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Active Recovery and Electro-Muscular Stimulation on Delayed Onset Muscle Soreness after Endurance Running: A Randomized Clinical Trial

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ACTIVE RECOVERY AND ELECTRO-MUSCULAR STIMULATION ON DELAYED
ONSET MUSCLE SORENESS AFTER ENDURANCE RUNNING:
A RANDOMIZED CLINICAL TRIAL

By

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A doctoral project submitted in partial fulfillment
of the requirements for the

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THE GRADUATE COLLEGE

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Amanda J. Gramly, Kitrick C. Rhodes, and Andrea F. Smith

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ABSTRACT

Background/Purpose: Current research on strategies to decrease delayed onset muscle soreness (DOMS) has focused on the effects of active and passive recovery on athletic performance across various sports, but there is little evidence regarding these recoveries at reducing DOMS induced by aerobic activities, such as running. In addition, there is limited research regarding the efficacy of recovery using electro-muscular stimulation (EMS). Therefore, the purpose of this study was to investigate the effects of active and EMS recovery in decreasing DOMS. **Subjects:** Forty-eight healthy subjects (25 males and 23 females) between the ages of 20 and 40 (25.1 ± 2.9) participated.

Methods: In this repeated measures design, each subject underwent two randomized testing periods, one for each of the recovery methods (active and EMS). Active recovery consisted of 15 minutes of brisk walking or submaximal jogging. EMS recovery consisted of 15 minutes of a biphasic symmetrical wave-form with a pulse width of 250 microseconds that started at 10Hz and then progressively decreased by 1 Hz every two minutes. Within each testing period, subjects were evaluated before and after a 1.5 mile run using blood lactate accumulation (BLA), visual analog scale for pain (VAS) on various muscle groups, pain pressure algometry (PPA) on the hamstrings, and sprint performance (40-yard dash). In addition, DOMS was assessed 48 hours later using the same outcomes. **Results:** There were no differences between recovery methods regarding BLA or VAS scores for the hamstrings or gastrocnemius/soleus. However, VAS scores for the quadriceps were different between the two recovery methods ($p=.001$), with more pain in the quadriceps after 48 hours in the EMS condition. There were no

differences between recovery methods for PPA or sprint performance. **Conclusions:** EMS recovery was just as effective as active recovery across all outcomes, except for increased DOMS of the quadriceps in the EMS condition. Due to electrode placement on the hamstrings, the recovery in the quadriceps for the EMS condition was essentially passive. While active recovery and EMS recovery were comparable across all outcomes, EMS recovery occurs without the increased heart rate and energy expenditure associated with active recovery.

Keywords: electro-muscular stimulation, active recovery, delayed-onset muscle soreness

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INTRODUCTION

Muscle soreness and fatigue are factors that limit the ability of both conditioned and unconditioned runners to increase their cardiovascular endurance efficiently enough to maintain a continuous training intensity. The timing of this muscular soreness and fatigue, especially in the days following an intense run, is another limiting factor. This specific limiting factor has become known as delayed-onset muscle soreness (DOMS). DOMS is a phenomenon that limits the ability of runners to perform at high intensities on consecutive days of training. DOMS has been described as a sensation of discomfort or pain in the skeletal muscle that occurs after unaccustomed activity or a maximal exertion of the muscle. DOMS typically increases within 24 hours after the activity, peaks between 24 to 72 hours, and subsides 5 to 7 days after the activity.^{1,2}

There are several theories regarding the mechanisms behind DOMS, including: lactic acid, muscle spasm, connective tissue damage, muscle damage, inflammation and the enzyme efflux theories.¹ It is more likely that DOMS is a result of a combination of these factors, but the exact mechanism as well as effects on performance remains unclear.¹ Symptoms related to DOMS may include reduced force generating capacity, significant alterations in biomechanical indices of muscle and connective tissue health, alteration of neuromuscular function, and changes in mechanical performance.³ Ultimately, DOMS impairs overall performance and may decrease motivation to continue exercise programs at a higher intensity.⁴

Various recovery methods have been implemented after high intensity running to prevent injury, decrease muscle soreness and enable increased levels of intensity and

duration for subsequent training seasons. The most widely researched forms of recovery include active and passive recovery, with active recovery being more effective at temporarily reducing muscle soreness.^{1,2,5} Current evidence suggests that active recovery is more effective than passive recovery across several different measures, both physiological and functional. Several studies have found active recovery to be more effective than passive recovery at lactate removal as well as certain functional measures following the recovery period such as improved swim sprint times, upper body Wingate tests, a special Judo fitness test, and competing in another Judo match.⁵⁻⁹

Active recovery is not superior to passive recovery for all activities. During interval training, passive recovery may result in more consistent interval work times as well as increasing the length of time until exhaustion.¹⁰⁻¹³ Passive recovery was also shown to be more effective at improving sprint time performance during interval training in young basketball players.¹⁰ These studies do not necessarily translate to recovery following endurance or non-interval activities, because subjects were given very short recovery periods (15-30 seconds) between intervals as compared to the long recoveries (10 minutes) following the activity in the Greenwood⁹ and current study. Additionally, it is impractical to suggest that players should stand still during and following repeated-sprint bouts, as in a game situation.¹²

A third type of recovery, electrical muscle stimulation (EMS), has also been studied to determine its effects on performance and muscle soreness after exercise. EMS recovery can be considered a combination of both active and passive recovery

methods. While the target muscle group is experiencing an active form of recovery through electrical stimulation, the rest of the body remains passive.¹⁴ Current evidence incorporating EMS as part of a recovery period during sprint swimming has shown that EMS is more beneficial during the post-exercise recovery period than passive recovery. EMS reduced lactate levels 20 minutes post-exercise significantly better than passive recovery.¹⁵ Likewise, a study by Warren et al examining recovery with baseball pitchers showed that EMS was the only condition that had a significant decrease in blood lactate accumulation (BLA) during the recovery period. There was no change in BLA for the active and passive recovery conditions. In addition, perceived recovery was best for the EMS and passive recovery conditions.¹⁶ This suggests that EMS training may be applicable to a broad spectrum of sports and activities both during the strengthening period and the recovery period following anaerobic activity.

There appears to be limited research evaluating the effectiveness of EMS recovery following aerobic activities such as running. In addition, there has been no study comparing the effectiveness at reducing DOMS by active and EMS recovery methods induced by aerobic activities. Therefore, the purpose of this study was to investigate the effects of active and EMS recovery related to blood lactic acid, pain (DOMS) and sprint performance following a bout of intense running. Based on current evidence, it was hypothesized that EMS recovery would produce better outcomes. In addition, EMS recovery would decrease heart rate faster than active recovery. It was also hypothesized that fitness of the subjects may have an influence on these outcomes, and therefore fitness level was also investigated.

METHODS

Overall Design

A repeated measures design with a crossover was used to determine the efficacy of EMS recovery compared to active recovery immediately following intense running. At the start of this study, subjects were randomly assigned to one of two interventions, an active recovery method and an EMS recovery method. After a washout period of one week, subjects were given the opposite intervention. Figure 1 provides a schematic of the steps involved in this design.

Subjects

Forty-eight subjects (25 males and 23 females) between the ages of 20 and 40 (25.1, \pm 2.9) participated in this study. Prior to inclusion, subjects were explained the risks and benefits associated with participation and asked to sign informed consents that were approved by a University of Nevada, Las Vegas Institutional Review Board. Subjects were also asked to fill out two medical history questionnaires adapted from the American College of Sports Medicine: Physical Activity Readiness Questionnaire and Health/Fitness Pre-participation Screening Questionnaire.^{17,18} Responses to these questionnaires were used to determine whether participants were healthy and able to safely participate in vigorous exercise. If any responses to these questionnaires caused concern, participants were asked to follow up with their doctor before participating in our study. Any subjects that were determined unable to safely participate in vigorous physical activity were excluded from this study (Figure 2). Additionally, subjects were divided into trained and untrained runners based on their performance during the

study, which was also used to estimate their maximal oxygen uptake (VO_{2MAX}). Those subjects whose VO_{2MAX} ranked above the 80th percentile for their age and gender were considered to be trained runners, and those below the 80th percentile were considered untrained runners.

Tests and Measures

Blood lactate accumulation. BLA was used to measure overall effort and exertion among participants. The Lactate Plus¹ was used to measure BLA. This device consists of a lancet device and a lactate meter. Reliability of this device has been assessed through inter-analyzer ($r=0.991$) and intra-analyzer correlations ($r=0.988$). The Lactate Plus also showed strong correlations with laboratory-based analyzers ($r=0.936$).¹⁹

Pain (DOMS). Pain levels across three muscle groups were measured using the Visual Analog Scale (VAS) for pain and a pain pressure algometer (PPA). Each subject completed a VAS, rating their current level of pain for each of the following muscle groups: hamstrings, quadriceps, and gastrocnemius-soleus complex. The VAS is a 10 cm line, in which subjects mark their level of pain between 0 and 10. Studies have demonstrated the reliability of the VAS to be high ($ICC=0.97-0.99$).^{20,21} A PPA called the Wagner Force Ten, FDX 50, Digital Force Gage² was used to establish a pressure-pain threshold (PPT) of the hamstrings (Figure 3.). The PPA records the amount of force (in kilograms per square centimeter) that is applied to the tissues using a small rubber force

¹ Lactate Plus, Nova Biomedical, 200 Prospect Street, Waltham, MA 02454-9141, USA, Phone: 1-800-350-5024, www.novalactate.com

² Force Ten FDX 50 Digital Force Gage, Wagner Instruments, Post Office Box 1217, Greenwich, CT 06836-1217 USA, Phone: (203) 698-9681

plate. Pressure algometry has been used to assess the hypoalgesic effects of physical therapy modalities as well as to assess muscle tenderness and stiffness related to DOMS.^{22,23} Evidence for inter-rater reliability has been good (ICC=.74-.89); however, using one examiner has been shown to enhance reliability (ICC=.88-.98).²² For this reason, one examiner was used in this study.

Sprint performance. The 40-yard (36.6 meters) dash was used as a functional measure to assess performance for each individual participant in this study. The Lafayette Multi-function Timer/Counter³, Model 54035A, was used for timing. Previous research has shown that electronic measurement of the 40-yard dash is the most reliable timing method.²⁴ The timer was set up on the straightaway section of a 200-meter rubberized indoor track.

Heart rate. Heart Rate (HR) was used to measure levels of exertion and to allow for a more standardized active recovery. HR was measured using a chest strap transmitter and a wrist receiver. Participants wore heart rate monitors during all physical activity and were asked to maintain a heart rate between 40 and 60 percent of their HR maximum during the active recovery period.

Procedures

Forty-eight subjects were randomly counterbalanced into one of two intervention groups, either active recovery or EMS recovery. Each subject was tested on four separate days over the course of two weeks. Each week included an intervention day, where subjects received an active recovery method or an EMS recovery method

³ Lafayette Instrument Company, PO Box 5729, Lafayette, IN 47903, Phone: (800) 428-7545

followed by a DOMS post-test day, 48 hours (45.5-50.5 hours) after the intervention day. All testing sessions took place at a student recreation center and all running was done on a 200-meter indoor rubberized track. Starting on the intervention day, baseline measures were recorded for HR, BLA, VAS, and PPA (Figure 1).

Participants were first asked to put on a heart rate monitor and then their BLA was measured. To obtain a quantitative blood lactate value, a small sample of blood was taken from the participants' fingertip with a single-use lancet device and this sample was analyzed using the Lactate Plus meter. Next, subjects were asked to mark their level of pain for hamstrings, quadriceps, and gastrocnemius-soleus complex on three separate VAS scales. The last measure taken was PPA. To administer this measure, the participant would lie prone while the examiner used the PPA to apply a force directly over the hamstring muscle belly via a 1cm² flat rubber tip. Participants were instructed to tell the examiner to stop at the onset of pain.

To determine a baseline performance level, participants were given a chance to warm up and run two timed 40-yard dashes. Subjects performed a warm up that consisted of brisk walking or jogging for a 5-minute period at a self-selected speed, with the requirement that they reach at least 60% of their maximum HR during the 5 minutes. After the warm-up, each subject was then instructed to perform his or her fastest possible time for both trials of the 40-yard dash. After a 1-2 minute rest break, participants completed a 1.5 mile (2.4 kilometers) timed run at maximal exertion, and were instructed to finish the 1.5 miles as fast as they could. The 1.5-Mile Run Test was adapted from the American College of Sports Medicine, to allow calculation of the

estimated VO₂ max for each subject.²⁴ The 1.5 miles were run on a 200-meter rubberized indoor track at a student recreation center. Immediately after the run, the first set of post-test measures was taken, values for HR, BLA, VAS, and PPA were collected, and either active recovery or EMS recovery methods were given.

Each recovery method, either EMS or active, was given for a period of 10-minutes immediately after the 1.5 mile run. Active recovery consisted of brisk walking or jogging at a self-selected speed with the only requirement being that each subject remain within 40-60% of his or her specified maximum heart rate. EMS recovery was administered using the Compex Performance, US Muscle Stimulator⁴. One large electrode was placed at the proximal end of the hamstring muscles and two smaller electrodes were placed near the distal insertion sites of the hamstrings on both the right and left legs (Figure 4.). The Compex was set to the “Active Recovery” mode and intensity levels were set based on participant preference. Subjects remained either prone or supine for the duration of the treatment. This Compex setting stimulates efferent motor neurons with a rectangular biphasic symmetrical wave- form, that had a pulse width of 250 microseconds (1 microsecond = 10⁻⁶ seconds).²⁵ The frequency of the pulses starts between 9 and 10Hz then progressively decreases by 1 Hz, automatically, every two minutes. As the frequency decreases, the pulses increase in amplitude to penetrate the muscle fibers more deeply.

A second set of post-test measures was taken after the 10-minute recovery and included HR, BLA, VAS, and PPA. Subjects then completed two more 40-yard dashes.

⁴ Compex, 1430 Decision Street Vista, CA 92081, Phone: (877) 266-7398

Afterwards, subjects were given five additional minutes of the previously given recovery method. This second recovery period of 5 minutes was implemented to alleviate any residual effects of the sprints after the first recovery period. After this five-minute recovery, the third set of post-test measures was given which included HR and BLA.

On the DOMS post-test day (approximately 48 hours after the 1.5 mile run), resting values for HR, BLA, VAS, and PPA were measured. Subjects then engaged in the five minute warm up and ran two 40-yard dashes as fast as they could. One week later, this protocol was repeated, but with each participant receiving the opposite recovery method.

Data analysis

All analyses were conducted using PASW 18.0.⁵

Blood lactate accumulation. To determine if the recovery method influenced BLA, a 2 (group: active recovery, EMS recovery) X 2(training: trained, untrained) X 5 (time: baseline, post-test1, post-test2, post-test3, DOMS test) mixed factorial ANOVA was conducted. For BLA, there was not a statistically significant three-way interaction ($p=.850$); however, there were interactions for group by time ($p=.047$) and time by training level ($p=.001$). There was not an interaction for group by training level ($p=.859$) (Huynh-Feldt corrected). In order to break down the group by time interaction, two repeated measures ANOVAs for each recovery method over time and five paired t-tests to compare the difference between recovery methods, one for each of the time points, were conducted using a Bonferroni corrected alpha of .007. To break down the time by

⁵SPSS North American Headquarters, 233 S. Wacker Drive, 11th Floor, Chicago, IL 60606, Phone: (312)651-3000

training level interaction, two repeated measures ANOVAs for each trained level (trained and untrained) over time and five independent t-tests to compare the difference between these, one for each of the time points, were conducted using a Bonferroni corrected alpha of .007.

Pain (DOMS). To determine if recovery method influenced pain levels (i.e., VAS, PPA), a 2 (group: active recovery, EMS recovery) X 2(training: trained, untrained) X 4 (time: baseline, post-test1, post-test2, DOMS test) mixed factorial ANOVA was conducted. VAS and PPA were not measured on the post-test3 because these values were not expected to change at this measurement time, and were thus thought to be insignificant.

For VAS of the hamstrings, there was no statistically significant interaction for group by time by training level ($p=.573$). Additionally, there were no significant interactions among group by time ($p=.186$), time by training level ($p=.265$), or group by training level ($p=.441$). Main effects were then analyzed for recovery group, training level, and time. VAS of the calves was similar to the hamstrings as no interactions were found, and thus main effects were analyzed.

For VAS of the quadriceps, there was no statistically significant interaction for recovery group by time by training level ($p=.698$), time by training level ($p=.374$), and group by training level ($p=.106$); however, there was a statistically significant interaction for group by time ($p=.041$) (Huynh-Feldt corrected). In order to break down the group by time interaction, two repeated measures ANOVAs for each recovery method over time

and four paired t-tests to compare the difference between recovery methods, one for each of the time points, were conducted using a Bonferroni corrected alpha of .0083.

For PPA, there was not a statistically significant interaction for group by time by training level ($p=.936$), time by training level ($p=.615$), and group by training level ($p=.561$); however, there was a statistically significant interaction for group by time ($p=.010$) (Huynh-Feldt corrected). In order to break down this interaction, two repeated measures ANOVAs for each recovery method over time and four paired t-tests to compare the difference between recovery methods, one for each of the time points, were conducted using a Bonferroni corrected alpha of .0083.

Sprint Performance. The influence of recovery method on sprint performance (40-yard dash) was analyzed with a 2 (group: active recovery, EMS recovery) X 2(training: trained, untrained) X 3 (time: baseline, post-test2, DOMS test) mixed factorial ANOVA. There was no statistically significant interaction for group by time by training level ($p=.491$). There were also no statistically significant interactions for group by time ($p=.926$), time by training level ($p=.420$), or group by training level ($p=.856$). The main effects were then analyzed for recovery group, training level, and time.

Heart Rate. Lastly, heart rate was analyzed using a 2 (group: active recovery, EMS recovery) X 2(training: trained, untrained) X 5 (time: baseline, post-test1, post-test2, post-test3, DOMS test) mixed factorial ANOVA. There was a statistically significant three-way interaction, $p=.002$. To break down this interaction two, 2 (group: active recovery, EMS recovery) X 5 (time: baseline, post-test1, post-test2, post-test3, DOMS test) ANOVAs with repeated measures on both factors were conducted, one for the

trained runners and one for the untrained runners. There was a significant group by time interaction for the trained runners ($p < .001$) and the untrained runners ($p < .001$). Subsequently, each of these was broken down, by conducting two repeated measures ANOVAs for each recovery method over time and five paired t-tests to compare the difference between recovery methods, one for each of the time points using a Bonferroni corrected alpha of .007.

RESULTS

Blood lactate accumulation. For the active and EMS groups over time, there were significant increases in BLA, immediately after the 1.5 mile run ($ps < .001$), which decreased significantly following recovery ($ps < .001$) and remained stable after the second 40-yard dash ($ps = 1.00$) (Figure 5). It then dropped significantly after the 48 hour recovery ($ps < .001$) and was consistent with baseline levels ($ps \geq .409$). There were no differences between the recovery methods at each of the measurement points, $ps \geq .027$.

For the trained and untrained runners over time, post-hoc tests revealed that there were significant increases in BLA, immediately after the 1.5 mile run ($ps < .001$), which decreased significantly following recovery ($ps < .001$) and remained stable after the second 40-yard dash ($ps \geq .031$). Levels dropped significantly after the 48 hour recovery ($ps < .001$) and were consistent with baseline levels ($ps \geq .410$). There were no differences between the trained and untrained runners at each of the measurement points, $ps \geq .018$.

Pain (DOMS). For VAS of the hamstrings, main effects for recovery group and training level were not significant ($ps \geq .112$); however, the main effect for time was

significant ($p=.001$). For all subjects, VAS scores for the hamstrings increased significantly immediately after the 1.5 mile run ($p=.001$), significantly decreased following 10 minutes of recovery ($p=.032$), and remained stable for the next 48 hours ($p=1.00$) (Figure 6). VAS scores after 48 hours were significantly higher than the baseline which is consistent with DOMS ($p=.002$). Results for the VAS of the calves were the same as for the hamstrings as time was the only main effect found to be significant, and displayed increases and decreases at the exact same time intervals (Figure 7).

In regards to VAS of the quadriceps, post-hoc tests revealed that for the active and EMS recovery groups over time VAS significantly increased immediately after the 1.5 mile run ($ps\leq.006$), but remained stable following recovery ($p\geq.474$) and after the 48 hour recovery period ($p\geq.263$) (Figure 8). For the EMS recovery group, VAS scores for the quadriceps after the 48 hour recovery were significantly higher than the baseline ($p=.001$); however, for the active recovery group, there was no significant difference between the baseline and 48 hour recovery period ($p=.038$). There were no statistically significant differences between the recovery methods at any of the measurement points, $ps\geq.015$.

For the PPA, post-hoc tests revealed no significant change in pain tolerance for the active and EMS recovery groups over time ($ps\geq.080$) (Figure 9). There were also no statistically significant differences between recovery methods at any of the measurement points, $ps\geq.014$.

Sprint performance. For the 40-yard dash times, main effects were not significantly different for recovery group and training level ($ps\geq.516$). However, a

statistically significant difference was found for time ($p < .001$). Forty-yard dash times were significantly slower immediately following recovery and significantly faster after 48 hours ($p < .001$) (Figure 10). There was no significant difference between the baseline and 48 hour 40-yard dash times ($p = 1.000$).

Heart rate. For both the trained and untrained runners, heart rate in the active recovery condition changed significantly over time, $p < .001$. There were significant increases in HR immediately after the 1.5 mile run ($p < .001$), which decreased significantly following recovery ($p < .001$) and remained stable after the second 40-yard dash ($p \geq .014$). After 48 hours, the HR had returned to baseline ($p \geq .366$) and was significantly lower than immediately following the 1.5 mile run, $p < .001$ (Figure 11). For both the trained and untrained runners, heart rate in the EMS recovery condition changed significantly over time, $p < .001$. All of the pairwise comparison results were the same as the active recovery condition. There were no differences in the HR between the active and EMS recovery groups at the baseline for the trained ($p = .454$) and the untrained ($p = .587$). Likewise immediately after the run, there were no differences between the trained ($p = .198$) and the untrained ($p = .589$). However, HR was significantly higher in the active recovery condition compared to the EMS recovery condition immediately after the 10 minute recovery for the both trained and untrained ($p < .001$). HR remained higher in the active recovery condition compared to the EMS recovery immediately after the second five minute recovery ($p < .001$). HR was not different in either the trained or untrained after 48 hours, $p \geq .610$.

DISCUSSION

Both EMS and active recovery methods were similar to one another across all outcome measures, except for VAS scores of the quadriceps muscle. Participants reported symptoms consistent with DOMS in their quadriceps 48 hours after receiving the EMS recovery condition, while participants receiving the active recovery condition reported no pain after 48 hours. Because participants received the EMS recovery on their hamstring muscles, the quadriceps muscles essentially received a passive recovery. Therefore this particular outcome measure provides evidence to suggest that active recovery following a 1.5 mile run, combined with 40 yard sprints before and after, is more effective than passive recovery at relieving symptoms of DOMS. All other outcome measures, regardless of recovery type, increased and decreased at the expected intervals in response to exercise.

Lactate levels are physiologically expected to rise after a bout of exercise, and all participants experienced an increase in BLA after the 1.5 mile run. Once the run was over, and participants were given one of two recovery methods, their BLA decreased. Since the intensity of exercise is much less during the recovery periods, further lactate production does not occur, and the circulating lactate is cleared. Additionally, the type of recovery did not make a difference in lactate clearance rates. This finding is contrary to prior studies that demonstrated a difference between active and EMS recovery conditions following anaerobic activities. Neric et al found active recovery to be more effective than EMS, and EMS to be more effective than passive at reducing BLA after sprint swimming.⁸ Warren et al found EMS recovery to be superior to active recovery at

reducing BLA for baseball players following pitching bouts.¹⁶ This may mean that the most efficient method of lactate clearance is dependent upon the type of activity performed prior to the recovery process. The current study may also suggest that aerobic activity may not allow for the same BLA clearance as anaerobic activity resulting in no difference between the recovery conditions. Alternatively, it is possible that active recovery may have been performed at too low of an intensity to see a difference. A study by Menzies et al confirmed that a low intensity active recovery (<40% lactate threshold) is no different than passive recovery (0% lactate threshold).²⁶

There was no difference between recovery conditions for the hamstrings or calves with regard to perceived pain, as measured by the VAS. However, after 48 hours, VAS for the quadriceps indicated improved outcomes for the active recovery condition. This contradicted the hypothesis that EMS recovery would result in decreased muscle soreness outcomes when compared to the active recovery condition. However, since EMS recovery was only used on the hamstring muscles then all other muscle groups, including the quadriceps, indirectly received passive recovery during the EMS recovery condition. This result is consistent with a similar study that examined different recovery methods following preseason soccer training, and found both EMS and active recovery to reduce DOMS more effectively than passive recovery. It can then be inferred that both EMS and active recovery are better at reducing symptoms of DOMS after a bout of intense running than no recovery at all.²⁷

While the EMS recovery condition seemed to increase DOMS in the quadriceps as compared to active recovery, there was no difference between recovery conditions

for the calves, which also received an indirect passive recovery. One explanation is that although the EMS recovery was used on the hamstring muscles, the medial and lateral origins of the gastrocnemius muscles are relatively close to where the distal electrode pads were placed on the posterior thigh, and as a result the calves may have received a form of cross-talk stimulation and subsequent EMS recovery during this condition.²⁸

The VAS measures were increased at the 48-hour follow-up for both conditions in all muscle groups except the active recovery condition quadriceps scores. This indicates that subjects experienced some level of DOMS for all other conditions, and that both recovery conditions may have been ineffective at reducing DOMS. However, in order to determine whether these recoveries were effective, a passive recovery condition would have needed to be included in this study. One review that did include a passive recovery condition, along with various other recoveries, including EMS and active, found no differences among recovery methods for elite athletes following high-intensity exercise.²⁹ It can thus be concluded that either more research is needed on the subject, or that there is simply no difference between the recovery methods in terms of VAS measures related to DOMS.

No differences for any of the PPA measures of the hamstrings between the recovery conditions were found, and there appeared to be some differences between the PPA values and reported VAS measures. This may be due to only using one measurement of PPA per leg during each time interval the measure was taken. A study by Nussbaum et al found the highest PPA reliability scores when the first trial measures were omitted.²² This may be due to subjects needing a few trials to familiarize

themselves with the sensation of pain experienced by the mechanism and being able to interpret a better stopping point for this device. It may also be due to the highly individualized and varying degree of what the individual subjects interpreted as pain. Prior experiences and reactions to painful stimuli greatly affect an individual's interpretation of pain. Lastly, these results may also be attributed to a carry-over effect caused by pushing on the exact same spot every time which could have added to or even induced some degree of muscle soreness. Perhaps there is a better location to palpate hamstring DOMS than the site that was used for this study, and multiple sites may be warranted in future studies to locate hamstring DOMS, including locations closer to the origination and insertion sites of the hamstring muscles.

There appears to be no difference between active recovery and EMS recovery concerning sprint performance and DOMS after an intense bout of running. After running 1.5 miles, all subjects were slower on their 40-yard dash times, regardless of recovery method. Engaging in unaccustomed exercise often leads to muscular discomfort¹ and can result in acute or delayed impairments in neuromuscular function.³⁰ Since none of the participants in this study were accustomed to the intensity and duration of the type of run test that was implemented, it is possible that sprint times increased as a result of muscular discomfort or acute neuromuscular impairments. Perceptions of fatigue may have also limited each subject's ability to perform sprints at their maximum level. Twist et al suggests that perceived soreness may impair voluntary action of muscles via centrally mediated, force-inhibiting neural mechanisms, which play a role during dynamic muscle action in an attempt to prevent muscular damage.³¹ In this

same study, decrements to sprint performance lasted through the final measurement at 48 hours. In the current study, however, sprint times returned to baseline times after 48 hours. Since sprint performance improved after 48 hours, it is likely that both recovery methods are equally effective at decreasing the effects of DOMS. Castagna et al found that with passive recovery, repeated sprint performances were least likely to decline, because there was a significantly longer time to exhaustion, as compared to active recovery.¹⁰ Results from our study are not consistent with this finding, since there appeared to be no difference between active recovery and EMS recovery, which for all muscle groups except the hamstrings, was essentially a resting recovery. One explanation may be that subjects were not given recoveries until after they had already reached the point of exhaustion while passive or resting recovery appears to allow for maximal sprint performances only before this point is reached. Another possible reason is that subjects were allowed some time to rest after the active recovery condition, making them less fatigued from this higher energy expenditure recovery condition and possibly negating the difference that would have been found.

In the active recovery condition, subjects maintained a higher heart rate, compared to the EMS recovery condition where HR decreased more rapidly. During the EMS recovery condition, subjects remained still while lying prone with only one specific muscle group (hamstrings) remaining active, and the rest of the body remaining inactive. These results provide useful evidence for clinical application. While active recovery is easier and less expensive to implement in the clinical setting, EMS may be

utilized as an effective recovery method while avoiding increased heart rate, energy expenditure and fatigue following an endurance run.

Whether participants were considered trained or untrained runners had no effect across any variables measured in this study. Since DOMS typically occurs after unaccustomed activity, it may be possible that there was carry-over for subjects from the first week to the second week. Subjectively, even the subjects classified as trained runners were not accustomed to running at this type of intensity.

Limitations to this study included a sample of convenience, not including a passive recovery group, and potential carry-over effects. The functional measure (40-yard dash) chosen for this study may have led to increased pain in the quadriceps muscles and future research should be careful to eliminate any functional measures that may actually cause or add to muscular soreness. Future studies could incorporate a different form of endurance running, such as downhill running that may induce more DOMS and allow for a larger effect to be observed. Alternative recovery methods including EMS recovery could provide further insight into the benefits of a combination type of recovery. A comparison of active recovery, EMS recovery, active recovery plus EMS recovery, and passive recovery would enable a true comparison of recovery methods across all muscle groups.

PRACTICAL APPLICATION

EMS recovery and active recovery were comparable across all outcomes; however, EMS recovery does not require the continued energy expenditure and increased heart rate that is associated with active recovery.

EMS and active recoveries appear to be similarly effective at reducing DOMS following endurance running. Active recovery is easier and less expensive to implement in the clinical setting; however, when increased heart rate or energy expenditure is not desirable based on the individual patient's circumstances, then EMS recovery is a viable alternative to active recovery. In addition, based on previous literature, both of these methods appear to be superior to passive recovery, although this cannot be stated for certain since a direct passive recovery condition was not included in this study.

Appendix

Figure 1. Overall design of the study.

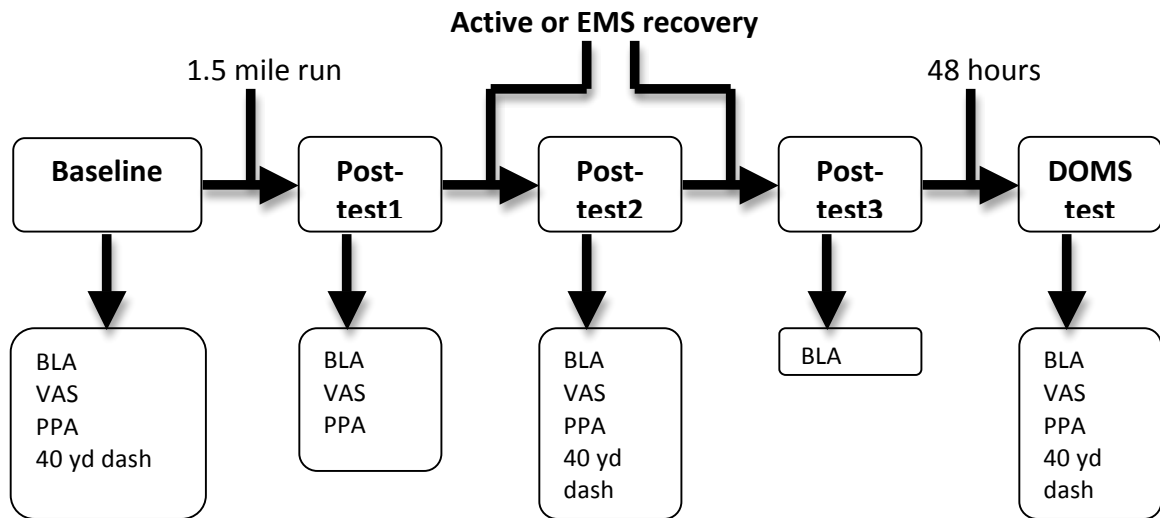


Figure 2. Subject inclusion/exclusion criteria.

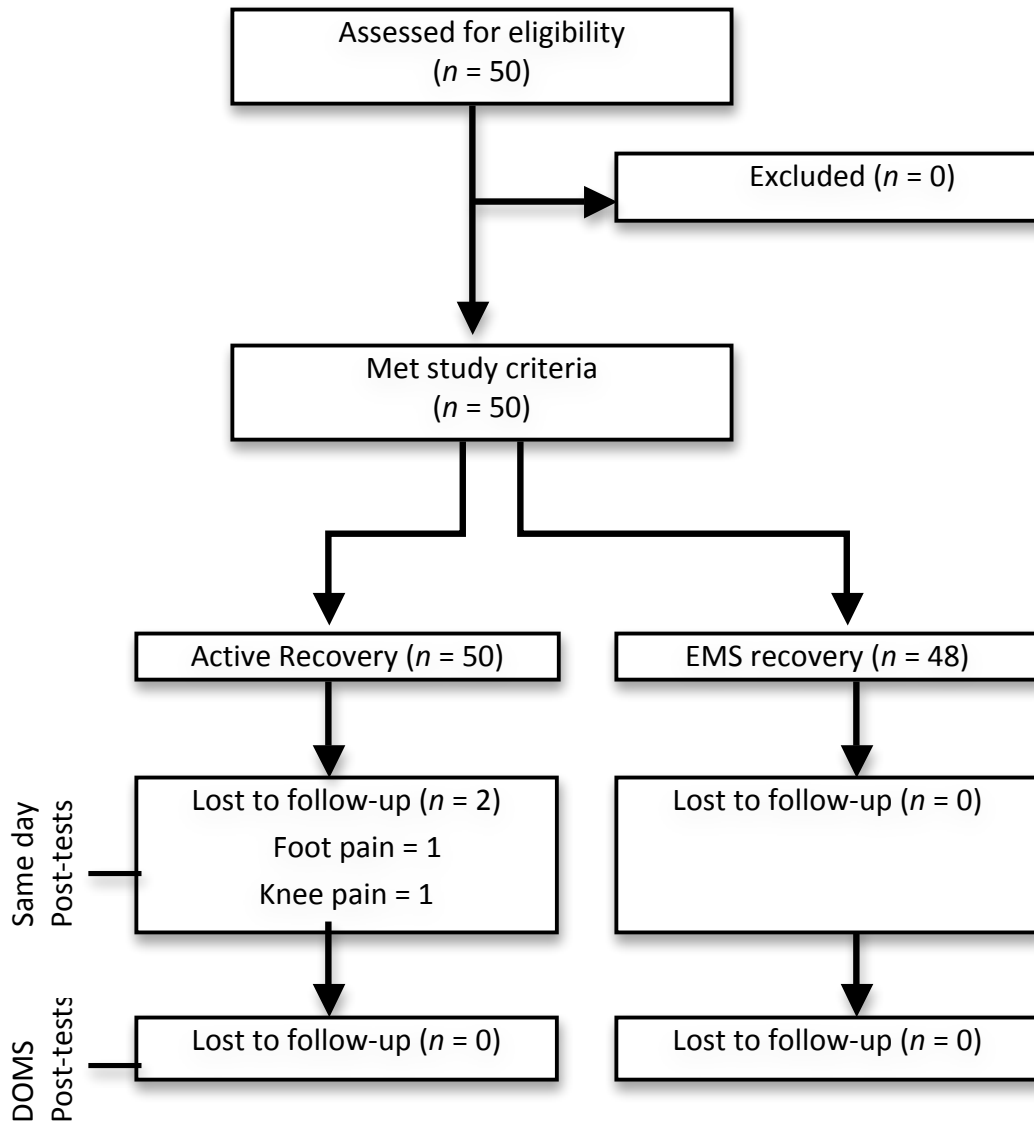


Figure 3. Set-up of the pain pressure algometer.



Figure 4. Set-up of the electro-muscular stimulation.

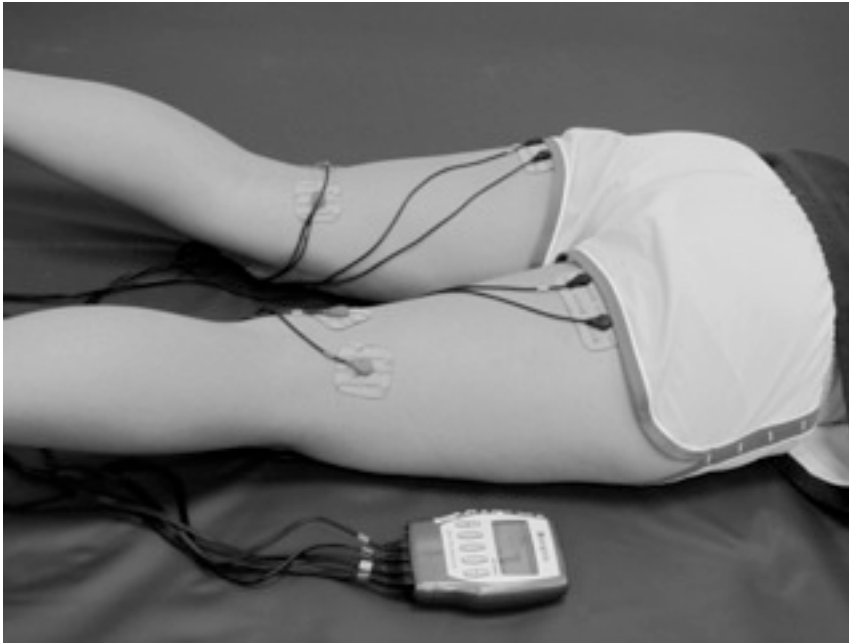


Figure 5. Means and standard deviations for blood lactate accumulation.

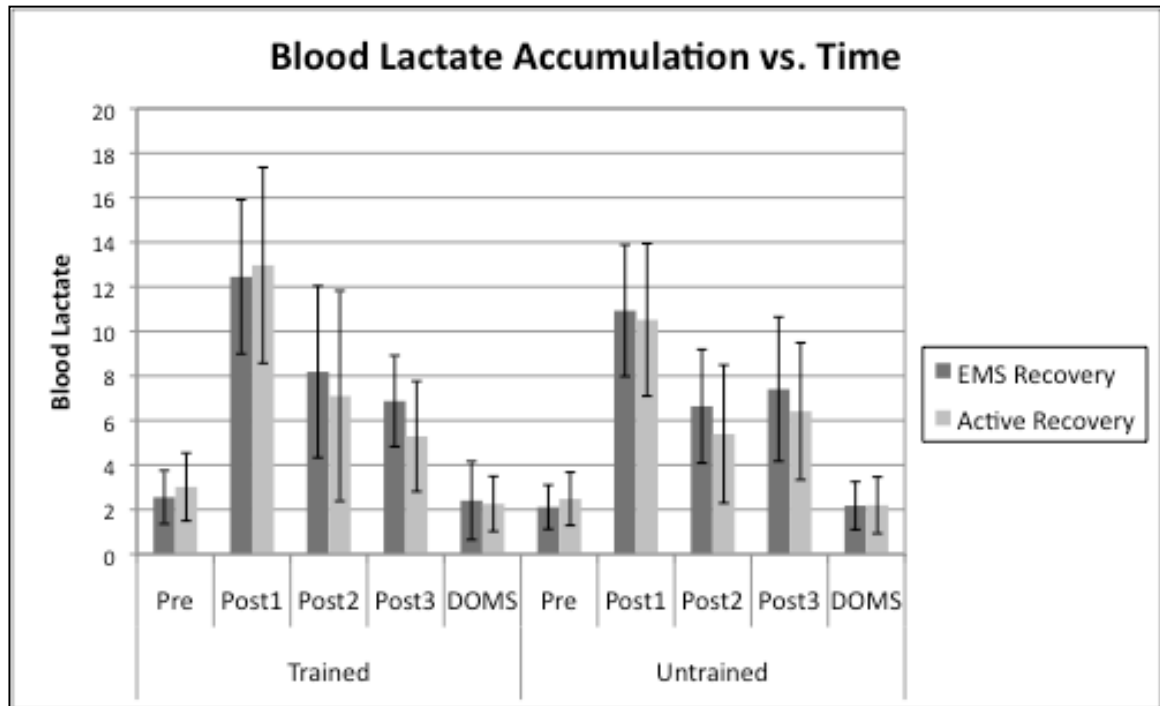


Figure 6. Means and standard deviations for the visual analogue scale of the hamstrings.

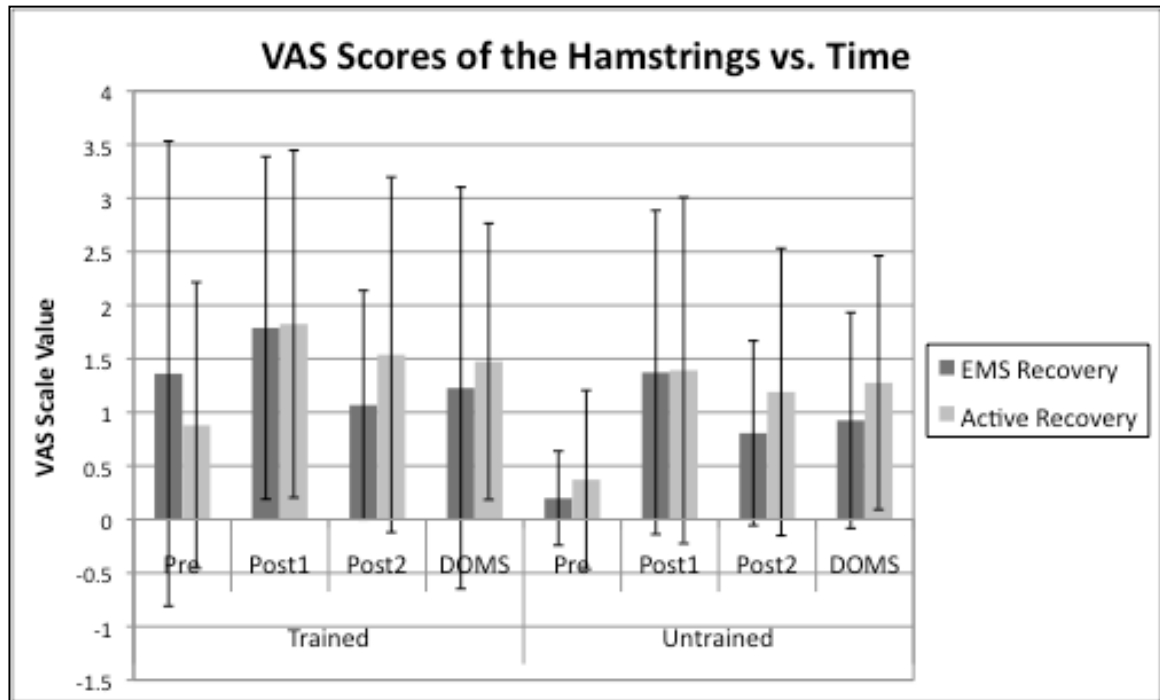


Figure 7. Means and standard deviations for the visual analogue scale of the calves.

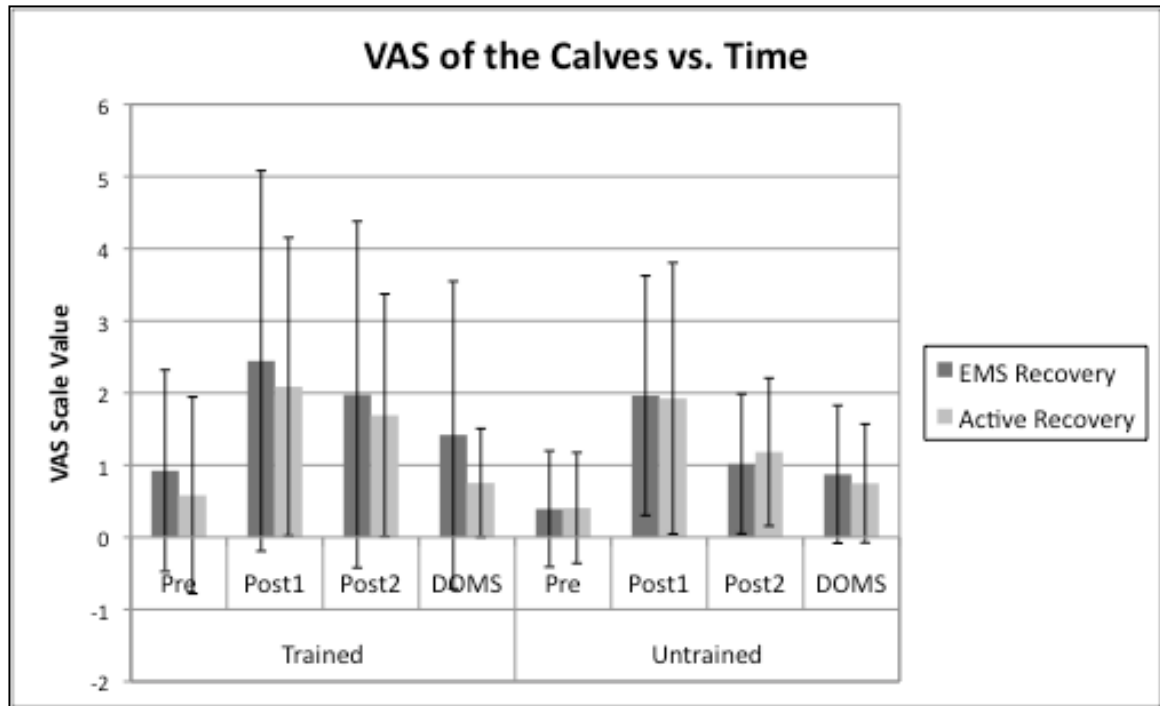


Figure 8. Means and standard deviations for the visual analogue scale of the quadriceps.

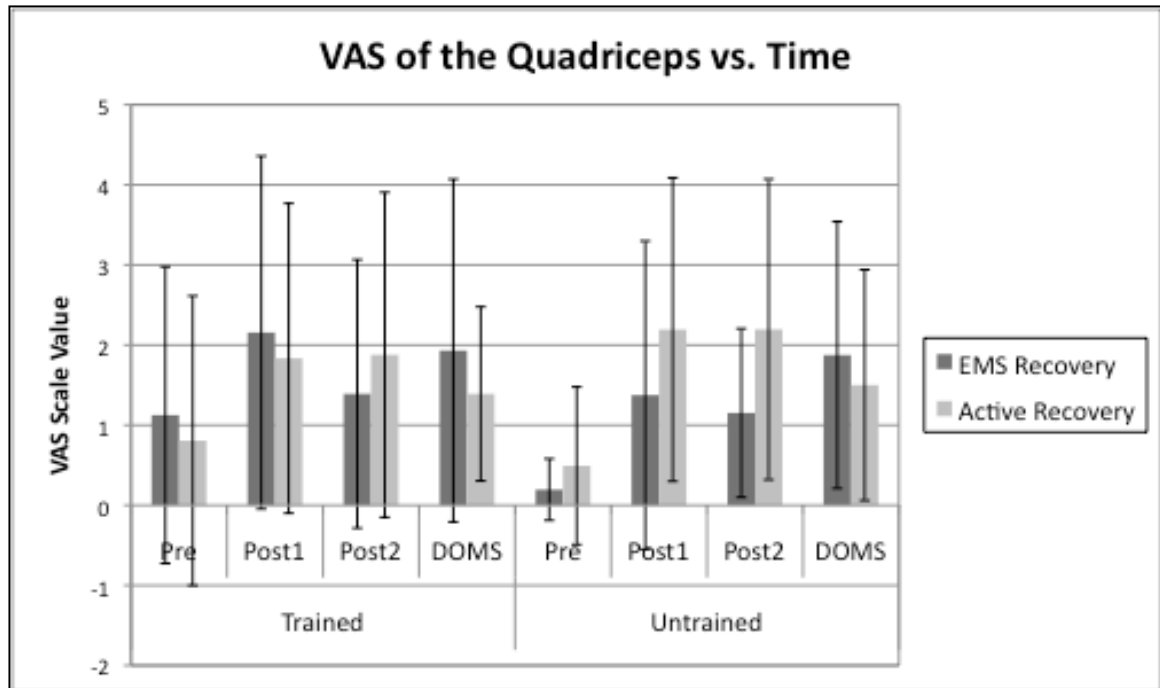


Figure 9. Means and standard deviations for pain pressure algometer.

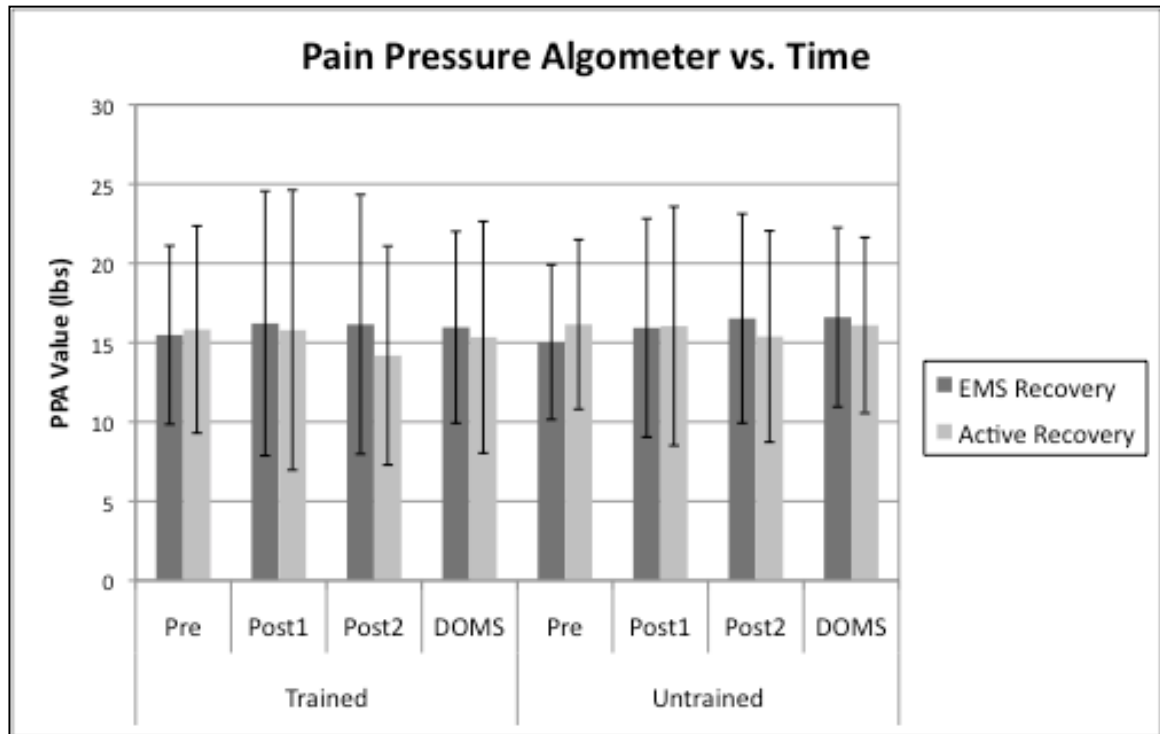


Figure 10. Means and standard deviations for sprint performance (36.6 meters).

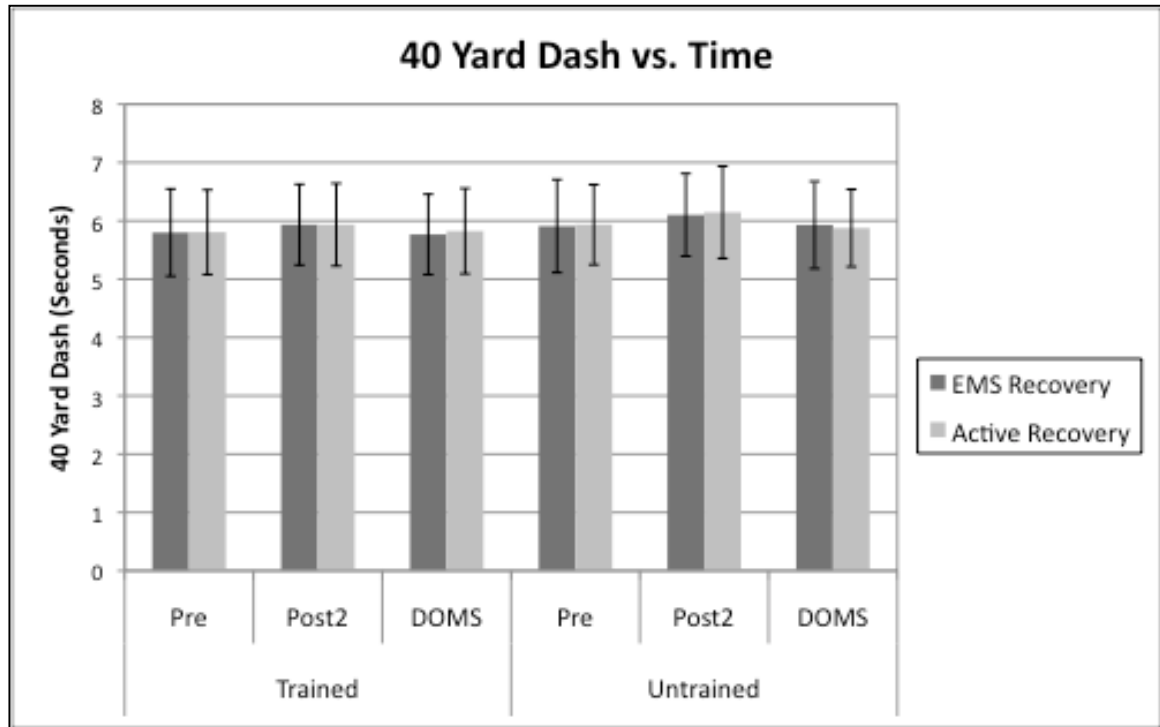
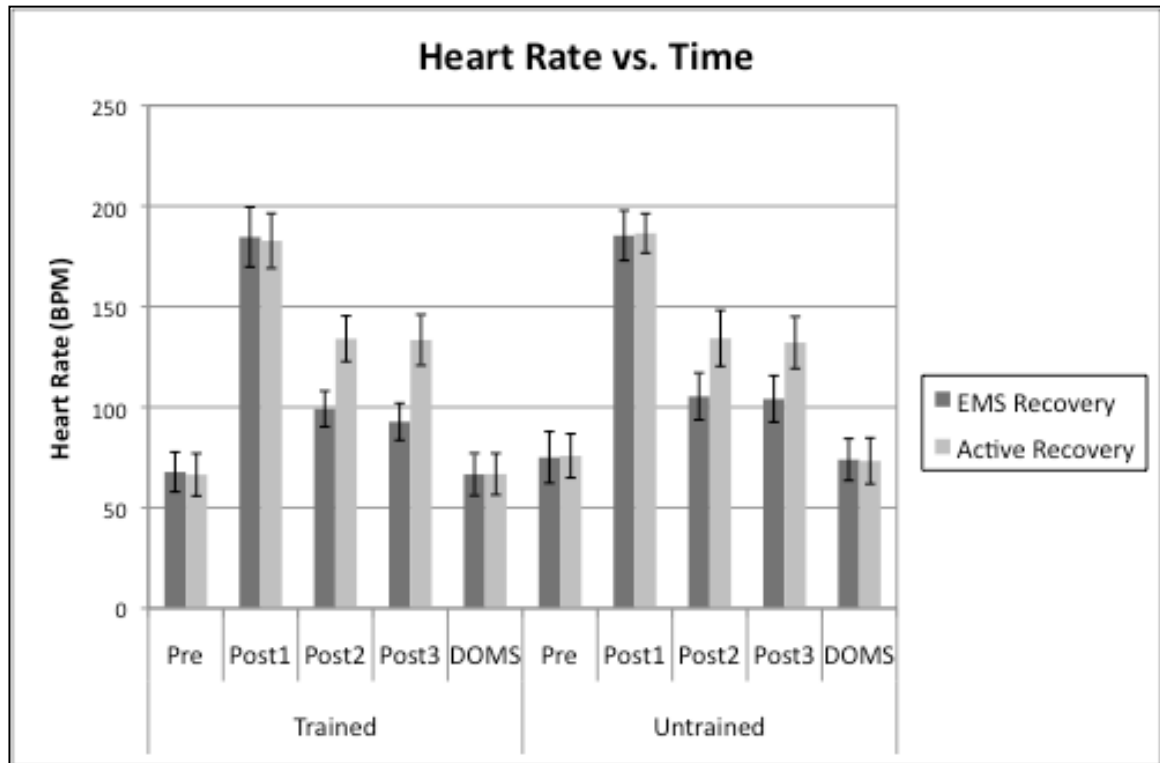


Figure 11. Means and standard deviations for heart rate.



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