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ABSTRACT

This study investigated the acute effects of NMES on blood lactate (BLa) and performance parameters in trained male triathletes. On three separate days, 13 trained male triathletes performed six 30 sec Wingate tests (30WanT) on a cycle ergometer. Each session consisted of performing 3 x 30WanT (bouts 1-3) followed by a randomly assigned 30 min recovery intervention of either: i) passive (seated), ii) active (cycling @ 30% VO_{2max}) or iii) NMES (1 Hz / 500 µs - ON:OFF 2:6 s). The 3 x 30WanT bouts were then repeated (bouts 4-6) and compared to bouts 1-3 for peak power (PP), mean power (MP) and fatigue index (FI). BLa and heart rate (HR) were recorded at designated time points throughout. Data were analyzed using repeated measures ANOVA with Tukey's HSD post hoc test. BLa decreased significantly faster during the active recovery intervention (P < 0.001), however, there were no significant differences between interventions for PP (P = 0.217), MP (P = 0.477) and FI (P = 0.234) when the post intervention bouts (4-6) where compared to the pre intervention bouts (1-3). NMES during recovery was not more effective than active or passive recovery for improving subsequent performance. Despite BLa clearing at a significantly faster rate for the active recovery intervention, PP, MP or FI did not improve significantly compared to NMES and passive. In conclusion, NMES does not appear to be more effective than traditional methods for enhancing short-term recovery from supra-maximal exercise bouts in trained male triathletes.

Keywords: NMES · Active Recovery · Passive Recovery · Supra-Maximal · Mean Power · Blood Lactate

INTRODUCTION

The ability to perform and recover from high intensity bouts of exercise is a prerequisite for success in many sporting situations. Inadequate recovery from short-term, high-intensity bouts of exercise can be a limiting factor to optimal sporting performance (Higgins et al. 2011), and can lead to tissue injury or over-training syndrome (Barnett 2006). Therefore, for athletic populations, it is important to maximize exercise recovery in order to increase performance restoration prior to subsequent physical activity (Pournot et al. 2010). This has led to a large body of research in the area of sport recovery, with the aim of developing recovery aids for enhancing exercise recovery both within and between high intensity sessions.

Previous research, investigating various recovery interventions from high-intensity exercise, including active recovery, massage, cryotherapy, contrast water therapy, low-level laser therapy and compression suits, have found positive (Gill et al. 2006; Bailey et al. 2007; Leal Junior et al. 2010; Sear et al. 2010) or inconclusive (Robertson et al. 2004; Howatson et al. 2005) results compared to passive recovery. Much of this previous research has investigated sports recovery using recovery periods of 24 hours (hrs) or more, where participant recovery between exercise sessions was investigated. However, a major limitation to sporting performance is often recovery from a bout(s) of high or supra-maximal intensity exercise within a competitive event or training session, where the allocated recovery time is often less than 1 hr. This time period is purported to be the time typically required for full homeostasis to be returned following very high intensity exercise (Barnett 2006). Examples of these events could include an athletics meet, or a rowing or swimming regatta, where multiple competition heats are performed on the same day. In such situations, athletes may have less than one hour between individual heats, where recovery from one heat to allow preparation for the next is critical (Sayers et al. 2011). For many field sports such as soccer or rugby, where designated periods of intermittent high intensity exercise are separated by an interval (half-time), enhancing recovery during the interval may be beneficial in terms of increased performance and decreased injury risk. Similar beneficial effects could be achieved if the quality of athlete recovery from supra-maximal exercise bouts in training sessions were enhanced.

The use of NMES has gained popularity in amateur as well as professional sports for enhancing both strength and recovery (Lattier et al. 2004). It appears that NMES can be used effectively for increasing indices of both strength and power in athletic populations, without interfering excessively with sports specific training (Maffiuletti and Cardinale 2010). However, there have been fewer studies that have examined the effects of

NMES as a recovery intervention to enhance sporting performance. It has been suggested that sub-tetanic NMES could be effective for enhancing sports recovery owing to its analgesic effects on muscle soreness (McLoughlin et al. 2004), and its role on post exercise muscle metabolite removal, secondary to increased blood flow and lymphatic drainage to the stimulated area (Neric et al. 2009). Studies performed to date have primarily used sub-tetanic NMES to enhance recovery over periods of 24 hrs or longer (Weber et al. 1994; Martin et al. 2004; McLoughlin et al. 2004), or periods between 1 and 24 hrs (Lattier et al. 2004; Tessitore et al. 2008; Cortis et al. 2010). However, to date, these investigations have not clearly demonstrated that this form of NMES is beneficial for enhancing recovery compared to other recovery interventions.

There have been few studies that have employed the use of NMES for short-term recovery (< 1 hr) from high-intensity exercise, as previously investigated using various other recovery interventions, such as low-frequency vibration (Carrasco et al. 2011), active recovery (Toubekis et al. 2010), various water immersions (Pournot et al. 2010) and leg massage (Robertson et al. 2004). A recent study by Heyman et al. (2009), found that NMES was less effective than active recovery or cold water immersion for enhancing rock climbing performance or reducing BLa during two trials of exhaustive rock climbing, separated by a 20 min recovery intervention. Another study, by Neric et al. (2009), investigated the BLa lowering effects of using NMES for short-term recovery (< 1 hr) between bouts of intense exercise. They compared NMES with active (sub-maximal swimming) and passive recovery (seated), for lowering post exercise Bla following sprint swimming. The authors concluded that NMES shows promise as an alternate recovery treatment; although NMES reduced BLa less than active recovery, it did reduce BLa post exercise significantly better than passive recovery. However, they did not repeat the sprint swimming bouts post recovery to determine whether NMES had an effect on performance parameters. Also, the effect of lowering BLa may not necessarily enhance subsequent performance (Franchini et al. 2003), especially given that lactate is no longer seen as a causative effect of muscle fatigue (Williams and Ratel 2009).

To the knowledge of the investigators, there have been no studies to date that have investigated the use of NMES as a short-term recovery intervention (≤ 1 hr) between sessions where repeated bouts of longer duration (≥ 30 sec) supra-maximal exercise were performed. The aim of the current study was to investigate the effectiveness of using NMES as a short-term recovery intervention, between two sessions of repeated 30 sec bouts of supra-maximal exercise, which were separated by a 30 min period. Similar to the study by Neric et al. (2009), NMES was compared to both passive and active recovery for BLa clearance during the post exercise period. However, in contrast to their study, repeat supra-maximal exercise bouts were performed post recovery to compare performance parameters between the three recovery intervention methods. This was to determine if NMES was more effective than traditional recovery methods for enhancing short-term recovery between supra-maximal exercise sessions. The hypotheses for this study were that the use of NMES would be as effective as active recovery, and more effective than passive recovery, for lowering post exercise BLa and minimizing performance decrements during subsequent bouts of supra-maximal cycling exercise. We based this hypothesis on the expectation that NMES would affect localized blood flow, thus increasing the efflux of contraction induced metabolites from the stimulated muscle mass, resulting in an effect similar to that of active recovery.

The rationale for conducting this study was to investigate whether NMES was more effective than traditional recovery methods for enhancing recovery from multiple bouts of supra-maximal exercise in a trained population. If NMES was shown to be more effective, this would help provide some justification for the use of NMES as an effective, time efficient and practical alternative to traditional methods for maximizing the quality of both high-intensity training and competition for trained athletic populations. We also wished to investigate whether there was an association between BLa levels and fatigue during the post-intervention exercise bouts. Because the use of BLa as a recovery marker is controversial due to inconsistencies in the relationships between BLa and sporting performance (Sayer et al. 2011), the findings of this research would provide an addition to the previous body of research, which has investigated the role of lactate in muscle fatigue.

METHODS

Experimental Design

Three successive 30WanT's were performed (bouts 1-3), with the purpose of inducing extreme fatigue prior to a randomly assigned 30 min recovery intervention period, consisting of either an active, passive or NMES recovery intervention. Immediately after the recovery intervention period, the exact same protocol for the pre-intervention bouts (1-3) was repeated for the post intervention bouts (4-6). Indices of PP, MP and FI during bouts 1-3 and 4-6 were compared across all three interventions to assess which of the intervention protocols were most effective for enhancing the recovery response prior to the commencement of the post-intervention bouts (bouts 4-6). BLa and HR were recorded at designated time points throughout the test protocol to monitor physiological responses to the supra-maximal bouts and during the recovery intervention periods.

Participants

Sixteen healthy trained male tri-athletes volunteered to participate in this study. Due to adverse events, three participants were subsequently withdrawn from the study prior to completion, leaving a total of thirteen participants included in the final analysis (Table 1). Participants were recruited from local triathlon clubs and were involved in triathlon training and competition on a regular basis. They were fully informed of all procedures relating to the study and were required to complete a pre-test medical screening questionnaire and provided written informed consent prior to participation. Inclusion criteria required participants to be males aged 18 – 40 y/o, healthy and physically trained, and free from recent injury (< 3 months) or any acute/ chronic cardiovascular or metabolic complications. Participation in this study was voluntary and participants had the right to withdraw from the study at any stage for whatever reason and without question. All procedures for this experiment protocol were approved by the institutional research ethics board.

(Insert Table 1 here)

Procedures

Participants attended the Human Performance Laboratory on four separate occasions. Each session was carried out at the same time of day (± 1 hr) to control for circadian rhythm (Souissi et al. 2007) and were separated by a minimum of 72 hrs to allow full recovery (Cortis et al. 2009). Participants were instructed to eat as normal and to stay well hydrated during the 24 hr period prior to each session. They were also instructed to record a food and activity log during these periods, in order to replicate their food intake and habitual activity for repeated sessions, and were made aware of the significance of their compliance to the accuracy of the collected data. They were instructed to refrain from any form of exercise and alcohol consumption 24 hrs prior to each session (Watt et al. 2002). Due to the possible stimulatory effects of caffeine on high intensity exercise (Astorino and Roberson 2010), participants were instructed to abstain from caffeine consumption on the day of each session. Nutritional supplementation or ergogenic aids that may have impacted on the study protocol (such as creatine supplementation) were not consumed by any of the participants during their participation in this study.

Session 1

Anthropometric: Stature (cm) was recorded using a wall mounted stadiometer (Holtain Ltd., Crymmych, Wales) to the nearest 0.1mm. Body mass (kg) was recorded using an electronic digital weighting scales (Seca 888, Germany) to the nearest 0.1kg. Body fat (%) was calculated using a skin-fold callipers (Harpenden Ltd., UK) at three anatomical sites: pectoralis major, abdominal and mid-thigh, using the Jackson and Pollock ∑3 site formula for males (Jackson and Pollack 1978) to the nearest 0.1%.

Incremental (VO_{2max}) Test: An incremental maximal aerobic cycle test (VO_{2max}) was conducted to validate participants' trained status and to determine the power output intensity (W) required for the subsequent active recovery intervention. All exercise tests for this study were carried out on an electro-magnetic braked cycle ergometer (Lode Sport Excalibur, Netherlands). Participants' expired gases were analyzed using a breath-by-breath (BBB) expired gas analyzer (Cosmed Quark b2, Italy), which was calibrated for O_2, CO_2 (known gas mixtures – 16 & 20.9% O_2/ 5 and 0.03% CO_2) and flow (3 Litre syringe – Hans Rudolph Inc, USA) immediately prior to the commencement of the test. Participants set-up the cycle ergometer to their own individual preference, with the settings chosen, used for all subsequent testing sessions. Participants were fitted with a HR monitor (Polar RS400, Finland) and HR was recorded continuously at 5 sec intervals throughout the protocol. The test consisted of participants cycling at approximately 90 revolutions per minute (rev.min^{-1}) at 100 Watts (W) for 1 min, with each 1 min stage thereafter increasing by 30 W until volitional exhaustion. The criteria for achieving VO_{2max} was when at least three of the following occurred: a plateau or decrease in O_2 uptake despite an increase in workload, an RER > 1.15, participant reaching within 10 beat.min^{-1} of their predicted maximum heart rate (220 – age), Borg Scale score of 19 or greater or failure to maintain at least 60 rev.min^{-1}. Participants' VO_{2max} score (ml.min.kg^{-1}) was the highest averaged 30 sec value attained during the test (Tessitore et al. 2008).

NMES Familiarization: Participants were familiarized with the NMES device (NT2010, Biomedical Research Ltd, Galway, Ireland), which delivers current waveforms via an array of adhesive electrodes to the lower extremity musculature (quadriceps and hamstrings, as shown in Fig. 1). The NMES device was programmed using a single phase programme that delivered intermittent contractions (2:6 sec ON:OFF contraction ratio) for a 20 min period. Bursts of 3 pulses, each of 500μs duration were delivered at a packet frequency of 1 Hz (i.e., 6 pulses in total during each 2 sec ON period). The maximum current output delivery was set at 140 mA. Specially designed garments were fitted to participants to hold the electrodes in place. Participants were fully informed about the NMES device, its function, potential risks (e.g., possible skin irritation) and the objectives of the familiarization session. Participants were instructed to adjust the stimulation intensity to a level as high as possible before feeling undue discomfort. The research investigator also visually observed participant leg movement during muscle stimulation, in order to assist the participant in determining the optimum intensity. The intensity selected by each participant was noted by the research investigator, and was used for the subsequent recovery intervention period.

(Insert Fig. 1 here)

30*WanT Familiarization:* To eliminate the practice/ learning effect of performing a 30WanT bout for research purposes, it is recommended that at least one full 30WanT bout be performed prior to baseline power measurements (Barfield et al. 2002). Participants were fully informed about the 30WanT protocol, any potential risks (such as feelings of nausea or syncope) and the physiological objectives of performing the multiple 30WanT familiarization protocol. Participants performed two bouts of the 30WanT study protocol for familiarization purposes to help eliminate the practice effect of performing 30WanT bouts.

Sessions 2-4

Multiple 30WanT Protocol: Each session, performed on different days at least 72 hrs apart, consisted of performing three successive 30WanT bouts (bouts 1-3) on the cycle ergometer, a 30 min recovery intervention, immediately followed by a repeat of the three successive 30WanT bouts (bouts 4-6) (Fig. 2). Participants' torque factor (force acting at the flywheel perimeter) was fixed at a resistance of 0.085kg.BM.min^{-1}, as recommended when using trained populations (MacIntosh et al. 2003). Firstly, participants performed a 5 min warm-up, which consisted of cycling at 80 W at 80 rev.min^{-1} cadence. This also included a 5 sec practice WanT trial (5WanT) at the end of the second minute. Participants then performed three successive 30WanT bouts (Bouts 1-3) in a seated position, interspersed by 4 min of cycling at 80 W at 80 rev.min^{-1}, to allow for recovery and to prevent blood pooling in the lower extremities (Kohler et al. 2010). A 30 min recovery intervention immediately followed the completion of bout 3, which included a 20 min randomly assigned intervention of either: 1) passive (seated), 2) active cycling (load corresponding to 30% of participants' VO_{2max} @ 90 rev.min^{-1}) or 3) NMES (1 Hz / 500 μs, ON:OFF ratio 2:6 s). The exact same protocol for bouts 1-3 was then repeated (bouts 4-6). At the completion of bout 6, the participant remained passively seated for 5 min so that a post HR and BLa sample could be taken. Strong standardized verbal encouragement (using a written script) was given by the investigator at the exact same time for all 30WanT performed in all sessions (Maffiuletti and Bendahan 2009).

Blood Lactate & Heart Rate: Whole BLa was analyzed using an Analox LM5 Champion lactate analyzer (Analox Instruments Ltd., London, England). Small (5 μL) capillary blood samples were taken from the index or middle finger of participants at specific time points throughout the protocol (Table 2). Participants' HR was also recorded specific time-points (Table 2).

(Insert Fig. 2 here)

(Insert Table 2 here)

Statistical Analysis

Statistical analysis was conducted using PASW statistics 18 software (SPSS Inc, Illinois, USA). Results are reported as Mean ± Standard Deviation (SD), unless otherwise stated (Mean ± Standard Error of Mean (SEM)). The threshold for statistical significance was set at $P < 0.05$ and is reported as this unless otherwise stated. Differences in performance parameters (PP, MP, and FI) between pre-intervention (bouts 1-3) and post intervention (bouts 4-6) were analyzed using a two-way repeated measures ANOVA to compare the effects of time (bouts 1-3 and 4-6) and intervention (NMES, passive, active). The effects of intervention (NMES, passive, active) on BLa and HR at specific time points during the protocol were analyzed using a two-way repeated measures ANOVA (recovery method x time). Where significant differences were observed, Tukey's honestly significant difference (HSD) *post hoc* test was used to determine specific differences found.

RESULTS

Of the 16 participants who volunteered to take part in this study, three were withdrawn from the study as a safety precaution, due to an adverse event occurring in the aftermath of performing the repeated supra-maximal bouts. This is not uncommon when extremely intense exercise protocols are performed (Crisafulli et al. 2003). That left the final number of participants that completed the study, and included in the final data analysis at 13.

There were no significant differences between recovery interventions for PP ($P = 0.217$), MP ($P = 0.477$) and FI ($P = 0.234$), when post intervention (bouts 4-6) performance was compared to pre intervention (bouts 1-3) performance (Fig. 3). Significant differences were observed for BLa measurements obtained during the three recovery intervention periods at 10, 15, 20 and 30 min ($P < 0.001$) (Fig. 4). Post hoc analysis indicated that BLa was significantly lower during the active recovery intervention at these time points compared to both the NMES and Passive recovery interventions ($P < 0.001$). There were no significant differences for BLa between the passive and NMES recovery interventions at all time points during the protocol ($P > 0.05$). Significant differences were observed for HR measurements obtained during the three recovery intervention periods at 5 and 30 min ($P < 0.05$), and at 10, 15, 20 and 25 min ($P < 0.001$). Significant differences were also found at the end of bouts 4 and 5 and also at 5 min post bout 6 ($P < 0.05$) during the post intervention period (Fig. 5). Post hoc analysis indicated that HR was significantly lower during the active recovery intervention at 10, 15, 20 and 25 min during the recovery intervention period compared to both other interventions ($P < 0.001$). HR was also significantly lower for the active recovery intervention compared to the passive recovery intervention at 5 min ($P = 0.004$) and 30 min ($P = 0.015$) into the recovery intervention period and at the end of bouts 4 ($P = 0.008$) and 5 ($P = 0.017$) and at 5 min post bout 6 ($P = 0.003$). There were no significant differences in HR measurements between NMES and passive recovery at any time point during the protocol, except at 20 min into the recovery intervention period, where the passive recovery intervention was significantly lower than the NMES recovery intervention ($P = 0.038$).

(Insert Fig. 3, 4 and 5 here)

DISCUSSION

The principal findings for this study were that there were no significant differences between NMES, active or passive recovery interventions for maintaining performance parameters during subsequent exercise bouts. Also, active recovery was associated with significantly lower levels of BLa throughout the recovery intervention period, compared to the NMES and passive recovery interventions, without resulting in significantly better performance parameters during the post intervention bouts.

The rationales for the design of this study and the primary parameters selected were: Firstly, to produce an anaerobic exercise protocol (3 x 30WanT) that would induce extreme fatigue prior to the implementation of the recovery intervention method. Secondly, to implement a recovery period (30 min) that would be too short to enable complete recovery to be achieved prior to the commencement of the post-intervention bouts (bouts 4). This was confirmed by our findings for MP for bouts 1 vs. 4, and the BLa and HR profiles, none of which had returned to pre exercise levels by the start of post-intervention (bouts 4-6). This enabled the effectiveness of the different recovery intervention protocols to be assessed and compared to each other.

NMES & Recovery: The parameters selected for the NMES intervention used in this study were low intensity and intermittent (sub-tetanic with 2:6 sec ON:OFF ratio). These parameters were designed to elicit a pattern of muscle activity that could increase local blood flow and increase efflux of contraction induced metabolites from the stimulated muscle mass, with the aim of enhancing recovery and minimizing any potential fatigue that NMES may induce. The results we observed partially support our hypothesis that NMES would be as effective as active recovery, and better than passive recovery, for lowering post exercise BLa and minimizing performance decrements. The lack of significant differences for performance parameters between NMES and active recovery were as anticipated. On the other hand, we had expected NMES to perform better than passive recovery and it did not. The lack of an observed difference between NMES and passive recovery interventions cannot be easily explained from our results. It is possible that NMES did not increase blood flow in the manner in which we had expected, however, this was not directly measured in this investigation.

Active vs. Passive: The primary purpose of this study was to investigate the effects of NMES on recovery. However, we have also observed some interesting results with regard to the comparative effects of active and passive recovery. Previous studies investigating active and passive recovery from bouts of supra-maximal exercise have generally found active recovery to be more effective when recovery interventions are greater than 3 min (Thiriet et al. 1993; Ahmaidi et al. 1996; Bogdanis et al. 1996; Connolly et al. 2003; Spierer et al. 2004). This is most likely due to active recovery aiding in venous return to the heart due to the muscle pump effect (Crisafulli et al. 2003), and increasing the efflux of contraction induced metabolites from the exercised muscles due to increased blood flow to the contracting muscles (Tessitore et al. 2007). However, when recovery periods are very short (< 2 – 3 min), passive recovery tends to be more effective than active recovery (Dupont et al. 2003; Dupont et al. 2004; Spencer et al. 2006; Spencer et al. 2008). This is likely due to active recovery impeding resynthesis of phosphocreatine [PCr] and restricting myoglobin reoxygenation (Dupont et al. 2004), as prevention of PCr resynthesis impairs recovery of power output (Billaut and Bishop 2009).

The findings for active versus passive recovery in the present study are somewhat surprising, as we expected active recovery to be more effective due to its purported positive effects on venous return and increased efflux of contraction induced metabolites. Also, because the recovery period was quite long, it is highly unlikely that PCr replenishment was a limiting factor to recovery, as at 30 min duration, this period should have been more than adequate for [PCr] to fully recover. Our findings somewhat contradict the findings of the aforementioned studies, in that active recovery was not found to be more effective than passive recovery for enhancing recovery between supra-maximal bouts, even though a recovery period of longer than 3 min was used. The reasons for these findings are unclear, but may be due to differences in population or protocol used. It has been previously suggested that sedentary people benefit more from active recovery, whereas athletic populations, show similar performance after active or passive recoveries (Tessitore et al. 2008). Of the aforementioned studies that found active to be more effective than passive, when recovery interventions of greater than 3 min were used, none used trained populations, instead only healthy or recreationally active populations were used. Two previous studies that did not find any differences between active and passive recovery for enhancing subsequent supra-maximal performance after a recovery intervention of 15 min (Lau et al. 2001) and 6 min (Toubekis et al. 2010), used trained competitive hockey players and swimmers respectively. Likewise, our study used trained triathletes and also found no significant differences between active and passive recovery which may suggest that the trained status of participants used may have contributed somewhat to these findings.

Recovery & BLa: The effects of NMES on BLa lowering during the recovery intervention period in this study is in contrast to the study by Neric et al. (2009), who found that NMES had a significantly greater BLa lowering effect than passive recovery after high intensity sprint swimming. This study found no significant differences between the NMES and passive recovery interventions for [Bla] at all time points during the 30 minute recovery intervention period. Whereas, as expected, [Bla] were significantly lower for the active recovery intervention. The NMES recovery intervention protocol was designed to increase localized blood flow in the area in order to increase the efflux of Bla and other contraction induced metabolites during the post exercise recovery period, as metabolites, such as inorganic phosphate (P_i), magnesium (Mg^{2+}), and ammonia (NH_3), generated during high-intensity exercise can adversely affect muscle function (Ament and Verkerke 2009). A possible explanation for our findings could be that NMES did indeed increase localized blood flow and metabolite removal from the stimulated area. However, the resultant stimulation of Type II muscle fibers may have simultaneously generated lactate, thus masking the lactate clearing effect of the NMES, as it is known that larger glycolytic type IIA fibers are major physiological producers of lactate when they are contracting (Philp et al. 2005). It is difficult to explain why similar findings to the Neric et al. (2009) study were not observed in this study. It may be related to the different stimulation protocols used in both studies. They used a transcutaneous electrical muscle stimulator to deliver low frequency (2 Hz) stimulation with a peak current of only 35 mA (as opposed to a maximum attainable peak current of 140 mA used in the present study) with the aim of inducing low-tension, non-fatiguing muscle contractions at approximately 10% of maximum voluntary contraction. This may have resulted in smaller muscle mass activation and intensity of activation and, therefore, the production of less lactate during their recovery intervention. As a direct measure of blood flow to the stimulated area was not carried out in either study, it is difficult to make definitive conclusions in this regard.

An interesting observation from the present study was that although NMES had no significant BLa lowering effect compared to passive recovery, the active recovery intervention did significantly reduce BLa during the recovery intervention period compared to both the NMES and passive recovery interventions. However, this significantly lower BLa for the active recovery intervention did not translate to a significantly better performance in the post-intervention bouts (bouts 4 – 6) compared to the NMES and passive recovery interventions. This finding could be viewed as further evidence that the role of lactate as a causative factor of muscle fatigue is ungrounded.

Other Considerations: Despite some studies showing a minimal effect of recovery interventions other than passive, on performance parameters, the psychological effects of these intervention strategies for promoting feelings of well-being should not be underestimated (Cortis et al. 2010). A study by Tessitore et al. (2008) found no significant differences between various active and passive recovery interventions for enhancing anaerobic performance. However, despite their findings, participants perceived significantly increased benefit from the use of NMES compared to passive recovery. They suggested that personal perceptions should be considered as an important factor due to the potential positive effects on performance. Anecdotally, the majority of participants in the current study expressed a preference for active recovery or NMES (approximately 65:35 ratio of active to NMES) over passive recovery. These participants reported feeling more fatigued at the start of the post-intervention bouts after the passive recovery intervention compared to the NMES and active recovery interventions. Only one participant reported that passive recovery would be their choice of recovery intervention. This is important as perceptions of fatigue are particularly important for psychological recovery (Sayers et al. 2011). Individual preference for one intervention over another, such as NMES over active or passive may be driven by a number of factors such as tolerance of electrical current, need for variety, and practical considerations.

Practical considerations may also affect the choice of recovery intervention chosen by an athlete(s). There may be certain situations, for example, where an athlete’s preference is to perform active recovery between exercise bouts or competitive heats, but it may not be possible to perform an active recovery. This may be because of lack of space/ -facility, for example, between heats at a swimming regatta when performing a suitable active recovery may not be practical due to space requirements. Also, during a half-time team talk in a field sport such as soccer or rugby, may not be practical for performing an active recovery. In these situations, the use of NMES may provide an alternative to athletes who may not be able to recovery actively and do not wish to recover passively. Even if NMES does not enhance subsequent exercise performance better than passive recovery, it may help enhance athlete's attitude and feelings of well-being compared to if passive recovery is undertaken.

From a safety perspective, the effects of different recovery interventions on the cardiovascular system following bouts of supra-maximal exercise should also be considered. This is because suddenly stopping intense exercise can lead to changes in cardiac preload, after-load and contractibility, which together with changes in blood electrolyte concentration, decreased circulating catecholamines and vagal rebound, can lead to a relatively high incidence of post exercise arrhythmias, hypotension and syncope (Crisafulli et al. 2003). More active forms of recovery can help facilitate venous blood flow to the heart via the muscle pump system, thus preventing blood pooling in the lower extremities and helping to maintain stroke volume and therefore cardiac output (Crisafulli et al. 2003). Interestingly, the majority of participants in the current study reported feeling 'less recovered' following passive recovery and many also reported feelings of discomfort, light-headedness and nausea especially during the passive recovery intervention. It must also be noted that the three incidents where participants' had to be withdrawn from the current study due to an adverse event, all occurred during seated passive recovery (two cases due to severe nausea and hypotension and one due to syncope). Therefore, even if passive recovery is not detrimental to subsequent performance, from a safety perspective and feelings of better well-being, an intervention other than passive recovery may be a preferred option.

Study Limitations: A possible limitation of the current study may be that NMES intensity was subjectively, rather than objectively selected. The use of a fixed NMES intensity parameter (i.e., objective) would likely prove inappropriate, especially as the consensus is that, perception of NMES intensity is highly variable among individuals and thus, needs to be selected on an individual basis (Maffiuletti, 2010). This relative discrepancy would likely be due to factors such as: a) underlying adipose tissue variations, which can affect current to the targeted muscles when using NMES (Maffiuletti, 2010), and b) different tolerances to electrical stimulation and individual perceptions to discomfort. The use of an individualized objective NMES intensity value, i.e., fixed at a percentage of participants' maximal voluntary contraction (MVC), had been investigated during the pre-study pilot testing phase of this study (using a cybex dynamometer). However, obtaining consistent results proved challenging and unreliable. Therefore, the decision was taken to abort this method and to instead, use the standard procedure of getting the participants to subjectively select the stimulation intensity, a process used previously in recovery research studies (Lattier et al. 2004; Tessitore et al. 2007; Cortis et al. 2010).

For the present study, each participant selected their intensity, with the assistance of the research investigator, during the familiarization session. The objective was to find a compromise between selecting an intensity that was not too high that it would fatigue the muscles, but not too low that it would have little effect. Participants were instructed to adjust the intensity as high as they could before feeling discomfort (average intensity selected by participants was 92 mA). The research investigator also visually observed participant leg movements during the stimulation and when a perceptible intensity was agreed upon, it was noted by the lead investigator to be used in the subsequent session.

Conclusions: The findings of the present study suggest that NMES is not a better alternative to other traditional recovery methods, namely active and passive, as a short term recovery intervention (< 1 hr), between sessions of repeated bouts of supra-maximal exercise. The active recovery intervention had a significantly greater BLa lowering effect during the recovery intervention period compared to both passive and NMES interventions. However, this did not translate to significantly better performance during the subsequent bouts. This suggests that BLa lowering effects may not be as important as initially thought for promoting recovery, especially given that lactate is no longer viewed as a major cause of muscle fatigue.

The use of NMES certainly does not appear to have any negative effects on recovery markers compared to traditional recovery methods. There are even situations where the use of NMES may be very advantageous, especially where active recovery cannot be performed, e.g., during heats at a swimming regatta or during the half-time interval of a soccer or rugby match. In these situations, it may be desirable to initiate muscle contractions and induce increased localized blood flow, which, even if it does not directly translate into increased performance, could potentially help to reduce perceived muscle soreness, lead to feelings of better well-being or from a safety perspective, reduce the possibility of an adverse reaction occurring after performing supra-maximal exercise.

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Conflict of interest

Funding for this study was partially supported by Bio Medical Research (BMR) Ltd., Galway, Ireland. BMR is the manufacturer of the NMES device used in this study.

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TABLES

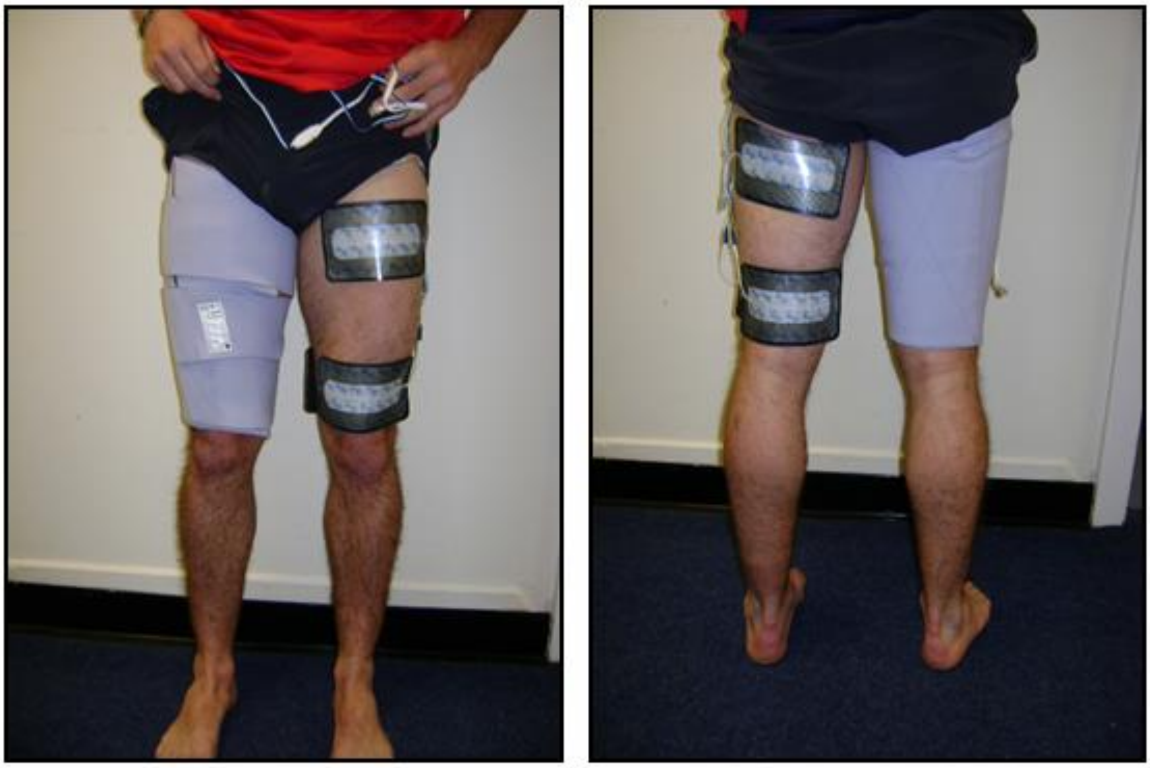
Table 1 Participant Physical characteristics (Mean ± SD).

	Mean ± SD	**Range**
Age (years)	31 ± 5	21 – 38
Height (cm)	182.8 ± 6.9	172.4 – 197.8
Body Mass (kg)	78.1 ± 8.4	66.4 – 93.4
Body Fat (3 sites) (%)	10.2 ± 3.8	3.6 – 16.3
VO_{2max} (mL.kg^{-1}.min^{-1})	55.6 ± 7.0	44.6 – 68

Table 2 Study protocol time line and measurements taken.

Time (min:sec)	Activity	Measurements Taken	Period
0'00" (Baseline)	Seated (passive)	HR / BLa	*PRE INTERVENTION (Bouts 1 – 3)*
0'00" - 01'55"	80 W @ 80 rev.min-1		
01'55" - 02'00"	*All out cycling (5WanT)*	HR	
02'00" - 05'00"	80 W @ 80 rev.min-1		
05'00" - 05'30"	All out cycling (bout 1)	PP / MP / FI / HR	
05'30" - 09'30"	80 W @ 80 rev.min-1		
09'30" - 10'00"	All out cycling (bout 2)	PP / MP / FI / HR	
10'00" - 14'00"	80 W @ 80 rev.min-1		
14'00" - 14'30"	All out cycling (bout 3)	PP / MP / FI / HR / BLa	
14'30" - 19'30"	Seated (Passive) (5 min)	HR / BLa	*RECOVERY INTERVENTION PERIOD*
19'30" - 24'30"	*Intervention (10 min)*	HR / BLa	
24'30" - 29'30"	*Intervention (15 min)*	HR / BLa	
29'30" - 34'30"	*Intervention (20 min)*	HR / BLa	
34'30" - 39'30"	*Intervention (25 min)*	*HR*	
39'30" - 44'30"	Seated (Passive) (30 min)	HR / BLa	
44'30" - 46'25"	80 W @ 80 rev.min-1		*POST INTERVENTION (Bouts 4 – 6)*
46'25" - 46'30"	All out cycling (5WanT)	HR	
46'30" - 49'30"	80 W @ 80 rev.min-1		
49'30" - 50'00"	All out cycling (bout 4)	PP / MP / FI / HR	
50'00" - 54'00"	80 W @ 80 rev.min-1		
54'00" - 54'30"	All out cycling (bout 5)	PP / MP / FI / HR	
54'30" - 58'30"	80 W @ 80 rev.min-1		
58'30" - 59'00"	All out cycling (bout 6)	PP / MP / FI / HR / BLa	
59'00" - 64'00"	Seated (Passive) (5 min)	HR / BLa	

FIGURES



A) B)

Fig. 1 Pictures showing A) anterior view and B) posterior view of the specially designed garment wraps and the position of electrodes on the quadriceps and hamstring muscle groups (left leg wrap omitted for illustration purposes only).

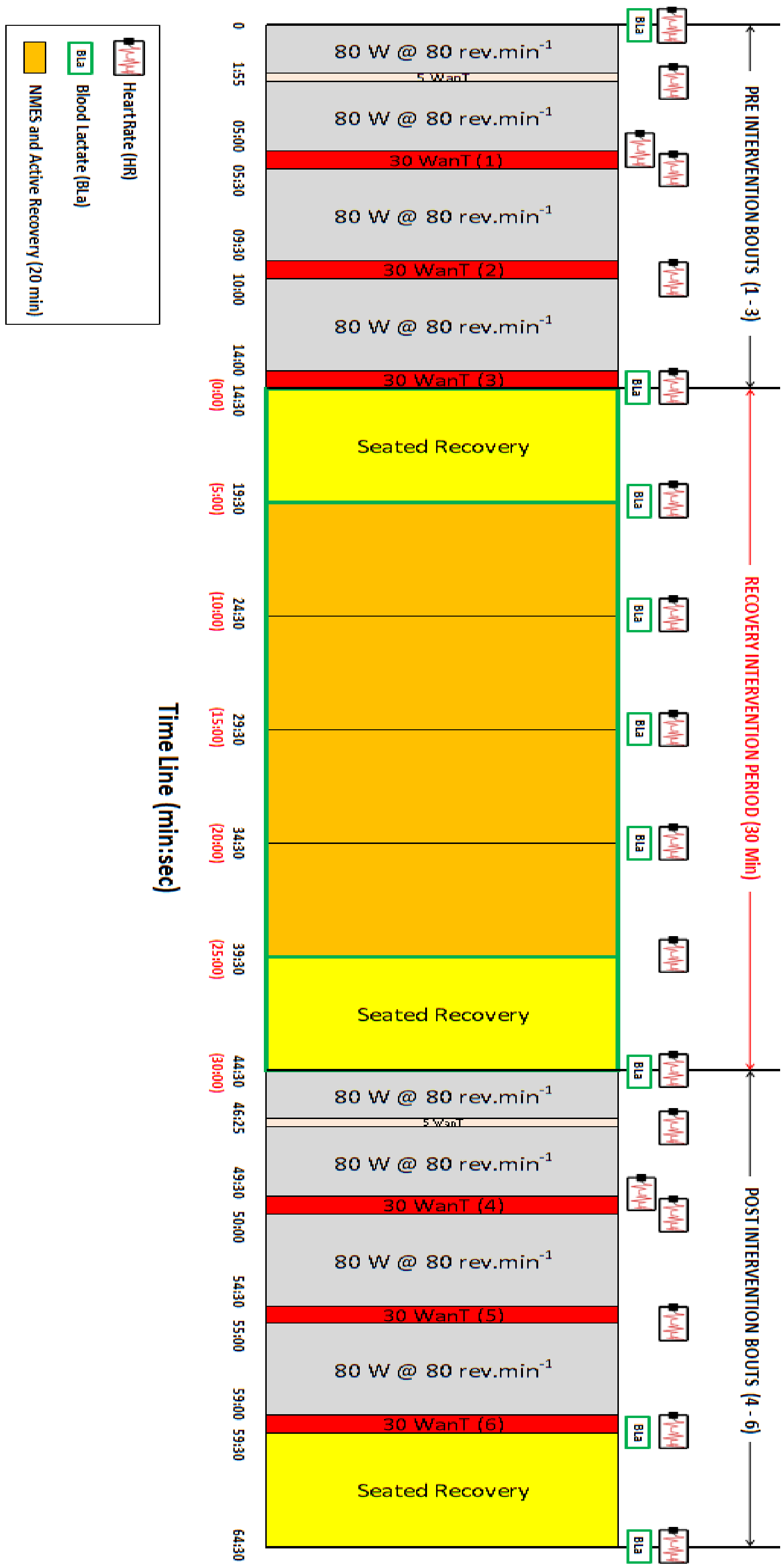


Fig. 2 Study protocol timeline showing Pre-Intervention period (L), Recovery Intervention period (M) and Post-Intervention period (R).

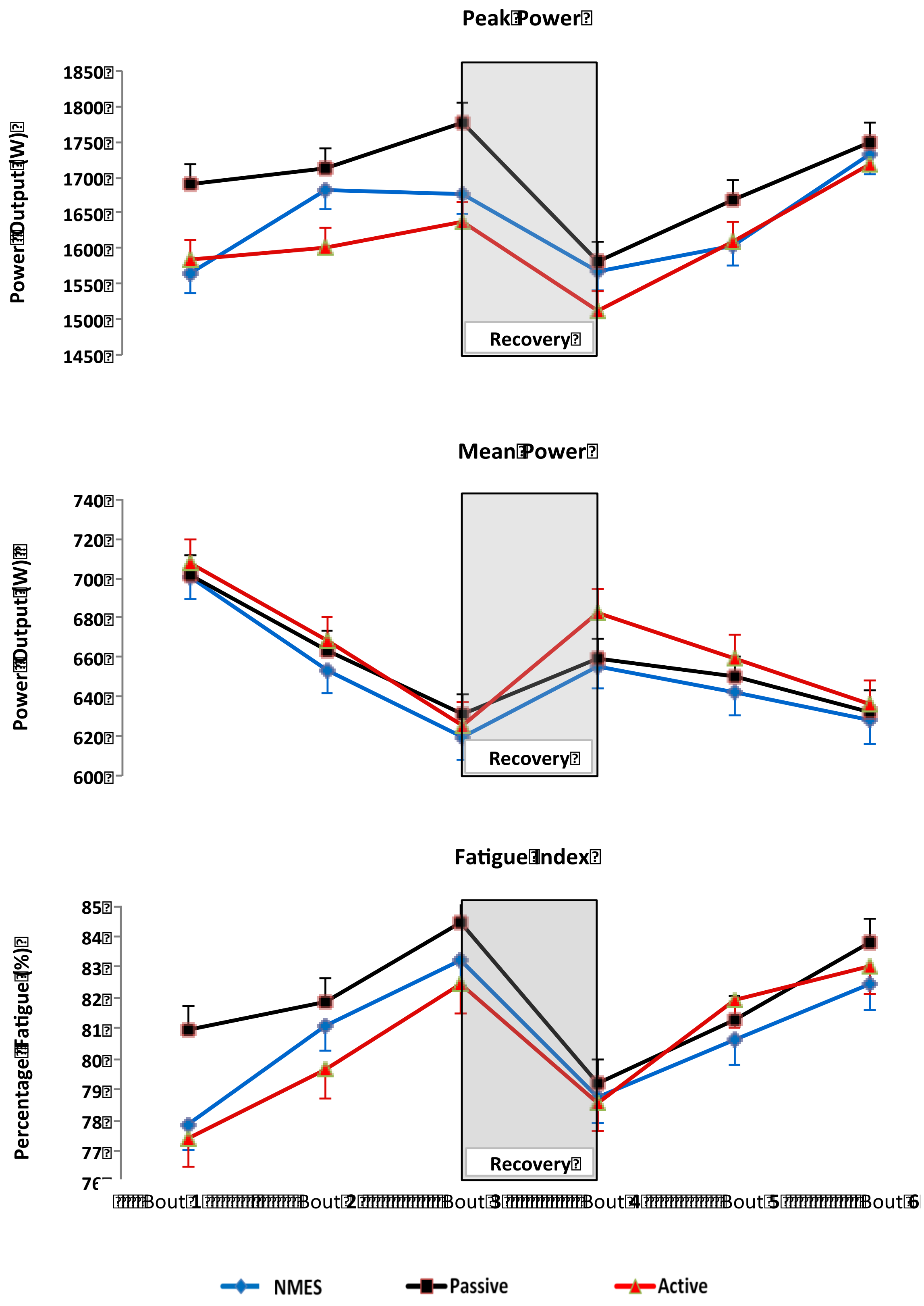


Fig. 3 Participant performance parameters (Mean ± SEM) for Pre intervention (Bouts 1 – 3) and Post intervention (Bouts 4 – 6) recovery interventions.

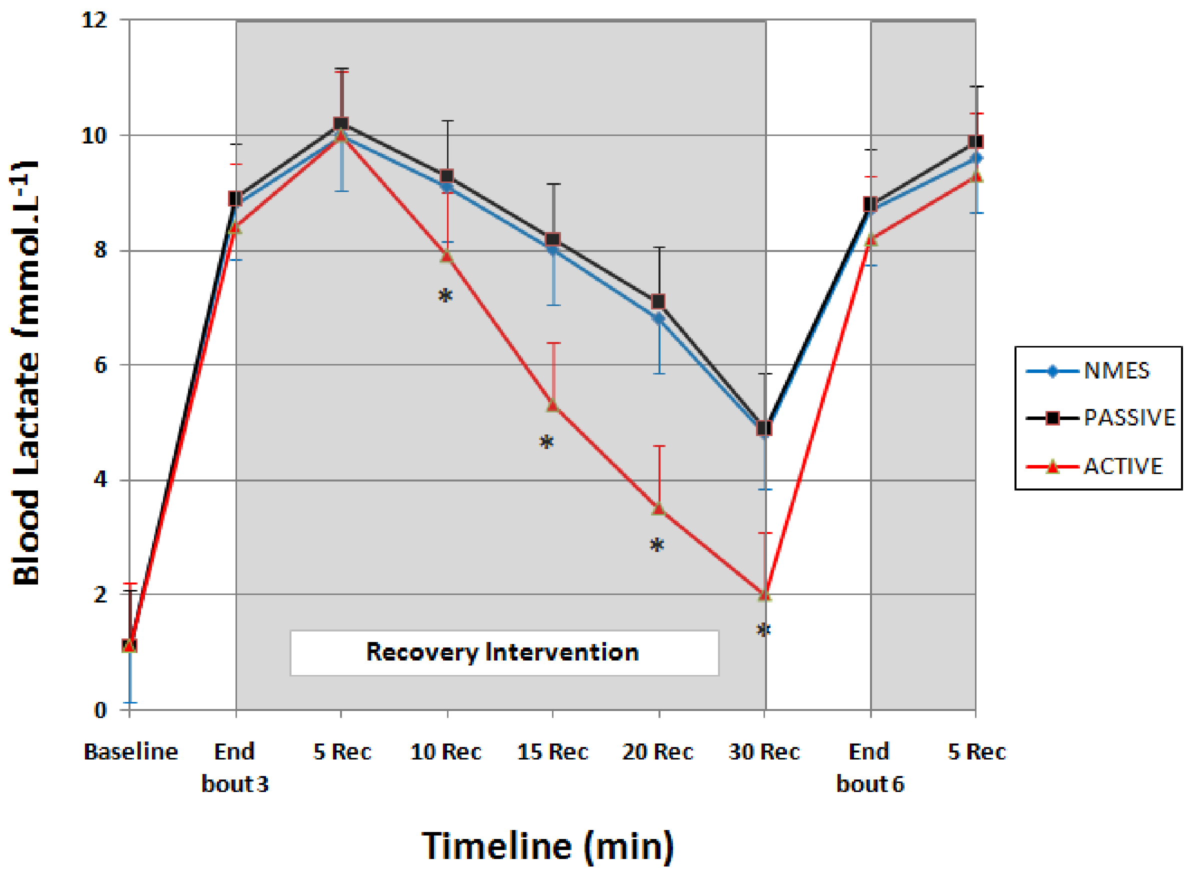


Fig. 4 Participant BLa (Mean ± SEM) during study protocol for NMES, passive and active recovery interventions

* Significant difference between active vs. NMES and passive recovery interventions ($P < 0.001$).

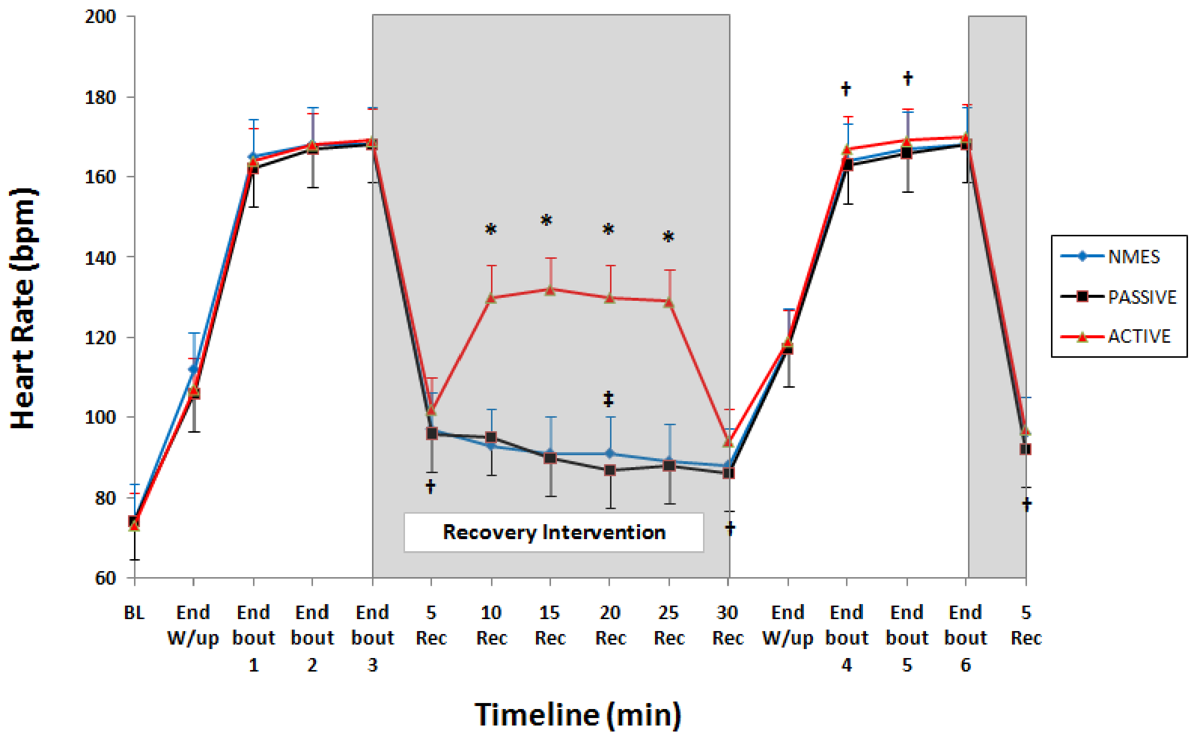


Fig. 5 Participant HR (Mean ± SEM) during study protocol for NMES, passive and active recovery interventions.

***** Significant difference between Active recovery vs. NMES and Passive recovery interventions ($P < 0.001$)

† Significant difference between active vs. passive recovery interventions ($P < 0.05$)

‡ Significant difference between NMES vs. passive recovery interventions ($P < 0.05$).