ELECTROSTIMULATION-RELATED RECOVERY STRATEGIES

ARE THEY EFFECTIVE?

– Written by Nicola A. Maffiuletti, Switzerland and Grégory Dupont, France

INTRODUCTION AND RATIONALE

Transcutaneous electrical stimulation (ES) consists of delivering small electrical pulses via electrodes that are positioned on the skin, usually around skeletal muscle motor points or painful body areas. Depending on electrical current (frequency and intensity) and electrode characteristics (size, position), two major ES categories can be distinguished:

1. 'Sensory' ES (no muscular contractions are evoked). Conventionally called transcutaneous electrical nerve stimulation. This is mainly delivered using relatively low current intensities (at or below the sensory threshold) in an attempt to relieve pain via spinal circuitry transmitting pain (gate theory) and endorphin release.
2. 'Motor' ES. Conventionally called neuromuscular electrical stimulation. This elicits visible muscular contractions (stimulations are delivered at or above the motor threshold), using either tetanic or sub-tetanic stimulations, whose clinical/physiological consequences are improved neuromuscular function and enhanced peripheral blood flow.

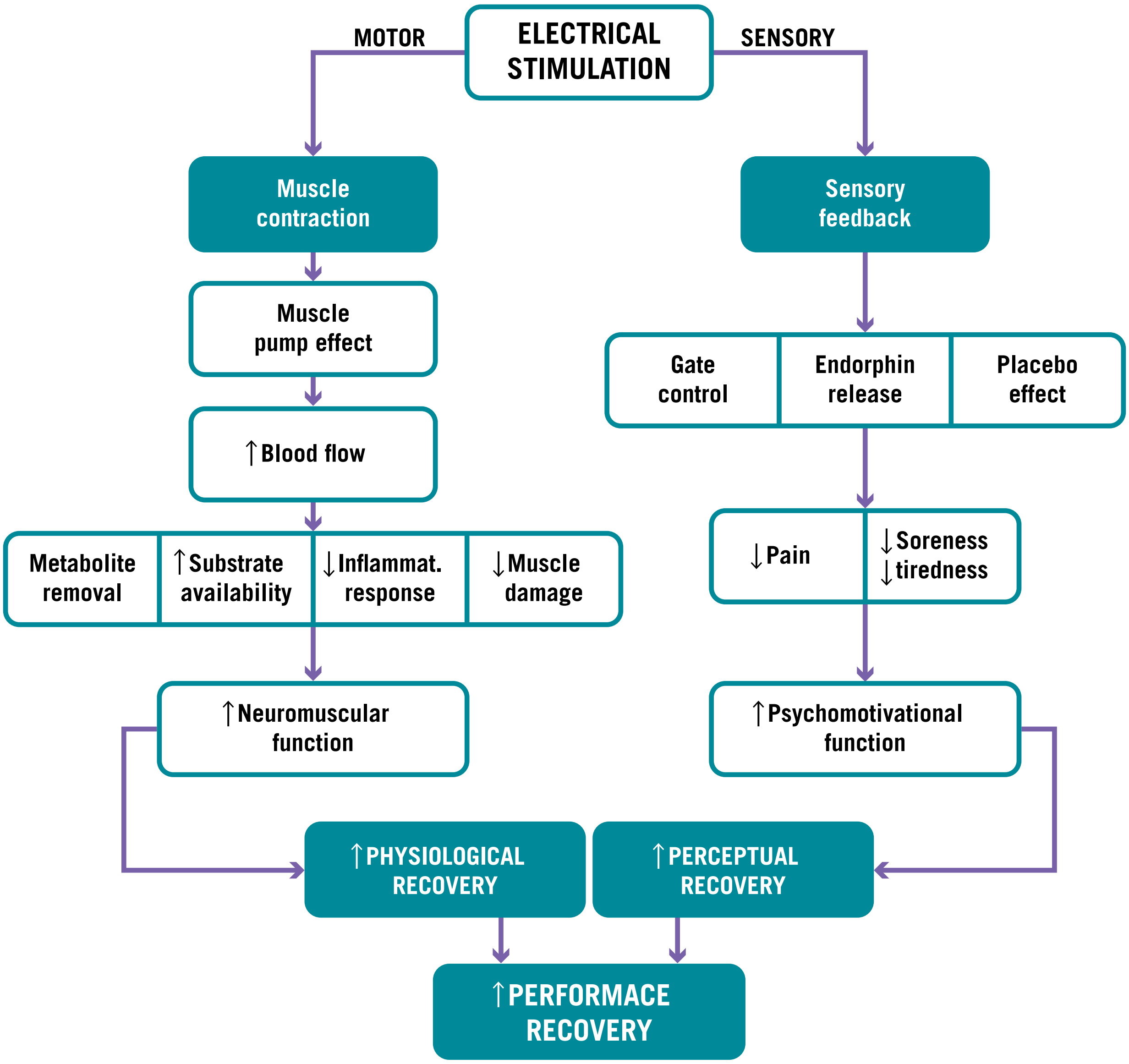
In reality, this distinction is not always respected and considerable confusion continues to surround the main physiological effects, methodological aspects and clinical/sports applications of transcutaneous ES.

Some individual and team sport athletes use motor ES modalities to complement their training/rehabilitation programmes for:

1. improving muscle strength during the pre-season,
2. maintaining/improving muscle function while injured/after an injury and
3. restoring physical performance after intense exercise (i.e. for accelerating recovery).

There is some evidence to suggest that motor (tetanic) ES is effective to increase muscle strength in athletes (for a review see Seyri and Maffiuletti[1]), and to preserve muscle mass during prolonged periods of inactivity[2]. Surprisingly, however, the growing interest in applied research on tetanic ES observed in the last few years corresponds to a reduced use by athletes and reduced development by manufacturers. At the same time, but with premature physiological background, subtetanic ES has gained popularity in sportspeople as a potentially effective strategy to accelerate post-exercise recovery.

This review article aims to assess the effectiveness of motor subtetanic and sensory ES as a recovery modality for athletes by following a simplified and non-systematic approach. Because the post-exercise decline in physical/sports performance is due to an impairment in neuromuscular and/or psychomotivational function, and because recovery modalities are designed to restore neuromuscular function and/or psychomotivational



function to the pre-exercise level as quickly as possible, we provide separate definitions, analyses and interpretations for 'physiological' and 'perceptual' recovery throughout the article. We therefore considered original research studies:

1. published in peer-reviewed journals,
2. comparing the effectiveness of ES-related recovery strategies to passive recovery or other recovery modalities (at least two conditions),
3. focusing on athletes or healthy subjects,
4. having quantified at least one physiological and/or perceptual variable of recovery.

In order to examine the effectiveness of ES-related strategies, we arbitrarily classified the studies as having demonstrated that recovery with ES was 'less effective', 'equally effective' and 'more effective' compared to passive rest and to other recovery modalities (submaximal exercise, cold water immersion, contrast water therapy, compression garments and also placebo ES in one study).

DOES ELECTROSTIMULATION IMPROVE PHYSIOLOGICAL RECOVERY?

In the context of this article, physiological recovery was considered successful when neuromuscular function, as measured objectively (strength, power or physical performance outcomes), was fully restored to pre-exercise levels. The rationale for the use of motor ES to promote physiological recovery is based on the assumption that evoked muscular contractions are able to enhance peripheral blood flow mainly due to the muscle pump effect. In turn, this would accelerate metabolite removal, improve substrate availability, decrease the inflammatory response and reduce muscle damage that could contribute to restoring the neuromuscular determinants of muscle strength/power and thus physical performance (cf. left portion of Figure 1).

In reality, subtetanic ES of the calf muscles and of the plantar muscles of the foot are able to enhance peripheral blood flow with respect to passive rest conditions, however

Table 1

	ES less effective	*ES equally effective*	*ES more effective*
Neric et al 2007	○		●
Heyman et al 2009	○		●
Cortis et al 2010		○ ●	
Malone et al 2012	○	●	
Argus et al 2013		○	●
Croci (unpublished data)	○	●	

Table 1: Effects of electrical stimulation-related recovery strategies on blood lactate concentration. ●=vs passive recovery, ○=vs other recovery modalities.

Table 2

	ES less effective	*ES equally effective*	*ES more effective*
Lambert et al 2002			●
Vanderthommen et al 2007			●
Bieuzen et al 2012		●	
Neric et al 2007		○	

Table 2: Effects of electrical stimulation-related recovery strategies on serum creatine kinase concentration. ●=vs passive recovery, ○=vs other recovery modalities.

active exercise (voluntary dynamic muscle contractions) is even more effective than ES to increase the ejected venous volume[3]. This observation fits well with recent recovery studies in which ES was found to be equally or more effective than passive rest in reducing post-exercise blood lactate concentration, while ES was less effective than active recovery modalities such as submaximal swimming and cycling (Table 1). It is nevertheless worth remembering that blood lactate should not be considered the best indicator of metabolite removal.

Four studies evaluated the changes in serum creatine kinase concentration, as an objective marker of muscle damage in the days consecutive to an exhaustive exercise bout (including eccentric exercise) and demonstrated that ES was equally or more effective than passive recovery, and equally effective compared to submaximal exercise (Table 2).

When evaluating the effectiveness of ES recovery-related strategies on muscle strength/power, physical performance and even on the neuromuscular determinants of muscle strength (e.g. muscle activation, muscle contractility), only 3 out of 19 studies demonstrated that ES was more effective than passive recovery (and only for one variable), while all the other studies were unable to detect a difference between the two modalities in healthy active individuals, recreational sportsmen and professional athletes (Table 3). ES was found to be equally effective compared to other recovery modalities in all but one study, in which better effectiveness of ES compared to active recovery (submaximal concentric contractions) was observed following isokinetic fatiguing exercise in male elite judo athletes.

> **"There is no justification to expect any physiological benefit from ES for post-exercise recovery"**

Table 3

	ES less effective	*ES equally effective*	*ES more effective*
Weber et al 1994		● ○	
Butterfield et al 1997		●	
Lambert et al 2002		●	
Martin et al 2004		● ○	
Lattier et al 2004		● ○	
McLoughlin et al 2004		●	
Tourville et al 2006		●	
Vanderthommen et al 2007		●	
Tessitore et al 2007		● ○	
Tessitore et al 2008		● ○	
Heyman et al 2009		● ○	
Cortis et al 2010		● ○	
Vanderthommen et al 2010		● ○	
Zarrouk et al 2011			● ○
Bieuzen et al 2012		●	
Malone et al 2012		● ○	
Finberg et al 2012		○	●
Bieuzen et al 2012			●
Argus et al 2013		●	

Table 3: Effects of electrical stimulation-related recovery strategies on neuromuscular function. ●=vs passive recovery, ○=vs other recovery modalities.

DOES ELECTROSTIMULATION IMPROVE PERCEPTUAL RECOVERY?

In the context of this article, perceptual recovery was considered successful when psychomotivational factors, as measured subjectively (basically, by replying to simple questions such as "what is your level of recovery following this intervention?", by ranking the perceived effectiveness of different recovery modalities using scales and scores or by quantifying the perceived level of energy and enthusiasm), were fully restored to pre-exercise levels. The rationale for the use of motor and sensory ES to promote perceptual recovery is based on theoretical models rather than on scientific evidence, as the biological basis of the analgesic and psychological effect of ES is not known. The underlying theories are the gate control theory, which proposes that pain transmission through small afferent fibres would be selectively blocked at the spinal cord level by the ES-induced activation of large afferents; the endorphin-release theory and the placebo theory. In turn, the neurophysiological/psychological mechanisms underlying these theories would be able to attenuate the perception of pain and tiredness (both locally and at a whole-body level), for example by reducing exercise-induced muscle soreness, which could ultimately result in recovered psychomotivational function and thus successful perceptual recovery (Figure 1, RHS).

The effects of ES recovery-related strategies on delayed onset muscle soreness (referred to as muscle pain in some studies) induced by heavy exercise (including

TABLE 4

	ES less effective	ES equally effective	ES more effective
Weber et al 1994		● ○	
Butterfield et al 1997		●	
Lambert et al 2002			●
Martin et al 2004		● ○	
McLoughlin et al 2004			●
Tourville et al 2006		●	
Vanderthommen et al 2007		●	
Tessitore et al 2007			● ○
Tessitore et al 2008		● ○	
Cortis et al 2010		● ○	
Vanderthommen et al 2010		● ○	
Bieuzen et al 2012		●	

Table 4: Effects of electrical stimulation-related recovery strategies on delayed onset muscle soreness. ●=vs passive recovery, ○=vs other recovery modalities.

eccentric exercise) have been compared to other recovery modalities in 12 studies. Subsensory (micro-current ES), sensory and subtetanic ES has been found to be more effective than passive rest in three studies (a placebo ES condition was used in one instance), and more effective than active water exercise in only one study, while in all the other instances ES was equally effective compared to both passive and active recovery modalities (Table 4).

More interestingly, ES recovery-related strategies have been found to be more effective than passive rest for restoring psychomotivational factors in three out of four studies conducted on highly-trained cyclists and team sport athletes. In the same way, ES has been demonstrated to be more effective compared to other recovery modalities (submaximal exercise, contrast water therapy and compression garments) for perceptual recovery in three out of five studies (Table 5).

CONCLUSIONS AND CONSIDERATIONS

We conclude that ES-related recovery strategies are:

- unlikely beneficial for improving physiological recovery compared to both passive rest (including a placebo condition in one study) and other recovery modalities;
- likely beneficial for improving perceptual recovery compared to passive rest, and possibly beneficial for improving perceptual recovery compared to other recovery interventions.

In other words, there is no justification to expect any physiological benefit from ES for post-exercise recovery purposes, while restoration of some psychomotivational factors – likely mediated by a placebo effect of ES[4] – appear to be enhanced when ES is used as a recovery modality compared to several passive and active recovery strategies.

Medical device manufacturers continuously introduce new electrical stimulators on the market with futuristic current characteristics, claiming superior effectiveness compared to previous systems, but with no preliminary physiological validation. ES users are therefore faced with considerable confusion, particularly with respect to the multitude of parameters, protocols and potential applications – their choice is often based on convenience. We believe that, in order to ensure solid credibility of newly developed units, their physiological (and eventually also perceptual) effectiveness should be scientifically demonstrated at all levels of our simplified model (Figure 1) e.g. by showing that ES is able to increase blood flow using ultrasonography, to accelerate metabolites removal by quantifying blood lactate concentration and to improve neuromuscular function by evaluating muscle strength/power and eventually sport-related performance (rather than only one of these mechanisms as it is the case for currently available units).

Based on subjective belief rather than on scientific evidence we propose that in order to maximise potential physiological benefits of ES for recovery purposes (with respect to passive rest), the following methodological precautions should be observed:

- ES would be better combined with submaximal voluntary dynamic

Table 5

	ES less effective	ES equally effective	ES more effective
Tessitore et al 2008			● ○
Cortis et al 2010		● ○	
Finberg et al 2012			● ○
Argus et al 2013		○	●
Beaven et al 2013			○

Table 5: Effects of electrical stimulation-related recovery strategies on psychomotivational function. ●=vs passive recovery, ○=vs other recovery modalities.

contractions (such as toe curls) whenever possible, in order to maximise blood flow increase,

- ES would be better applied distally (to the calf or foot muscles and eventually to the common peroneal nerve[5]) rather than proximally (to the quadriceps muscle belly) to maximise the muscle pump effect,
- ES would be better used in weight-bearing and contact sports to reduce signs and symptoms of muscle damage,
- ES would be better delivered with low doses but for long-term periods (such as overnight)[6], during travel or by means of electrostatically charged self-adhesive membranes[7]).

ES-related recovery interventions represent an alternative and potentially useful way of restoring sports performance after intense exercise because they are practical, relatively cheap and quite beneficial for promoting perceptual (not physiological) recovery. Many athletes are, however, still reluctant to apply ES to their muscles mainly because of the discomfort induced by the electrical current, and therefore its use for recovery purposes should be proposed on an individual basis (and according to expectations). There is limited research in this area, particularly on upper limb muscles and in female athletes, and further efforts are required to demonstrate the physiological effectiveness, the biological basis of the analgesic and psychological effect of ES.

References

1. *Seyri KM, Maffiuletti NA. Effect of electromyostimulation training on muscle strength and sports performance. Strength Cond J 2011; 33:70-75.*
2. *Gibson JN, Smith K, Rennie MJ. Prevention of disuse muscle atrophy by means of electrical stimulation: maintenance of protein synthesis. Lancet 1988; 2:767-770.*
3. *Broderick BJ, Corley GJ, Quondamatteo F, Breen PP, Serrador J, Olaighin G. Venous emptying from the foot: influences of weight bearing, toe curls, electrical stimulation, passive compression, and posture. J Appl Physiol 2010; 109:1045-1052.*
4. *Thorsteinsson G, Stonnington HH, Stillwell GK, Elveback LR. The placebo effect of transcutaneous electrical stimulation. Pain 1978; 5:31-41.*
5. *Tucker A, Maass A, Bain D, Chen LH, Azzam M, Dawson H et al. Augmentation of venous, arterial and microvascular blood supply in the leg by isometric neuromuscular stimulation via the peroneal nerve. Int J Angio. 2010; 19:e31-37.*
6. *Beaven CM, Cook C, Gray D, Downes P, Murphy I, Drawer S et al. Electrostimulation's enhancement of recovery during a rugby preseason. Int J Sports Physiol Perform 2013; 8:92-98.*
7. *Lambert MI, Marcus P, Burgess T, Noakes TD. Electro-membrane microcurrent therapy reduces signs and symptoms of muscle damage. Med Sci Sports Exerc 2002; 34:602-607.*
8. *Argus CK, Driller MW, Ebert TR, Martin DT, Halson SL. The effects of four different recovery strategies on repeat sprint cycling performance. Int J Sports Physiol Perform 2013; 8:542-548.*
9. *Bieuzen F, Pournot H, Roulland R, Hausswirth C. Recovery after high-intensity intermittent exercise in elite soccer players using VEINOPLUS sport technology for blood-flow stimulation. J Athl Train 2012; 47:498-506.*
10. *Butterfield DL, Draper DO, Ricard MD, Myrer JW, Schulthies SS, Durrant E. The effects of high-volt pulsed current electrical stimulation on delayed-onset muscle soreness. J Athl Train 1997; 32:15-20.*
11. *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.*
12. *Denegar CR, Perrin DH, Rogol AD, Rutt RA. Influence of transcutaneous electrical nerve stimulation on pain, range of motion, and serum cortisol concentration in females experiencing delayed onset muscle soreness. J Orthop Sports Phys Ther 1989; 11:100-103.*
13. *Finberg M, Braham R, Goodman C, Gregory P, Peeling P. Effects of electrostimulation therapy on recovery from acute team-sport activity. Int J Sports Physiol Perform 2013;8 :293-299.*
14. *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.*
15. *Lattier G, Millet GY, Martin A, Martin V. Fatigue and recovery after high-intensity exercise. Part II: Recovery interventions. Int J Sports Med 2004; 25:509-515.*
16. *Malone JK, Coughlan GF, Crowe L, Gissane GC, Caulfield B. The physiological effects of low-intensity neuromuscular electrical stimulation (NMES) on short-term recovery from supra-maximal exercise bouts in male triathletes. Eur J Appl Physiol 2012; 112:2421-2432.*
17. *Martin V, Millet GY, Lattier G, Perrod L. Effects of recovery modes after knee extensor muscles eccentric contractions. Med Sci Sports Exerc 2004; 36:1907-1915.*
18. *McLoughlin TJ, Snyder AR, Brolinson PG, Pizza FX. Sensory level electrical muscle stimulation: effect on markers of muscle injury. Br J Sports Med 2004; 38:725-729.*
19. *Neric FB, Beam WC, Brown LE, Wiersma LD. Comparison of swim recovery and muscle stimulation on lactate removal after sprint swimming. J Strength Cond Res 2009; 23:2560-2567.*
20. *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.*
21. *Tessitore A, Meeusen R, Pagano R, Benvenuti C, Tiberi M, Capranica L. Effectiveness of active versus passive recovery strategies after futsal games. J Strength Cond Res 2008; 22:1402-1412.*
22. *Tourville TW, Connolly DA, Reed BV. Effects of sensory-level high-volt pulsed electrical current ondelayed-onset muscle soreness. J Sports Sci 2006; 24:941-949.*
23. *Vanderthommen M, Makrof S, Demoulin C. Comparison of active and electrostimulated recovery strategies after fatiguing exercise. J Sports Sci Med 2010; 9:164-169.*
24. *Vanderthommen M, Soltani K, Maquet D, Crielaard JM, Croisier JL. Does neuromuscular electrical stimulation influence muscle recovery after maximal isokinetic exercise? Isok Exerc Sci. 2007; 15:143-149.*
25. *Weber MD, Servedio FJ, Woodall WR. The effects of three modalities on delayed onset muscle soreness. J Orthop Sports Phys Ther 1994; 20:236-242.*
26. *Zarrouk N, Rebai H, Yahia A, Souissi N, Hug F, Dogui M. Comparison of recovery strategies on maximal force-generating capacity and electromyographic activity level of the knee extensor muscles. J Athl Train 2011; 46:386-394.*

Nicola A. Maffiuletti
Neuromuscular Research Laboratory
Schulthess Clinic
Zurich, Switzerland

Grégory Dupont
University of Lille Nord de France
Ronchin
LOSC
Lille, France
Contact: nicola.maffiuletti@kws.ch