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The Effect of Low Intensity Wearable Ultrasound on Blood Lactate and Muscle Performance after High Intensity Resistance Exercise

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ABSTRACT

Langer MD, Byrne HK, Henry T, Lewis G, Mattern C. The Effect of Low Intensity Wearable Ultrasound on Blood Lactate and Muscle Performance after High Intensity Resistance Exercise. **JEPonline** 2017;20(4):132-146. The purpose of this study was to determine if a low intensity wearable ultrasound (LIWU) device enhances recovery from exercise by reducing blood lactate resulting in improved isokinetic muscle performance after lower extremity resistance exercise. The impact of LIWU on exercise recovery and performance were explored through, a double-blind, sham-controlled, crossover design. Sixteen subjects completed 1-repitition maximum (1-RM) estimation for five lower-body resistance exercises. The subjects performed identical exercise sessions wearing either an active LIWU or a sham device applied to the quadriceps and hamstrings at rest and during exercise. Blood lactate concentration was measured before circuit weight training at 70% of the 1-RM and during the 60-min recovery. After recovery, the subjects performed leg extension and flexion exercises on an isokinetic dynamometer at two movement speeds. At each post-exercise time point, the lactate concentration was significantly reduced in the active treatment compared to the sham treatment. There were also significant differences between the active and sham conditions on muscle performance. These data suggest the LIWU device is an effective modality for reducing post-exercise blood lactate and improving slow speed knee extension.

Key Words: Lactate, Recovery, Strength Ultrasound

INTRODUCTION

The accumulation of lactic acid in skeletal muscle during intense anaerobic exercise contributes to fatigue and has a negative influence on subsequent exercise performance. Specifically, it is the protons (H^+) that are disassociated from the lactic acid, which cause a decrease in muscle pH. It has been shown that this decreased pH can inhibit enzymatic function, particularly phosphofructokinase. The result is a slowing of the glycolytic pathway and a consequent compromise in ATP production. In addition, the accumulation of H^+ in skeletal muscle has been suggested to displace Ca^{++} from troponin that compromises cross-bridge cycling and production of muscular force (4).

Therefore, it is advantageous to lower blood lactate levels after an initial bout of intense exercise in order to assure optimal subsequent exercise performance. Several therapeutic interventions that show modest results have been evaluated for their ability to enhance the return of lactate towards baseline. Generally, these interventions center their efforts upon promoting post-exercise blood flow in order to enhance the movement of lactate and accompanying H^+ out of the muscle and into lactate consuming tissues such as type I skeletal muscle, liver, and heart (4).

Massage, active recovery, and stretching have been used post-exercise to increase muscle performance by decreasing lactate levels. Several current investigations (6,12,16) have shown massage to be ineffective, and possibly detrimental with regards to blood flow and lactate reduction. A 5-min massage did not reduce lactate levels when compared to passive recovery after a super-maximal exercise performance (12,16). A separate study concluded that sports massage was detrimental to lactate level due to the promotion of retrograde arterial blood flow (20). Ce et al. (6) concluded that neither deep nor superficial massage affected the post-exercise lactate removal after heavy intense cycle exercise.

By contrast, active recovery, defined as light to moderate intensity exercise at 40 to 50% of maximal oxygen consumption (VO_2 max) may be of benefit to lactate clearance (6,16). The difference in lactate removal kinetics among recovery techniques including active recovery, passive recovery, and massage have been evaluated after high intensity exercise (6,16). In both of these investigations by Ce et al. (6) and Monedero and Donne (16), active recovery reduced lactate levels compared to passive recovery by ~16% ($P<0.05$); whereas, massage had no effect. Additionally, an increase in heart rate was observed, which suggests an increase in blood flow to the working muscle.

Stretching has also been proposed as a mechanism to increase muscle blood flow post-exercise. However, the role of stretching on lactate level remains unclear. Miladi et al. (15) indicates that dynamic stretching decreases lactate compared to passive recovery, while static stretching actually has a detrimental effect when compared to passive recovery by reducing blood flow to the muscles (6).

The potential benefits of therapeutic ultrasound include increased blood flow, increased rate of tissue repair, and increased nutrient transport through cellular membranes (8,9,11,17). These are physiological effects of ultrasound that have been studied in the clinical setting and documented in the literature. Therapeutic ultrasound caused a 4-fold increase in oxygenated hemoglobin in local muscle tissue as measured by near-infrared spectroscopy. This effect persisted for 20 min after ultrasound treatment was terminated (17). Applied to soft tissue injuries that include calcific tendinitis, therapeutic ultrasound has been linked to tissue repair and return to function (9).

These physiologic responses to ultrasound result from biological effects that are dependent upon the treatment parameters selected by the clinician, including frequency, intensity, and duration (19). When ultrasound (i.e., an acoustic wave) enters the body, the acoustic energy is gradually absorbed, attenuating the wave. As it is absorbed, some of the energy is converted to heat, some of the energy is absorbed by the fluid moving in the direction of the wave (a phenomenon called acoustic streaming), and a portion of the force is absorbed by the fluid through stable cavitation (low pressure induced bubbles expanding and contracting in a pressure field). The application of such a low intensity, long duration field has been documented to elicit a biological response at least 3 cm below the surface of the tissue (12).

Advancements in therapeutic ultrasound device design and delivery technology have given rise to a new type of treatment using a low intensity wearable ultrasound (LIWU) device (11) (Figure 1). While worn in a single location, the device emits low intensity, long duration, continuous ultrasound within the accepted safe limits for thermal exposure (18). Its wearable nature also means that it can be applied by a layperson, and it can be used during normal everyday activities as well as during exercise.

Transducer Power Output	0.65 W ± 20%
Transducer Intensity	0.132 W/cm^2 ± 20%
Ultrasound Frequency	3 MHz ± 20%
Duty Cycle	100% - continuous wave
Beam Non-uniformity Ratio (BNR)	< 5:1
Effective Radiating Area (ERA)	6 cm^2 ± 20%

Figure 1. A Low Intensity Wearable Ultrasound (LIWU) Device Featuring Two Ultrasound Transducers Connected to Coupling Patches Attached to a Single Power Controller. The specifications for the system are in the Table.

This study seeks to examine the effects of a LIWU device before, during, and after high-intensity lower extremity resistance exercise on blood lactate levels and lower extremity isokinetic muscle performance. It is hypothesized that the LIWU device will enable recovery by facilitating the reduction of lactate and associated ions from the muscle tissues resulting in improved muscle performance after lower extremity resistance exercise.

METHODS

Subjects

The Institutional Review Board of The College at Brockport-SUNY approved the protocol (#2013-129). Research personnel reviewed the protocol, measurements, and requirements with the subjects who provided informed consent prior to enrollment. Sixteen healthy, active, males between 20 and 24 yrs of age (Table 1) participated in this study. All subjects reported previous resistance training experience of at least 3 $d \cdot wk^{-1}$ for 6 months or longer. They were free of lower body orthopedic injuries, and each subject agreed not to use anti-inflammatory medications, get a massage, seek the help of physical therapist, or consume nutritional supplements for the duration of the study and the preceding 2 wks during screening. None of the subjects dropped out, and there were no adverse events reported during the study.

Table 1. Descriptive Data of the Subjects

Variables	
Subjects	16
% Male	100
	Mean ± SD
Age (yrs)	22 ± 2
Height (cm)	179 ± 7
Weight (kg)	87 ± 12

Experimental Approach to the Problem

The intention of the study design was to compare blood lactate levels and post-exercise muscle peak torque, work, and power with an active LIWU device (model sam-12; ZetrOZ Inc, Trumbull, CT) versus a sham device. A crossover design was utilized to control for variations in lactate processing. A washout period of 3 to 7 days between treatments prevented any carryover effects between the experimental conditions. The independent variables were time (for the lactate time course measurements) and treatment arm (the application of an active LIWU device versus a sham device). Dependent variables were the blood lactate concentration, and three measures of muscle performance (peak torque, average power, and total work) as recorded by an isokinetic dynamometer (Biodex System 2, Biodex Medical Systems, Shirley, NY).

Subjects attended three laboratory appointments: one baseline/familiarization assessment and two treatment sessions. Each visit was separated by 3 to 7 days to allow for adequate muscle recovery between visits. Visit 1 included the explanation of the study, signing of the informed consent, familiarization with the isokinetic muscle performance assessment, and the measurement of maximal dynamic lower-body muscular strength via estimated 1-repetition maximum (1-RM) testing. Visits 2 and 3 were identical to each other, with the exception that one of the visits involved the application of active LIWU devices on the lower extremities, while the other visit employed sham devices, as per the crossover design. The order of the treatment was randomized, with 8 subjects receiving the sham treatment first, and the other 8 receiving the active treatment first. Both visits 2 and 3 entailed the application of active or sham devices followed by the completion of a lower body circuit weight training protocol. Lower body circuit weight training was selected as the method of elevating blood lactate and creating muscle fatigue based upon pilot work by the authors. Initial pilot testing measured blood lactate concentration following the anaerobic step test (2), however the values of 6 to 7 mmol·L^{-1} were lower than desired. Therefore, a lower-body focused circuit weight training protocol was developed to produce post-exercise blood lactate levels in the range of 10 to 12 mmol·L^{-1}. Following performance of the circuit weight training protocol, subjects recovered for 60 min during which blood lactate was measured, and ended with the evaluation of isokinetic muscle performance (Figure 2).

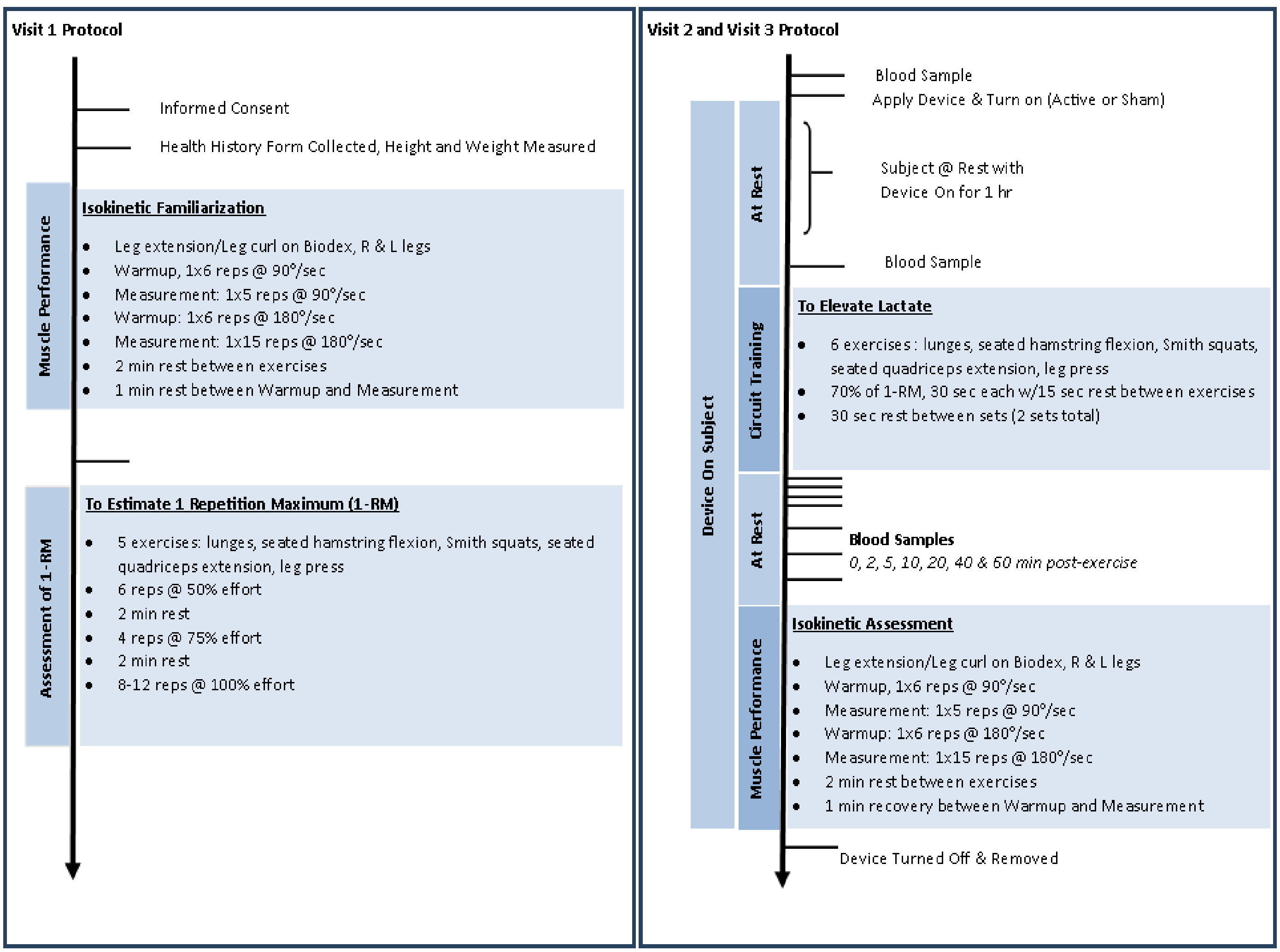

Figure 2. Visual Guide to Study Protocol. The left panel represents the first visit, where the subjects were familiarized to muscle performance assessments and 1-RM was estimated. The right panel contains the protocol for visits 2 and 3 where the subjects wore active or sham low intensity wearable ultrasound devices while performing circuit weight training, followed by measurements of blood lactate and muscle performance.

Familiarization and Assessment of Isokinetic Muscle Performance

Subjects were familiarized with the assessment of isokinetic muscle torque, power, and work for leg extension and leg flexion during visit 1, such that measurements were more accurate when they were performed at end of visits 2 and 3. Prior to use, the isokinetic dynamometer was calibrated according to the manufacturer's specifications. A warm-up set of 6 sub-maximal repetitions was performed at an angular velocity 90 deg·sec^{-1} followed by 1 min of rest. Then, the subjects performed 1 set of 5 rep at an angular velocity of 90 deg·sec^{-1}. Subjects were instructed to perform each repetition in this set at a maximal effort in order to obtain consistent results. After 2 min of rest, a warm-up set of 6 sub-maximal repetitions was performed at an angular velocity of 180 deg·sec^{-1}, followed by 1 min of rest. Finally, 1 set of 15 maximal effort repetitions were performed at 180 deg·sec^{-1}. The muscle force exerted during exercise was recorded by the equipment, and three output data were collected from each exercise: the peak torque, the total work, and the average power.

Estimation of Maximal Dynamic Muscular Strength (1-Repetition Maximum; 1-RM)

An estimate of 1-RM was determined for the exercises listed below (5). Each subject warmed up by performing 6 rep of each exercise at ~50% of maximal effort followed by 4 rep at ~75% of maximal effort. Each warm-up set was followed by 2 min. For each exercise the subject was asked to perform 8 to 12 rep of the exercise using a weight that would lead to exhaustion by the 12th rep. All exercises were performed on circuit training equipment with the exception of the lunges. A description of each exercise is provided below:

Lunges

Using a large stepping motion, and holding dumbbell weights, the subject stepped forward in an alternating manner such that the body was lowered until the front leg was at ~90° knee angle. The subject then pushed off the ground forcefully to return to the starting position to then repeat the exercise with the other leg.

Seated Hamstring Flexion

While in the seated position and using the Cybex Leg Curl Model 11061, the legs were extended and parallel to the floor. The subject flexed the knees to ~90° and then returned to the starting position.

Smith Squats

While using the Cyber Smith Press model 5341 with the squat bar on the subject's shoulders, the subject squatted and lowered the bar to a knee angle of ~90° and then returned to standing.

Seated Quadriceps Extension

Using the Cybex Leg Extension model 11051, the subject assumed a seated position with the legs flexed at the knees to ~90°, the subject extended the legs to as close to parallel to the floor as possible and then returned to the starting position.

Leg Press

From a seated position with knees at 90°, the subject used the Cybex Leg Press model 11041 to fully extend the hips while pressing the shoulders and back into the back pad, and then returned to the starting position.

Equation 1 was used to estimate the 1-RM for each exercise (5):

$$1 - RM = \frac{weight\ lifted}{[1.00 - (0.02 * number\ of\ reps)]} \qquad \text{(Eq 1)}$$

Application of LIWU Devices
Leg hair was removed to control for individual variation in ultrasound coupling and the skin was cleaned with alcohol prior to bandage placement. A total of 8 adhesive ultrasound coupling patches were placed on the lower extremities with four on each leg. For each leg, two patches were placed on the quadriceps muscle; one 3 to 4 inches above the top of the patella and the other 4 inches above the first bandage. Two patches were also placed on the hamstring muscles; one 3 to 4 inches above the knee and the other approximately at the juncture of the hamstrings and the gluteus maximus muscle (Figure 3).

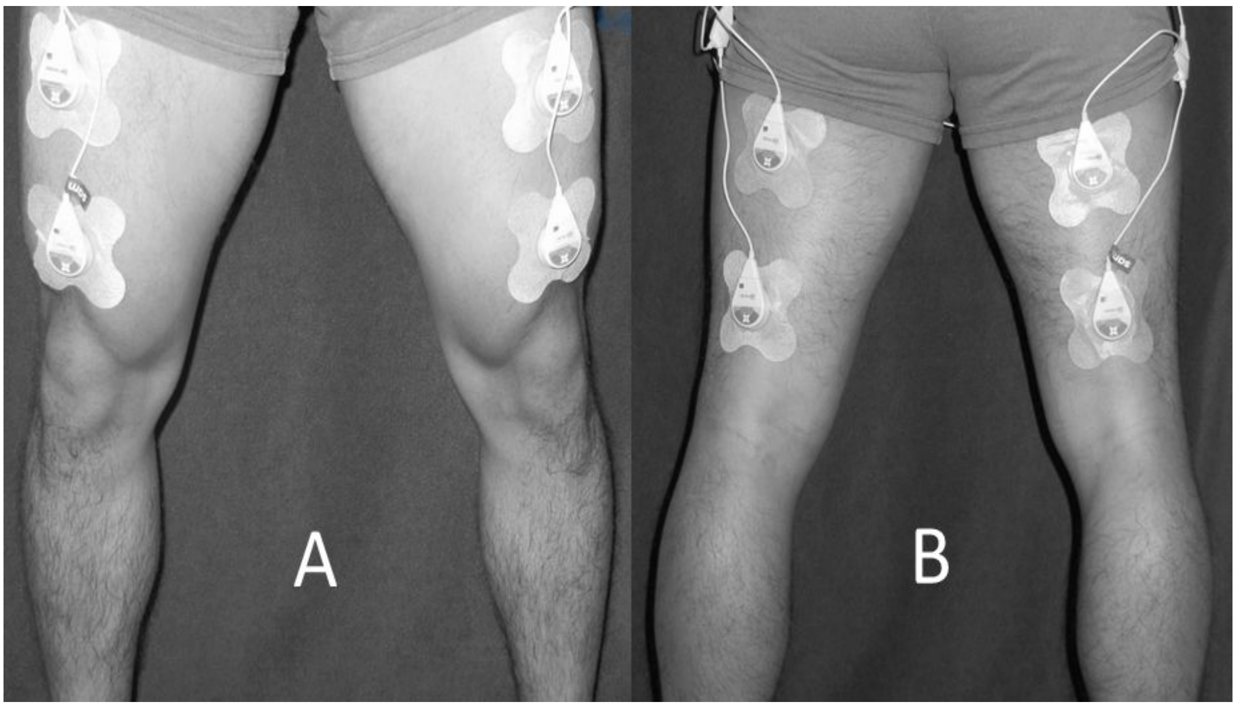

Figure 3. (A) Device Placement on the Quadriceps. (B) Device Placement on the Hamstrings.

Once the patches were adhered to the skin, a system to deliver active or sham treatment was attached to each patch. Devices were turned on and the subjects were asked to quietly rest in a supine position to prevent lactate generation for a 1 hr warm-up period prior to testing. In the active condition, ultrasound was delivered at a frequency of 3 MHz and an intensity of 0.132 $w \cdot cm^{-2}$ (Figure 1), while the sham treatment applied no ultrasound. Power controllers and transducer heads were coded by an independent party not involved in the data collection process to support the double-blinded study design. The researchers were only un-blinded to the level of the independent variable after all data were collected on all subjects.

Circuit Weight Training Protocol

Each subject completed 2 sets of the following 5 resistance training exercises at an intensity of 70% of their 1-RM: (a) Lunges; (b) Seated hamstring flexion; (c) Smith squats; (d) Seated quadriceps extension; and (e) Leg press. Each exercise was performed as described in the 1-RM measurement section at a metronome setting of 48 beats·min^{-1} for 30 sec with 15 sec of rest between exercises, and 30 sec of rest between the 2 circuits. Pilot testing demonstrated this regimen raised blood lactate to approximately 10 mmol·L^{-1}.

Measurement of Blood Lactate

Lactate was measured at the following time-points: (a) Baseline (BL) (prior to application of either active or sham treatment); (b) prior to circuit weight training (pre); (c) immediately following circuit weight training (post; also time 0); and (d) at 2, 5, 10, 20, 40, and 60 min into recovery. All measurements were performed with subjects in the supine position on a padded table. Subjects remained at rest to prevent active recovery from interfering with the results. At each time point, two 25 µl samples of blood were collected from a finger and immediately analyzed (YSI 1500 Sport Lactate Analyzer, Yellow Springs, Ohio) for blood lactate concentration (mmol·L^{-1}). The average of 2 samples was recorded as lactate concentration for each time point.

Statistical Analyses

All data are reported as mean ± standard deviation unless explicitly stated otherwise. The alpha level was set at $P \leq 0.05$. A repeated measures ANOVA with time and treatment as within subjects factors was used to compare the blood lactate concentrations for active versus sham conditions. A paired *t*-test compared baseline-normalized area under the curve (AUC) values at 60 min in the active versus the sham condition. The AUC was determined using numeric integration with the trapezoid rule. The AUC provides an overall description of changes in lactate level over a defined period of time. A one tailed matched pairs *t*-test was used to compare the active condition versus the sham condition for the three output measures of muscle performance (total work, peak torque, and average power) in the dominant leg. The movement speeds were 90^{o} and 180 deg·sec^{-1}. Based on the standard deviations observed in previous studies of post-exercise lactate removal (10,13), a sample size of 16 was 80% powered to observe a difference of 0.978 mmol·L^{-1}.

RESULTS

Blood Lactate Concentration

The average baseline levels of lactate were similar for both treatment groups. The pre-exercise blood lactate levels were significantly lower in the active condition compared to the sham treatment. At each post-exercise time point, the lactate concentration observed in the blood was significantly reduced with the active LIWU treatment device compared to the sham treatment (see Figure 4).

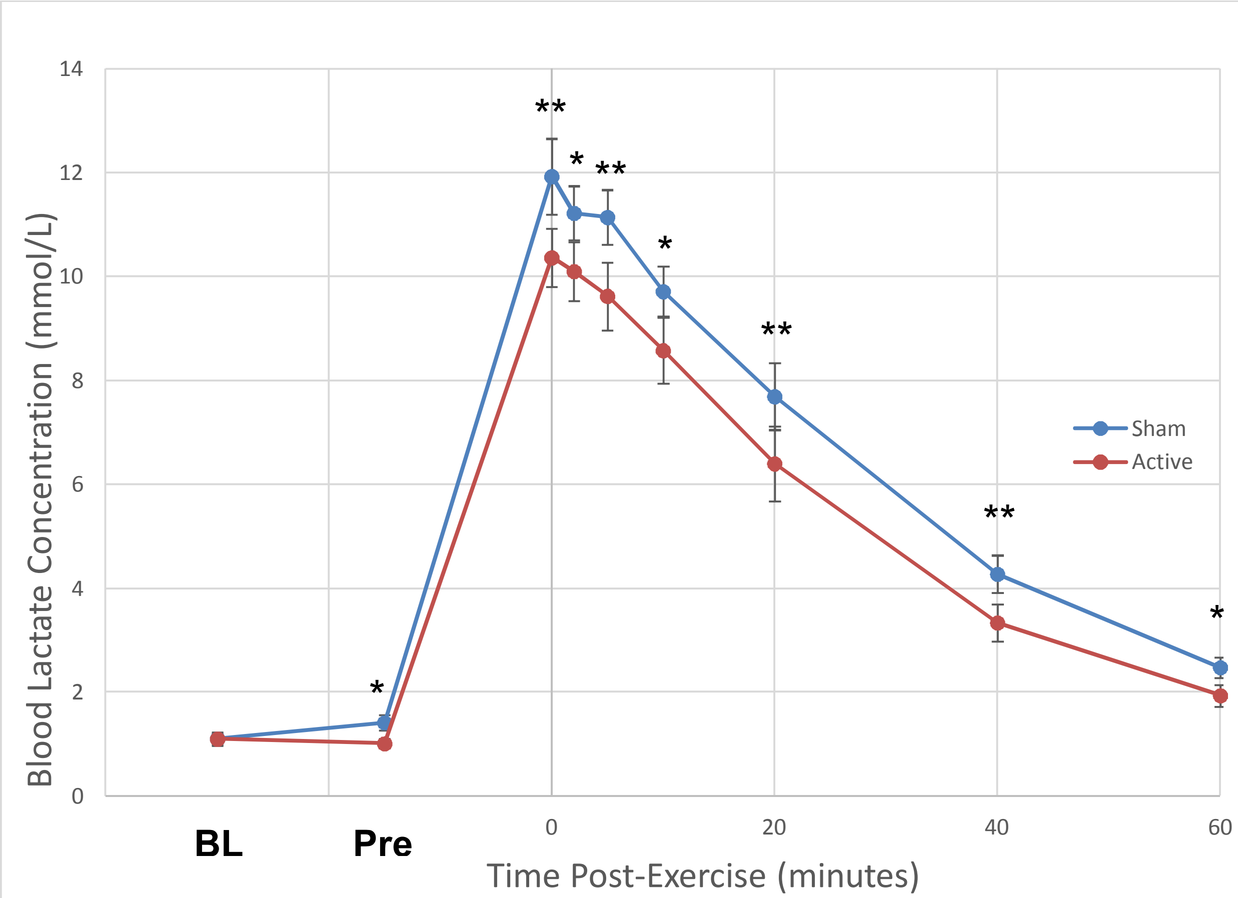

Figure 4. Blood Lactate Concentrations. Values presented are means ± SD. (BL) indicates the baseline and (Pre) indicates a pre-exercise measurement. *Indicates significant ($P<0.05$) difference between active and sham conditions. **Indicates significant ($P<0.01$) difference between active and sham conditions.

An overall assessment of the total blood lactate level for the 1-hr post-exercise interval was performed by calculating the (AUC). The AUC was significantly ($P=0.002$) lower in the active LIWU condition (255.8 ± 120.0 $mmol \cdot min \cdot L^{-1}$) versus the sham condition (318.5 ± 86.0 $mmol \cdot min \cdot L^{-1}$). This difference reflects an average decrease of 20% in total blood lactate level over the 1 hr of recovery.

Post-Exercise Muscle Performance

All 16 subjects successfully completed isokinetic testing after the blood lactate assessment was completed. The matched pairs *t*-test for the muscle performance variables indicated a significant difference between the active and sham conditions for three variables. The variables exhibiting the difference were peak torque at 90 $deg \cdot sec^{-1}$ into extension ($P=0.031$), total work at 90 $deg \cdot sec^{-1}$ into extension ($P=0.027$) and average power at 90 $deg \cdot sec^{-1}$ into extension ($P=0.024$). None of the other muscle performance variables exhibited a significant difference between the active and sham conditions.

Table 2. Matched-Pairs P-Palues for Isokinetic Muscle Performance Measures. *P-value <0.05

Side	Measure	P-value: Extension 90 $deg{\cdot}sec^{-1}$	Extension 180 $deg{\cdot}sec^{-1}$	Flexion 90 $deg{\cdot}sec^{-1}$	Flexion 180 $deg{\cdot}sec^{-1}$
Dominant	**Ave Power** (W)	0.024*	0.133	0.303	0.269
	Total Work (N-m)	0.027*	0.093	0.160	0.331
	Peak Torque (N-m)	0.031*	0.088	0.215	0.426

DISCUSSION

This was the first investigation to study the influence of a LIWU device on post-exercise blood lactate and subsequent muscle performance. The primary findings demonstrated that after a fatiguing bout of circuit weight training, the LIWU device lowered post-exercise lactate values at all recovery time-points, reduced the overall lactate AUC during recovery, enhanced subsequent slow-velocity leg extension muscle performance, and did not affect measures of fast-velocity leg extension nor measures of leg flexion at either movement velocity. Thus, our hypothesis was partially supported in that LIWU reduced blood lactate concentrations, and showed an improvement in three of the twelve measures of lower body muscle performance.

Recovery Lactate Levels

Various post-exercise strategies such as active recovery, stretching, and massage have been explored in an attempt to improve subsequent exercise performance. A recent study by Ce et al. (6) compared lactate dynamics after high-intensity exercise followed by 10 min of five different recovery interventions: active recovery, passive recovery, stretching, and two types of massage. The most effective recovery technique for accelerating lactate removal was active recovery. Based on a mono-exponential decay model, 10 min of active recovery caused approximately a 16.5% reduction in lactate AUC over the course of 1 hr when compared to passive recovery. For the current work, LIWU reduced the lactate AUC by 20%. Recovery time could prove to be an important factor influencing the post-exercise lactate reduction. Had Ce et al. (6) utilized a longer recovery interval it is possible that the reduction in AUC might have been greater and more similar to the current results. In addition to duration, the timing of the recovery intervention could have influenced the outcome of these studies. The intervention by Ce et al. (6) was exclusively applied after exercise, as compared with the current work, where LIWU was used before, during, and after exercise. Mondero and Donne (16) examined cycling time trial performance and lactate levels after active recovery, passive recovery, massage, and a combination of massage and active recovery. The active recovery method was the most efficient at lactate reduction and the authors speculated that possible mechanisms of improvement were an increase in local blood flow and/or an increase in muscle glycogen synthesis.

Stretching has also been proposed as a post-exercise recovery strategy. Miladi et al. (15) examined the effectiveness of passive, active, and dynamic stretching on blood lactate responses after supramaximal exercise. They reported that dynamic stretching between bouts of high-intensity intervals reduced lactate levels compared to passive recovery (15). In the previously described study by Ce et al. (6), static stretching failed to reduce lactate levels when compared to passive recovery (6). It could be speculated that the dynamic stretching maintained the muscle blood flow, while the static stretching reduced flow and the potential for lactate reduction. The current investigation provides strong evidence that LIWU reduces post-exercise blood lactate. Coupled with the aforementioned stretching investigations by Ce et al. (6) and Miladi et al. (15), it is possible that the reduction in lactate levels witnessed in the present study with the LIWU device is a function of an elevated blood flow.

A number of studies (6,12,16) have investigated the use of massage as a recovery method from exercise. Although the investigations used different protocols to produce high levels of blood lactate, the use of massage (whether deep or superficial) resulted in higher post-treatment lactate levels when compared to active recovery methods. Although both active recovery and specific massage techniques are thought to produce increases in skeletal muscle blood flow and therefore reductions in blood lactate levels, active recovery was more effective. Although the present study indicates that the use of LIWU resulted in reduced recovery lactate levels when compared to the sham device, the study did not directly compare LIWU to active recovery.

Isokinetic Measurements of Muscle Performance

The differences observed for the 90 $deg \cdot sec^{-1}$ extension exercises were present across peak torque, total work, and average power values. None of the variables assessed at 180 $deg \cdot sec^{-1}$ or for knee flexion indicated any differences between the treatment groups. Other studies (6,12,15,16) have investigated the effects of various treatment methods (such as active recovery, stretching, and massage) on muscle performance following muscle fatigue protocols. The conclusions from these studies have been varied. However, the general consensus supports the idea that active recovery may be beneficial for muscle performance following fatigue (14). One of the primary mechanisms by which active recovery enhances muscle performance is by increasing blood flow to the muscles. Fatigue during exercise is accompanied by a decrease in electromyographic activity of the muscle, which may be attributed to insufficient muscle blood supply (14,16). An investigation by Zarrouck et al. (21) examined the effect of electromyostimulation (EMS) on isokinetic peak torque in the knee extensors following fatigue. The EMS treatment modality has gained popularity for strength training. It is reported to enhance muscle blood flow by lowering the peripheral resistance. The research indicates that EMS is superior to both active and passive recovery in reducing muscle fatigue in the knee extensors. Zarrouck et al. (21) conclude that, “the smaller amount of fatigue reported with EMS recovery might be explained by the fact that specific electric stimulation increases regional blood flow. Thus, increased blood flow could improve oxygen delivery and the efflux of noxious substances and, consequently, enhance recovery” (21).

In addition to increased blood flow, other factors that may contribute to muscle performance are increases in body temperature, elasticity of the muscles, and neuronal activity (7). These factors have been linked to thermal or non-thermal effects of continuous therapeutic ultrasound. However, the current investigation did not study specific mechanism(s) of action and, therefore, all of the above are potential contributors.

Interestingly, only the extension exercises at 90 $deg \cdot sec^{-1}$ produced significant findings in our study. If increased blood flow is the primary mechanism of change, the impact of applying LIWU may simply be larger on a more voluminous muscle group such as the quadriceps, compared to the relatively smaller hamstring muscle group. The significant surface area and accompanying vascularization of the large quadriceps muscle group may exacerbate the thermal effects of the wearable ultrasound. With regard to isokinetic angular velocities, 90 $deg \cdot sec^{-1}$ is considered a relatively slow speed, while 180 $deg \cdot sec^{-1}$ is more of a moderate to fast speed. The improvements experienced in the present study at 90 $deg \cdot sec^{-1}$ and not at 180 $deg \cdot sec^{-1}$ are similar to the findings reported by Analan et al. (1). In their study, they investigated the effects of therapeutic ultrasound on shoulder rotator strength of patients with rotator cuff disease. They found that isokinetic peak torque improved in the ultrasound and sham groups only at 60 $deg \cdot sec^{-1}$ and not at 180 $deg \cdot sec^{-1}$. This result is similar to our findings of improvement at only the relatively slow speed of 90 $deg \cdot sec^{-1}$. Analan et al. (1) state that the low angular velocity component of the isokinetic evaluation is typically the most uncomfortable and difficult for the patients to complete. This may be a plausible explanation in subjects with rotator cuff pain, but it may not be particularly relevant to the healthy subjects in the present study.

Another investigation that shows disparate effects on hamstrings versus quadriceps muscle performance reported a greater increase in strength in the quadriceps when compared to the hamstrings following a warm-up protocol (7). The study also found that the warm-up protocol that utilized concentric hamstring curls did not show as much improvement in hamstring strength as compared to those using more functional hamstring exercises. The hamstring exercise included in the current study utilized a concentric hamstring contraction. It is plausible that the LIWU device had a similar mechanism of action as a warm-up protocol, and that this may help to explain the observed increase in the quadriceps performance without an accompanying hamstring improvement.

CONCLUSIONS

While the current investigation supports that LIWU can reduce recovery blood lactate and some measures of subsequent muscle performance, the mechanism of action was not studied. Temperature induced vasodilation resulting in increased blood flow, enhanced muscle oxygenation, and acoustic streaming/stable cavitation are all possible mechanisms of action for LIWU that warrant further investigation. A recent study by Borne et al. (3) measured limb blood-flow during recovery from exercise. In that study there was a positive correlation between an increase in blood flow and performance recovery, but the increase in limb blood flow was not related to a change in blood lactate levels. However, the limb blood flow was measured in the calf and not the quadriceps muscles, which are typically dominant in many lower extremity exercises. It would be informative to measure blood flow in the exercising muscle groups while comparing recovery interventions.

The current investigation delivered LIWU for an hour prior to fatiguing exercise, during exercise, and during recovery. In the future, it would be helpful to identify if this duration of exposure is necessary, or if a shorter ultrasound application protocol could yield a similar outcome. Finally, it should be acknowledged that this study did not directly compare LIWU with other recovery enhancement interventions such as low intensity exercise, massage, or stretching. A comparison of these various approaches within the same experiment would limit the procedural variability between different investigations and allow for a more direct comparison among these techniques.

Practical Application
LIWU may be used to reduce lactate levels following short duration anaerobic exercise. This may lead to an improvement in some but not all markers of lower body muscle performance.

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