©Journal of Sports Science and Medicine (2010) **9**, 164-169
http://www.jssm.org

Research article

Comparison of active and electrostimulated recovery strategies after fatiguing exercise

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Abstract

The purpose of this study was to compare an electrostimulated to an active recovery strategy after a submaximal isometric fatiguing exercise. Nineteen healthy men completed three sessions (separated by at least 4 weeks) which included a knee extensors provocation exercise consisting of 3 sets of 25 isometric contractions. Contraction intensity level was fixed respectively at 60%, 55% and 50% of previously determined maximal voluntary contraction for the first, second and third sets. This provocation exercise was followed by either an active (AR) recovery (25 min pedaling on a cycle ergometer), an electrostimulated (ESR) recovery (25-min continuous and non-tetanic (5 Hz) stimulation of the quadriceps) or a strictly passive recovery (PR). Peak torques of knee extensors and subjective perception of muscle pain (VAS, 0-10) were evaluated before (pre-ex), immediately after the provocation exercise (post-ex), after the recovery period (post-rec), as well as 75 minutes (1h15) and one day (24h) after the exercise bout. Time course of peak torque was similar among the different recovery modes: ~ 75% of initial values at post-ex, ~ 90% at post-rec and at 1h15. At 24h, peak torque reached a level close to baseline values (PR: 99.1 ± 10.7%, AR: 105.3 ± 12.2%, ESR: 104.4 ± 10.5%). VAS muscle pain scores decreased rapidly between post-ex and post-rec ($p < 0.001$); there were no significant differences between the three recovery modes ($p = 0.64$). In conclusion, following a submaximal isometric knee extension exercise, neither electrostimulated nor active recovery strategies significantly improved the time course of muscle function recovery.

Key words: Electrical stimulation, muscle recovery, isometric contraction, muscle fatigue.

Introduction

During the last century, competitive sport has progressively become more professional; march of technological progress and improvement in exercise physiology knowledge have contributed to improve efficiency of training. Current training sessions (often performed twice daily) are quantitatively and qualitatively optimized to induce a maximal or supra-maximal training load (Barnett, 2006). Consequently, it is crucial for competitive athletes to make the most of rest periods and to consider that the loading-recovery cycle constitutes the key point of the training process (Kentta and Hassmen, 1998; Reilly and Ekblom, 2005).

Besides a purely passive rest, several recovery strategies have been proposed to sportsmen to enhance muscle function recovery. Despite the popularity of massage in sports medicine to treat post-exercise muscle damage and traumatic muscles disorders (Tiidus and Shoemaker, 1995; Tiidus, 1997; Ogai et al., 2008), several controversies exist in the scientific community about its physiological effects (Barnett, 2006; Callaghan, 1993; Goats and Keir, 1991; Hemmings et al., 2000; Tiidus, 1997; Vanderthommen et al., 1999; Weerapong et al., 2005). Sauna and hydrotherapy, including immersion in warm or tepid bath (Nakamura et al., 1996), as well as warm underwater-jet massage (Viitasalo et al., 1995) and contrast water immersion (Cochrane, 2004) have been confidentially studied and are still prescribed empirically based on personal beliefs. However, such passive techniques might be less efficient than active strategies to enhance recovery (Gupta et al., 1996; Mika et al., 2007; Spierer et al., 2004). Indeed, active warm down recovery, e.g. running or cycling at moderate intensity, has demonstrated its ability to increase the rate of lactate oxidation after strenuous exercises (Gupta et al., 1996; Hermansen and Stensvold, 1972; Hildebrandt et al., 1992; Mika et al., 2007; Monedero and Donne, 2000; Rontoyannis, 1988) and might be more beneficial in the preservation of performance during repeated maximal exercise (Thiriet et al., 1993).

Specific neuromuscular electrical stimulation (NMES) programs (continuous non-tetanic muscle stimulation) designed by manufacturers are very popular to improve muscle recovery after exercise. However, only a few studies evaluated the efficiency of this specific stimulation modality, and most of them focused on post-exercise recovery after exercise-induced muscle damage; they reported that NMES (low frequency stimulation) had no effect (Craig et al., 1996; Martin et al., 2004; Weber et al., 1994) or only moderate influence (Vanderthommen et al., 2007) on delayed onset muscle soreness (DOMS) and maximal voluntary contraction (MVC) following eccentric exercises. With regard to the other studies, Lattier et al. compared various recovery modalities including passive, active and NMES interventions following a fatiguing exercise consisting on a high-intensity uphill running exercise (Lattier et al., 2004); the latter intervention resulted in a greater performance for an all-out running test following the recovery period (Lattier et al., 2004). Besides, Tessitore et al. reported that electrostimulation was more beneficial than water-aerobic exercises and passive rest for reducing muscle pain after a soccer training (Tessitore et al., 2007). Therefore, further investigating electrostimulated recovery (with larger samples) following non eccentric contractions appears particularly relevant. As far as we know, this is the first study that compared effectiveness of an electrostimulated recovery (ESR) and an active cycling recovery (AR) following a specific

Received: 20 June 2009 / Accepted: 24 December 2009 / Published (online): 01 June 2010

isometric provocation exercise of knee extensor muscles.

The purpose of the present work was to compare both strategies and examine whether or not they are more efficient than a purely passive recovery (PR) on the pattern of torque recovery and the changes in subjective perception of muscle pain. Based on the theory that EMS increases local blood flow (Cramp et al., 2000) and consequently might enhance metabolite clearance, we hypothesized that EMS would be as effective as active recovery in accelerating muscle pain decrease and muscle function restoration and that recovery would be quicker for these modalities than after a purely passive recovery.

Methods

All subjects gave written informed consent to participate. The Medical Ethics Committee of the Liege University, Belgium, approved the study protocol.

Subjects and protocol

Nineteen healthy male volunteers (no or leisure time physical activity) participated in this study. Their mean age (SD) was 23.4 (2.1) years and mean body mass was 74.1 (11.3) kg. None were currently involved in any lower body strength, resistance or endurance training program.

Subjects completed three sessions separated by at least 4 weeks. Each session included a one-legged (left) knee extensor provocation/fatiguing exercise followed by either an active cycling recovery (AR), an electrostimulated recovery of the quadriceps muscle (ESR) or a strictly passive recovery (PR). The order of the three sessions was randomly assigned. Subjects were instructed to abstain from consumption of any form of medication and to refrain from strenuous exercise from 72 h prior to the provocation session to 24 h after each session. Furthermore, they were asked to use no technique that might influence muscle recovery (e.g. stretching, hydrotherapy, massage) during each post-exercise period.

During each session, knee extensors peak torque and subjective perception of muscle pain were measured before and after the fatiguing exercise.

Maximal voluntary contraction measurement

A standard warm-up phase consisting of 5-min cycling at 75 W on a bicycle ergometer (70 rpm) was followed by a 5-min stretching of quadriceps and hamstring muscles. Then subjects were seated on a knee extensor testing chair with the trunk vertical; pelvic girdle was stabilized by belts placed across hips and thigh. The left knee and hip were flexed respectively to 60° and 90°. A resistance pad was fixed on the lever arm of the testing chair and was adjusted to face a point 4 cm above the malleoli. Torque of left knee extensor muscles was measured by a static strain-gauge transducer (DS Europe, FS100kg) fixed on the lever arm at 49 cm from the axis of rotation. Subjects were familiarized with the test by performing 5 graded submaximal isometric contractions of knee extensor muscles whereby subjects built up to a near-maximum effort on the last repetition. Afterwards subjects exerted three 4-seconds isometric maximal voluntary knee extension contractions (MVC) at two-minute intervals. The best result of the four contractions was selected as the true MVC value. Strong verbal encouragements were provided during the testing procedure. The gravity torque of the leg was also measured and taken into account in the MVC measurement.

Provocation/fatiguing exercise

Subjects were installed on the testing chair in the same position than for the MVC measurement. Exercise consisted of 3 sets of isometric contractions of the left knee extensor muscles with 30 s rest between sets. Each set lasted 5 min and was composed of 25 6-s isometric contraction / 6-s rest cycles. Contraction intensity level was fixed respectively at 60%, 55% and 50% of previously determined MVC for the first, second and third sets. A visual feedback system, displaying the torque in real time, was positioned in front of the subject in order to adjust the torque at the required level.

Subjective perception of muscle pain

Subjects were asked to rate the muscle (quadriceps) pain intensity on a visual analogue scale (VAS) graded from 0 (no pain) to 10 (very severe, maximal pain).

Testing time course

To study influence of recovery modes on muscle function, MVC and VAS muscle pain scores were measured before (pre-ex) and immediately after (post-ex) the provocation exercise as well as after the 25-min recovery period (post-rec). Measurements were repeated 75 minutes (1h15) and one day (24h) after the provocation exercise, with the same procedure.

Active recovery (AR)

The active recovery consisted in 25 min of pedaling on a stationary bicycle at a rate of 60 rpm. The load (49 ± 9 W) was individually adjusted so that heart rate was close to 100 bpm (about 50% of theoretical maximal heart rate). Such effort intensity is similar to the one used in literature (Choi et al., 1994; Crisafulli et al., 2003; Fairchild et al., 2003).

Electrostimulated recovery (ESR)

The subject was seated with hip and knee flexed to 90° and 60°, respectively. A generator (Compex1, Medicompex, Switzerland) provided bi-directional symmetric rectangular impulses directly to the skin through surface electrodes placed on the left thigh. Three independent channels were employed. They were composed of two poles, one of which was connected to a “stimulating” electrode (5x5 cm) and the other to a “dispersive” electrode (9x5 cm). The 3 stimulating electrodes were placed over the motor points of the vastus medialis, vastus lateralis and rectus femoris of the quadriceps. The dispersive electrodes were placed transversally on the proximal portion of the thigh. Pulse width was 0.25 ms and pulse frequency was 5 Hz. Pulse characteristics (shape, width, amplitude and frequency) were checked previously by means of an oscilloscope. The investigators adjusted the current intensity independently on each channel in order to get an homogenous non-tetanic contraction tolerated by the subject. During the ESR (25 minutes), the current intensity was regularly increased to maintain a visible and palpable muscle contraction in order to reproduce the traditional use conditions of such NMES program. At the end of stimulation, the mean (± SD) current intensity was 47 (± 13), 49 (± 15) and 45 (± 14) mA respectively for the vastus medialis, vastus lateralis and rectus femoris.

Passive recovery (PR)

The subject was placed in the same seated position as for the ESR and was instructed to observe a strictly passive rest for 25 min.

Statistical analysis

Peak torque data were normalized to baseline values. Values are expressed throughout this study as mean ± SD. With regard to torque values, normal distribution was checked using the Shapiro-Wilk test of normality. Each variable was compared using a two-way ANOVA with repeated measures. Scheffé *post-hoc* test was applied to determine between-means differences if the analysis of variance revealed significant effect for time, recovery mode or interaction (time x recovery mode). A p-value ≤ 0.05 was considered to represent statistical significance.

Results

Peak torque

The mean ± SD pre-exercise MVC measured before each provocation test were not statistically different (AR: 263 ± 35 N.m; ESR: 260 ± 44 N.m; PR: 263 ± 33 N.m).

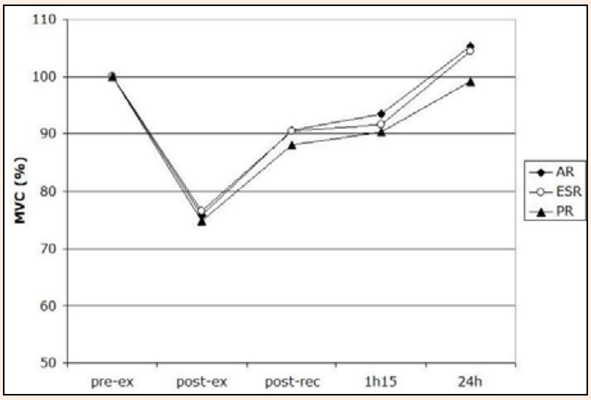

Figure 1. Changes in MVC (percentage of initial values) following the three different recovery strategies (AR: active recovery; ESR: electrostimulated recovery; PR: passive recovery). pre-ex: before the provocation exercise; post-ex: immediately after exercise; post-rec: after the recovery period; 1h15: 75min after the recovery period; 24h: one day after the recovery period.

Changes in MVC following the three different recovery strategies are illustrated in Figure 1. The time courses of MVC appeared relatively similar among the different recovery modes. Analysis of variance revealed a "time" effect ($p < 0.001$): immediately after the provocation exercise (post-ex), the mean MVC decreased severely and significantly ($p < 0.001$); it reached 75.8 ± 12.4%, 76.5 ± 16.2% and 74.8 ± 11.6% of baseline values respectively after the AR, ESR and PR. Mean MVC increased significantly ($p < 0.001$) following the recovery periods (post-rec) (90.7 ± 10.9% (AR), 90.4 ± 13.4% (ESR) and 88.1 ± 8.8% (PR)) and plateaued ($p = 0.6$) 1h15 after the provocation exercise. A further significant rise ($p < 0.001$) appeared 24 h after the provocation exercise and MVC values reached a level close to baseline performances i.e. 105.3 ± 12.2% (AR), 104.4 ± 10.5% (ESR) and 99.1 ± 10.7% (PR).

Analysis of variance indicated that there was no effect for the "recovery mode" ($p = 0.89$).

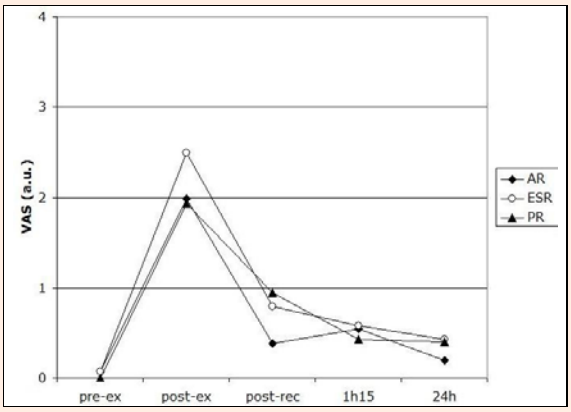

Figure 2. Changes in mean subjective muscle pain perception (VAS, 0-10 a.u.) following the three different recovery strategies (AR: active recovery; ESR: electrostimulated recovery; PR: passive recovery). pre-ex: before the provocation exercise; post-ex: immediately after exercise; post-rec: after the recovery period; 1h15: 75min after the recovery period; 24h: one day after the recovery period.

Subjective perception of muscle pain

The influence of the provocation exercise on the subjective perception of muscle pain is illustrated in Figure 2. Analysis of variance revealed a "time" effect ($p < 0.001$): a significant increase ($p < 0.001$) in muscle pain sensations was observed immediately after exercise (post-ex) (AR: 1.98 ± 2.18 arbitrary units (a.u.); ESR: 2.50 ± 2.39 a.u.; PR: 1.93 ± 1.85 a.u.). VAS scores decreased rapidly and significantly ($p < 0.001$) following recovery (post-rec) and remained stable after this period (1h15, $p = 0.923$). Twenty-four hours after the provocation exercise, the VAS scores (0.20 ± 0.52 a.u. (AR), 0.43 ± 0.96 a.u. (ESR) and 0.40 ± 0.92 a.u. (PR)) were not statistically different from baseline ($p = 0.712$).

Analysis of variance indicated no significant effect for the "recovery mode" ($p = 0.64$).

Discussion

The aim of this study was to compare, by means of a longitudinal follow-up of knee extensor peak torque and subjective perception of muscle pain, three different kinds of recovery strategies following an isometric fatiguing exercise. The quadriceps constitutes a relevant model because this muscle is often involved in sporting activities (e.g. cycling (Akima et al., 2005), skiing (Neumayr et al., 2003), rowing (Yoshiga and Higuchi, 2003), etc.) and is therefore frequently electrostimulated in a recovery mode by athletes after training sessions or a competition. In order to avoid any "repeated bout effect", the sessions were separated by at least 4 weeks and the order of the three sessions was randomly assigned. The similar peak torques measured before each of the three experimental sessions confirmed the absence of such effect.

All subjects managed to complete the 3 sets of 25 contractions at the requested level (50-60% of maximal torque); the decrease in knee extensor maximal performances averaged 25% soon after the provocation exercise, 10% after recovery and 0% after 24h. The rapid drop of knee extensor maximal performances illustrates the phenomenon of post-exercise fatigue which is, indeed, defined as a reduction in the ability to exert muscle force (Gandevia, 2001). It is well known that lactate, hydrogen ion, inorganic phosphates and plasma ion potassium accumulations, decrease of intracellular potassium ion concentration, depletion of high energy phosphates and glycogen, loss of calcium homeostasis or local ischemia may be some of the causative factors associated with disruption of the muscle excitation-contraction cycle (Mika et al., 2007). Indeed, a previous study monitored the human quadriceps by interleaved ^{1}H and ^{31}P-NMR spectroscopy during a protocol strictly similar to our provocation exercise (25 isometric contraction (6s)/rest (6s) cycles, contraction level = 50-60% of maximal torque); results revealed, at the end of the bout, that phosphocreatine depletion, pH and myoglobin desaturation reached 88%, 6.64 and 40%, respectively (Vanderthommen et al., 2003). In the present experimental conditions, muscle pain sensations were markedly reduced one day after the provocation exercise and were not statistically different from baseline confirming the hypothesis of no muscle damage. Thus, our study shows that our provocation exercise induced an early fatigue without DOMS but did not lead to exhaustion.

Our active recovery consisted in pedaling on a bicycle ergometer with a moderate load (~50W) leading to a heart rate close to 100 bpm. This kind of light aerobic exercise has already demonstrated its ability to improve the recovery process after strenuous contractions in comparison with a resting recovery (Bangsbo et al., 1994; Gupta et al., 1996; Hermansen and Stensvold, 1972; Hildebrandt et al., 1992; Mika et al., 2007; Rontoyannis, 1988). According to some authors, a level intensity reaching 30 to 60% of VO_2max is appropriate for aerobic recovery-exercises (Ahmaidi et al., 1996; Hermansen and Stensvold, 1972; Monedero and Donne, 2000). Active recovery strategies, by enhancing muscle blood flow via the "muscle pump effect" and consequently optimizing lactate clearance (Bulbulian et al., 1987; Gupta et al., 1996; Monedero and Donne, 2000; Rontoyannis, 1988; Tiidus and Shoemaker, 1995), are thought to play a key role in the recovery process from exercise.

Literature suggests that electrostimulation could be useful as a recovery tool. Lattier et al. compared passive (seated), active (sub-maximal running) and ESR (quadriceps, hamstrings, triceps surae) interventions after high-intensity uphill running exercise (10 one-minute runs at 120% of the maximal aerobic velocity at 18% grade) (Lattier et al., 2004). They reported no difference between interventions with regard to recovery of neuromuscular function (MVC and EMG recordings). However, they found a tendency toward better subsequent all-out running performance after electromyostimulation without managing to give clear explanations for their observations (Lattier et al., 2004). A recent study explored the effects of an electrostimulated recovery identical to the one used in the current study after a maximal eccentric exercise that induced severe DOMS (Vanderthommen et al., 2007). Whereas literature reported no beneficial effect of ESR following eccentric contractions (Craig et al., 1996; Martin et al., 2004; Weber et al., 1994), Vanderthommen et al. reported that ESR had no impact on the magnitude of the initial muscle damages but appeared slightly more effective than passive recovery in decreasing DOMS as reflected by reduced serum activity of creatine kinase (Vanderthommen et al., 2007). As active strategy, ES is supposed to accelerate recovery by enhancing muscle blood flow (Cramp et al., 2000); the NMES sequence applied in the present study was composed of a continuous and non-tetanic stimulation (5 Hz) with a regular current intensity increase (visible and palpable muscle contraction) in accordance with the programs often used and recommended in sports and rehabilitation to facilitate the recovery process. In animals, former studies showed that 4-10 Hz stimulation induced an increase in the muscle perfusion in the cat (Johansson, 1962), in the dog (Clement and Shepherd, 1974) and in the rat muscle (Hawker and Egginton, 1999). The current intensity used in the present work was selected in order to standardize the action on muscles. Indeed, in most studies, subjects just selected the most comfortable intensity (Lattier et al., 2004; Martin et al., 2004; Tessitore et al., 2007) resulting in potential excessive intensity (that might lead to partial ischemia) or in intensity which might not be sufficient to enhance muscle blood flow (Martin et al., 2004).

Surprisingly, in the present study, no significant effect of the "recovery mode" was found for muscle pain perception and peak torque; one day after the provocation exercise, the latter returned approximately to baseline values whatever the recovery strategies. The absence of significant difference between AR or ESR and passive recovery, suggesting that these strategies did not enhance the regenerative process, might result from the low aggressive provocation exercise (3 sets of submaximal isometric contractions) designed in the present work. We preferred such kind of exercise rather than efforts leading to muscle damages (as in most studies) in order to better reproduce some conditions of the field. Unfortunately our protocol did not lead to exhaustion; therefore, the resulting recovery was probably too rapid to be much improved by active or electrostimulated contractions

At the moment, one cannot recommend specifically active or electrostimulated recovery following an effort because it still remains unknown whether or not recovery strategies are sensible to the kind of efforts. Besides, Tessitore et al. reported a high interindividual variability with regard to the effectiveness of various recovery interventions (Tessitore et al., 2007) suggesting the relevance of exploring the most optimal individual recovery strategy.

We acknowledge some potential limitations of the current study. We did not investigate metabolites removal and the rate of post-exercise glycogen synthesis during and following the recovery periods. Besides, subjects included in the current study were relatively untrained individuals, who might display a different fatigue and recovery pattern compared to highly trained athletes (Barnett 2006).

Conclusion

The present study showed no significant differences between the effects of passive, active and electrostimulated recovery strategies on muscle pain and peak torque following three sets of submaximal isometric contractions at 60%, 55% and 50% of MVC. Such fatiguing protocol induced an early fatigue without DOMS but did not lead to exhaustion. Further investigations are required to compare ESR and AR efficiency following a provocation exercise more intense than the one used in the current study but less aggressive than maximal eccentric efforts that are known to cause DOMS; besides it would be relevant to study such recovery methods after more functional provocation efforts (e.g. multiple jumps) and with assessments better reflecting field situations.

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Key points

- Three sets of submaximal isometric contractions at 60%, 55% and 50% of MVC induced an early fatigue without DOMS but did not lead to exhaustion.
- In comparison with passive recovery, active and electrostimulated recovery did not lead to significantly higher MVC torques 24h after the exercise bout.
- No significant differences were demonstrated between the effects of passive, active and electrostimulated recoveries on muscle pain after repeated submaximal isometric contractions.

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