

DIFFERENT RECOVERY METHODS AND MUSCLE PERFORMANCE AFTER EXHAUSTING EXERCISE: COMPARISON OF THE EFFECTS OF ELECTRICAL MUSCLE STIMULATION AND MASSAGE

■ Accepted
for publication
02.03.2012

AUTHORS: Pinar S., Kaya F., Bicer B., Erzeybek M.S., Cotuk H.B.

Marmara University School of Physical Education and Sport, Turkey

ABSTRACT: In this study we assessed the influence of the three different recovery interventions massage (MSG), electrical muscle stimulation (EMS), and passive rest (PR) on lactate disappearance and muscle recovery after exhausting exercise bouts. Twelve healthy male sport students participated in the study. They attended the laboratory on five test days. After measurement of $\dot{V}O_2\text{max}$ and a baseline Wingate test (WG_b), the three recovery interventions were tested in random counterbalanced order. High intensity exercise, which consisted of six exhausting exercise bouts (interspersed with active recovery), was followed by MSG, EMS or PR application (24 minutes); then the final Wingate test (WG_f) was performed. Lactate, heart rate, peak and mean power, rating of perceived exertion (RPE), and total quality of recovery (TQR) were recorded. In WG_f mean power was significantly higher than in WG_b for all three recovery modalities (MSG 6.29%, EMS 5.33%, PR 4.84% increase, $p < 0.05$), but no significant differences in mean and peak power were observed between the three recovery modes ($p > 0.05$). The heart rate response and the changes in blood lactate concentration were identical in all three interventions during the entire protocol ($p = 0.817$, $p = 0.493$, respectively). RPE and TQR scores were also not different among the three interventions ($p > 0.05$). These results provide further evidence that MSG and EMS are not more effective than PR in the process of recovery from high intensity exercise.

KEY WORDS: electromyostimulation, massage, recovery, muscle performance

Reprint request to:

Salih Pinar

Marmara University School of PE
and Sports Anadoluhisar Campus
Beykoz, 34815 Istanbul, Turkey
E-mail: salih.pinar@marmara.edu.tr

INTRODUCTION

Many sport events are characterized by intermittent activity patterns and short inter-bout rest periods. Fast muscle recovery after fatiguing exercise is a crucial factor for better performance in these sports [28]. In this context muscle fatigue can be defined as any exercise-induced reduction in voluntary muscle force or power [11]. Muscle fatigue may arise from peripheral changes at the level of the muscle, such as exercise-induced alterations in muscle homeostasis (e.g. depletion of creatine phosphate or accumulation of inorganic phosphate), a relative mismatch of oxygen supply by capillaries to cellular energy demand or alterations in excitability due to K^+ efflux from the cell [1]. Another possibility is the development of 'central' fatigue, which denotes that the central nervous system fails to drive the motoneurons adequately [11].

It is evident that in the sport setting there is need for suitable methods to enhance the rate of recovery after fatiguing exercise. Thus, many research groups have tried to define the most appropriate recovery interventions [5,7,24,28,29,32,40]. One efficient mechanism of recovery enhancement at muscle level may be the augmented removal of exercise metabolites by improving microcir-

ulation. Massage (MSG) has been assumed to be an efficient technique in this regard. But scientific studies could not substantiate the effects of massage on physiological variables affecting muscle recovery from exercise. Also, the efficacy of manual massage after exercise as a means to improve performance or to shorten the time needed for muscle recovery could not be validated [5,16,28,35,37,38]. Light exercise after strenuous exercise may be even more effective than manual massage in improving blood flow [13,37].

In this context, electrical muscle stimulation (EMS) has been introduced as an additional method to facilitate recovery by enhancing removal of metabolites [5,9]. EMS employs transcutaneous electrical currents to peripherally stimulate motor neurons and induce muscle contraction and relaxation cycles which may increase blood flow via the 'muscle pump effect'. But concrete evidence about the positive effects of EMS intervention on fatigued muscle after exhausting exercise is still lacking [20,24,25,30,31].

With these considerations in mind, the aim of this study was to examine the effects of three recovery modalities (EMS, Massage and Passive Rest) after exhausting exercise on blood lactate, heart rate,

rate of perceived exertion (RTE), total quality of recovery (TQR), and subsequent power output in the Wingate test. We hypothesized that EMS and massage would allow a better recovery than passive resting modality and hence would improve the subsequent high intensity exercise performance.

MATERIALS AND METHODS

Subjects. This study follows the Helsinki Declaration [14] to fulfil the ethical standard requirements. Twelve healthy male game players (mean (SD) age: 20.92 (2.47) years, body mass: 68.42 (7.25) kg, height: 174.25 (6.11) cm, $\dot{V}O_{2max}$: 50.67 (4.37) ml·kg⁻¹·min⁻¹) volunteered to participate in the study. All participants regularly took part in sports involving bouts of high intensity effort such as soccer and basketball. After being informed about the nature and protocol of the experiment, the volunteers provided their informed consent. Obligatory requirements for participation in the study were not to have received electromyostimulation in the last 6 months, and not to present medical contraindications related to application of electrical muscle stimulation (back problems, heart rhythm disorders, and recent surgical operations).

Experimental procedures

We adapted and modified the experimental procedures from Robertson et al. [32]. Subjects entered the laboratory on five separate occasions at least 48 hours apart and at the same time of day. Familiarization was completed on the first and second visit to ensure that they all knew the protocol. During these two visits baseline performance parameters were obtained: a baseline Wingate test (WG_b) was performed to acquire peak power (Pp) and mean power (Pm). The peak power was measured in the first 5-second interval of the Wingate test. A ramp test on a cycle ergometer (Ergoline® S100) yielded maximal oxygen uptake (25 W·min⁻¹ increments). The following three visits constituted the experimental phase. The study had a counterbalanced crossover design. Each of the subjects was subjected to the following recovery protocols in a randomized counterbalanced order: (a) massage, (b) electrical muscle stimulation, and (c) passive rest.

Dietary intake, and exercise intensity and duration were recorded for two days before the familiarization visit. Subjects replicated this dietary intake habit for two days before each subsequent laboratory visit. Subjects were instructed not to exercise heavily in the 24 hours

before the visits. They were also asked not to consume food 2 hours before testing. They were only tested when they had complied with their individual dietary intake and exercise pattern.

On arrival for each test session subjects were seated, and after a 10-minute rest period, a baseline blood sample for lactate was drawn. They performed a standardized light warm up of five minutes and a short stretching period (three minutes of static stretches of hamstrings, calf, and quadriceps muscle groups). Then they performed six standardized 30-second high intensity bouts of exercise on the cycle ergometer (load was 85% of load in WG_b, 60 rpm), each interspersed with 30 seconds of active recovery (unloaded cycling with 60 rpm). Power output was monitored during these high intensity bouts of exercise through a PC interface. On completion of the six high intensity bouts, subjects were delegated to the three recovery interventions, all lasting 24 minutes.

After the recovery intervention period, the subject completed the same standardized five-minute warm up and three minutes of static stretching as previously described. Then the subjects tried to reach maximal power output in the subsequent final Wingate test (WG_f). Heart rate was recorded continuously by a heart rate monitor (Polar® RS800). Perceived exertion (RPE) was assessed by the Borg scale (scale ranging from “no exertion at all” (6 points) to “maximal effort” (20 points)) and the quality of recovery was evaluated by the Total Quality of Recovery (TQR) scale (scale ranging from “very very poor recovery” (6 points) to “very very good recovery” (20 points)) [6,23].

Capillary blood samples were drawn for lactate analysis at rest, 5 minutes after the six high intensity bouts, at completion of the recovery intervention, and 5 minutes after the Wingate test. Blood lactate was measured using the Scout lactate analyser (SensLab GmbH, Leipzig, Germany). Wingate test variables were recorded through a PC interface and included peak power (Pp) and mean power (Pm).

Massage intervention

The massage was applied for a total of 24 minutes by two certified specialists. The massage techniques were standardized (Table 1) and applied synchronously to both legs. During the first application subjects were lying in a prone position on a standard treatment couch for 12 minutes. Then they assumed a supine position for 12 minutes, and the massage routine was repeated. Most strokes were grade 1 or 2, but three grade 3 effleurage strokes, using a clenched fist, were

TABLE 1. MASSAGE PROTOCOL

Massage technique	Description	Grade
Stroking	Whole hand two handed in a centripetal direction	Four strokes grade 1, two strokes grade 2 range: 1/2
Effleurage	Whole hand two handed, centripetal and multidirectional	Grade 1 up to grade 2
Kneading	Whole hand two handed, centripetal and centrifugal	Grade 1 up to grade 2
Picking up	Whole hand two handed v-shaped, centripetal	Grade 1 up to grade 2
Wringing	Whole hand two handed, centripetal, centrifugal, multidirectional	Grade 1
Rolling	Muscle rolling, centripetal	Grade 2
Effleurage	Whole hand two handed, centripetal	Grade 2

applied in a centripetal direction to the left and right iliotibial band midway through the supine massage. All massage was administered using a conventional bland mineral oil (40 mL)—that is, 10 mL per massage area.

Electrical muscle stimulation

EMS recovery consisted in simultaneous electrical stimulation of both lower limbs (quadriceps and hamstring muscles) in a supine position. Electrical stimulation was elicited using bipolar electrodes and two portable battery-powered 4-channel electrical stimulators (Compex-MI-Sport, Medicomplex SA, Ecublens, Switzerland). For the quadriceps femoris, a cathode (10x5 cm rectangular electrode) was positioned on the upper part of the thigh, and two anodes (5x5 cm) were placed over the motor point of the vastus lateralis and medialis. For the hamstring muscles, the cathode was positioned proximally below the gluteal fold, and the anode (10x5 cm) was placed over the belly of the hamstring muscles. Stimulation frequency starting at a frequency of 9 Hz decreased during the intervention period until reaching 1 Hz (rise time=1.5 second; pulse width= 400 μseconds; fall time= 0.5 seconds). The subjects selected the most comfortable intensity (i.e., level 10-20 mA). Recovery interventions lasted 24 minutes, according to the duration of the EMS recovery programme [36].

Passive rest

Subjects quietly lay in a supine position during the passive rest period.

Statistical analysis

A one-way analysis of variance with repeated measures was used to calculate the statistical significance of the difference between initial measurement and the end of recovery (for mean and peak power), and a two-way analysis of variance (recovery intervention x time) with

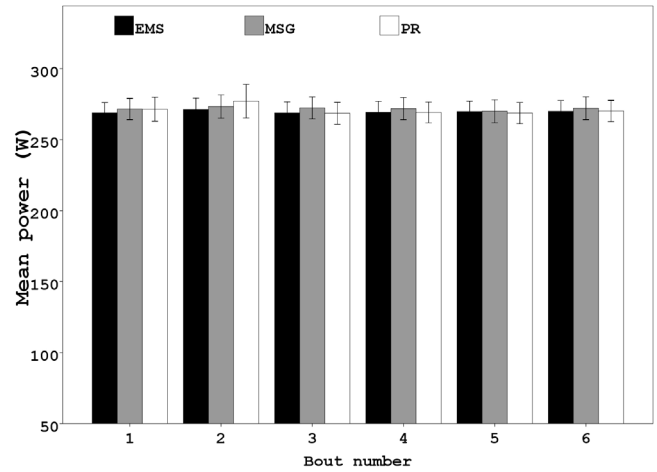


FIG. 1. MEAN (SEM) POWER OUTPUT IN EACH OF THE SIX EXHAUSTING EXERCISE BOUTS

Note: No significant difference was observed between trials at any time ($p > 0.05$).

repeated measures was used to detect significant differences across the three different recovery interventions (for blood lactate concentration, heart rate response, rating of perceived exertion, and total quality of recovery) with checks for sphericity completed (within subjects design). Post-hoc comparisons were performed with a Bonferroni adjustment of the alpha level (0.05). Descriptive statistics (means, standard deviation, standard error, and percentile change) were used for dependent variables. Pearson correlations between variables were calculated. The level of significance was determined at $p < 0.05$ and analyses were performed using SPSS 14 for Windows.

RESULTS

All subjects coped well with the test procedures and all showed compliance with pre-test diet and exercise controls.

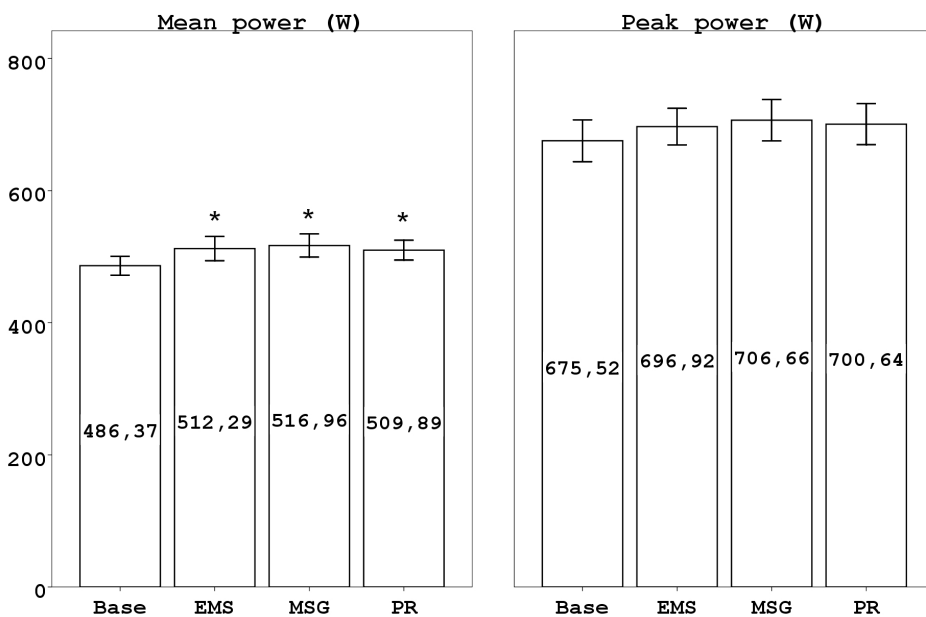


FIG. 2. MEAN (SEM) PM AND PP VALUES AT BASELINE AND AFTER EACH OF THE RECOVERY INTERVENTIONS

Note: Mean power values in EMS, Massage, and Passive recovery interventions were significantly different from baseline ($*p < .05$). Peak power values were not significantly different from baseline ($p > 0.05$).

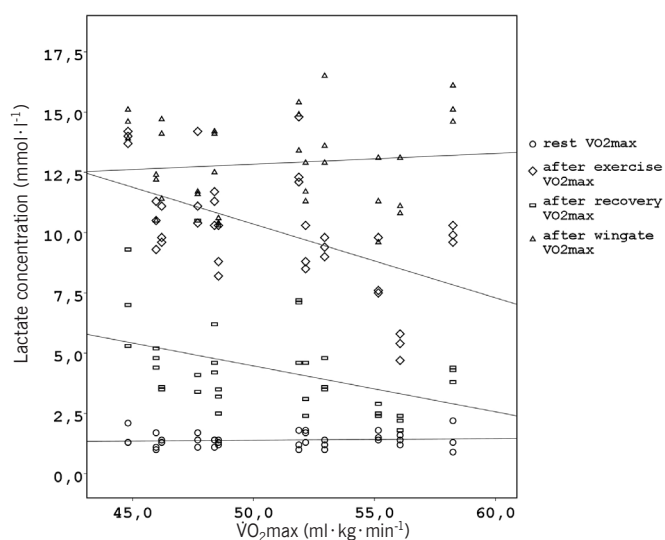


FIG. 3. CORRELATION BETWEEN $\dot{V}O_{2\max}$, BLOOD LACTATE AND TEST POINTS AFTER THE EXHAUSTING EXERCISE BOUTS ($r=-0.55$, $p=0.001$) AND AFTER THE RECOVERY INTERVENTION ($r=-0.42$, $p=0.011$).

There was no significant difference between interventions in the power output sustained during the standardized high intensity exercise bouts ($F_{2,22} = 0.698$, $p = 0.51$, $\eta^2 = 0.06$) (Figure 1).

The one-way analysis of variance with repeated measures revealed that Pm values in WG_f were higher than those in WG_b for all three intervention modalities ($F_3 = 7.83$, $p < 0.001$, $\eta^2 = 0.42$). Between the three different recovery interventions there was no significant difference in mean power output of WG_f ($p > 0.05$) (Figure 2).

For Pp values of WG_f , there were neither significant differences between the three intervention modalities nor was there a difference to WG_b Pp values ($F_{1,79,19.64} = 0.848$, $p = 0.432$, $\eta^2 = 0.07$) (Figure 2).

$\dot{V}O_{2\max}$ as a covariate had no effect on these parameters ($F_{3,30} = 1.650$, $p = 0.199$, $\eta^2 = 0.14$ for mean power, $F_{3,30} = 0.453$, $p = 0.717$, $\eta^2 = 0.04$ for peak power).

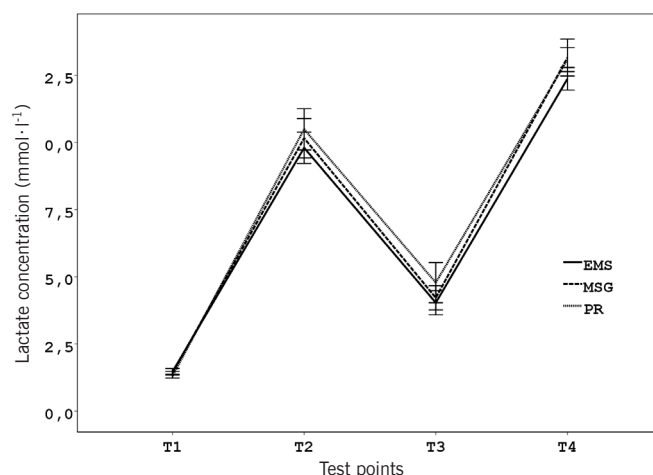


FIG. 4. MEAN (SEM) BLOOD LACTATE CONCENTRATION AT REST (T1), AFTER THE EXHAUSTING EXERCISE BOUTS (T2), 24 MINUTES OF INTERVENTION (T3), AND FIVE MINUTES AFTER THE WINGATE TEST (T4)

Note: No significant difference was observed between the three recovery interventions at any time ($p > 0.05$).

According to baseline values mean changes after the three interventions were 5.33% for Pm, 3.17% for Pp in EMS intervention; 6.29% for Pm, 4.61% for Pp in MSG intervention; and 4.84% for Pm, 3.71% for Pp in PR.

Regarding blood lactate concentrations, there was no significant main effect of the type of recovery ($F_{2,22} = 1.81$, $p = 0.186$, $\eta^2 = 0.14$), and no significant interaction between the type of recovery and test points ($F_{6,66} = 0.91$, $p = 0.493$, $\eta^2 = 0.08$) (Figure 4). However, there was a significant main effect difference among the four test points ($F_{1,87,20.57} = 226.51$, $p < 0.001$, $\eta^2 = 0.95$), and only in this case was a significant interaction between $\dot{V}O_{2\max}$ and test points observed ($F_{3,30} = 5.60$, $p = 0.004$, $\eta^2 = 0.36$). $\dot{V}O_{2\max}$ was responsible for 36% of variation of blood lactate concentrations regardless of the recovery interventions. Blood lactate concentrations were negatively correlated with $\dot{V}O_{2\max}$ after the high intensity exercise

TABLE 2. MEAN AND MAXIMUM (SEM) HEART RATE RESPONSES (BEATS/MIN) AT INITIAL WINGATE TEST, AT REST, AT STANDARDIZED EXHAUSTING EXERCISE BOUTS, AT INTERVENTION FOR 24 MINUTES, AND AT THE FINAL WINGATE TEST IN THE EMS, MSG AND PR TRIALS

	WGb (mean-30s)	WGb (max-30s)	Resting (mean- 10m in)	Exh. Exer bouts (mean-6min)	Exh. exer bouts (max-6min)	Intervention (mean-24min)	WGf (mean-30s)	WGf (max-30s)	After WGf (mean-5min)
EMS			65.67 (2.01)	162.50 (2.70)	185.75 (2.65)	89.08 (2.44)	173.42 (2.52)	188.75 (2.40)	125.00 (2.55)
MSG	172.92 (3.09)	187.17 (2.32)	64.67 (2.37)	161.00 (2.71)	183.33 (3.52)	89.50 (2.02)	174.00 (2.77)	188.67 (3.17)	124.50 (2.60)
PR			65.42 (2.62)	163.08 (3.48)	185.33 (2.83)	92.75 (3.24)	173.08 (2.58)	188.42 (2.55)	126.00 (3.84)

TABLE 3. MEAN (SEM) RPE AND TQR AT REST, AFTER THE STANDARDIZED EXHAUSTING EXERCISE BOUTS, AFTER 24 MINUTES OF INTERVENTION, AND AFTER WINGATE TEST IN THE EMS, MSG AND PR TRIALS

	TQR at rest	RPE after exhausting exercise bouts	TQR after recovery	RPE after Wingate test
EMS	190.33 (0.23) very very good recovery	150.83 (0.87) 80% effort-hard	180.08 (0.51) very very good recovery	150.83 (1.06) 80% effort-hard
MSG	190.42 (0.23) very very good recovery	150.58 (0.80) 80% effort-hard	190.25 (0.35) very very good recovery	160.00 (0.73) 85% effort-hard
PR	190.50 (0.15) very very good recovery	150.67 (0.96) 80% effort-hard	170.83 (0.53) very good recovery	150.58 (0.82) 80% effort-hard

bouts ($r = -0.55$, $p = 0.001$) and after the recovery interventions ($r = -0.42$, $p = 0.011$), but not during rest or after WG; ($p > 0.05$). This also indicated the appropriate standards of the test protocol (Figure 3).

Regarding the heart rate response, there was no significant main effect of the type of recovery intervention ($F_{2,22} = 0.466$, $p = 0.634$, $\eta^2 = 0.041$), and no significant interaction between the type of recovery and test points ($F_{16,176} = 0.674$, $p = 0.817$, $\eta^2 = 0.058$) (Table 2).

There was no significant main effect of the type of recovery intervention on TQR ($F_{2,22} = 2.126$, $p = 0.143$, $\eta^2 = 0.16$) and RPE ($F_{2,22} = 0.076$, $p = 0.927$, $\eta^2 = 0.007$). There was no significant interaction between the type of recovery and TQR ($F_{2,22} = 3.028$, $p = 0.069$, $\eta^2 = 0.22$), and this was also true for RPE ($F_{2,22} = 0.090$, $p = 0.915$, $\eta^2 = 0.008$) (Table 3). A significant negative correlation between blood lactate concentration and TQR scores was observed only after the EMS intervention ($r = -0.74$, $p < 0.01$).

DISCUSSION

This investigation was carried out to evaluate the effects of three different recovery interventions after exhausting exercise on performance and physiological parameters in the subsequent anaerobic Wingate test. No significant differences were demonstrated between the effects of EMS, MSG, and PR on physiological and psychological recovery after the high intensity exercise. Wingate test scores (mean and peak power) were not significantly different between the three different passive recovery interventions after the high intensity exercise. However, in the Wingate test a significant higher mean power output was observed after all three recovery interventions compared to baseline scores. Such increase of power output (roughly 5%) during exhaustive exercise has been reported when preceded by prior heavy (“priming”) exercise [21]. To our knowledge this could be the first study reporting equivocal effects of different recovery interventions after such priming exercise.

In all trials we carefully tried to guarantee an identical exercise and recovery profile; mean power output was nearly identical during the high-intensity cycle exercise for all three conditions. This was also reflected in the blood lactate and heart rate responses; blood lactate concentrations and heart rate were not significantly different

between the three recovery protocols at any time point. Although the subject’s $\dot{V}O_{2\max}$ capacity showed a significant correlation with blood lactate concentrations after the exhausting exercise and all three recovery interventions, the overall effect on individual lactate variations was modest ($p = 0.004$, $\eta^2 = 0.36$).

Studies on recovery interventions were criticized because of lack of standardization of exercise and recovery protocols. Therefore, we kept the duration of the massage intervention identical to that of the EMS intervention, both of which were sufficiently long to be effective [32]. We employed a standardized massage intervention for all subjects with identical type, intensity, and duration of strokes. The EMS protocol of low frequency (1 to 9 Hz) was chosen to resemble massage by increasing blood flow and endorphin release, as well as to reduce spasms and increase relaxation [20,42]. Further standardization procedures targeted dietary intake and exercise patterns in the days preceding the visits to the laboratory. We tried to ensure similar pre-exercise muscle glycogen content and acid-base status, because both of these factors significantly affect the ability to perform high intensity work as well as the metabolite responses to exercise and recovery interventions [12,13,22,29].

Only a few studies in the literature have focused on the efficiency of different recovery modalities and EMS [8,17,24,26,36]. To our knowledge, our study is the first comparison of recovery interventions using EMS and MSG. This is surprising, because similar physiological benefits have been proposed for both modalities. It was hypothesized that EMS and MSG may accelerate metabolite clearance and then improve recovery of neuromuscular function following high-intensity exercise [4,29,39,42]. However, the lack of an observed effect on lactate clearance by MSG or EMS compared with PR in our study implies that there were no changes in muscle blood flow and/or lactate efflux or removal in either recovery modality. Although blood flow was not assessed in this study, our findings are supported by studies which also failed to show any advantageous effect of MSG on lactate clearance and blood flow [10,13,27,33,37]. Massage could even become counterproductive by increasing skin blood flow without an increase in arterial blood flow, and so potentially diverting blood flow away from recovering muscle [18]. Similarly, studies investigating the effects of EMS on blood flow showed that low frequency stimulation increased skin blood flow, especially when applied

above the motor threshold inducing muscle contractions [9]. But it was also possible to increase blood flow in the femoral artery by low frequency EMS at intensities sufficient to produce contractions equivalent to 15% of Maximal Voluntary Contraction (MVC) [39, 42]. In other studies these changes in hemodynamic functions could not be produced by application of EMS [2, 19, 41]. These discrepancies can be attributed to the wide variety of EMS parameters employed and different assessment methods of blood flow. However, it seems obvious that when EMS produces sufficient muscle contraction, the increased metabolic demand should also enhance blood flow [3, 39].

Another possibility of recovery improvement by EMS is the finding that electromyostimulation leads to an increase in the activation rate of motor units; this increase in neural drive seems to originate from spinal as well as supraspinal centres [34]. But on the whole, evidence that EMS improves post recovery performance is scarce, and a significant effect has not been observed in the literature [24]. EMS had no positive impact on post-recovery anaerobic exercise performance and maximal voluntary contraction force [26, 36]. EMS also had no significant effect on physiological parameters of submaximal aerobic performance [8]. In a sport specific rock climbing test, EMS was even detrimental to performance when compared with active recovery [17]. The results of our study confirm these findings, because EMS did not produce any advantageous recovery profile or perception, and had no differential effect on maximal performance in the Wingate test.

In our study we also evaluated psychological load by RPE and psychological recovery by TQR. Both EMS and MSG have been reported to provide psychological regeneration in addition to physiological restoration. Especially for MSG, beneficial effects on release of endorphins, decreased arousal levels and enhanced perception of recovery have been observed [8, 15]. Although non-significant, the higher TQR score we observed after the massage intervention in our study support this line of thought. But the validity of the TQR scale for monitoring perceived recovery after high intensity exercise needs further investigation.

CONCLUSIONS

In conclusion, the results of this study suggest that neither massage nor electrical muscle stimulation as a method of post-exercise recovery intervention represents a performance enhancement modality superior to passive rest only.

Acknowledgements

The funding sources of this study (SAG-A-070808-0209) were provided by the Scientific Research Projects Department of Marmara University.

REFERENCES

- Allen D.G., Lamb G.D., Westerblad H. Skeletal muscle fatigue: cellular mechanisms. *Physiol. Rev.* 2008;88:287-332.
- Balogun J.A., Tang S., He Y., Hsieh J.M., Katz J. Effects of high volt galvanic stimulation of ST36 and ST37 acupuncture points on peripheral blood flow and skin temperature. *Disabil. Rehabil.* 1996;18:523-528.
- Balogun J.A., Biasci S., Han L. The effects of acupuncture, electrostimulation and transcutaneous electrical stimulation therapies on peripheral haemodynamic functioning. *Disabil. Rehabil.* 1998;20:41-48.
- Bale P., James H. Massage, warm-down and rest as recuperative measures after short-term intense exercise. *Physiother. Sport* 1991;13:4-7.
- Barnett A. Using recovery modalities between training sessions in elite athletes: does it help? *Sports Med.* 2006;36:781-796.
- Borg G., Ljunggren G., Ceci R. The increase of perceived exertion, aches and pain in the arms, heart rate and blood lactate during exercise on a bicycle ergometer. *Eur. J. Appl. Physiol.* 1985;54:343-349.
- Coffey V., Leveritt M., Gill N. Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables. *J. Sci. Med. Sport* 2004;7:1-10.
- Cortis C., Tessitore A., D'Artibale E., Meeusen R., Capranica L. Effects of post-exercise recovery interventions on physiological, psychological, and performance parameters. *Int. J. Sports Med.* 2010;31:327-335.
- Cramp F.L., McCullough G.R., Lowe A.S., Walsh D.M. Transcutaneous electric nerve stimulation: the effect of intensity on local and distal cutaneous blood flow and skin temperature in healthy subjects. *Arch. Phys. Med. Rehabil.* 2002;83:5-9.
- Dolgener F.A., Morien A. The effect of massage on lactate disappearance. *J. Strength Condit. Res.* 1993;7:159-162.
- Gandevia S.C. Spinal and Supraspinal Factors in Human Muscle Fatigue. *Physiol. Rev.* 2001;81:1725-1789.
- Greenhaff P.L., Gleeson M., Maughan R.J. The effects of dietary manipulation on blood acid-base status and the performance of high-intensity exercise. *Eur. J. Appl. Physiol.* 1987;56:331-337.
- Gupta S., Goswami A., Sadhukhan A.K. Comparative study of lactate removal in short term massage of extremities, active recovery and a passive recovery period after supramaximal exercise sessions. *Int. J. Sports Med.* 1996;17:106-110.
- Harriss D.J., Atkinson G. Ethical standards in sport and exercise science research. *Int. J. Sports Med.* 2009;30:701-702.
- Hemmings B., Smith M., Graydon J., Dyson R. Effects of massage on physiological restoration, perceived recovery, and repeated sports performance. *Br. J. Sports Med.* 2000;34:109-114.
- Hemmings B.J. Physiological, psychological and performance effects of massage therapy in sport: a review of the literature. *Phys. Ther. Sport* 2001;2:165-170.
- Heyman E., De Geus B., Mertens I., Meeusen R. Effects of four recovery methods on repeated maximal rock climbing performance. *Med. Sci. Sports Exerc.* 2009;41:1303-1310.
- Hinds T., McEwan I., Perkes J., Dawson E., Ball D., George K. Effects of massage on limb skin blood flow after quadriceps exercise. *Med. Sci. Sports Exerc.* 2004;36:1308-1313.
- Indergard H.J., Morgan M.J. Effects of high-frequency transcutaneous electrical nerve stimulation on limb blood flow in healthy humans. *Phys. Ther.* 1994;74:361-367.
- Johnston B.D. ElectroMyoStimulation, Synergy [Internet]. 2004 [cited 2010 Feb 20]. Available from: <http://www.trimform.no/electromyo.pdf>
- Jones A.M., Koppo K., Burnley M. Effects of prior exercise on metabolic and gas exchange responses to exercise. *Sports Med.* 2003;33:949-971.

22. Jones N.L., Sutton J.R., Taylor R. Effects of pH on cardiorespiratory and metabolic responses to exercise. *J. Appl. Physiol.* 1977;43:959-964.
23. Kentta G., Hassmen P. „Overtraining and Recovery: A Conceptual Model”. *Sports Med.* 1998;26:1-16.
24. Lattier G., Millet G.Y., Martin A., Martin V. Fatigue and recovery after high-intensity exercise. Part II: Recovery interventions. *Int. J. Sports Med.* 2004;25:509-515.
25. Maffiuletti N.A., Cometti G., Amiridis I.G., Martin A., Pousson M., Chatard J.C. The effects of electromyostimulation training and basketball practice on muscle strength and jumping ability. *Int. J. Sports Med.* 2000;21:437-443.
26. Martin V., Millet G.Y., Lattier G., Perrod L. Effect of recovery modes after knee extensor muscles eccentric contractions. *Med. Sci. Sports Exerc.* 2004;36:1907-1915.
27. Martin N.A., Zoeller R.F., Robertson R.J. The comparative effects of sports massage, active recovery, and rest in promoting blood lactate clearance after supramaximal leg exercise. *J. Athl. Train.* 1998;33:30-35.
28. Mika A., Mika P., Fernhall B. Comparison of recovery strategies on muscle performance after fatiguing exercise. *Am. J. Phys. Med. Rehabil.* 2007;86:474-481.
29. Monedero J., Donne B. Effect of recovery interventions on lactate removal and subsequent performance. *Int. J. Sports Med.* 2000;21:593-597.
30. Pichon F., Chatard J.C., Martin A., Cometti G. Electrical stimulation and swimming performance. *Med. Sci. Sports Exerc.* 1995;27:1671-1676.
31. Pournizam M., Andrews B.J., Baxendale R.H., Phillips G.F., Paul J.P. Reduction of muscle fatigue in man by cyclical stimulation. *J. Biomed. Eng.* 1988;10:196-200.
32. Robertson A., Watt J.M., Galloway S.D.R. Effects of leg massage on recovery from high intensity cycling exercise. *Br. J. Sports Med.* 2004;38:173-176.
33. Shoemaker J.K., Tiidus P.M., Mader R. Failure of manual massage to alter limb blood flow: measures by Doppler ultrasound. *Med. Sci. Sports Exerc.* 1997;29:610-614.
34. Smith G.V., Alon G., Roys S.R., Gullapalli R.P. Functional MRI determination of a dose-response relationship to lower extremity neuromuscular electrical stimulation. *Exp. Brain Res.* 2003;150:33-39.
35. Steele D.S., Duke A.M. Metabolic factors contributing to altered Ca²⁺ regulation in skeletal muscle fatigue. *Acta Physiol. Scand.* 2003;179:39-48.
36. Tessitore A., Meeusen R., Cortis C., Capranica L. Effects of different recovery interventions on anaerobic performances following preseason soccer training. *J. Strength Cond. Res.* 2007;21:745-750.
37. Tiidus P.M., Shoemaker J.K. Effleurage massage, muscle blood flow and long-term post-exercise strength recovery. *Int. J. Sports Med.* 1995;16:478-483.
38. Tiidus P.M. Manual massage and recovery of muscle function following exercise: a literature review. *J. Orthop. Sports Phys. Ther.* 1997;25:107-112.
39. Tracy J.E., Currier D.P., Threlkeld A.J. Comparison of selected pulse frequencies from two different electrical stimulators on blood flow in healthy subjects. *Phys. Ther.* 1988;68:1526-1532.
40. Vanderthommen M., Soltani K., Maquet D., Crielaard J.M., Croisier J.L. Does neuromuscular electrical stimulation influence muscle recovery after maximal isokinetic exercise? *Isokinetics Exerc. Sci.* 2007;1:143-149.
41. Walker D.C., Currier D.P., Threlkeld A.J. Effects of high voltage pulsed electrical stimulation on blood flow. *Phys. Ther.* 1988;68:481-485.
42. Zicot M., Rigaux P. Effect of the frequency of neuromuscular electric stimulation of the leg on femoral arterial blood flow. *J. Maladies Vasculaires* 1995;20:9-13.