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Original

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Knee proprioception may be altered by treatment in athletes suffering from delayed onset muscle soreness

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1 ABSTRACT

2 Delayed onset muscle soreness (DOMS) is a very common 3 musculoskeletal problem in athletes involved in extreme competitions. The aim of this study is to compare the effect of diathermy, sham diathermy and massage 4 on the knee proprioception of athletes treated for DOMS. Forty athletes were 5 6 enrolled after the second day of a demanding ski mountaineering race. They were 7 randomly assigned to 4 groups: no treatment (n = 10), massage (n = 10), 8 diathermy (n = 10), and sham diathermy (n = 10). The knee reposition error was 9 measured after the treatments in order to assess knee proprioception. Significant 10 differences between the diathermy and sham diathermy groups were found (p =0.01) with an absolute effect size of 4.7°. No other significant differences were 11 found among groups. This means that diathermy has a negative impact on joint 12 proprioception and can be explained by the spindle desensitization consequent 13 14 to deeper tissue heating. This information can be important in the DOMS management of athletes, since an altered proprioception may interfere with the 15 16 athlete's performance and can increase the risk of injury.

17 **KEYWORDS**: Joint position sense; deep-tissue heating; manual therapy; ski
18 mountaineering.

19 **1. INTRODUCTION**

In recent years, extreme competitions that involve athletes for long 20 21 distances are becoming increasingly popular. In this kind of races, musculoskeletal problems are very common,¹ the most frequent of which is 22 delayed onset muscle soreness (DOMS).² DOMS entails symptoms that can 23 range from muscle tenderness to severe debilitating pain³ localized at the muscle 24 belly and tendon-bone junction,⁴ and are classified as muscle injuries.⁵ DOMS 25 usually result from strenuous, unaccustomed tasks of an eccentric nature.³ Ski 26 mountaineering has been described as a strenuous exercise involving different 27 kinds of metabolic changes⁶ and, in particular, downhill skiing implies eccentric 28 contractions.⁷ Hence, in ski mountaineering races, the long-lasting eccentric 29 effort during the downhill part of the race is a typical cause of DOMS. 30

While excessive and prolonged eccentric muscle contractions are a welldocumented cause of DOMS^{2,8}, the underlying mechanisms are still a source of debate. Many theories have been proposed to explain DOMS, among which: connective tissue damage, muscle damage,⁹ inflammation¹⁰ and enzyme efflux theory.³ Furthermore, some authors suggested that pain is related to an adaptive remodelling of the myofibril proteins rather than myofibril damage.¹¹

DOMS typically appear between 8 and 24 hours post-exercise, peaks between 24 and 72 hours and can last up to 7 days.¹² Pain related to DOMS is associated to reduced joint range of motion, oedema, increased risk of injury,³ and altered proprioception.¹³ In particular, the effect of DOMS on proprioceptive sensibility and motor control is extensively studied in literature, especially at the level of the ankle and knee joints.^{13–16} As a matter of fact, muscle soreness

produces a deterioration of proprioception in all its aspects, such as joint 43 positioning, muscle tension perception and threshold to detect passive 44 movements.¹³ Proprioceptive alterations associated to DOMS may have a heavy 45 impact on athletic performance. For this reason, it is important that DOMS are 46 effectively treated. The proper management of DOMS is particularly important for 47 athletes involved in multiday races, since they have to maintain high 48 performances throughout the race, in spite of the strenuous eccentric effort 49 sustained each and every day of the race. 50

Different treatments to manage DOMS are described in literature, among which vibration therapy,^{17,18} cold water immersion,¹⁹ curcumin supplementation,²⁰ and massage.^{21–25} In particular, massage is suggested to be effective for pain management,²³ proprioceptive restoration²⁶ and recovery of muscle function²⁷, whereas vibration at low frequencies and amplitudes significantly improves knee joint proprioception.²⁸

Diathermy is frequently used in sports-related musculoskeletal problems, 57 and more generally in the management of musculoskeletal conditions.^{29,30} 58 Diathermy produces deep heating via conversion of electromagnetic energy to 59 thermal energy.³¹ Previous research highlighted an improvement in muscle 60 flexibility using diathermy.³² Furthermore, manufacturers of diathermy devices 61 suggest the possibility to have an improvement in local circulation and metabolic 62 activities, promoting muscle recovery after an injury. However, in the current 63 64 literature there is no evidence supporting the effectiveness of diathermy for the treatment of DOMS. Furthermore, it is not known how diathermy influences 65 66 proprioception.

The aim of this study is to analyse knee proprioception on athletes suffering from DOMS as a consequence of the participation to the first 2 days of a demanding ski mountaineering race. The knee reposition error was quantitatively assessed after receiving manual massage, diathermy, sham diathermy, or no treatment. The DOMS pain at baseline and after treatment was also evaluated.

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74 2. MATERIALS AND METHODS

75 **2.1. Subjects**

Forty male athletes were enrolled in the study right after the second day of 76 the international ski mountaneering race (removed for review) held in April 2016 77 in (removed for review). The race lasted overall three days, and the subjects 78 79 were treated and tested after the second day, in correspondence to the peak of pain, approximately after 30 h from the initial intense eccentric activity. Eligibility 80 81 criteria were age comprised between 20 and 55 years and DOMS complaint. 82 Subjects were assessed by a physical therapist with 10 years of experience in manual therapy, to rule out any contraindication to treatment. Exclusion criteria 83 were reporting a trauma or declaring the use of drugs for pain management. Data 84 were collected in the indoors medical facility near the racing organization center. 85 Athletes were randomized to receive 4 physical therapy cares: A) no treatment, 86 B) massage, C) diathermy, D) sham diathermy (parallel study). Each treatment 87 group was composed of 10 athletes (allocation ratio: 1:1). Athletes did not receive 88 static stretching exercises, but only the treatments described below. 89

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2.2. Treatments

Treatments were administered by physiotherapy students in their last semester of study, supervised by expert physiotherapists. Prior to the experiment, they received formal training on the techniques used during the study. Typical pain areas reported by athletes were quadriceps muscles and, to a lesser extent, gastrocnemii muscles.

97 Students treating athletes in group B were instructed to perform a 10-min 98 effleurage, without causing pain, on both lower limbs, with a particular emphasis 99 on the areas reported to be more symptomatic. The athlete was placed in prone 100 position for the treatment of muscles of the posterior compartment of the lower 101 limb (hamstrings and triceps surae) and in the supine position for the treatment 102 of muscles of the anterior compartment (quadriceps and foot dorsiflexors). A 103 neutral cream was used to perform the massage.

Athletes in group C received a 10-min diathermy treatment (Red Coral Tecnosix, Sixtus, Italy) on symptomatic areas of both lower limbs, in capacitive mode (750 kHz).

107 Athletes in group D received a 10-min sham diathermy treatment (Red 108 Coral Tecnosix, Sixtus, Italy) on symptomatic areas of both lower limbs. To 109 perform sham diathermy, the device was switched on for 30 s, to give the feeling 110 of warmth and then switched off.

111 The operator who switched on/off the diathermy device was not the same 112 who performed the therapy. Thus, the operator who performed diathermy was 113 blind.

114 To avoid bias caused by negative expectations,³³ both diathermy and sham

diathermy groups started the treatment with the operator stating that the devicewas active. In both cases a neutral cream was used.

117 The athletes of group A (no treatment) could benefit from a physical 118 therapy treatment of their choice after the assessment, and they were no more 119 evaluated by the research team (no cross-over was applied).

All outcomes were collected by blinded assessors. Participants, as well as care providers, ignored if diathermy or sham diathermy was being administered. Athletes were randomly assigned to the treatment groups on the basis of a sequence downloaded by a casual sequence generator on the internet (https://www.random.org/).

126 Consent to perform the study was obtained from the local ethical 127 committee and all procedures conformed to the Helsinki declaration. Each subject 128 gave written informed consent prior to participating in this study.

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130 **2.3. Protocol**

Anagraphic and anthropometric data of ski mountaineering racers were collected (see **TABLE 1**). After randomization in the 4 treatment groups, baseline DOMS intensity on lower extremities was assessed by numeric pain rating scale (NPRS).³⁴ Then, athletes received the treatment they were assigned to. Thereafter, DOMS intensity was evaluated again with NPRS (except group A, that received no treatment).

Afterwards, the knee reposition error was assessed. To this purpose, a knee electrogoniometer (STEP32, Medical Technology, Italy; accuracy: 0.5°), commonly used in clinical gait analysis,³⁵ was attached to the lateral side of the

140 athlete's dominant lower limb (see FIGURE 1). The dominant leg was established asking the athlete their preferred foot for kicking a ball. A headband occluded the 141 142 athlete's vision. The athlete assumed a bipedal quiet upright stance, corresponding to the 0° reference angle of knee flexion. Then he was instructed 143 to reach 30° of knee flexion with both knees (target position). A vocal feedback 144 was given to the athlete for reaching the target position, with instructions like "flex 145 more", or "flex less", and "keep the position". When the athlete reached the target 146 147 he was asked to maintain it for 5 seconds and memorize the position. The entire "instruction" procedure was repeated 3 times, with intervals of 3-5 s between trials 148 during which the athlete could rest in upright stance. Then, a second phase of 149 150 the test followed in which the athlete was asked to reproduce the target position as precisely as he could (performed position), for 10 consecutive times. Again he 151 could rest 3-5 s in upright stance between trials. The entire protocol lasted less 152 than 10 minutes (including the sensor positioning). All of the 40 athletes 153 154 successfully completed the protocol.

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156 **2.4. Data analysis**

The experimental protocol was composed of two test phases: A) an instruction phase (with feedback) necessary for the athlete to learn the target position (3 trials), B) a reposition phase (without feedback) aimed at evaluating the athlete's performance while he tried to reproduce the target position (10 trials). The knee reposition error, measured in degrees, was defined as:

$$Knee reposition error = target angle - performance angle, (1)$$

where the "target angle" is the angle of knee flexion that the athlete reached, and maintained for 5 s, during the instruction phase (approximately 30°), and the "performance angle" is the angle obtained during the attempts to reproduce the target position.

An example of the knee joint kinematics measured during the instruction 169 and reposition phases is shown in **FIGURE 2**, for a representative athlete. From 170 171 this figure it can be noticed that there are no clear plateau, in the various trials, for the estimation of the target and performance angles. To obtain reliable and 172 repeatable estimate of these angles, it is important that data processing is not 173 174 based upon the subjective choices of an operator. Instead, automatic and robust techniques of signal processing are advisable, based on histograms obtained 175 from the data.³⁶ 176

177 In particular, for each signal collected, the following steps were 178 performed³⁷:

179 1) selection of the start and end points of each test phase (represented by
red vertical lines in FIGURE 2 and in FIGURE 3 A),

2) building the histogram of the knee angle values measured during the
instruction phase: the target angle was calculated as the mode of this histogram
(see FIGURE 3 B),

3) building the histogram of the knee angle values measured during the reposition phase: the performance angle was calculated as the mode of this histogram (see **FIGURE 3 C**). Notice that both histograms can be bimodal, showing one peak in proximity of 0° (corresponding to the athlete's upright

position) and another peak in proximity of 30° (corresponding to the athlete's knee
flexion). For this reason, to correctly calculate the mode of interest (near 30°),
only the values of the histogram greater than 15° were considered.

For each athlete, the target and performance angles were estimated with the described procedure. The athlete's knee reposition error was calculated as the difference between these two angles (as defined by Eq. 1).

All the calculations were performed by Matlab[®] custom routines, which will
be made available upon request.

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197 **2.5. Statistical analysis**

198 The Matlab[®] Statistics Toolbox was used to implement the statistical 199 analysis.

To verify, a-posteriori (after randomization), that there were no significant differences in anagraphic (age) and anthropometric characteristics (height, weight) among the 4 groups, we applied Kruskas-Wallis tests, choosing a significance level α = 0.05.

204

205 Knee reposition error (main outcome measure)

The average reposition error was estimated for each treatment group (A: no treatment, B: massage, C: diathermy, D: sham diathermy). Two-sample Wilcoxon rank-sum tests (significance level: $\alpha = 0.05$) were used to determine if there were significant differences, in the reposition error, among the 4 treatment groups.

211 Bootstrapping was used for power calculation and confidence interval 212 estimation (number of bootstrap samples = 10000).³⁸

213

214 DOMS pain evaluation

DOMS intensity was evaluated at baseline by NPRS for all the treatment groups (A, B, C, D). It was evaluated a second time, after the physical therapy cares, only for groups B, C, and D, since group A underwent no treatment. In order to check, a-posteriori, if the athletes assigned to the 4 groups had comparable pre-treatment DOMS, a Kruskas-Wallis test was used.

To establish if the treatments were effective in relieving DOMS, onesample Wilcoxon signed-rank tests (significance level: α = 0.05) were applied to compare pre- and post-treatment NPRS, for groups B, C and D.

223

224 **3. RESULTS**

Anagraphic and anthropometric data of the athletes are reported in **TABLE** 1. There were no statistically significant differences among the 4 treatment groups for age (p = 0.24), height (p = 0.49) and weight (p = 0.71).

228 Knee reposition error (main outcome measure)

The average knee reposition error, for the 4 groups, is reported in **TABLE** 230 **2**. The knee reposition error was different between diathermy ($-3.7^{\circ} \pm 4.2^{\circ}$) and 231 sham diathermy ($1.0^{\circ} \pm 2.6^{\circ}$), with p = 0.01. The test power was 0.77. The 232 confidence intervals of the knee reposition error was C.I. = [-6.0; -1.2] for 233 diathermy (it does not contain the zero value), and C.I. = [-0.6° ; 2.2°] for sham 234 diathermy (it contains the zero value), respectively. Hence, the diathermy had a statistically significant effect on the knee reposition error, while sham diathermy
had no statistically significant effect on it.

237 DOMS pain evaluation

DOMS pain intensity, at baseline and post-treatment, is reported in **TABLE** 3. At baseline, the athletes presented comparable DOMS intensity in the 4 treatment groups. In fact, pre-treatment NPRS was not different among groups (p = 0.16). Massage (B), diathermy (C) and sham diathermy (D) were all effective in reducing pain, as demonstrated by the decrease of NPRS after treatment (p =0.002, in all cases).

244

245 4. DISCUSSION

While there is a limited and equivocal evidence describing the effect of 246 cryotherapy on proprioception in the form of joint position sense,³⁹ there is even 247 less information about thermotherapy. An old study suggested that superficial 248 heat applications (hot water immersion of the ankle and foot) can be used prior 249 to therapeutic exercise programs without interfering with normal sensory 250 perception.⁴⁰ However, superficial heating treatments achieve their maximum 251 tissue temperature in the skin and subcutaneous fat.⁴¹ On the contrary, 252 diathermy^{42,43} and ultrasound therapy^{44,45} can directly heat deep tissues, and 253 might affect sensory perception. 254

Previous literature analyzed the effects of therapeutic heat (surface and deep) mainly on the following aspects: DOMS relief and the decrease of painful muscle spasms,^{46,47,48,49} decrease of joint stiffness,⁵⁰ increase of the (static) range of motion of joints,⁵¹ increase of muscle length⁵² and enhancement of connective

tissue elasticity.⁴⁹ In particular, comparing the effect of deep and superficial
heating on tissue extensibility, it was demonstrated that deep heating, in the
absence of stretching, increases tissue extensibility more than superficial heating
or no heating.⁵³

In general, diathermy is administered by physiotherapists and sport 263 264 healthcare professionals to heat deeper tissue including muscle, tendons and ligaments, since the electromagnetic fields generated are able to penetrate the 265 skin and subcutaneous fat.⁵⁴ Our study demonstrated that joint position sense is 266 altered after diathermy compared to sham diathermy, in athletes suffering from 267 DOMS. After diathermy, the knee reposition angle was significantly higher than 268 269 the target angle by 3.7°. On the contrary, after sham diathermy, the knee reposition error was lower than the target angle by 1.0°, but this difference cannot 270 be considered significantly different from zero. The absolute effect size measured 271 between diathermy and sham diathermy was 4.7°. The substantial difference 272 between diathermy and sham diathermy is the presence of deep tissue heating 273 274 in the first case. Indeed, sham diathermy provides a slight massage to the skin and subcutaneous tissue layers, but does not cause heating of deep tissue. 275 Heating induced by diathermy desensitizes the involved muscle spindles.⁵⁵ This 276 277 could explain our finding that the athletes, after diathermy, have to flex more the knee to reproduce the target angle. The desensitization of the muscle spindles 278 requires the athlete to produce an increased flexion to perceive the same joint 279 280 position.

281 Our results suggest that proprioception is degraded after diathermy 282 applied to treat DOMS. Future studies should investigate if diathermy alters

proprioception also in the absence of DOMS. Furthermore, it would be interesting 283 to establish for how long proprioception is affected after a diathermy treatment. 284 This latest point requires a longitudinal study for evaluating the joint position error, 285 at various time instants, in the hours after the diathermy application. Our study 286 287 design did not allow for this kind of assessment, due to organizational reasons. Indeed, our athletes were assessed right after the second day of a demanding 288 ski-mountaineering race, while they were very tired and needed rest before facing 289 290 the third day of race. From this point of view, it was essential that our protocol of 291 assessment lasted no more than 10 minutes for each athlete, including the positioning of the electrogoniometer. To keep to a minimum the time commitment 292 293 of the volunteers, it was also preferred to test the athletes only once, with a parallel design, instead of testing them twice, both before and after the treatment. 294 For the same reason, the protocol was limited to a single knee position (30°) 295 instead of considering several positions at different angles. 296

New diathermy devices have come on the market and diathermy is 297 available in more facilities than it was a few years ago.⁵⁴ In spite of this increasing 298 interest, scarce attention has been paid to evaluate the effectiveness of diathermy 299 300 for DOMS management. We found that both diathermy and sham diathermy were 301 beneficial to treat pain. Our results suggest that pain relief is probably related to the slight superficial massage performed with the device handpiece, and to 302 303 positive expectation for the treatment (placebo effect), rather than to deep thermal 304 effect. However, further research is needed to confirm this result.

305 Apart from the already mentioned difference between diathermy and sham 306 diathermy, no other significant difference was found, for the knee joint reposition

error, among groups. This suggests that, in all the other cases, only a small effect
size is present, if any. This can be affirmed in spite of the relatively small number
of subjects included in each group.

We chose to evaluate joint position sense examining the knee flexion from 310 311 upright bipedal stance. A limitation of this study is that sensory inputs from hip 312 and ankle joints, and cutaneous sensory inputs from the feet, may be confounding factors, as well as the stabilizing function of the spine muscles, the applied torque 313 314 of the quadriceps muscles, the lower limb flexibility, and the possible knee valgus/varus change in frontal plane. Nevertheless, we believe that the proposed 315 dynamic task is more indicated for this specific population of ski mountaineering 316 athletes with respect to tasks performed in sitting or prone postures.^{56,57} In fact, 317 the chosen dynamic task is definitely closer to the "natural" posture and 318 proprioceptive inputs of the athletes while they are skiing. Furthermore, since we 319 have chosen a parallel design, all the other factors possibly influencing the knee 320 flexion angle are present in all cases (e.g. both after diathermy and sham 321 322 diathermy). Hence, these other factors should not bias the results. Therefore, the only practical difference between diathermy and sham diathermy remains a 323 temperature increase in the treated areas in the case of diathermy. This seems 324 325 to cause a proprioception alteration that might negatively impact the athlete and potentially cause injuries. 326

We provided a quantitative estimation of the proprioceptive performance based on joint angle measures in dynamic conditions. In particular, the data analysis proposed was aimed at reducing subjective factors, to obtain results – as much as possible – operator independent. This has been made possible

thanks to the use of histograms for the estimation of the knee reposition angle.
The only operator's choice was the segmentation of the instruction phase from
the reposition phase. This was performed by "manually" placing markers
indicating the start and end of each phase. However, this manual selection is not
critical, since slightly different marker placements exactly lead to the same final
results.

337

338 5. CONCLUSIONS

339 In athletes affected by DOMS diathermy has a negative impact on joint proprioception. This can be explained by the desensitization of the muscle 340 spindles consequent to deeper tissue heating. This desensitization causes the 341 athlete's need for an increased knee flexion to perceive the same joint position. 342 Indeed, we found an increased knee flexion after diathermy, while the knee 343 344 flexion was slightly reduced after sham diathermy. Future studies should investigate for how long the proprioception remains altered after a diathermy 345 treatment. 346

While diathermy alters joint proprioception in athletes suffering from DOMS, massage does not significantly impact the joint position sense. This information can be useful in the DOMS management of athletes, since an altered proprioception may worsen athlete performance and increase the risk of injury.

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TABLE 1. Anagraphic and anthropometric data of ski mountaineering athletes (N = 40 males)

	Age (years)	Height (cm)	Weight (kg)
A: No treatment (N=10)	35.4 ± 6.8	178.8 ± 8.1	71.7 ± 14.1
B: Massage (N=10)	39.2 ± 7.3	178.3 ± 5.1	72.1 ± 6.5
C: Diathermy (N=10)	41.9 ± 6.6	175.6 ± 5.8	70.4 ± 6.2
D: Sham diathermy (N=10)	38.9 ± 6.9	179.0 ± 6.1	71.4 ± 3.9

Mean \pm standard deviation over the population is reported.

No significant differences were found among treatment groups for age (p = 0.24), height (p = 0.49) and weight (p = 0.71).

TABLE 2. Knee joint position sense assessed in athletes after they underwent different treatments for DOMS

Knee reposition error (°)		
-0.8 ± 4.3		
0.5 ± 4.0		
-3.7 ± 4.2*		
1.0 ± 2.6*		

Abbreviation: DOMS, Delayed Onset Muscle Soreness.

Mean \pm standard deviation over the population is reported.

The asterisk * indicates a statistically significant difference between groups (p = 0.01).

TABLE 3. DOMS	pain intensit	y at baseline	and after treatment
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	NPRS pre-treatment (scale: 1-10)	NPRS post-treatment (scale: 1-10)	<i>p</i> -value
A: No treatment (N = 10)	5.9 ± 1.7	-	-
B: Massage (N = 10)	5.4 ± 2.1	$3.4 \pm 2.2^{\dagger}$	0.002
C: Diathermy (N = 10)	6.2 ± 0.8	$4.0\pm1.1^{\dagger}$	0.002
D: Sham diathermy (N = 10)	$\textbf{6.8} \pm \textbf{1.8}$	$\textbf{4.2} \pm \textbf{1}, \textbf{1}^{\dagger}$	0.002

Abbreviations: NPRS, Numeric pain rating scale; DOMS, Delayed Onset Muscle Soreness.

Mean \pm standard deviation over the population is reported.

No significant differences were found among groups at baseline (pre-treatment).

The symbol [†] indicates a statistically significant difference between pre- and post-treatment.

FIGURE LEGENDS

FIGURE 1. Knee electrogoniometer fixed to the dominant side of a ski mountaineering athlete to measure the knee joint angle, in the sagittal plane, during a position-reposition test.

FIGURE 2. CONSORT flowchart of the study.

FIGURE 3. Knee joint angle signal measured, on a representative athlete, during a positionreposition test. First the athlete is instructed to reach 30° of knee flexion for 3 times (target position), then he must try to reproduce, as accurately as possible, the same knee flexion for 10 times (performance position).

FIGURE 4. Example of data analysis to estimate the knee reposition error. **A**: Knee joint angle signal measured on a representative athlete. The start and end points of both the instruction and the reposition phase are indicated by red vertical lines. **B**: Histogram of knee angle values acquired during the instruction phase. **C**: Histogram of knee angle values acquired during the reposition phase.