example, Taylor and colleagues (2015) recruited rugby and football players who completed baseline CMJ, after which they performed maximal sprints while wearing a NMES (frequency 1 Hz, duration 140μs, current 27mA) device or remained in normal attire (CON) for eight hours. Player jump height decreased from baseline at all time points under both conditions. However, at the 24-hour mark, NMES led to a significantly greater recovery in jump height compared to CON. Creatine kinase concentrations increased at all time points under both conditions, but at 24 hours, it was lower in the NMES group. Similar to these researchers' findings, perceived soreness using the Likert scale was significantly lower in the NMES group than CON after 24 hours (Taylor et al., 2015). Taylor and colleagues (2015) observed a significant outcome after 24 hours, employing NMES for eight hours. However, Neric and colleagues (2009) conducted a study also utilizing recovery treatments that included passive resting recovery, submaximal swimming recovery, or NMES at a low intensity of 2 Hz and 35 mA. Blood lactate levels were measured at baseline, after a 200-yard sprint, and after 10 and 20 minutes of recovery. Submaximal swimming emerged as the most effective method for lowering blood lactate levels. However, NMES also demonstrated a significant reduction in blood lactate levels, outperforming passive recovery, particularly at the 20-minute post-exercise mark. Notably, Neric was able to show significant differences using even lower current intensity and a similar resting time (Neric et al., 2009). Neric's findings suggest that NMES at even lower intensities can be effective in reducing biomarkers of fatigue, supporting the potential efficacy of NMES as a recovery modality.

The variation in this study's results could be attributed to several factors. Firstly, some studies have reported improvements in outcomes after a 24-hour period, whereas the current study included only immediate responses. Additionally, it appears that interventions lasting

longer than 20 minutes may yield more significant effects. Moreover, the choice of fatigue indicators can influence outcomes; we focused on performance and perception, whereas other researchers included physical biomarkers such as blood lactate or creatine kinase. These differences in study design, intervention duration, and fatigue indicators may contribute to the disparities observed in the results.

Our study found that HT exhibited no significant difference in muscle recovery compared to the control group, similar to the results observed with NMES. Moreover, the overall trend within the HT group indicated a negative linear trajectory, although the SDIR approach showed participants experiencing a more substantial effect compared to NMES.

Similarly, Jayaraman et al. (2004) investigated the effects of topical heat and static stretching on muscle recovery post-eccentric exercise in untrained males, using MVC of the quadriceps as a measure, similar to our study. They also found no significant difference in performance or recovery rate with heat therapy. Jayaraman et al. used perceptual data (pain ratings), similar to our use of RPE data, and reported no significant improvement in pain relief compared to the control group. These results suggest that HT does not effectively enhance recovery, reinforcing the need for clinicians to consider alternative recovery strategies following intense exercise (Jayaraman et al., 2004).

Due to the lack of research focusing specifically on the effect of heat therapy on performance metrics rather than physiological factors, we were unable to compare our findings with a broader range of relevant studies.

Limitations

This study presented several limitations. While utilizing a fixed NMES intensity parameter might seem preferable, it is important to note that the perception of NMES intensity

varies greatly among individuals (Maffiuletti, 2010). This discrepancy can be attributed to factors such as differences in adipose tissue distribution, which can impact current delivery to targeted muscles during NMES, as well as varying tolerances to electrical stimulation and individual discomfort perceptions (Maffiuletti, 2010). Furthermore, the lack of blood flow measurements in the present study and the absence of direct measurements preclude a definitive conclusion in this regard. However, despite this possibility, our investigation did not directly assess blood flow changes induced by NMES and/or HT. Although the total participant number was high, the sample per group was quite low, potentially impacting our findings. Lastly, the current study involved participants who were as recreationally active as athletes, where experience may differ greatly between participants, which would affect the individual's hang-high pull technique. Despite the encouragement to pull as fast and as hard as they could to exert maximal effort, some participants consistently reported an average rating of 12 to 15 on the Borg scale, indicating exercise exertion ranging from fairly light to hard. This suggests that the fatiguing exercise may not have been sufficiently taxing for all participants and should have potentially been more fatiguing to better assess their capabilities.

Future Applications

Considerations related to practicality can play a pivotal role in an athlete's decision-making process when selecting a recovery intervention. In contexts where athletes demonstrate a proclivity towards utilizing NMES regimens or HT, the accessibility of appropriate spatial and facility resources significantly impacts their efficacy in implementing these modalities. This highlights the importance of ensuring adequate resources are accessible to athletes, empowering them to make optimal choices for their recovery strategies (Malone et al., 2012). Future studies could consider implementing a repeated measures design to mitigate intersubjective variability

and enhance the reliability of results. Additionally, extending the duration of the intervention and implementing follow-up assessments could provide deeper insights into the sustained effects of the interventions over time. These methodological adjustments would contribute to a more comprehensive understanding of the efficacy and potential long-term benefits of the interventions in athletic performance and injury prevention contexts. Overall, the interventions demonstrated a favorable impact when compared to the control group, as indicated by the observed alterations in peak total GRFz. This suggests that the implemented interventions effectively influenced the ground reaction forces, potentially contributing to improved performance or injury prevention. These findings underscore the significance of incorporating targeted interventions into training or rehabilitation protocols to optimize outcomes and enhance overall athletic performance.

CHAPTER SIX: CONCLUSION

In conclusion, our study did not find statistically significant differences in muscle recovery among the intervention groups (HT, NMES, and HT+NMES) compared to the control group. Despite this, positive trends in the data suggest that the interventions may have potential benefits. The variability in individual responses indicates that further research is needed to fully understand the efficacy of these recovery modalities.

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APPENDIX A:

Institutional Review Board Information

Application for Review of Research Involving Human Subjects

Northern Michigan University Institutional Review Board (IRB)

NORTHERN MICHIGAN UNIVERSITY

STEP ONE: Complete the CITI Basic Human Subjects Research Course and attach a .pdf of your results with your application. *Note: Some research projects may require you to take additional modules.*

STEP TWO: Complete the all applicable sections of the application below.

STEP THREE: Generate all applicable supporting documents including: recruitment letters, informed consent forms, questionnaire/interview questions, etc.

STEP FOUR: Submit all materials to faculty advisor (students) or co-researchers (faculty) for feedback on revisions.

STEP FIVE: Faculty advisor (for student research) or principal investigator (faculty research) must submit all materials to the following in a single email including:

- Co-researchers
- The head of your department
- IRB Chair, Derek Anderson (dereande@nmu.edu)
- IRB Office, (hsrr@nmu.edu)

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1. **Principal Investigator Information**

   a. Name of Principal Investigator: Dr. Lukus Klawitter

   b. Department: Health and Human Performance

a. Phone: +1(320) 583-7409

b. Email: lklawitt@nmu.edu

2. **Co-PI Information**

a. Name of co-PI: Diana Dzasezeva
b. Department: Health and Human Performance

c. Phone: +1(858)-322-3342

d. Email: ddzaseze@nmu.edu

3. **Co-Researchers' Information (name and email)**

a. Dr. Lukus Klawitter (lklawitt@nmu.edu)

b. Dr. Megan Nelson (msuer@nmu.edu)

c. Dr. Julie Rochester (jrochest@nmu.edu)

4. **Research Type: Is this research primarily:**

☐Faculty Research
☒Graduate Student Research
☐Undergraduate Student Research

5. **Project Title: Neuromuscular Electrical Stimulation in comparison to heat therapy as a modality to enhance skeletal muscle recovery**

6. **Project Dates: Format: MM/DD/YYYY – MM/DD/YYYY**

05/01/2023 – 04/01/2024

7. **Funding**

☒ Pending funding decision
☐ Currently funded
☐ Not funded

List source of funding (if applicable):

Excellence in Education Research Award Graduate Research Grant

8. Type of Review

a. <u>Limited IRB Review</u> (Benign behavioral interventions that are brief in duration, harmless, painless, not physically invasive, not likely to have significant adverse lasting impact on subjects, and investigator has no reason to think subjects will find the interventions offensive or embarrassing.)

Check one and provide a short justification in the text box below for how it applies to your project:

☐ Instructional setting practices/educational methods not likely to adversely affect instructional time or student performance. [*Note: in K-12 settings an approval letter from a school administrator is required but not informed consent from the students*]

☐ Educational testing or interviews outside of normal instructional setting practices, provided that any recorded information is completely de-identified <u>or</u> disclosure outside of the research would not put subjects at risk of harm.

☐ Surveys/Questionnaires

☐ Observations

☐ Research Conducted Cooperatively with another Institution (be sure the NMU researcher's and graduate dean's contact information is included on all consent forms).

Provide a short explanation for why your project fits the category you selected:

b. <u>Expedited IRB Review</u>(Research that does not qualify for Limited IRB Review but poses no more than minimal risks to participants and does not involve vulnerable populations.)

Common examples include, but are not limited to the following[1]. Check one and provide a short justification in the text box below if it applies to your project:

☐ Collection of blood samples by finger stick, heel stick, ear stick, or venipuncture

☐ Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves.

☒ Collection of data through normal exertional physical tasks, such as running, jumping, lifting weights etc., under proper supervision

☐ Collection of data from video or image recordings made for research purposes.

☐ Research conducted on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior), which typically includes interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

☐ Other

Provide a short explanation for why your project fits the category you selected:

Participants will include up to 30 18-35-year-old recreationally active healthy individuals. Data will be conducted in the lab where participants will perform a Maximal Voluntary Contraction (MVC) via a static hang high pull. A barbell will be positioned over AMTI force plates and participants will perform an isometric hang high pull and maximum ground reaction forces will collected to determine MVC.

c. **<u>Convened IRB Review</u>** (Research involving more than minimal risk to participants or includes one or more of the following vulnerable populations as participants.)

Check one or more of the following if it applies to your project:

☐ More than minimal risk to participants
☐ Children (not in standard classroom settings)
☐ Prisoners
☐ Individuals with impaired decision-making capacity

☐ Economically disadvantaged persons
☐ Educationally disadvantaged persons

Note: Convened IRB Review projects are approved for one year. Applicants must submit a Project Extension Form if their research will last longer than one year.

9. Study Objectives (Explain what you seek to determine by conducting your study)

To determine if Neuromuscular Electrical Stimulation (NMES) and Heat Therapy (HT) will increase recovery measured by hang high pull MVC.

10. Study Procedures (Explain what you will do and what your participants will do)

This research will involve a minimum of 48 healthy females and males, which is previously determined by G*Power software to get the appropriate sample size for the study. All participants will be required to meet regular physical fitness guidelines for American Adults HHS. (2018). Physical Activity Guidelines for Americans 2nd edition. All eligible participants will be fully informed of all procedures related to the study and will be required to complete a written consent form before participating. The study will be reviewed by the Northern Michigan Universities Internal Review Board. A cross-sectional study design will be utilized to accomplish the purposes of this study, the data will be measured and collected in an estimated time of 60-minutes. Subjects will be asked to wear shorts and a comfortable athletic wear on top. Participants will be randomly assigned to 4 different groups, including NMES, HT, NMES + HT, and a control group, passive recovery (PR). These 4 groups will perform pre-tests, a fatigue protocol, and post-tests.

Pre-test

For the pre-test participants will be instructed to perform maximal isometric contractions in the high hang pull position, with a clean grip and knee angle fixed at 45-degrees. The subject will be asked to exert maximum force on the barbell for a duration of 30 seconds. The subject will be verbally encouraged and instructed to pull as fast and as hard as possible. Participant's hands will be fixed to the bar using athletic tape to prevent their hand movement and to ensure a maximum effort could be given without the limitation of handgrip strength (Bailey et al., 2013). AMTI (Advanced Mechanical Technology, Watertown, MA) force plates will be placed beneath the participant to measure ground reaction Fz force output, while a fingertip pulse oximeter SpO_2 will be utilized to detect any potential fatigue due to hypoxia. Recent studies have found that a parallel decline and restoration of force occurs with alterations in O2 supply but not blood flow alone during submaximal contractions (Hepple, 2002). Additionally, participants will be asked to report their rate of perceived exertion (RPE) immediately after completing the exercise bout. The collected data of the ground reaction Fz force output, SpO_2, and RPE for each participant will help to determine fatiguability and improvement due to a recovery intervention. After the pre-test, a 1-minute window will be provided for each group to set up for the group they were randomly assigned to and ensure a comfortable position for the subject.

NMES Intervention

The targeted treatment approach involves the activation of the Vastus Medialis (VM) and Rectus Femoris (RF) muscles through the application of NMES. This intervention will be administered by placing 5x3 inch adhesive electrodes at 80% of the line running from the anterior spina iliaca superior to the superior part of the patella. The NMES will operate at a frequency of 4 Hz, with a phase duration of 250 µs (500 µs biphasic pulse), a contraction time of 4 s (inclusive of 1 s ramp-up/-down time), and an 8-seconds rest period in between (Malone et al., 2014). The entire recovery protocol will span 15 minutes, during which time the NMES group will receive the targeted treatment.

Heat Therapy

In the HT group, each subject will be instructed to assume a comfortable position on the chair, as proper positioning is essential for obtaining accurate and reliable results. The treatment modality employed will involve the application of 15x24 inch hydrocollator moist heat packs, which will be carefully placed in microfiber covers and applied longitudinal to each leg with focused placement over the VM and RF muscles. A compression wrap will then be applied over the heat modality to prevent it from moving, with the duration of application set to last for 15-minutes. To ensure maximum comfort and safety, a towel will be placed between the skin and the microfiber cover to prevent the occurrence of burns or any other form of extreme discomfort that may arise from the treatment.

NMES and HT Intervention
The NMES and HT groups will follow the same fatigue protocol setting. NMES will be administered by placing 5x3 inch adhesive electrodes at 80% of the line running from the anterior spina iliaca superior to the superior part of the patella. The NMES will operate at a frequency of 4 Hz, with a phase duration of 250 µs (500 µs biphasic pulse), a contraction time of 4-seconds (inclusive of 1-seconds ramp-up/-down time), and an 8-seconds rest period in between. Towel will be placed over the NMES setup to prevent the occurrence of burns or any other form of extreme discomfort. Following with 10x24 inch hydrocollator moist heat packs, which will be carefully placed in microfiber covers and applied longitudinal to each leg with focused placement over the VM and RF muscles. A compression wrap will then be applied over the heat modality to prevent it from moving, with the duration of application set to last for 15-minutes.

Passive Recovery
The control group will be subjected to passive recovery, with no modality provided, allowing for natural recuperation. Participants will be directed to maintain a comfortable seated position during the 15-minute recovery period to promote relaxation and reduce the likelihood of muscle fatigue or discomfort. This will serve as a baseline comparison for the experimental groups receiving either NMES or HT treatments.

Post-test
After a 1-minute window, participants will be instructed to perform isometric contractions in the high hang pull position with a clean grip, while maintaining a fixed knee angle at 45- degrees. They will be asked to exert maximum force on the barbell for a duration of 30-seconds, with verbal instructions to pull as fast and as hard as possible. In order to prevent limitations in handgrip strength and ensure maximal effort, participants' hands will be secured to the bar using athletic tape. During the exercise, force plates will be positioned beneath the participant to accurately measure the force output generated, while a fingertip pulse oximeter will be utilized to detect any potential fatigue due to hypoxia. Additionally, participants will be asked to report their RPE after completing the exercise bout. The data obtained from force output, oxygen content, and RPE for each participant and group will be collected and compared with pre-test results to determine the recovery rate.

11. Participant Recruitment

a. Who will you recruit to participate in your study?

Recreationally active male and female individuals who are 18 – 35 years in age and meet the physical active requirements for American adults. Participants must complete and pass the PAR-Q+ form and will be excluded from the study if they have any musculoskeletal injuries or surgical procedures that limit them from performing the hang high pull task.

b. Age range of subjects:

18 - 35

c. How specifically will you recruit participants?

d. How many participants will you recruit?

Word of mouth
Flyers
E-mail list serve

e. How many participants need to participate in your study for you to accomplish your objectives stated in #7 above?

A priori power analysis revealed a sample size of 48 participants is needed with input paraments and with a power of 0.8 and an alpha of 0.05.

f. Attach a sample of your recruitment documents (email text, posters, announcement scripts, etc.)

12. Assurance of Voluntary Participation

Describe how you will ensure subject participation is voluntary (with the exception of studies involving classroom practices/educational methods). A copy of the consent form must be included in your application materials.

To ensure subject participation is voluntary, I will:

1. Informed Consent: Provide the subject with a detailed explanation of the study, including the purpose, procedures, risks, benefits, and alternatives. The subject should be given enough time to read and understand the informed consent document and to ask any questions they may have before deciding whether or not to participate.
2. Right to Withdraw: Make it clear to the subject that they have the right to withdraw from the study at any time, without any negative consequences. The subject should be informed that they can discontinue their participation without having to provide a reason.
3. Confidentiality: Assure the subject that their personal information and any data collected will be kept confidential and will only be used for the purposes of the study.
4. No Coercion: Do not coerce the subject into participating in the study. The subject should participate voluntarily and without any pressure or influence from the researcher or anyone else.

13. Risk

Describe all reasonably expected risks, harms, and/or discomforts that may apply to the research. Discuss severity and likelihood of occurrence. As applicable, include

potential risks to an embryo or fetus if a woman is or may become pregnant. ***Consider the range of risks, including physical, psychological, social, legal, and economic***.

The use of Neuromuscular Electrical Stimulation (NMES), heat therapy, and isometric hang high pull as part of a research study can involve certain risks for the participant. Some of these risks include:

1. NMES: The use of NMES may cause discomfort or pain, muscle twitching, skin irritation, or muscle soreness. In some cases, NMES may also interfere with the normal functioning of muscles or nerves.
2. Heat Therapy: Heat therapy may cause dehydration, overheating, or skin irritation. Isometric Deadlifts: Performing isometric deadlifts can be physically demanding and may result in muscle fatigue, soreness, or strain. There is also a risk of injury, such as a strain or sprain, if the exercise is performed improperly or if the participant has a pre-existing condition that affects their ability to perform the exercise.
3. Resistance exercise, in general, is recommended by the American College of Sports Medicine and National Strength and Conditioning Association as a safe and effective method to enhance musculoskeletal health. To minimize risk such as muscular strains, resistance training will adhere to American College of Sports Medicine guidelines at a moderate intensity, will always include the appropriate warm-up, cool-down, and proper exercise technique.

14. Benefits

Describe the anticipated benefit to the participants and/or to society as a result of this research.

Participants may contribute knowledge about NMES and HT as recovery modalities, which may help others in the future. This knowledge may also aid in increasing their performance.

Data Confidentiality and Storage

Federal regulations require IRBs to determine the adequacy of provisions to protect the privacy of subjects and to maintain the confidentiality of their data. To meet this requirement, federal regulations require researchers to provide a plan to protect the confidentiality of research data. Today, the majority of data is at some point collected, transmitted, or stored electronically. The Principal Investigator (PI) is responsible for ensuring that research data is secure when it is collected, stored, transmitted, or shared. All members of the research team should receive appropriate training about securing and safeguarding research data.

Describe how you plan to protect the confidentiality of the data collected. Include a description of where the data will be stored and who will have access to it. If the data will be coded to protect subject identity, this should be explained.

I will treat participants' identity with professional standards of confidentiality. The data from this study may be published, but the participants' identity will not be shown. All data will be collected in a locked password protected Microsoft Excel file, then transferred to a locked password protected hard drive. Once on the hard drive, the data will be deleted from Excel. The password will only be known by the principle and co-principle investigators.

Upon approval from the IRB, you will be issued a project number. You must list this project number on all materials distributed to your participants.

At any point, should you wish to make changes to your protocol, you must submit a Project Modification Form before initiating the changes.

If any unanticipated problems arise involving human subjects, you must immediately notify the IRB chair Derek Anderson (dereande@nmu.edu) and NMU's IRB administrator Lisa Schade Eckert (leckert@nmu.edu) and must submit an Unanticipated Problem/Adverse Event form.