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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
4 of this study is to compare the effect of diathermy, sham diathermy and massage
5 on the knee proprioception of athletes treated for DOMS. Forty athletes were
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 ($p =$
11 0.01) with an absolute effect size of 4.7° . No other significant differences were
12 found among groups. This means that diathermy has a negative impact on joint
13 proprioception and can be explained by the spindle desensitization consequent
14 to deeper tissue heating. This information can be important in the DOMS
15 management of athletes, since an altered proprioception may interfere with the
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**

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

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

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

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

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

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

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

73

74 **2. MATERIALS AND METHODS**

75 **2.1. Subjects**

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

90

91 **2.2. Treatments**

92 Treatments were administered by physiotherapy students in their last
93 semester of study, supervised by expert physiotherapists. Prior to the experiment,
94 they received formal training on the techniques used during the study. Typical
95 pain areas reported by athletes were quadriceps muscles and, to a lesser extent,
96 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.

104 Athletes in group C received a 10-min diathermy treatment (Red Coral
105 Tecnosix, Sixtus, Italy) on symptomatic areas of both lower limbs, in capacitive
106 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

115 diathermy groups started the treatment with the operator stating that the device
116 was 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).

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

125
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.

129

130 **2.3. Protocol**

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

137 Afterwards, the knee reposition error was assessed. To this purpose, a
138 knee electrogoniometer (STEP32, Medical Technology, Italy; accuracy: 0.5°),
139 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
141 asking the athlete their preferred foot for kicking a ball. A headband occluded the
142 athlete's vision. The athlete assumed a bipedal quiet upright stance,
143 corresponding to the 0° reference angle of knee flexion. Then he was instructed
144 to reach 30° of knee flexion with both knees (target position). A vocal feedback
145 was given to the athlete for reaching the target position, with instructions like "flex
146 more", or "flex less", and "keep the position". When the athlete reached the target
147 he was asked to maintain it for 5 seconds and memorize the position. The entire
148 "instruction" procedure was repeated 3 times, with intervals of 3-5 s between trials
149 during which the athlete could rest in upright stance. Then, a second phase of
150 the test followed in which the athlete was asked to reproduce the target position
151 as precisely as he could (performed position), for 10 consecutive times. Again he
152 could rest 3-5 s in upright stance between trials. The entire protocol lasted less
153 than 10 minutes (including the sensor positioning). All of the 40 athletes
154 successfully completed the protocol.

155

156 **2.4. Data analysis**

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

162

$$163 \quad \text{Knee reposition error} = \text{target angle} - \text{performance angle}, \quad (1)$$

164

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

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

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
180 red vertical lines in **FIGURE 2** and in **FIGURE 3 A**),

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

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

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

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

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

196

197 **2.5. Statistical analysis**

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

200 To verify, a-posteriori (after randomization), that there were no significant
201 differences in anographic (age) and anthropometric characteristics (height,
202 weight) among the 4 groups, we applied Kruskas-Wallis tests, choosing a
203 significance level $\alpha = 0.05$.

204

205 *Knee reposition error (main outcome measure)*

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

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

213

214 *DOMS pain evaluation*

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

220 To establish if the treatments were effective in relieving DOMS, one-
221 sample Wilcoxon signed-rank tests (significance level: $\alpha = 0.05$) were applied to
222 compare pre- and post-treatment NPRS, for groups B, C and D.

223

224 **3. RESULTS**

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

228 *Knee reposition error (main outcome measure)*

229 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

235 statistically significant effect on the knee reposition error, while sham diathermy
236 had no statistically significant effect on it.

237 **DOMS pain evaluation**

238 DOMS pain intensity, at baseline and post-treatment, is reported in **TABLE**
239 **3.** At baseline, the athletes presented comparable DOMS intensity in the 4
240 treatment groups. In fact, pre-treatment NPRS was not different among groups
241 ($p = 0.16$). Massage (B), diathermy (C) and sham diathermy (D) were all effective
242 in reducing pain, as demonstrated by the decrease of NPRS after treatment ($p =$
243 0.002, in all cases).

244

245 **4. DISCUSSION**

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

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

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

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

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

283 proprioception also in the absence of DOMS. Furthermore, it would be interesting
284 to establish for how long proprioception is affected after a diathermy treatment.
285 This latest point requires a longitudinal study for evaluating the joint position error,
286 at various time instants, in the hours after the diathermy application. Our study
287 design did not allow for this kind of assessment, due to organizational reasons.
288 Indeed, our athletes were assessed right after the second day of a demanding
289 ski-mountaineering race, while they were very tired and needed rest before facing
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
292 positioning of the electrogoniometer. To keep to a minimum the time commitment
293 of the volunteers, it was also preferred to test the athletes only once, with a
294 parallel design, instead of testing them twice, both before and after the treatment.
295 For the same reason, the protocol was limited to a single knee position (30°)
296 instead of considering several positions at different angles.

297 New diathermy devices have come on the market and diathermy is
298 available in more facilities than it was a few years ago.⁵⁴ In spite of this increasing
299 interest, scarce attention has been paid to evaluate the effectiveness of diathermy
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
302 the slight superficial massage performed with the device handpiece, and to
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

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

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

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

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

337

338 **5. CONCLUSIONS**

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

347 While diathermy alters joint proprioception in athletes suffering from
348 DOMS, massage does not significantly impact the joint position sense. This
349 information can be useful in the DOMS management of athletes, since an altered
350 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 ± 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)	<i>p</i> -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.