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Differences in delayed onset muscle soreness behavior and joint position sense in men and women

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HIGHLIGHTS
- DOMS effects on joint position sense are similar in men and women.
- Joint angle eliciting different muscle lengths influences joint position sense in DOMS condition.
- A lengthened position results in a worse joint position sense under the DOMS condition.

ABBREVIATIONS

DOMS	Delayed onset muscle soreness
ESF	Effect size F
ESW	Kendall's W concordance coefficient
IPAQ	International Physical Activity Questionnaire
IQR	Interquartile range
MRV	Maximum number of voluntary repetitions
NPRS	Numerical pain rating scale
PPT	Pressure pain threshold
ΔPPT	Variation in pain threshold

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BACKGROUND: Delayed onset muscle soreness (DOMS) typically appears within 48 hours of exercise, causing strength deficits and movement difficulty. Its impact on joint position sense, a key proprioceptive function, and potential sex differences remain unclear.
AIM: In this study, we investigated whether DOMS affects the joint position sense of men and women.
METHODS: 15 men (25 ± 4.37 years, body mass index 26.52 ± 5.22 kg/m^2) and 15 women (24.7 ± 4.06 years, body mass index 26.75 ± 5.06 kg/m^2), self-reported healthy adults, performed an exhaustive unilateral elbow flexion and extension exercise to induce DOMS in the biceps brachii. Measurements of DOMS (with numeric pain scale), pressure pain threshold (with algometer), and joint position sense evaluation (with 2D angular kinematics) were taken pre and 48 hours post-exercise for two different elbow angles (biceps shortened or lengthened), without visual assistance.
RESULTS: DOMS increased, and the pressure pain threshold decreased 48 hours post-exercise, with no sex difference. Error in joint position sense in the lengthened biceps position was greater than in the shortened position 48 hours post-exercise (muscle extended: 7.78 ± 6.24° vs. muscle shortened: 4.83 ± 3.21°, $F_{(1.232)} = 7.487$; $p < 0.01$ and ESF= 0.17). There were no sex differences.
INTERPRETATION: With the presence of DOMS, joint position sense differs between the conditions of shortening or lengthening of the biceps brachii, with the lengthened position causing worse joint position sense. Such an effect did not differ between men and women participants. This information can be useful for rehabilitation and training programs, aiding monitoring post-exercise recovery and helping to understand the influence of DOMS on motor accuracy.

KEYWORDS: Joint position sense | Proprioception | Motor control

INTRODUCTION

Physical exercise is recommended for improving quality of life and maintaining, and restoring various physiological functions. To achieve beneficial outcomes, whether in sports performance or rehabilitation, proper manipulation of exercise loads—particularly volume and intensity—is essential [1]. If these loads are not appropriately defined, one potential consequence is exacerbated muscle damage, accompanied by inflammation and delayed onset muscle soreness (DOMS) [2]. DOMS is perceived as a sensation of tenderness and pain during movement (mechanical hyperalgesia), typically appearing within 48 hours after performing exercises predominantly involving eccentric muscle actions and/or an unfamiliar exercise that leads to muscle fatigue [3].

There is still no consensus on the determining mechanisms of DOMS, but it is known that intense exercises involving eccentric muscle actions or performed at different ranges of motion or loads than usual tend to trigger it [4]. The responses to DOMS can vary among individuals, influenced by factors such as strength levels, training status, and recovery time [5]. Another relevant aspect is the difference in DOMS behavior between sexes. Some studies suggest that women may be more sensitive to painful stimuli than men, potentially due to hormonal activity or contraceptive use [6,7]. However, other studies have found that women experience improved sports performance and reduced muscle soreness during the luteal phase of the menstrual cycle [8,9].

In daily life, the most common symptoms of DOMS, such as strength deficits and reduced range of motion, can hinder the execution of basic daily tasks, negatively affecting motor precision [4]. One factor influencing proprioceptive aspects may be the effect of muscle damage on the availability or quality of sensory information, such as that provided by muscle spindles, which relay muscle length information to the central nervous system and play a crucial role in joint position sense [10]. Joint position sense is described in the literature as the ability to perceive limb position in the absence of vision [11] and is an essential factor to assess, given that many daily tasks involve processing sensory information and generating motor responses [10].

Joint position during measurement appears to influence motor precision [12]. In the literature, most studies measure joint position sense at predefined, single angles [11]. Additionally, many studies choose to evaluate only one joint without visibility of the upper limb and passive assistance from the examiner [11,13].

When a participant performs elbow flexion and extension, the muscles involved in this movement either shorten or lengthen, causing the role of contractile proteins at the sarcomere level to differ depending on the muscle activation [14]. Muscle spindle information is used in both feedforward (anticipatory) and feedback (regulatory) mechanisms in an exercise-dependent manner [15]. A post-exercise DOMS condition may have a similar effect, as these mechanisms may be altered, affecting muscle spindle sensitivity and how the nervous system anticipates or regulates responses to stimuli. In the case of the knee joint, this influence of joint angle, which alters muscle length, appears to interfere with joint position sense [16].

In the present study, we aim to understand **how** DOMS induced by physical exercise influences elbow joint position sense in men and women. We hypothesize that women subjected to vigorous exercise will experience greater DOMS and a greater deficit in joint position sense than men performing the same task. Additionally, we speculate that the joint angle at which the joint position sense is measured will influence the results.

METHODS

Participants and experimental design

The study included 15 men with a mean (standard deviation) age of 25 ± 4.37 years old, body mass of 77.22 ± 15.38 kg, height of 1.70 ± 0.10 m, and body mass index of 26.52 ± 5.22 kg/m², and 15 women with a mean (standard deviation) age of 24.7 ± 4.06 years old, body mass of 76.72 ± 15.32 kg, height of 1.69 ± 0.09 m, and body mass index of 26.75 ± 5.06 kg/m². The sample size was determined using the G* Power 3.1 software (University of Düsseldorf, Düsseldorf, Germany) considering a median effect size expected to error-index of joint position sense (effect size F = 0.3) in a repeat measure ANOVA designed including three factors (arm with 2 levels, group with 2 levels and condition with 2 levels) with 80% of power and error of 10%.

To be included in the study, participants had to be at least 18 years old, self-report as healthy, have no history of upper limb injury in the past six months, and not have engaged in physical exercise in the week before assessments. Additionally, all female participants had to be in the luteal phase of their menstrual cycle, which was controlled based on self-reported menstrual cycle dates. In this sense, women performed the entire exercise protocol during the same phase of the menstrual cycle (luteal phase). Participants were classified as physically active based on their physical activity level according to the short version of the International Physical Activity Questionnaire (IPAQ) [17].

All procedures followed the ethical guidelines established in the Declaration of Helsinki, and all participants signed an informed consent form. This study was approved by the local ethics committee (IRB: 26037119.9.0000.5323).

The participation in the study involved two visits to the laboratory. During the first visit, all participants underwent an exercise protocol to induce unilateral delayed onset muscle soreness (DOMS) in the biceps brachii of their non-dominant limb, determined using a simple questionnaire. Additionally, assessments of DOMS perception, pressure pain threshold (PPT), and joint position sense were conducted before and immediately after the exercise protocol. The second visit took place 48 hours after the exercise session, during which pain and joint position sense assessments were repeated.

Pain perception assessment

The assessment of delayed onset muscle soreness (DOMS) was conducted using a numerical pain rating scale (NPRS) [18], presented to participants before the exercise protocol, immediately after, and 48 hours post-DOMS induction. For the numerical scale assessment, participants were seated at rest and instructed to consider pain exclusively in the upper limbs, reporting their perceived pain level based on the scale, with "0" representing no pain and "10" indicating the worst pain experienced [19]. Participants were then asked to evaluate their pain perception while performing an elbow extension movement [20].

Pressure pain threshold (PPT) was also assessed bilaterally at the muscle belly of the biceps brachii using a digital algometer (Instrutherm DD-200, São Paulo, Brazil) with a resolution of 0.01 N and a flat 1 cm² tip. The algometer was positioned perpendicular to the skin surface and pressed by a researcher until the participant verbally reported feeling pain, as per the evaluator's instructions [21]. The muscle belly position was determined with the participant lying supine on an examination table, and arms supinated. Participants were asked to perform a concentric contraction, after which the evaluator marked the muscle region before conducting the measurement with the algometer. All participants received prior instructions on how to indicate the moment when the pressure sensation became an uncomfortable pain [22]. The pain threshold was recorded in N/cm², following a protocol similar to that described in a previous study [21]. The evaluation was consistently performed by the same trained researcher to minimize potential inter-evaluator errors.

Joint position sense

Joint position sense was measured before and 48 hours after exercise using 2D kinematic data obtained with a smartphone camera (iPhone 11, Apple, California, USA) with a 12 MP resolution. The camera was mounted on a tripod positioned 1.2 m from the participant, perpendicular to the sagittal plane, with its height adjusted to align the lens with the participant's elbow joint. The recorded images were analyzed using Kinovea software (Joan Charmant & Contrib, France), referencing retroreflective markers placed on the acromioclavicular joint, lateral epicondyle of the humerus, and styloid process of the radius [23].

For joint position sense assessment, participants were seated with hips and knees at 90°, eyes blindfolded, arms at their sides, and elbows extended. The evaluator placed the participant's elbow in a random position, alternating between flexion angles greater or lesser than 90°, maintaining the posture for 5 seconds. The elbow was then fully extended, and the participant was asked to actively reposition it to the previously held position and maintain it for 5 seconds, always without visual guidance. This procedure was repeated twice for each limb (exercised and non-exercised control), and the difference between the actual and target positions was considered the joint position sense error.

Protocol of DOMS

To induce DOMS (Delayed Onset Muscle Soreness) and muscle damage, a unilateral exercise protocol was performed based on concentric and eccentric muscle actions during elbow flexion. The external load was determined according to the protocol of a previous study, set at 3 kg for men and 2 kg for women [24]. The exercise involved elbow flexion (concentric phase) and extension (eccentric phase) while holding a dumbbell, with participants seated on a bench, and their non-exercised arm relaxed along their body. The non-preferred arm was the arm exercised, and the execution speed was controlled by a digital metronome set at 40 repetitions per minute. The protocol began with the participant being instructed to perform the maximum number of voluntary repetitions (MRV), followed by an indefinite number of additional sets with repetitions equal to or fewer than 75% of the MRV until they were unable to complete more than 50% of the MRV. When the participant could no longer perform more than 50% of the MRV or showed a significant loss of range of motion, the protocol was terminated. To ensure greater effectiveness in the execution of the protocol, the evaluator provided feedback on the desired quality of movement during the exercise. The mean ± standard deviation of the values obtained on the Borg Scale was 16.26 ± 1.61 points. This indicates an effort perception of the activity classified as "very hard," corresponding to a high effort perception by the participants.

Statistical Analysis

The normality of the data was assessed using the Shapiro-Wilk test. The NPRS and PPT values for all participants are presented with median values and interquartile range (IQR). The joint position sense error-index and the variation in the pain pressure threshold ΔPPT (48h – pre) are presented with mean values and standard deviation. The intensity of DOMS and PPT for all participants were compared across time points using the Friedman test and post-hoc Dunn-Bonferroni test. Additionally, the intensity of DOMS was compared between groups (men vs. women) using the Mann-Whitney U test. The Kendall's W concordance coefficient [Kendall's W; ESW] was calculated for significant differences ($p<0.05$) and classified as small (ESW 0.2–0.4), moderate (ESW 0.5–0.7), or large (ESW >0.8) [25].

The joint position sense error index was compared using a Two-Way ANOVA with a Bonferroni post-hoc, considering three factors: group (men and women), arm (control vs. experimental), and condition (angle greater than 90 vs. angle less than 90). A similar approach was used for the variation in pain threshold (ΔPPT). The effect size f (ESF) was determined for significant differences and classified as large (ESF >0.4), medium (ESF 0.26 - 0.4), and small (ESF 0.1 - 0.25) [25]. Finally, Spearman correlation tests were used to verify the association between number of repetitions in the DOMS protocol and the outcomes of joint position sense. All statistical analyses were performed using SPSS version 21 (SPSS Inc., Chicago, IL), with an alpha level set at 0.05.

RESULTS

DOMS and pressure pain thresholds

Men performed an average of 90.94 ± 94.01 repetitions, while women performed 41.79 ± 33.12 repetitions of elbow flexion during the exercise protocol to induce DOMS. DOMS increased 48 hours after exercise compared to pre-exercise (pre-exercise: 0.00 IQR 0.0 points vs. 48 hours post-exercise: 5.00 IQR 5.0 points, $p<0.01$ and ESW = 1.0). On the other hand, the intensity of DOMS did not differ between men and women ($p = 0.76$). Here, the effect of the arm was not considered, as participants consistently reported a value of zero pain (no pain) in the control arm at all assessed time points using the Numerical Pain Rating Scale (NPRS).

The PPT in the experimental arm decreased 48 hours post-exercise compared to pre-exercise (pre-exercise: 29.07 IQR 22.76 N/cm² vs. 48 hours post-exercise: 19.85 IQR 20.29 N/cm², $p<0.05$ and ESW = 0.1). The PPT in the control arm, however, did not change significantly after the induction of DOMS ($p = 0.77$) (Figure 1).

Additionally, the variation in PPT [ΔPPT (48h - pre)] showed no difference between groups (men vs. women) for both the control arm ($F_{(1,56)}$ = 0.60; p = 0.92, men: 0.50 ± 9.79 N/cm² vs. women: -1.35 ± 10.15 N/cm²) and the experimental arm ($F_{(1,56)}$ = 0.60; p = 0.32, men: 4.16 ± 18.85 N/cm² vs. women: 10.03 ± 12.17 N/cm²).

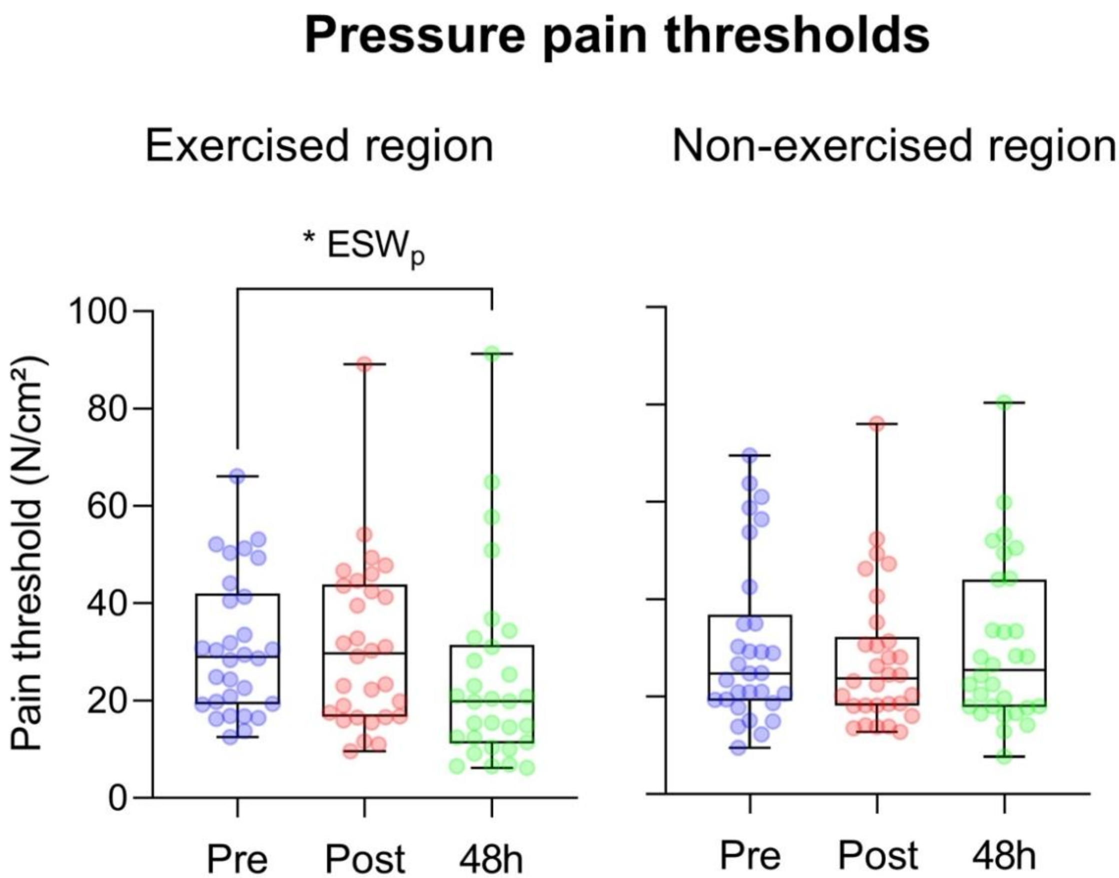

Figure 1. Median and interquartile range of the pressure pain threshold from the exercised region and control region and individual data. Differences between moments are identified by symbols (pre-exercise vs. 48h post-exercise, * p< 0.05) and letters identify the magnitudes of the effect sizes (Small effect size ESW_P; Medium effect size ESW_M; Large effect size ESW_G).

Joint position sense

The error-index of joint position sense did not differ between pre-exercise and 48 hours post-DOMS induction for both the experimental and control groups, considering angles greater than 90° [experimental ($F_{(1,232)}$ = 1.487; p = 0.22) and control ($F_{(1,232)}$ = 1.249; p = 0.26)] as well as angles smaller than 90° [experimental ($F_{(1,232)}$ = 1.487; p = 0.72) and control ($F_{(1,232)}$ = 1.249; p = 0.90)]. However, when comparing stretching and shortening muscle postures, the error-index was higher 48 hours post-exercise with the muscle extended compared to when it was shortened in the experimental group (extended muscle: 7.78 ± 6.24° vs. shortened muscle: 4.83 ± 3.21°, $F_{(1,232)}$ = 7.487; p < 0.01 and ESF = 0.17). Additionally, the experimental group showed a higher error index than the control group at 48 hours post-exercise considering angles greater than 90° [$F_{(1,232)}$ = 4.443; p < 0.05 and ESF = 0.13] (Figure 2). No significant correlations were observed between the number of repetitions performed and the error-index of joint position sense for men considering angles smaller than 90° [ρ = 0,174 e p>0.05] and greater than 90° [ρ = -0,004 e p>0.05]. A similar behavior was observed considering women to angles smaller than 90° [ρ = 0,047 e p>0.05] and greater than 90° [ρ = -0,353 e p>0.05].

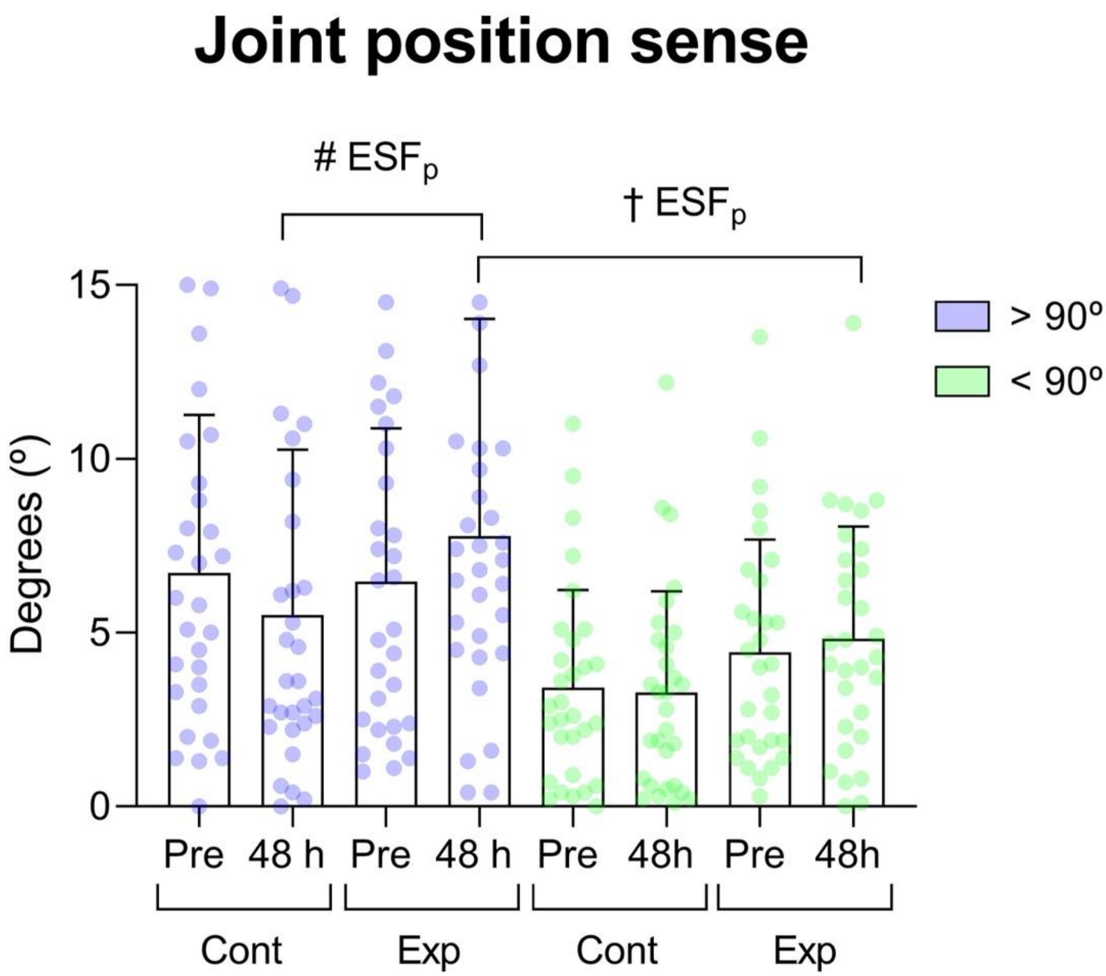

Figure 2. Mean and standard deviation of the error-index in joint position sense (difference between positioned by the evaluator and positioned by the evaluated). Symbols identify difference between moments (pre-exercise vs. 48h post-exercise, # $p < 0.05$), and in relation to elbow posture (Angles greater than 90° vs. Angles lower than 90° lower, † $p < 0.05$). Letters identify the magnitudes of the effect sizes (small effect size ESF_P; medium effect size ESF_M; large effect size ESF_G).

DISCUSSION

In this study, we aimed to determine whether delayed onset muscle soreness (DOMS) affects elbow joint position sense in men and women. We also investigated whether muscle length, due to a more shortened or elongated condition, could influence the results. We hypothesized that DOMS would increase the joint position sense error in the affected limb and that women would experience greater pain in the exercised arm and worse joint sense. We found that DOMS was successfully induced, reducing the pain threshold in the exercised muscle, but with no differences between sexes. Furthermore, it was observed that the joint position sense at 48 hours was worse in the affected limb compared to the baseline and the control (non-exercised) limb. This effect was even more pronounced when comparing the muscle in a shortened position (elbow angle less than 90°) and a more elongated position (elbow angle greater than 90°). We observed that joint position sense differed between the shortened and elongated positions of the biceps brachii, with the elongated position resulting in worse joint position sense in the muscle subjected to the exercise with DOMS.

DOMS is an uncomfortable sensation experienced by people who engage in physical exercise that differs from their usual routine in terms of loads and ranges of motion [4]. Thus, its effects can be seen in both clinical practice and in the sports training of professional or amateur athletes [26]. Especially in individuals with low adherence to physical activity, modifying the training routine can lead to high levels of DOMS, which may have negative consequences on performance [27]. DOMS affects running kinematics, decreasing knee flexion range of motion [28], as well as lower limb kinetics during vertical jumping, altering landing time, and increasing knee and hip flexion angles [29]. However, it is not yet clear whether the changes in the biomechanics of these tasks are due to strength deficits, motor planning issues, or the pain sensation itself.

In this sense, we sought to replicate a protocol where it would be possible to determine whether DOMS impairs the precision of simple movements. It is known that DOMS can affect proprioceptive and nociceptive pathways [30], supporting our hypothesis. However, it remains to be determined whether these alterations are responsible for the impairment in performing simple motor tasks, such as positioning a joint at a specific angle. Inducing DOMS is a task that requires tight control over variables, and its measurement faces challenges, including participant understanding and limitations of subjective scales. In this study, we used pressure pain threshold assessment with an algometer, which appears to be the most sensitive measure for this phenomenon [22]. Our results indicate that 48 hours after the DOMS induction exercise, participants had a lower pain threshold, meaning their muscles were more vulnerable to painful stimuli. This result is consistent with the known temporal nature of DOMS, which peaks two days after intense fatigue [31].

DOMS manifested in both groups (men and women) 48 hours after exercise in the experimental arm, with no difference in DOMS intensity between sexes, contrary to our hypothesis that women would have a lower pain threshold than men [7]. A previous study by Roditi et al. showed that muscle fatigue is not influenced by the follicular or luteal phase of the menstrual cycle [32], but there is a reduction in motor accuracy for knee flexion movements when compared to knee extension during the same menstrual phases. In our study, the error in joint position sense did not differ between sexes pre-exercise and 48 hours after DOMS induction. However, both sexes showed greater error 48 hours post-exercise when evaluated in a posture where the painful muscle was extended. No differences in joint position sense were observed in the shortened position due to the presence of DOMS.

Few studies have chosen to establish random angles to induce different muscle lengths and compare them, as we did in our study. It is also worth noting that in our study, the assessment was carried out without any equipment limiting or controlling the movement of the participant, allowing for a broader and more realistic assessment of how muscle length can affect joint position sense. This is because most studies evaluating the joint position sense of the biceps brachii used some type of equipment that "restricted" the limb, allowing only controlled movements [24,33]. However, this can be a limitation of those studies, as it may affect the naturalness of the movement and, consequently, the joint position sense of the evaluated limb.

During the elbow flexion and extension movements, muscles shorten and elongate, altering the role of contractile proteins in the sarcomere, as described by Herzog [14]. In the concentric phase of the movement, the muscle shortens to support the load, and in the eccentric phase, when it elongates, it performs fine-tuning to adjust the limb and stabilize the movement [34]. We noted that when the muscle is more elongated (elbow angle greater than 90°), there is greater error in joint position sense than in the shortened position (elbow angle less than 90°). Thus, muscle length appears to influence the effect of DOMS on joint position sense, as it affects the tension and alignment of muscle fibers, influencing the sensitivity of muscle and joint receptors and proprioception [35]. When the muscle is elongated, there is increased passive tension in the muscle tissues, altering the response of muscle spindles and Golgi tendon organs, which also increases the error-index in joint position sense [35].

This study has some limitations, such as variability in the number of repetitions in the DOMS induction protocol, both in men and women, which may have resulted in different magnitudes of muscle damage, which we were unable to determine in this study.

CONCLUSION

Physical exercise-induced delayed onset muscle soreness in the exercised limb but did not influence position sense in different elbow postures assessed. Such an effect did not differ between men and women participants. However, the perception of position, in the presence of pain, appears to be influenced by the muscle length at which it is evaluated, with greater errors in position sense when the biceps brachii muscle is stretched.

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