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

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ABSTRACT

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

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

1. INTRODUCTION

In recent years, extreme competitions that involve athletes for long distances are becoming increasingly popular. In this kind of races, musculoskeletal problems are very common,[1] the most frequent of which is delayed onset muscle soreness (DOMS).[2] DOMS entails symptoms that can range from muscle tenderness to severe debilitating pain[3] localized at the muscle belly and tendon–bone junction,[4] and are classified as muscle injuries.[5] DOMS usually result from strenuous, unaccustomed tasks of an eccentric nature.[3] Ski mountaineering has been described as a strenuous exercise involving different kinds of metabolic changes[6] and, in particular, downhill skiing implies eccentric contractions.[7] Hence, in ski mountaineering races, the long-lasting eccentric effort during the downhill part of the race is a typical cause of DOMS.

While excessive and prolonged eccentric muscle contractions are a well-documented 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] inflammation[10] 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 positioning, muscle tension perception and threshold to detect passive movements.[13] Proprioceptive alterations associated to DOMS may have a heavy impact on athletic performance. For this reason, it is important that DOMS are effectively treated. The proper management of DOMS is particularly important for athletes involved in multiday races, since they have to maintain high performances throughout the race, in spite of the strenuous eccentric effort sustained each and every day of the race.

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 restoration[26] and recovery of muscle function[27], whereas vibration at low frequencies and amplitudes significantly improves knee joint proprioception.[28]

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

2. MATERIALS AND METHODS

2.1. Subjects

Forty male athletes were enrolled in the study right after the second day of the international ski mountaineering race **(removed for review)** held in April 2016 in **(removed for review)**. The race lasted overall three days, and the subjects 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 criteria were age comprised between 20 and 55 years and DOMS complaint. Subjects were assessed by a physical therapist with 10 years of experience in manual therapy, to rule out any contraindication to treatment. Exclusion criteria were reporting a trauma or declaring the use of drugs for pain management. Data were collected in the indoors medical facility near the racing organization center. Athletes were randomized to receive 4 physical therapy cares: A) no treatment, B) massage, C) diathermy, D) sham diathermy (parallel study). Each treatment group was composed of 10 athletes (allocation ratio: 1:1). Athletes did not receive static stretching exercises, but only the treatments described below.

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.

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

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

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

To avoid bias caused by negative expectations,[33] both diathermy and sham diathermy groups started the treatment with the operator stating that the device was active. In both cases a neutral cream was used.

The athletes of group A (no treatment) could benefit from a physical therapy treatment of their choice after the assessment, and they were no more 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/).

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

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 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 athlete's vision. The athlete assumed a bipedal quiet upright stance, corresponding to the 0° reference angle of knee flexion. Then he was instructed to reach 30° of knee flexion with both knees (target position). A vocal feedback was given to the athlete for reaching the target position, with instructions like "flex more", or "flex less", and "keep the position". When the athlete reached the target 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 during which the athlete could rest in upright stance. Then, a second phase of 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 could rest 3-5 s in upright stance between trials. The entire protocol lasted less than 10 minutes (including the sensor positioning). All of the 40 athletes successfully completed the protocol.

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:

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

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 and reposition phases is shown in **FIGURE 2**, for a representative athlete. From 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 repeatable estimate of these angles, it is important that data processing is not based upon the subjective choices of an operator. Instead, automatic and robust techniques of signal processing are advisable, based on histograms obtained from the data.[36]

In particular, for each signal collected, the following steps were performed[37]:

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.

2.5. Statistical analysis

The Matlab® Statistics Toolbox was used to implement the statistical 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 $\alpha = 0.05$.

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.

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

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, one-sample Wilcoxon signed-rank tests (significance level: $\alpha = 0.05$) were applied to compare pre- and post-treatment NPRS, for groups B, C and D.

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 ($p = 0.71$).

Knee reposition error (main outcome measure)

The average knee reposition error, for the 4 groups, is reported in **TABLE 2**. The knee reposition error was different between diathermy (-3.7° ± 4.2°) and sham diathermy (1.0° ± 2.6°), with $p = 0.01$. The test power was 0.77. The confidence intervals of the knee reposition error was C.I. = [-6.0; -1.2] for diathermy (it does not contain the zero value), and C.I. = [-0.6°; 2.2°] for sham 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.

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).

4. DISCUSSION

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

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 length[52] 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 healthcare professionals to heat deeper tissue including muscle, tendons and ligaments, since the electromagnetic fields generated are able to penetrate the skin and subcutaneous fat.[54] Our study demonstrated that joint position sense is altered after diathermy compared to sham diathermy, in athletes suffering from DOMS. After diathermy, the knee reposition angle was significantly higher than 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 be considered significantly different from zero. The absolute effect size measured between diathermy and sham diathermy was 4.7°. The substantial difference between diathermy and sham diathermy is the presence of deep tissue heating 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. Heating induced by diathermy desensitizes the involved muscle spindles.[55] This 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 requires the athlete to produce an increased flexion to perceive the same joint position.

Our results suggest that proprioception is degraded after diathermy applied to treat DOMS. Future studies should investigate if diathermy alters proprioception also in the absence of DOMS. Furthermore, it would be interesting to establish for how long proprioception is affected after a diathermy treatment. This latest point requires a longitudinal study for evaluating the joint position error, at various time instants, in the hours after the diathermy application. Our study 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 ski-mountaineering race, while they were very tired and needed rest before facing the third day of race. From this point of view, it was essential that our protocol of assessment lasted no more than 10 minutes for each athlete, including the positioning of the electrogoniometer. To keep to a minimum the time commitment 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. For the same reason, the protocol was limited to a single knee position (30°) instead of considering several positions at different angles.

New diathermy devices have come on the market and diathermy is available in more facilities than it was a few years ago.[54] In spite of this increasing interest, scarce attention has been paid to evaluate the effectiveness of diathermy for DOMS management. We found that both diathermy and sham diathermy were 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 positive expectation for the treatment (placebo effect), rather than to deep thermal effect. However, further research is needed to confirm this result.

Apart from the already mentioned difference between diathermy and sham 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 upright bipedal stance. A limitation of this study is that sensory inputs from hip 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 of the quadriceps muscles, the lower limb flexibility, and the possible knee valgus/varus change in frontal plane. Nevertheless, we believe that the proposed dynamic task is more indicated for this specific population of ski mountaineering athletes with respect to tasks performed in sitting or prone postures.[56,57] In fact, the chosen dynamic task is definitely closer to the "natural" posture and proprioceptive inputs of the athletes while they are skiing. Furthermore, since we have chosen a parallel design, all the other factors possibly influencing the knee flexion angle are present in all cases (e.g. both after diathermy and sham diathermy). Hence, these other factors should not bias the results. Therefore, the only practical difference between diathermy and sham diathermy remains a temperature increase in the treated areas in the case of diathermy. This seems to cause a proprioception alteration that might negatively impact the athlete and potentially cause injuries.

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.

5. CONCLUSIONS

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

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.

REFERENCES

1. Ristolainen L, Heinonen A, Turunen H, Mannström H, Waller B, Kettunen JA, *et al.*, Type of sport is related to injury profile: A study on cross country skiers, swimmers, long-distance runners and soccer players. A retrospective 12-month study, *Scand. J. Med. Sci. Sports* **20**: 384–393, 2009.
2. Armstrong RB, Mechanisms of exercise-induced delayed onset muscular soreness: a brief review., *Med. Sci. Sports Exerc.* **16**: 529–38, 1984.
3. Cheung K, Hume PA, Maxwell L, Delayed onset muscle soreness: Treatment strategies and performance factors, *Sport. Med.* **33**: 145–164, 2003.
4. Gibson W, Arendt-Nielsen L, Graven-Nielsen T, Delayed onset muscle soreness at tendon-bone junction and muscle tissue is associated with facilitated referred pain, *Exp. Brain Res.* **174**: 351–360, 2006.
5. Mueller-Wohlfahrt H-W, Haensel L, Mithoefer K, Ekstrand J, English B, McNally S, *et al.*, Terminology and classification of muscle injuries in sport: the Munich consensus statement., *Br. J. Sports Med.* **47**: 342–50, 2013.
6. Duc S, Cassirame J, Durand F, Physiology of ski mountaineering racing, *Int. J. Sports Med.* **32**: 856–863, 2011.
7. Tesch PA, Aspects on muscle properties and use in competitive Alpine skiing., *Med. Sci. Sports Exerc.* **27**: 310–4, 1995.
8. Schwane JA, Johnson SR, Vandenakker CB, Armstrong RB, Delayed-onset muscular soreness and plasma CPK and LDH activities after downhill running., *Med Sci Sport. Exerc* **15**: 51–56, 1983.
9. Proske U, Morgan DL, Muscle damage from eccentric exercise: Mechanism, mechanical signs, adaptations and clinical applications, *J. Physiol.* **537**: 333–345,

2001.

10. Pedersen BK, Ostrowski K, Rohde T, Bruunsgaard H, The cytokine response to strenuous exercise., *Can. J. Physiol. Pharmacol.* **76**: 505–511, 1998.

11. Yu JG, Carlsson L, Thornell LE, Evidence for myofibril remodeling as opposed to myofibril damage in human muscles with DOMS: An ultrastructural and immunoelectron microscopic study, *Histochem. Cell Biol.* **121**: 219–227, 2004.

12. Cleak MJ, Eston RG, Delayed onset muscle soreness: Mechanisms and management, *J. Sports Sci.* **10**: 325–341, 1992.

13. Proske U, Gregory JE, Morgan DL, Percival P, Weerakkody NS, Canny BJ, Force matching errors following eccentric exercise, *Hum. Mov. Sci.* **23**: 365–378, 2004.

14. Paschalis V, Nikolaidis MG, Giakas G, Jamurtas AZ, Pappas A, Koutedakis Y, The effect of eccentric exercise on position sense and joint reaction angle of the lower limbs, *Muscle Nerve* **35**: 496–503, 2007.

15. Torres R, Vasques J, Duarte JA, Cabri JMH, Knee Proprioception after Exercise-Induced Muscle Damage, *Int. J. Sports Med.* **31**: 410–415, 2010.

16. Vila-Chã C, Riis S, Lund D, Møller A, Farina D, Falla D, Effect of unaccustomed eccentric exercise on proprioception of the knee in weight and non-weight bearing tasks, *J. Electromyogr. Kinesiol.*2011doi:10.1016/j.jelekin.2010.10.001.

17. Broadbent S, Rousseau JJ, Thorp RM, Choate SL, Jackson FS, Rowlands DS, Vibration therapy reduces plasma IL6 and muscle soreness after downhill running., *Br. J. Sports Med.* **44**: 888–94, 2010.

18. Veqar Z, Imtiyaz S, Vibration Therapy in Management of Delayed Onset Muscle Soreness (DOMS), *J. Clin. DIAGNOSTIC Res.* **8**: LE01-4, 2014.

19. Glasgow PD, Ferris R, Bleakley CM, Cold water immersion in the management of delayed-onset muscle soreness: Is dose important? A randomised controlled trial, *Phys. Ther. Sport* **15**: 228–233, 2014.

20. Nicol LM, Rowlands DS, Fazakerly R, Kellett J, Curcumin supplementation likely attenuates delayed onset muscle soreness (DOMS), *Eur. J. Appl. Physiol.* **115**: 1769–1777, 2015.
21. Hilbert JE, The effects of massage on delayed onset muscle soreness, *Br. J. Sports Med.* **37**: 72–75, 2003.
22. Torres R, Ribeiro F, Alberto Duarte J, Cabri JMH, Evidence of the physiotherapeutic interventions used currently after exercise-induced muscle damage: Systematic review and meta-analysis, *Phys. Ther. Sport* **13**: 101–114, 2012.
23. Nelson N, Delayed onset muscle soreness: Is massage effective?, *J. Bodyw. Mov. Ther.* **17**: 475–482, 2013.
24. Han J-H, Kim M-J, Yang H-J, Lee Y-J, Sung Y-H, Effects of therapeutic massage on gait and pain after delayed onset muscle soreness., *J. Exerc. Rehabil.* **10**: 136–40, 2014.
25. Kargarfard M, Lam ETC, Shariat A, Shaw I, Shaw BS, Tamrin SBM, Efficacy of massage on muscle soreness, perceived recovery, physiological restoration and physical performance in male bodybuilders, *J. Sports Sci.* **34**: 959–965, 2016.
26. Shin M-S, Sung Y-H, Effects of massage on muscular strength and proprioception after exercise-induced muscle damage, *J. Strength Cond. Res.* **29**: 2255–2260, 2015.
27. Zainuddin Z, Newton M, Sacco P, Nosaka K, Effects of Massage on Delayed-Onset Muscle Soreness, Swelling, and Recovery of Muscle Function, *J. Athl. Train.* **4040**: 174–180, 2005.
28. Lin H-T, Chen Y-Y, Wang D-C, Chou P-H, Guo L-Y, Wu W-L, The acute effect of training frequencies and number of sets of whole body vibration on knee joint proprioception, *J. Mech. Med. Biol.* **14**: 1450036, 2014.
29. Goats GC, Continuous short-wave (radio-frequency) diathermy., *Br. J. Sports Med.*

23: 123–7, 1989.

30. Jan M-H, Chai H-M, Wang C-L, Lin Y-F, Tsai L-Y, Effects of Repetitive Shortwave Diathermy for Reducing Synovitis in Patients With Knee Osteoarthritis: An Ultrasonographic Study, *Phys. Ther.* **86**2006.
31. Draper DO, Hawkes AR, Johnson AW, Diede MT, Rigby JH, Muscle Heating With Megapulse II Shortwave Diathermy and ReBound Diathermy, *J. Athl. Train.* **48**: 477–482, 2013.
32. Draper DO, Castro JL, Feland B, Schulthies S, Eggett D, Shortwave Diathermy and Prolonged Stretching Increase Hamstring Flexibility More Than Prolonged Stretching Alone, *J. Orthop. Sport. Phys. Ther.* **34**: 13–20, 2004.
33. Benedetti F, How the doctor's words affect the patient's brain., *Eval. Health Prof.* **25**: 369–386, 2002.
34. Ferreira-Valente MA, Pais-Ribeiro JL, Jensen MP, Validity of four pain intensity rating scales, *Pain* **152**: 2399–2404, 2011.
35. Agostini V, Knaflitz M, Antenucci L, Lisco G, Gastaldi L, Tadano S, Wearable sensors for gait analysis, *2015 IEEE Int. Symp. Med. Meas. Appl. Proc.*, IEEE: pp 146–1502015doi:10.1109/MeMeA.2015.7145189.
36. Agostini V, Knaflitz M, An algorithm for the estimation of the signal-to-noise ratio in surface myoelectric signals generated during cyclic movements, *IEEE Trans. Biomed. Eng.* **59**: 219–225, 2012.
37. Agostini V, Rosati S, Balestra G, Trucco M, Visconti L, Knaflitz M, Estimation of joint position error, *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, IEEE: pp 2474–24772017doi:10.1109/EMBC.2017.8037358.
38. Efron B, J. Tibshirani R, An Introduction To The Bootstrap, *J. Am. Stat. Assoc.* **89**: 436, 1993.
39. Costello JT, Donnelly AE, Cryotherapy and Joint Position Sense in Healthy

Participants: A Systematic Review, *J. Athl. Train.* **45**: 306–316, 2010.

40. Ingersoll CD, Knight KL, Merrick MA, Sensory perception of the foot and ankle following therapeutic applications of heat and cold., *J. Athl. Train.* **27**: 231–4, 1992.

41. Preisinger E, Kryo-, Kälte-, Wärmetherapie, *Man. Medizin* **54**: 387–393, 2016.

42. Hawkes AR, Draper DO, Johnson AW, Diede MT, Rigby JH, Heating capacity of ReBound shortwave diathermy and moist hot packs at superficial depths, *J. Athl. Train.* **48**: 471–476, 2013.

43. Garrett CL, Draper DO, Knight KL, Heat Distribution in the Lower Leg from Pulsed Short-Wave Diathermy and Ultrasound Treatments, *J. Athl. Train.* **35**: 50–55, 2000.

44. Aydin E, Tastaban E, Omurlu IK, Turan Y, Şendur ÖF, Effects of deep heating provided by therapeutic ultrasound on demyelinating nerves, *J. Phys. Ther. Sci.* **28**: 1278–1283, 2016.

45. Magalhães FEX, Junior AR de M, Meneses HT de S, Moreira Dos Santos RP, Rodrigues EC, Gouveia SSV, *et al.*, Comparison of the effects of hamstring stretching using proprioceptive neuromuscular facilitation with prior application of cryotherapy or ultrasound therapy., *J. Phys. Ther. Sci.* **27**: 1549–53, 2015.

46. Petrofsky J, Berk L, Bains G, Khowailed IA, Lee H, Laymon M, The Efficacy of Sustained Heat Treatment on Delayed-Onset Muscle Soreness, *Clin. J. Sport Med.* **27**: 329–337, 2017.

47. Petrofsky J, Berk L, Bains G, Khowailed IA, Hui T, Granado M, *et al.*, Moist heat or dry heat for delayed onset muscle soreness., *J. Clin. Med. Res.* **5**: 416–25, 2013.

48. Nadler SF, Weingand K, Kruse RJ, The Physiologic Basis and Clinical Applications of Cryotherapy and Thermotherapy for the Pain Practitioner, *Pain Pract. 395 Pain Physician Pain Physician* **77**: 395–399, 2004.

49. Malanga GA, Yan N, Stark J, Mechanisms and efficacy of heat and cold therapies for musculoskeletal injury, *Postgrad. Med.* **127**: 57–65, 2015.

50. Brosseau L, Yonge K, Welch V, Marchand S, Judd M, Wells GA, *et al.*, Thermotherapy for treatment of osteoarthritis, *Cochrane Database Syst. Rev.*2003doi:10.1002/14651858.CD004522.

51. Minussi Ananias B, Braghiroli FL, Prudêncio DA, Buzzi da Silveira C, Sanada LS, Okubo R, Therapeutic heat and cryotherapy increases knee range of movement on hamstring muscles of healthy volunteers., *Int. J. Ther. Rehabil.* **24**: 528–533, 2017.

52. Cosgray NA, Lawrance SE, Mestrich JD, Martin SE, Whalen RL, Effect of Heat Modalities on Hamstring Length: A Comparison of Pneumatherm, Moist Heat Pack, and a Control, *J. Orthop. Sport. Phys. Ther.* **34**: 377–387, 2004.

53. Robertson VJ, Ward AR, Jung P, The effect of heat on tissue extensibility: A comparison of deep and superficial heating, *Arch. Phys. Med. Rehabil.* **86**: 819–825, 2005.

54. Denegar CR, Saliba E, Saliba SF, *Therapeutic modalities for musculoskeletal injuries*.

55. Mense S, Effects of temperature on the discharges of muscle spindles and tendon organs, *Pflügers Arch. Eur. J. Physiol.* **374**: 159–166, 1978.

56. Olsson L, Lund H, Henriksen M, Rogind H, Bliddal H, Danneskiold-Samsøe B, Test–retest reliability of a knee joint position sense measurement method in sitting and prone position, *Adv. Physiother.* **6**: 37–47, 2004.

57. Relph N, Herrington L, Interexaminer, Intraexaminer, and Test–Retest Reliability of Clinical Knee Joint-Position-Sense Measurements Using an Image-Capture Technique, *J. Sport Rehabil.* **Technical Notes 12**2015.

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 ± 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 (°)
A: No treatment (N = 10)	-0.8 ± 4.3
B: Massage (N = 10)	0.5 ± 4.0
C: Diathermy (N = 10)	-3.7 ± 4.2*
D: Sham diathermy (N = 10)	1.0 ± 2.6*

Abbreviation: DOMS, Delayed Onset Muscle Soreness.

Mean ± standard deviation over the population is reported.

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

TABLE 3. DOMS pain intensity at baseline and after treatment

	NPRS pre-treatment (scale: 1-10)	NPRS post-treatment (scale: 1-10)	*p*-value
A: No treatment (N = 10)	5.9 ± 1.7	-	-
B: Massage (N = 10)	5.4 ± 2.1	3.4 ± 2.2†	0.002
C: Diathermy (N = 10)	6.2 ± 0.8	4.0 ± 1.1†	0.002
D: Sham diathermy (N = 10)	6.8 ± 1.8	4.2 ± 1,1†	0.002

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

Mean ± 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 position-reposition 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.