Effects of Adding Post-Workout Microcurrent in Males Cross Country Athletes

Authors: Fernando Naclerio[1], Diego Moreno-Perez[2], Marcos Seijo[1], Bettina Karsten[3], Mar Larrosa[4], Jose Ángel García-Merino[4], Jack Thirkell[5], Eneko Larumbe-Zabala[4]

Affiliations:

[1] Institute for Lifecourse Development, School of Human Sciences, Centre for Chronic Illness and Ageing. University of Greenwich, United Kingdom.

[2] Department of Education, Research and Evaluation Methods, Comillas Pontifical University, Spain.

[3] Lunex International University of Health, Exercise and Sports, Department of Exercise & Sport Science, Luxemburg.

[4] MAS microbiota group, Faculty of Biomedical and Health Sciences, Universidad Europea de Madrid, Spain.

[5] Department of Biological Sciences, Royal Holloway, University of London, United Kingdom.

Corresponding author: Dr. Fernando Naclerio. E-mail: f.j.naclerio@gre.ac.uk

Department of Sport Science and Physical Education, School of Human Science, University of Greenwich, Avery Hill Campus

Sparrows Farm. Avery Hill Road Eltham (SE9 2BT), United Kingdom.

Tel +44 (0) 20 8331 8441

ABSTRACT

Post-exercise microcurrent based treatments have shown to optimise exercise-induced adaptations in athletes. We compared the effects of endurance training in combination with either, a microcurrent or a sham treatment, on endurance performance. Additionally, changes in body composition, post-exercise lactate kinetics and perceived delayed onset of muscle soreness (DOMS) were determined. Eighteen males (32.8±6.3 years) completed an 8-week endurance training programme involving 5 to 6 workouts per week wearing a microcurrent (MIC, n=9) or a sham (SH, n=9) device for 3-h post-workout or in the morning during non-training days. Measurements were conducted at pre- and post-intervention. Compared to baseline, both groups increased (P<0.01) maximal aerobic speed (MIC, pre =17.6±1.3 to post=18.3±1.0; SH, pre=17.8±1.5 to post =18.3±1.3 km·h^{-1}) with no changes in $\dot{V}O_{2peak}$. No interaction effect per group and time was observed (P=0.193). Although both groups increased (P<0.05) trunk lean mass (MIC, pre=23.2±2.7 to post=24.2±2.0; SH, pre=23.4±1.7 to post=24.3±1.6 kg) only MIC decreased (pre=4.8±1.5 to post=4.5±1.5, p=0.029) lower body fat. At post-intervention, no main differences between groups were observed for lactate kinetics over the 5 min recovery period. Only MIC decreased (P<0.05) DOMS at 24-h and 48-h, showing a significant average lower DOMS score over 72-h after the completion of the exercise-induced muscle soreness protocol. In conclusion, a 3-h daily application of microcurrent over an 8-week endurance training programme produced no further benefits on performance in endurance-trained males. Nonetheless, the post-workout microcurrent application promoted more desirable changes in body composition and attenuated the perception of DOMS over 72-h post-exercise.

Keywords: Endurance Performance, Body Composition, Recovery, DOMS, Lactate, Non-invasive electrical microampere stimulus.

Introduction

Microcurrent is a non-invasive, safe and feasible electrotherapy involving the application of a series of subsensory electric currents (less than 1 mA), which are of a similar magnitude to the currents generated endogenously by the human body. Previous studies reported the effectiveness of microcurrent to increase myogenesis differentiation in animals (Ohno et al., 2019), activating intracellular signalling pathways for triggering the mechanistic target of rapamycin complex 1 (mTORC1) favouring a more efficient muscle protein synthesis response (Moon, Kwon, & Lee, 2018; Ohno et al., 2019). Furthermore, compared to sham treatment, acute microcurrent therapy attenuates markers of muscle damage in humans after applications lasting 20 minutes (Curtis, Fallows, Morris, & McMakin, 2010), 40 minutes (Kwon et al., 2017) and 96 hours (Lambert, Marcus, Burgess, & Noakes, 2002) in humans.

Regarding the impact of adding microcurrent to exercise in humans, Noites et al. (2015), observed significant reduction of visceral and subcutaneous abdominal fat during or after the completion of a 30 minute endurance exercise protocol with respect to performing the exercise alone More recently, Naclerio et al. (2019) reported promising effects of combining microcurrent with resistance training (3-h per day for 8 weeks) to maximise muscular architectural changes and attenuate the perception of muscle soreness in eighteen young recreationally trained males.

To the best of the authors' knowledge no research has assessed the effect of using regular microcurrent interventions on training-induced outcomes and adaptations in endurance athletes. The aim of this investigation, therefore, was to analyse the effects of a daily microcurrent treatment using a complex pulsed waveform with a fundamental frequency of 1.0309 kHz along with a variety of current intensities between 50 and 400 µA, on performance and adaptive responses in a group of cross-country trained athletes.

Given the potential benefits of microcurrent to optimise cellular energy production (Poltawski & Watson, 2009) and muscular function (Hiroshige et al., 2018), the primary outcome measure was focused on assessing the change in endurance performance. Additionally, considering the effects of

microcurrent treatments on lipolysis, enhancing the exercise induced adipose tissue decrease (Noites et al., 2015), promoting muscle mass accretion (Naclerio et al., 2019), hastening recovery and reducing markers of muscle damage (Udani, Singh, Singh, & Sandoval, 2009), secondary outcome measures included changes in body composition, post-exercise lactate concentration and the perception of muscular soreness. We hypothesised that combining microcurrent with endurance training induces additional performance benefits when compared to the training intervention alone (sham group). Furthermore, the use of microcurrent will help to maintain a more favourable body composition, optimise lactate removal and attenuate the delayed onset of muscle soreness (DOMS).

Methods

Participants

Twenty two well-trained (6 - 10 h per week) male cross country athletes (18–45 years), who compete at national level and who were free from anaemia, musculoskeletal limitations, injury, metabolic conditions and/or diseases and who declared not taking any medication or potentially performance enhancing nutritional supplements 8 weeks prior to the start of the study were recruited.

The study was approved by the institutional University Research Ethics Committee and all procedures were followed in accordance with the declaration of Helsinki. Prior to signing written informed consent, participants were informed about the nature and risks of the study. The project was registered as a clinical trial at the U.S. National Institutes of Health. www.clinicaltrials.gov (NCT03477747).

To determine the appropriate sample size, an interim analysis was performed once 12 participants (n=6 per group) completed the study. For the most relevant performance outcome [changes in maximal aerobic speed (MAS)], effect sizes were calculated using analysis of variance (ANOVA). Data were adjusted for their respective baseline levels. The interim analysis revealed a large effect size of f=0.88. With a confidence level of 0.05 and power of 80%, it was determined that 18 participants (n=9 per group) were required to achieve statistical significance for the difference

between groups. As summarised in Figure 1, there were 22 participants initially recruited. Of these, 18 participants completed all aspects of the study.
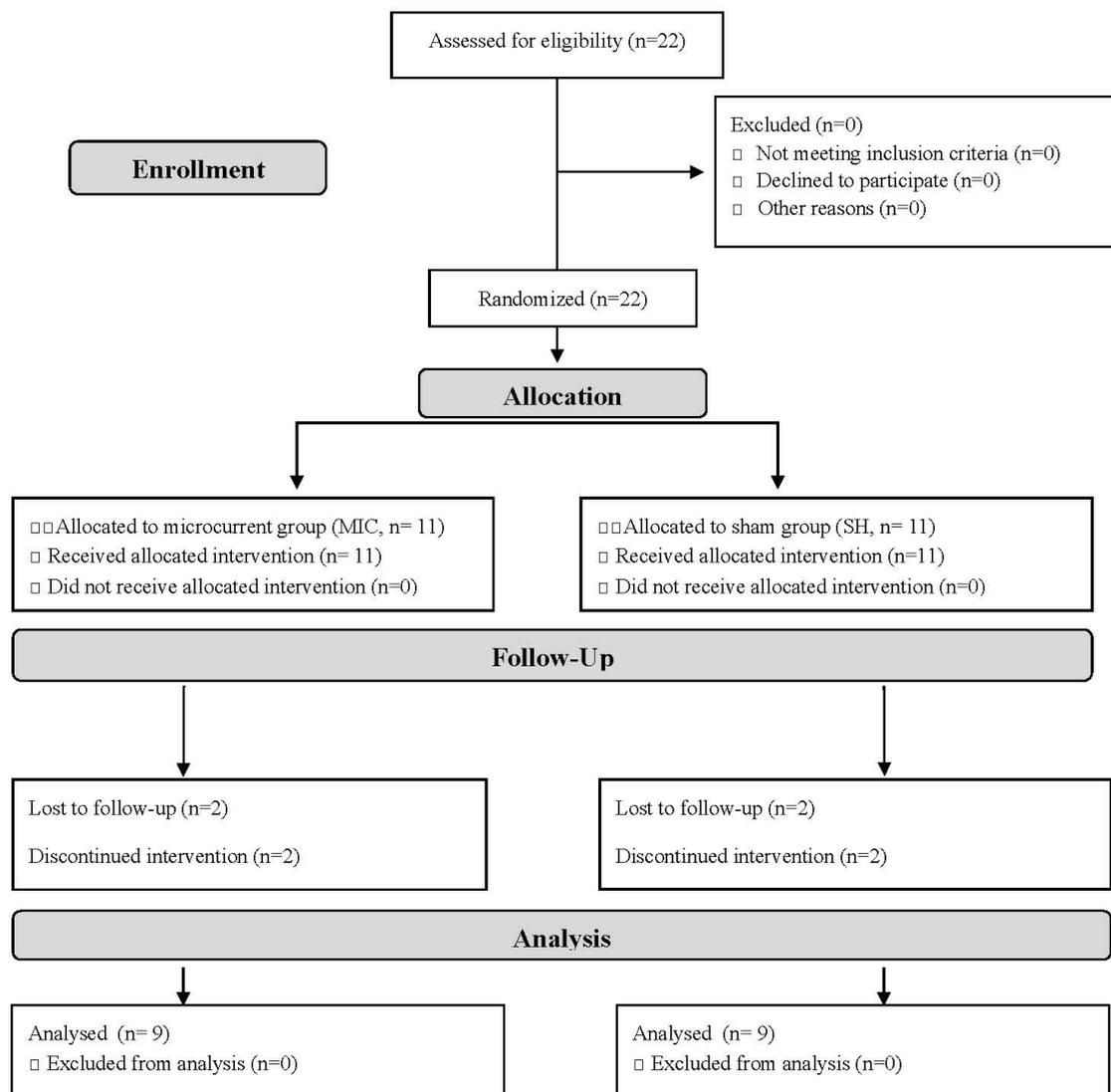

Figure 1. Flow diagram of participants throughout the course of the study.

Presented as mean ± standard deviation the final composition of the groups was as follows: MIC (n=9): age: 33.2±7.6 yrs; height: 175.4±5.9 cm; BM: 67.7±6.6 kg; $\dot{V}O_{2peak}$: 61.2±5.1 ml·kg^{-1}·min^{-1}; MAS 17.6±1.2 km·h^{-1}. SH (n=9): age: 32.2±8.1 yrs; height: 172.8±4.4 cm; BM: 67.2±5.9 kg; $\dot{V}O_{2peak}$: 60.8±7.0 ml·kg^{-1}·min^{-1}; MAS 17.8±1.4 km·h^{-1}.

Experimental Design

The study utilised a two-parallel group randomised controlled trial design. Following the initial assessment, and after being matched by body mass (BM) and peak oxygen consumption

($\dot{V}O_{2peak}$), participants were randomly allocated into a Microcurrent (MIC; n=9) or a Sham (SH; n=9) group. Measures of body composition, performance, post-exercise lactate concentration and DOMS were assessed before and after an 8-week intervention period. Both groups performed a similar endurance training programme throughout the study.

Measurements

Before and after an 8-week intervention period, measurements of endurance performance, body composition, blood lactate and DOMS were determined. The participants were instructed to refrain from any vigorous activity and avoid caffeine ingestion for at least 48-h. All tests were performed at the same time of the day for the same participant.

Performance: A progressive to volitional exhaustion running test (PGT) was used to determine $\dot{V}O_{2peak}$ and MAS. After a general warm-up, starting at 10 km·h^{-1}, running speed was increased by 0.3 km·h^{-1} every 30-sec until volitional exhaustion. Gas exchange data were collected continuously using an automated breath-by-breath system (Ultima^{TM} Series, MGC Diagnostic Corporation, St. Paul, Minnesota, USA Vmax 29C), which was calibrated according to the manufacturer's instructions. The volume calibration was performed at different flow rates with a 3-L calibration syringe ensuring an error of <3%. The calibration of gas analysers was performed automatically using reference values of environmental gases and cylinders (16% O_2, 4% CO_2). Additionally, heart rate (HR) was continuously monitored using a Polar Sporttester (Polar Electro, Jyväskylä, Finland). $\dot{V}O_{2peak}$ was recorded as the highest $\dot{V}O_2$ value obtained for any continuous 30-sec period. MAS was associated with the last completed 30-sec stage before exhaustion (Esteve-Lanao, Foster, Seiler, & Lucia, 2007).

Body Composition: BM, whole body fat mass, whole body lean mass, total trunk fat mass, estimated visceral fat mass, and fat and lean mass for upper and lower limbs (right and left) were measured using dual-energy X-ray absorptiometry (General Electric Healthcare, Madison, WI). These measurements were performed under standardized conditions, in the morning and in a fasted state.

Blood Lactate: Whole capillary 0.2 μl capillary blood samples were collected from a fingertip site immediately at <30-sec, 3-min and 5-min after the completion of the PGT. After completing the last stage of the PGT the participants were instructed to reduce the treadmill speed, to walk for about 30-sec and then to remain in a seated position until the completion of the final blood sample collection (~ 5-min). A Lactate Scout 4 (Lactate Scout; EKF, Barleben, Germany) portable analyser was used for determining all lactate measurements. The analyser was cleaned and operated in accordance with the manufacturer's instructions.

DOMS: Muscle soreness in anterior and posterior thigh (lower limb) was evaluated pre- and post-the 8-week intervention protocol at 24-h, 48-h and 72-h after performing a single bout of the Exercise Induced Muscle Soreness Protocol (EIMS). The EIMS involved 10 sets of 10 repetitions with 1-min rests between the sets of the parallel squat exercise (100 squats) with a 20 kg load bar using a Smith machine (Life Fitness, OSSM RT, Hungary) with a no counterweight mechanism.

Participants were instructed to perform the descending controlled phase until reaching a parallel position (posterior tight parallel to the floor) and to complete the ascending concentric phase with a maximal possible movement velocity. At three assessed time points (24-h, 48-h and 72-h, post-EIMS), the participants performed a standardized warm-up involving five slow squat movements without external overload followed by a short walk and slow jog. Thereafter, participants assisted by the same researcher were asked to evaluate lower extremity muscle soreness on a visual analogue scale (VAS) ranging from no pain at all (0 mm) to worst possible pain (100 mm) as described elsewhere (Bijur, Silver, & Gallagher, 2001).

Control of Training and Diet: All the participants committed to follow the 8-week training programme using a polarised intensity distribution model (Esteve-Lanao et al., 2007). The polarised training included three intensity speed-based zones delineated according to the localisation of the second ventilatory threshold (VT2). The polarised distribution model involves significant proportions of both high- and low-intensity training and only a small proportion of moderate-intensity training. The intensity zones were calculated as zone 1, low intensity: ≤75% of VT2, 72% of HRmax, zone 2,

moderate intensity: between 76% and 95% of VT2, 73% to 82% HRmax, and zone 3, high intensity: between 96% and 120% of VT2, 83% to 97% HRmax. All the participants started the intervention at the beginning of their training season, and they were consistently supervised by the same coach. They trained 5 to 6 sessions per week with a distribution of 75%–80% in zone 1, ~5% in zone 2, and 15%–20% in zone 3. The associated HR, determined during the testing procedures, was used to quantify the intensity performed within each training zone. The training volume was quantified through the total distance covered in each workout. The volume and the performed intensity were recorded on a daily base using a personalised training diary. Adjustment in training intensity during the 8-week intervention period were determined through the heart rate response. All the participants trained during the afternoon (12:00 – 18:00).

A 3-day diet record was analysed using the Dietplan 7 software (Forestfield Software Ltd, Horsham, UK). The average relative amount in $g \cdot kg^{-1} \cdot BM^{-1}$ of proteins, carbohydrates and fat were as follows: MIC 1.75±0.3, 3.65±1.4, 1.40± 0.4; SH 1.85±0.4; 3.5±1.0, 1.40±0.4. The relative daily energy intake was 34.7±10.5 $kcal \cdot kg^{-1} \cdot BM^{-1}$ and 34.7±8.3 $kcal \cdot kg^{-1} \cdot BM^{-1}$ for MIC and SH respectively. No between groups significant differences in the macronutrient intake or energy consumption were observed. To avoid potential confounding effects, the participants were instructed to maintain their normal diet throughout the intervention and to report any minimal change in food composition, serving size, or compliance with the reported meals including breakfast, lunch, post-workout food intake and dinner. If any change in their feeding patterns were reported or identified (i.e. becoming vegetarian, restricting calories, taking nutritional supplements, etc.) participants' data would have been excluded from the analysis.

Intervention: After completing the initial evaluation and in accordance with the randomisation, each participant received a microcurrent or sham device. Both devices were identical in appearance, i.e. size [45 mm (width) x 15 mm (depth) x 105 mm (length)], colour and weight (~64 g)]. All participants were instructed to place the device on the dominant lower leg, at about the midpoint between the knee and ankle for 3-h immediately after the completion of each training session or in

the morning during non-training days. The Arc4Sports (ARC Microtech Ltd, East Sussex, UK) is a rechargeable battery-operated commercially available device that sends a pulsating stream of electrons in a relatively low concentration throughout the body (between 2 and 11 pulses per bunch). Set by the manufacturer, the device delivers ubiquitous electrical currents to the human body by output channels utilising a complex pulsed waveform with a fundamental frequency of 1.0309 kHz, which is given in bursts of varying length and separation. The intensity of the current varies between 50 and 400 µA in a ratio of 2:1 (on:off), using two blocks involving two consecutive cycles of 5 min:2.5 min and 10 min:5min, for a duration of 45 minutes each cycle (3 hours in total). The effect of the microcurrent is to induce a flow of electrons into the tissue.

Since the current transmitted from the microcurrent device is insufficient to stimulate sensory nerve fibres, the stimulus was imperceptible and consequently neither participants nor researchers were able to identify participants' group allocation. One independent researcher, who was not in contact with participants, decoded the devices after completing the analysis of the data. Potential adverse events and compliance with the treatments were evaluated continuously with an individual follow up of the participants.

The researchers controlled compliance with all aspects of the study (e.g. workout configuration, diet patterns, post-workout and non-training days device use) using instant phone texts and checking in with participants during regular weekly interviews. Only participants who completed all training sessions and who self-declared 100% compliance using their assigned device, with no meaningful changes in their eating and recovery patterns were considered for analysis.

Statistical Analysis: A descriptive analysis was performed and subsequently the Shapiro-Francia test was applied to assess normality. Sample characteristics at baseline were compared between groups using an independent-means Student's t-test. All pre- and post- intervention data were summarised and reported as mean ± standard deviation unless stated otherwise.

A 2-way [2 (groups: MIC vs. SH) × 2 (moments: pre- vs. post-intervention)] ANOVA was conducted to assess the effect of the intervention on performance and body composition. As DOMS

and blood lactate concentrations were respectively assessed at three-time points (24-h, 48-h and 72-h) after the completion of the EIMS and at <30-sec, 3 min and 5 min after the completion of the PGT, a 3-way [2 (groups: MIC vs. SH) × 3 (times: pre, post 24-h or 30-sec; post-48-h or 3-min and post 72-h or 5-min) or 1 (average value calculated from the three collected lactate or DOMS measures) × 2 moments (pre- vs. post-intervention)] ANOVA was used for examining these two dependent variables.

Differences over time were compared using Bonferroni-adjusted pairwise comparisons when appropriate. Eta Square (η^2) and Cohen's d standardized effect sizes of the adjusted differences between intervention groups were calculated from ANOVA F tests, and compared to common benchmarks (small η^2=0.01, d=0.2; moderate η^2 =0.06 d=0.5; and large η^2=0.14, d=0.8) (Cohen, 1988).

All statistics were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 20.0; SPSS, Inc., Chicago, IL, USA). Significance level was set to $P < 0.05$.

Results

No between groups differences in any of the performance and body composition variables were observed at baseline. Pre- and post- values of main time and group effects, as well as interactions between treatments and time, are provided in Table 1.

Table 1. Mean (M) ± standard deviation (SD) of the pre and post values of the body composition and performance analysed variables for the two intervention groups

Variables	Microcurrent (n = 9)			Sham (n = 9)			Repeated Measure ANOVA
	pre	post	ES	pre	post	ES	(2 groups x 2 times)
$\dot{V}O_{2peak}$ (ml·kg·min^{-1})	62.2 ± 5.4	63.1 ± 3.8	0.50	60.8 ± 7.5	62.9 ± 9.1	0.53	Moment: $F_{(1,16)}$=4.80, p=0.044, η^2=0.23 Group: $F_{(1,16)}$=0.01, p=0.927, η^2=0.01 Group x Moment: $F_{(1,16)}$=0.033, p=0.956, η^2=0.01
Maximal aerobic speed (km·h^{-1})	17.6 ± 1.3	18.3 ± 1.0**	2.12	17.8 ± 1.5	18.3 ± 1.3**	1.48	Moment: $F_{(,)}$=58.86, p=0.001, η^2=0.78 Group: $F_{(1,16)}$=0.03, p=0.876, η^2=0.01 Group x Moment: $F_{(1,16)}$=1.86, p=0.193, η^2=0.02
Body mass (kg)	67.7 ± 7.0	67.5 ± 6.9	0.31	67.2 ± 6.3	67.8 ± 6.1*	0.79	Moment: $F_{(1,16)}$=1.01, p=0.330, η^2=0.04 Group: $F_{(1,16)}$=0.01, p=0.927, η^2=0.01 Group x Moment: $F_{(1,16)}$=5.46, p=0.033, η^2=0.25
Whole body fat mass (kg)	13.0 ± 4.0	12.4 ± 4.0^T	0.69	12.9 ± 4.7	13.0 ± 4.7	0.16	Moment: $F_{(1,16)}$=1.26, p=0.279, η^2=0.06 Group: $F_{(1,16)}$=0.01, p=0.909, η^2=0.01 Group x Moment: $F_{(1,16)}$=3.23, p=0.091, η^2=0.16
Whole body lean mass (kg)	52.7 ± 5.0	53.3 ± 4.2	0.42	53.2 ± 3.7	53.7 ± 3.4	0.42	Moment: $F_{(1,16)}$=3.19, p=0.093, η^2=0.17 Group: $F_{(1,16)}$=0.06, p=0.805, η^2=0.01 Group x Moment: $F_{(1,16)}$=0.01, p=0.998, η^2=0.01
Total trunk fat mass (kg)	5.7 ± 1.8	5.5 ± 1.8	0.41	5.6 ± 2.4	5.8 ± 2.4	0.38	Moment: $F_{(1,16)}$=0.01, p=0.956, η^2=0.01 Group: $F_{(1,16)}$=0.01, p=0.907, η^2=0.01 Group x Moment: $F_{(1,16)}$=2.77, p=0.116, η^2=0.15
Trunk lean mass (kg)	23.2 ± 2.7	24.2 ± 2.0*	0.95	23.4 ± 1.7	24.3 ± 1.6*	0.81	Moment: $F_{(1,16)}$=14.01, p=0.002, η^2=0.47 Group: $F_{(1,16)}$=0.03, p=0.858, η^2=0.01 Group x Moment: $F_{(1,16)}$=0.08, p=0.776, η^2=0.01
Visceral fat mass (kg)	0.31 ± 0.11	0.25 ± 0.10	0.48	0.26 ± 0.14	0.26 ± 0.13	0.02	Moment: $F_{(1,16)}$=0.95, p=0.344, η^2=0.06 Group: $F_{(1,16)}$=0.22, p=0.649, η^2=0.01 Group x Moment: $F_{(1,16)}$=1.09, p=0.313, η^2=0.06
Total lower body limb fat mass (kg)	4.8 ± 1.5	4.5 ± 1.5*	0.80	4.7 ± 1.7	4.7 ± 1.7	0.16	Moment: $F_{(1,16)}$=1.84, p=0.194, η^2=0.10 Group: $F_{(1,16)}$=0.01, p=0.957, η^2=0.01 Group x Moment: $F_{(1,16)}$=4.13, p=0.059, η^2=0.19
Total lower body limb lean mass (kg)	19.5 ± 1.9	19.3 ± 1.9	0.34	19.7 ± 1.4	19.7 ± 1.5	0.08	Moment: $F_{(1,16)}$=0.30, p=0.595, η^2=0.02 Group: $F_{(1,16)}$=0.16, p=0.696, η^2=0.01 Group x Moment: $F_{(1,16)}$=0.81, p=0.381, η^2=0.05
Total upper body limb fat mass (kg)	1.5 ± 0.8	1.4 ± 0.7	0.58	1.6 ± 0.7	1.4 ± 0.6	0.61	Moment: $F_{(1,16)}$=6.30, p=0.023, η^2=0.28 Group: $F_{(1,16)}$=0.02, p=0.878, η^2=0.01 Group x Moment: $F_{(1,16)}$=0.01, p=0.933, η^2=0.01
Total upper body limb lean mass (kg)	6.3 ± 0.9	6.1 ± 0.7	0.59	6.3 ± 0.9	6.2 ± 0.8	0.13	Time: $F_{(1,16)}$=2.35, p=0.145, η^2=0.01 Group: $F_{(1,16)}$=0.02, p=0.881, η^2=0.01 Group x Moment: $F_{(1,16)}$=0.97, p=0.338, η^2=0.06

Note: Pairwise comparison *p<0.05; **p<0.01 respect to pre-intervention values. ^{T}p >0.05 and <0.1. ES= Cohen's d, effects size for two dependent means.

Both groups similarly increased MAS with no significant difference between groups. Although a significant time effect was observed for $\dot{V}O_{2peak,}$ no significant differences between pre and post values were observed in either group.

Main group per moment interaction effect was determined for BM (P=0.033, η^2=0.25). Similarly, a close to significant interaction (group × moment) with large effect sizes were observed for whole body fat mass (p=0.091, η^2=0.16) and total lower body limb fat mass (p=0.059, η^2=0.19). At post-intervention, BM increased significantly in the SH group (P=0.031) but not in the MIC group, which however showed a non-significant (P=0.056, d=0.69) decrease in whole-body fat. Both groups showed no changes in total trunk fat (including visceral fat component) along with significant increases in trunk lean mass (MIC, P=0.012, SH, P=0.027) but only the MIC group significantly decreased lower body limb fat (P=0.029).

Blood Lactate: A close to significant main interaction (moment x time x group) effect [F(2, 16)=3.11, P=0.058, η^2=0.13] was observed. However, no main effects were determined for the average lacticaemia. At pre-intervention, no significant differences were observed between groups (P>0.05) for the three analysed time points (<30-sec, 3-min and 5-min post-PGT) or the average lacticaemia. At post-intervention, the SH group showed a very similar response as observed at pre-intervention. However, compared to pre-intervention, only the MIC group produced a different response, achieving a non-significant higher lactate concentration at <30-sec (P=0.087, ES=0.61). Furthermore, only the MIC group achieved significantly (P=0.043) lower lactate concentrations at 3-min post-PGT. Nonetheless, no differences between groups were determined on the average lacticaemia calculated over the post-exercise 5 min recovery period (Figure 2).
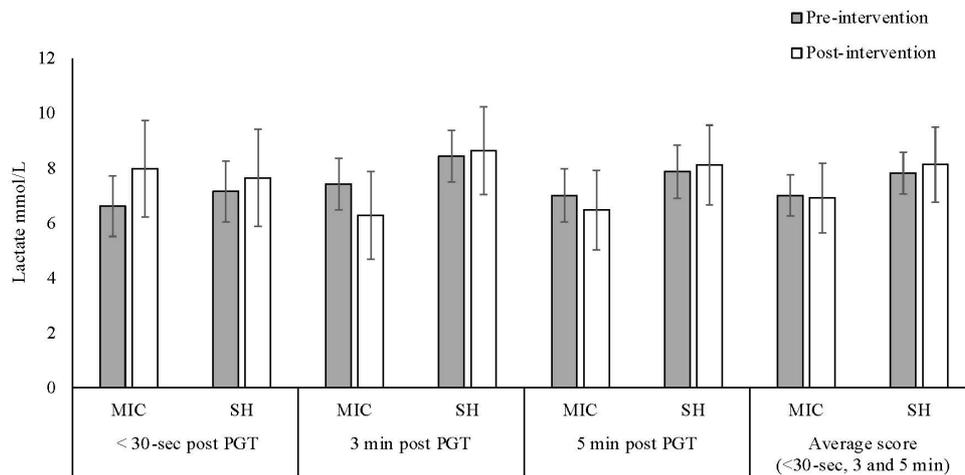
Figure 2. Estimated means and 95% confidence intervals of blood lactate concentration determined before and after the 8-weeks intervention period at pre- vs. post-intervention, classified by group, each post-PGT time point and the calculated average score resulted from the three collected measures. No significant differences (all P>0.05) were observed from pre- to post-intervention in both treatments. MIC = microcurrent group; SH= sham group; PGT = progressive to volitional exhaustion running test.

DOMS: A main interaction (moment x time x group) effect was observed between the three measured time points [$F_{(2,16)}=3.78$, P=0.033 $\eta^2=0.18$] and for the three-value averaged DOMS score [$F_{(1,16)}=30.13$, P=0.001 $\eta^2=0.08$]. At pre-intervention, no significant differences were observed between groups (p>0.05) for either the three post-EIMS time points (24, 48 and 72-h) or the average score. Compared to pre-intervention, only MIC significantly reduced DOMS at 24-h post-EIMS (P=0.001) at 48-h (P=0.010) and 72-h (P=0.001) post-EIMS. These values were also significantly lower than those measured in SH at 24-h (P=0.014), 48-h (P=0.038) and for the average score (P=0.019). Moreover, SH significantly increased DOMS at 24-h (P=0.040) with no differences to pre-intervention values at 48-h and 72-h after the completion of EIMS (Figure 3).
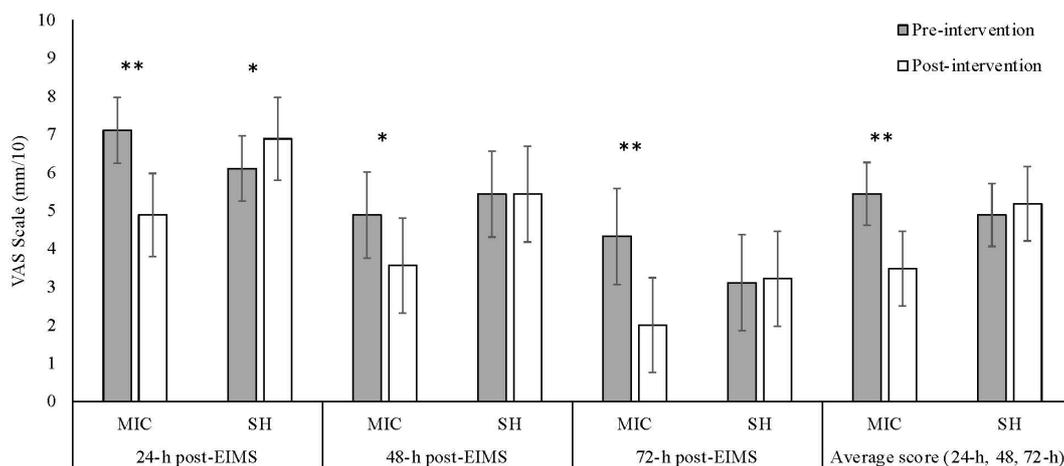
Figure 3. Estimated means and 95% confidence intervals of the delayed muscle soreness measured from the visual analogue (VAS) scale at pre- vs. post-intervention, classified by group, each post-EIMS time point and the calculated average score resulted from the three collected measures. *p<0.05; **p<0.01 from pre- to post- intervention.
MIC = microcurrent group; SH = sham group; EIMS= Exercise Induced Muscle Soreness Protocol.

Discussion

Results of the present study suggest that applying a microcurrent with an intensity varying between 50-400 µA and with a fundamental frequency of ~1 kHz, for 3 hours after workouts or during the morning of non-training days, produces no additive benefits on endurance performance. Nonetheless, it is worth noting that using microcurrent promotes more desired body composition changes for endurance athletes by maintaining BM and decreasing lower limb fat, along with a trend toward decreasing whole body fat. Furthermore, including microcurrent during the post-workout time reduced DOMS over 72-h after performing an exhaustive lower body exercise.

Based on the observed results we have to reject our hypothesis that supports the additive effect of microcurrent to maximise performance outcomes in male endurance athletes. Conversely, for optimising body composition and attenuating DOMS our hypothesis can be accepted with regards to the beneficial effects of adding microcurrent to endurance training.

The food analysis showed similar macronutrient and energy intake for both groups. Regardless of the group, the daily protein consumption for all participants was between 1.4 and 2.1 $g \cdot kg^{-1} \cdot BM^{-1}$. These figures are within the accepted daily protein range to support training adaptations

14

in endurance athletes and to compensate for the relatively low carbohydrate intake <5 $g{\cdot}kg^{-1}{\cdot}BM^{-1}$ observed for the two groups (Thomas, Erdman, & Burke, 2016). Consequently, within the context of the present study, no limitations due to sub-optimal nutrition should have affected the observed results.

Both groups showed significant increases in the MAS values with no statistically significant changes on $\dot{V}O_{2peak}$ (Table 1). As may be expected for well-trained endurance athletes, changes in the capacity to sustain the absolute speed will ultimately dictate the level of performance regardless of changes in $\dot{V}O_{2peak}$ (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999; González-Mohíno et al., 2016). This observed outcome could be related to an increased anaerobic capacity which, due to a more efficient lactate turnover during the last part of the PGT, allowed athletes to tolerate a higher amount of protons and consequently improve their work capacity (Billat, Renoux, Pinoteau, Petit, & Koralsztein, 1994; Faina et al., 1997). In this regard, it seems that compared to SH, the 8-week microcurrent treatment did not maximise such adaptations. Nonetheless, given the reduced DOMS perception, it could be possible that the instructions not to modify the training load (e.g. intensity, volume or frequency) which was equalised between groups, prevented participants in the MIC group to take advantage of a more efficient recovery and consequently to undertake a higher-quality training programme, as this scenario would have likely resulted in better performance outcomes compared to SH.

Although mainly determined by the lean component, the observed increase of BM in the SH group could be interpreted as a non-desirable change associated with higher caloric expenditure that potentially impairs endurance performance in runners (Saunders, Pyne, Telford, & Hawley, 2004). As all participants maintained their eating patterns, considering the daily estimated caloric intake ($\sim$35 $kcal{\cdot}kg^{-1}{\cdot}BM^{-1}$ representing $\sim$44 $kcal{\cdot}kg^{-1}{\cdot}whole\ body\ lean\ mass^{-1}$) was relatively low for endurance athletes (Loucks, Kiens, & Wright, 2011), it is unlikely the observed BM increase could be a consequence of an overeating behaviour but mainly due to a training-induced adaptation. It is also notorious that in contrast to the SH group which showed no changes in fat mass, participants

using microcurrent compensated the increase of lean mass by reducing the fat component with no changes in total BM. Indeed, only MIC significantly decreased lower body fat and showed a close to statistically significant reduction ($P=0.056$, $d=0.69$) in whole-body fat. In this regard, it seems that adding microcurrent to the endurance programme promoted better body composition changes by optimising fat reduction and by supporting lean mass accretion. These observed changes have previously been associated with more efficient recovery, reduced overload related injuries and better training outcomes in long-distance athletes (Doering, Reaburn, Phillips, & Jenkins, 2016).

The significant decrease of lower body fat observed in MIC is, furthermore, worth noting. As all participants wore the device placed on the dominant lower leg, we cannot disregard a potential local lipolytic effect of microcurrent to maximise fat mobilisation. Even though the manufacturer highlighted that the used microcurrent technology transmits a ubiquitous electrical current, the observed results suggest a stronger local lipolytic effect. Indeed, regional electrolipolysis stimulation using microcurrent transmitted by transcutaneous electrodes placed in the abdominal region enhanced local lipolysis, accentuates the reduction of subcutaneous abdominal fat in females exposed to a 30-min endurance exercise protocol (Noites et al., 2015). Moreover, it has been proposed that microcurrent extends lipolysis by a further stimulation of β-adrenergic receptors which in turn produce higher levels of cAMP (Lee et al., 2010). Therefore a greater lipolysis activation through the protein kinase-mediated phosphorylation of hormone-sensitive lipase is produced (Ahmadian, Wang, & Sul, 2010).

Despite the lower lactate concentration measured in MIC at 3-min post-PG, the lack of differences observed at both 5 min and the average values calculated over the entire recovery period (Figure 2) precludes any conclusion on the potential benefits of microcurrent to enhance lactate kinetics during and after fatiguing exercises performed with a high metabolic glycolytic component.

On the other hand, similarly with previous studies (Curtis et al., 2010; Lambert et al., 2002; Naclerio et al., 2019), the application of the microcurrent reduced the perception of DOMS after performing a severe exercise bout (Figure 3). In our study, the regular post-exercise application of

microcurrent could have optimised the capacity of the muscles to attenuate the induced muscular disruption by the maintenance of a more favourable intracellular Ca^{2+} homeostasis, after the completion of the EIMS protocol (Naclerio et al., 2019). Indeed, it has been proposed that microcurrent can optimise recovery and muscle remodelling after exercise by stimulating of the muscle protein synthesis and satellite cell proliferation (Fujiya et al., 2015; Hiroshige et al., 2018). Furthermore, given the association between the severity of DOMS with a loss of range of motion, which affects the correct exercise technique (Allen, Mattacola, & Perrin, 1999), the reduced level of DOMS in MIC could express a more efficient capacity of the muscles to recover from an exhaustive exercise session. This could be of relevance in sports where athletes are required to undertake frequent training or competitions with a high level of physical and technical performance (Owens, Twist, Cobley, Howatson, & Close, 2018).

Our study is not without limitations: The intervention period lasted only 8 weeks and although it is an acceptable time to produce measurable changes in athletic performance and body composition, it is possible that results between groups could have showed different patterns of response if the intervention had lasted longer (e.g. >3 months). Furthermore, as only endurance trained males were assessed, further studies involving females are warranted.

From a practical perspective our results do not support the use of microcurrent as a potential ergogenic method for improving performance in endurance athletes. Nonetheless, coaches can consider microcurrent as an alternative non-invasive method to reduce the level of muscle soreness after exhaustive exercise sessions in well endurance-trained athletes.

Conclusions

Although no significant differences in performance outcomes were observed after 8 weeks of endurance training, compared to a sham group, a 3-h daily application of microcurrent promoted more desirable changes in body composition. Moreover, the regular application of a post-workout microcurrent treatment attenuated the perception of DOMS in endurance trained men.

References

Ahmadian, M., Wang, Y., & Sul, H. S. (2010). Lipolysis in adipocytes. *International Journal of Biochemistry and Cell Biology*, *42*, 555–559. https://doi.org/10.1016/j.biocel.2009.12.009

Allen, J. D., Mattacola, C. G., & Perrin, D. H. (1999). Effect of Microcurrent Stimulation on Delayed-Onset Muscle Soreness: A Double-Blind Comparison. *Journal of Athletic Training*, *34*(4), 334–337.

Bijur, P., Silver, W., & Gallagher, E. (2001). Reliability of the visual analog scale for measurement of acute pain. *Academic Emergency Medicine*, *8*(12), 1153-11577. https://doi.org/10.1111/j.1553-2712.2001.tb01132.x

Billat, V. L., Flechet, B., Petit, B., Muriaux, G., & Koralsztein, J. P. (1999). Interval training at $\dot{V}O(2max)$: Effects on aerobic performance and overtraining markers. *Medicine and Science in Sports and Exercise*, *31*, 156–163. https://doi.org/10.1097/00005768-199901000-00024

Billat, V., Renoux, J. C., Pinoteau, J., Petit, B., & Koralsztein, J. P. (1994). Reproducibility of running time to exhaustion at VO2max in subelite runners. *Medicine and Science in Sports and Exercise*, *26*(2), 254–257. https://doi.org/10.1249/00005768-199402000-00018

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum.

Curtis, D., Fallows, S., Morris, M., & McMakin, C. (2010). The efficacy of frequency specific microcurrent therapy on delayed onset muscle soreness. *Journal of Bodywork and Movement Therapies*, *14*, 272–279. https://doi.org/10.1016/j.jbmt.2010.01.009

Doering, T. M., Reaburn, P. R., Phillips, S. M., & Jenkins, D. G. (2016). Postexercise Dietary Protein Strategies to Maximize Skeletal Muscle Repair and Remodeling in Masters Endurance Athletes: A Review. *Int J Sport Nutr Exerc Metab*, *26*(2), 168–178. https://doi.org/10.1123/ijsnem.2015-0102

Esteve-Lanao, J., Foster, C., Seiler, S., & Lucia, A. (2007). Impact of training intensity distribution on performance in endurance athletes. *Journal of Strength and Conditioning Research*, *21*(3), 943–949. https://doi.org/10.1519/R-19725.1

Faina, M., Billat, V., Squadrone, R., De Angelis, M., Koralsztein, J. P., & Dal Monte, A. (1997). Anaerobic contribution to the time to exhaustion at the minimal exercise intensity at which maximal oxygen uptake occurs in elite cyclists, kayakists and swimmers. *European Journal of Applied Physiology and Occupational Physiology*, *76*(1), 13–20. https://doi.org/10.1007/s004210050207

Fujiya, H., Ogura, Y., Ohno, Y., Goto, A., Nakamura, A., Ohashi, K., … Goto, K. (2015). Microcurrent electrical neuromuscular stimulation facilitates regeneration of injured skeletal muscle in mice. *Journal of Sports Science and Medicine*, *14*, 297–303.

González-Mohíno, F., González-Ravé, J. M., Juárez, D., Fernández, F. A., Barragán Castellanos, R., & Newton, R. U. (2016). Effects of Continuous and Interval Training on Running Economy, Maximal Aerobic Speed and Gait Kinematics in Recreational Runners. *Journal of Strength and Conditioning Research*, *30*(4), 1069–1066. https://doi.org/10.1519/JSC.0000000000001174

Hiroshige, Y., Watanabe, D., Aibara, C., Kanzaki, K., Matsunaga, S., & Wada, M. (2018). The Efficacy of Microcurrent Therapy on Eccentric Contraction-Induced Muscle Damage in Rat Fast-Twitch Skeletal Muscle. *Open Journal of Applied Sciences*, *8*, 98–102. https://doi.org/10.4236/ojapps.2018.83008

Kwon, D. R., Kim, J., Kim, Y., An, S., Kwak, J., Lee, S., … Park, J. W. (2017). Short-term microcurrent electrical neuromuscular stimulation to improve muscle function in the elderly: A randomized, double-blinded, sham-controlled clinical trial. *Medicine (United States)*, *96*(26), e7407. https://doi.org/10.1097/MD.0000000000007407

Lambert, M. I., Marcus, P., Burgess, T., & Noakes, T. D. (2002). Electro-membrane microcurrent therapy reduces signs and symptoms of muscle damage. *Medicine & Science in Sports & Exercise*, *34*(4), 602–607. https://doi.org/10.1249/00005768-200204000-00007

Lee, B. Y., Al-Waili, N., Stubbs, D., Wendell, K., Butler, G., Al-Waili, T., & Al-Waili, A. (2010). Ultra-low microcurrent in the management of diabetes mellitus, hypertension and chronic wounds: Report of twelve cases and discussion of mechanism of action. *International Journal of Medical Sciences*, *7*(1), 29–35. https://doi.org/10.7150/ijms.7.29

Loucks, A. B., Kiens, B., & Wright, H. H. (2011). Energy availability in athletes. *Journal of Sports Sciences*, *29*, S7-S15. https://doi.org/10.1080/02640414.2011.588958

Moon, Y. S., Kwon, D. R., & Lee, Y. J. (2018). Therapeutic effect of microcurrent on calf muscle atrophy in immobilized rabbit. *Muscle and Nerve*, *52*(8), 270–276. https://doi.org/10.1002/mus.26110

Naclerio, F., Seijo, M., Karsten, B., Brooker, G., L., C., Thirkell, J., & Larumbe-Zabala, E. (2019). Effectiveness of

combining microcurrent with resistance training in trained males. *European Journal of Applied Physiology*, *119*(11), 2641–2643. https://doi.org/10.1007/s00421-019-04243-1

Noites, A., Nunes, R., Gouveia, A. I., Mota, A., Melo, C., Viera, Á., … Bastos, J. M. (2015). Effects of Aerobic Exercise Associated with Abdominal Microcurrent: A Preliminary Study. *The Journal of Alternative and Complementary Medicine*, *21*, 229–236. https://doi.org/10.1089/acm.2014.0114

Ohno, Y., Egawa, T., Yokoyama, S., Fujiya, H., Sugiura, T., Ohira, Y., … Goto, K. (2019). MENS-associated increase of muscular protein content via modulation of caveolin-3 and TRIM72. *Physiological Research*, *68*, 265–273. https://doi.org/10.33549/physiolres.933992

Owens, D. J., Twist, C., Cobley, J. N., Howatson, G., & Close, G. L. (2018). Exercise-induced muscle damage: What is it, what causes it and what are the nutritional solutions? *European Journal of Sport Science*, *15*, 1–15. https://doi.org/10.1080/17461391.2018.1505957

Poltawski, L., & Watson, T. (2009). Bioelectricity and microcurrent therapy for tissue healing – a narrative review. *Physical Therapy Reviews*, *14*(2), 104–114. https://doi.org/10.1179/174328809x405973

Saunders, P. U., Pyne, D. B., Telford, R. D., & Hawley, J. A. (2004). Factors affecting running economy in trained distance runners. *Sports Medicine*, *34*(7), 465–485. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15233599

Thomas, T., Erdman, K. A., & Burke, L. M. (2016). American College of Sports Medicine Joint Position Statement: Nutrition and athletic performance. *Medicine & Science in Sports & Exercise*, *48*(3), 543–568. https://doi.org/10.1001/jama.1956.02970290016006

Udani, J. K., Singh, B. B., Singh, V. J., & Sandoval, E. (2009). BounceBack[TM] capsules for reduction of DOMS after eccentric exercise: A randomized, double-blind, placebo-controlled, crossover pilot study. *Journal of the International Society of Sports Nutrition*, *6*, 14. https://doi.org/10.1186/1550-2783-6-14.