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Pain reduction following massage after induced fatigue is not mediated by changes in muscle stiffness or intramuscular fluid content: a randomized controlled trial with mediation analysis

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1	Pain Reduction Following Massage After Induced Fatigue Is Not Mediated by Changes in
2	Muscle Stiffness or Intramuscular Fluid Content: A Randomized Controlled Trial With
3	Mediation Analysis
4	ABSTRACT
5	Context: Massage therapy is a common intervention for athletic recovery. However, its
6	effects on fatigue, muscle stiffness, and intramuscular fluid content, or the mechanism for
7	pain reduction remain uncertain.
8	Objectives: To evaluate the immediate and subacute effects (24-72 hours) of massage on
9	pain, fatigue, muscle stiffness, and intramuscular fluid content in university athletes
10	following an induced fatigue protocol. Additionally, we investigated whether changes in
11	muscle stiffness and intramuscular fluid content mediate the effects of massage on pain and
12	fatigue.
13	Design: Randomized controlled clinical trial.
14	Settings: Laboratory.
15	Patients or Other Participants: Eighty-six university athletes, who completed a quadriceps
16	fatigue protocol involving isokinetic concentric contractions.
17	Interventions: Participants receive either a 10-minute massage therapy targeting the
18	quadriceps, or a sham control intervention. They were applied immediately after the fatigue
19	protocol and repeated 48 hours later.
20	Main Outcome Measures: Pain and fatigue were assessed using numeric rating scales.
21	Muscle stiffness and intramuscular fluid content were evaluated using ultrasound

- 22 elastography and echo intensity, respectively.
- 23 **Results:** Massage therapy reduced pain immediately after the intervention compared to
- sham group by -1.4 points (95% CI -2.8 to -0.1). No differences were observed for pain at

- 1 subsequent time points or for fatigue, muscle stiffness, or intramuscular fluid content at any
- 2 time. Mediation analysis did not reveal indirect effects of changes in muscle stiffness or
- 3 intramuscular fluid content on changes in pain or fatigue.
- 4 **Conclusion:** Massage therapy provides immediate pain relief following induced fatigue but
- 5 does not produce lasting effects on pain, fatigue, muscle stiffness, or intramuscular fluid
- 6 content. The observed pain reduction was not mediated by changes in muscle stiffness or
- 7 intramuscular fluid content.
- 8 **Key words:** Musculoskeletal Manipulations, Post-Exercise Recovery, Athletes, Quadriceps
- 9 Muscle, Sports.
- 10 Key Points
- 11 Massage reduces pain after induced fatigue
- Massage does not influence perceived fatigue, stiffness or intramuscular content
- 13 Massage effect is not explained by change in stiffness or intramuscular content

1 Team and high-speed sports often involve repeated high-load, explosive muscle actions, which results in muscle overload.¹ This can lead to nociceptor depolarization, 2 reduced muscle performance, and the development of pain and fatigue, which are common 3 complaints following exercise.^{1,2} While the initial inflammatory response typically resolves 4 within a short period, complete recovery may require several days.³ For athletes, post-5 6 exercise soreness and fatigue not only impair performance but also contribute to discomfort and hinder the ability to maintain optimal training loads.⁴ 7 Various interventions have been proposed to support recovery and mitigate the 8 adverse effects of exercise-induced soreness and fatigue.^{5,6} Among these, massage therapy 9

is one of the most commonly employed methods due to its practicality, ease of application, 10 and high acceptance among athletes.⁷ It is often applied immediately after exercise, with 11 substantial evidence suggesting its role in enhancing recovery following intense physical 12 activity. For instance, two systematic reviews concluded that massage effectively alleviates 13 acute exercise-induced pain.^{2,5} However, findings regarding the effects of massage on 14 perceived fatigue remain less clear. While some studies reported significant fatigue 15 reductions following events such as Ironman triathlons⁸ and ultramarathons,⁹ others, such 16 as investigations after a habitual 10-km run,¹⁰ found no detectable impact of massage on 17 fatigue. These inconsistent findings highlight the need for further research to clarify 18 massage therapy's effects on fatigue. 19

Despite conflicting findings regarding fatigue and the variable effect sizes for pain relief, massage is widely regarded as a useful tool for athletic recovery.^{2,5} Nevertheless, questions remain about the underlying mechanisms by which massage influences exerciseinduced impairments. Proposed mechanisms suggest that massage may exert its effects through biomechanical and vascular pathways.¹¹ Biomechanical effects include increased

1 muscle-tendon compliance and potential reductions in stiffness due to applied mechanical pressure.¹¹ Vascular effects may involve enhanced blood and lymphatic circulation, 2 promoting the clearance of intramuscular fluids, metabolic byproducts, and pain-inducing 3 substances.¹¹ For instance, reductions in blood creatine kinase levels following massage 4 5 have been reported, suggesting a potential role in mitigating inflammation and exerciseinduced muscle damage.^{5,12} Yang et al.¹³ explored massage's impact on intramuscular fluid 6 dynamics, such as a reduction in fluid content in the thoracolumbar fascia following 7 massage-gun application, and found a significant reduction in the intramuscular content. 8 However, this study presented notable methodological limitations, such as the absence of 9 an intention-to-treat analysis and blinding of assessors.¹³ Additionally, participants were not 10 under a fatigue condition, limiting the generalizability of the findings.¹³ Similarly, the 11 evidence for massage-induced changes in muscle stiffness is promising but inconclusive.^{14,15} 12 Crommert et al.¹⁴ found that massage significantly reduced muscle stiffness in treated legs 13 compared to untreated legs. Similarly, Jelen et al.¹⁵ compared two massage techniques and 14 found no difference between groups, but both techniques effectively reduced stiffness. 15 Despite these promising findings, methodological limitations and the absence of sport-16 related contexts prevent definitive conclusions about the effects of massage on muscle 17 stiffness. 18

Given the theoretical nature of the proposed mechanisms, it remains uncertain
whether massage therapy can truly induce changes in intramuscular fluids or stiffness and
how these factors may influence clinical outcomes, such as pain and fatigue. To address
these gaps, the aim of this study was to investigate the effects of massage therapy, applied
immediately and 48 hours after fatigue induction, on pain, fatigue, intramuscular fluid
content, and muscle stiffness in university athletes, compared to a sham technique. A

1 secondary aim was to investigate whether acute changes in intramuscular fluid content and

2 muscle stiffness mediate the effects of massage on pain and fatigue.

- 3 METHODS
- 4 Design

5 This randomized, parallel-group, single-blind, controlled trial was reported according the CONSORT checklist (Supplementary Material F).¹⁶ Ethical approval was obtained from 6 the XXX Human Research Ethics Committee (registration number CAAE XXX). The trial was 7 prospectively registered in the XXX Registry of Clinical Trials (XXX) on 15th September 2023. 8 Participants were randomly allocated to either the experimental or control group 9 (Figure 1) using a concealed randomization process. Allocation was achieved through sealed, 10 opaque, and sequentially numbered envelopes, which were prepared by an independent 11 individual with no involvement in the study procedures. To ensure allocation concealment 12 during recruitment, the envelopes were opened only after the completion of baseline 13 assessments, at which point group assignment was disclosed. The data collection was 14 conducted in a university biomechanics laboratory between October 2023 and May 2024. 15 Participants 16

Eighty-six university athletes participated in the study. The participants engaged in a
variety of team and individual sports, including soccer, handball, volleyball, padel,
taekwondo, dance, and track and field. Written informed consent was obtained from all
participants before enrollment.

The inclusion criteria were: (i) university athletes aged 18 to 30 years who trained at least three times per week with activities related to their respective sports, (ii) no history of cardiovascular, pulmonary, or metabolic diseases, and (iii) no use of performance-enhancing or recovery-boosting substances. Potential participants were excluded if they had

1	discontinued sports activities in the past six months due to injury or reported neurological,
2	musculoskeletal, cardiovascular, pulmonary, or metabolic conditions that could interfere
3	with or contraindicate the research procedures. University athletes were defined as
4	undergraduate students who had been training consistently for at least one year and had
5	recently competed in sports events.
6	Throughout the data collection period, participants were instructed to maintain their
7	regular routines while refraining from recovery techniques such as anti-inflammatory
8	medications, stretching, cryotherapy, or massage therapy targeting the evaluated region.
9	They were also advised to avoid engaging in high-intensity physical activities.
10	Procedures
11	After confirming eligibility, participants completed a questionnaire to provide
12	anthropometric data and details about their sports practice. Baseline assessments included
13	pain and fatigue levels, as well as ultrasound (US) evaluations of intramuscular fluid content
14	and muscle stiffness via muscle echo intensity and elastography, respectively (A1). Following
15	these initial assessments, participants performed a quadriceps muscle fatigue protocol.
16	Immediately after the fatigue protocol, pain and fatigue levels were reassessed, and US
17	evaluations were repeated (A2).
18	Participants were subsequently randomized by a researcher uninvolved in the
19	assessments. Randomization and interventions were conducted at a separate setting to
20	ensure evaluator blinding. After the allocated intervention, pain and fatigue levels were

reassessed, along with US parameters (A3). A blinded evaluator contacted participants

remotely via phone message (i.e. WhatsApp) 24 hours after the initial intervention to collect

23 additional data on pain and fatigue (A4).

Forty-eight hours post-fatigue protocol, participants returned to the laboratory for a follow-up assessment, which included pain, fatigue, and US parameters (A5). Participants subsequently received the second intervention according to their original allocation. Postintervention assessment of pain, fatigue, and US parameters were then performed (A6). Finally, 72 hours after the first interventions, the same blinded evaluator conducted remote assessments of pain and fatigue (A7). The flowchart summarizing the study timeline and procedures is presented in Figure 1.

8 Induced Fatigue Protocol

The fatigue protocol targeted knee extensor muscles and was performed using a 9 Biodex System isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA). 10 Participants first completed a warm-up set of four submaximal repetitions. This was 11 followed by four sets of 20 maximal concentric contractions at a velocity of 60°/s, with a 12 two-minute rest interval between sets.¹⁷ This protocol effectively reduced maximal 13 strength, with an approximate 60% decline in performance over the course of the protocol 14 (Figure 2). Additionally, the protocol significantly increased pain and fatigue levels while 15 reducing muscle stiffness. However, no significant changes were observed in intramuscular 16 fluid content (Supplementary Material A). 17

18 Interventions

Participants in the experimental group received a 10-minute massage applied by a trained physiotherapist who was not involved in the assessments (Figure 3A). The massage protocol included the following steps: 1 minute of superficial effleurage, during which the therapist performed gentle gliding movements from distal to proximal along the muscle fibers of the quadriceps; 3 minutes of deep effleurage, which involved the same technique but with increased pressure; 3 minutes of petrissage, in which the therapist used the palms

to compress, lift, and knead the tissue sequentially; 1 minute of tapotement, where the 1 2 therapist applied rhythmic, oscillatory movements to the thigh using cupped hands; and 2 minutes of superficial effleurage to conclude the intervention.¹⁰ A neutral, soap-based foam 3 was applied to facilitate smooth gliding during the massage. The massage protocol was 4 5 designed to replicate common post-race clinical practice, prioritizing short, low-intensity interventions. Techniques were selected to promote relaxation and venous return with 6 minimal discomfort and were applied in order of increasing intensity, ending with the least 7 8 intense technique.

Participants in the control group underwent sham joint mobilizations targeting the 9 knee (5 minutes, Figure 3B) and hip (5 minutes, Figure 3C) while lying supine with the knee 10 flexed at 90° and the sole of the foot resting on the table.¹⁰ These mobilizations involved 11 gentle traction using a belt, designed exclusively to provide tactile sensation without 12 inducing actual joint movement. The therapist avoided direct contact with the participants' 13 legs. For the sham hip joint mobilization, the belt was positioned across the participant's 14 inguinal region and around the therapist's lower back. For the sham knee joint mobilization, 15 the belt was placed around the proximal tibial region of the participant and secured around 16 the therapist's lower back. In both cases, the therapist applied a slight, oscillatory 17 movement by shifting the body away from the participant, producing mild pressure on the 18 skin. To ensure evaluator blinding, the same neutral foam used in the massage group was 19 applied to the participants in the control group at the end of the intervention.⁸ 20

The same intervention procedures were repeated 48 hours after fatigue protocol for the second application. The TIDieR (Template for Intervention Description and Replication) checklist is reported in Supplementary material B.

24 Assessments

1 All assessments were conducted by a trained evaluator who was blinded to the

2 group allocation.

3 Pain and Fatigue

Pain and fatigue levels were measured using the numeric rating scale (NRS).^{10,18} This 4 scale demonstrates high reliability¹⁸ and is responsive to changes in both pain and fatigue.⁸ 5 6 Participants were asked the following questions: "What is your current pain level in your thigh?" on a scale from 0 (no pain) to 10 (worst possible pain), and "How much fatigue do 7 you feel in your thigh right now?" with 0 indicating no fatigue and 10 indicating extreme 8 9 fatigue. Ultrasound Measurements 10 Echo intensity (intramuscular fluid content) and shear-wave elastography (muscle 11 stiffness) were assessed using an ultrasound system (Acuson S2000, Siemens, Germany) 12 equipped with a 40-mm linear transducer (Acuson 9L4, Siemens, Germany). Three US 13 images were obtained for each assessment, with a depth of 5 cm, an intensity of 8 MHz, and 14 a general gain of 0 dB/DR65. The transducer was placed longitudinally, aligned with the 15 direction of the vastus lateralis muscle fibers, at 50% of the distance between the greater 16 trochanter and the lateral femoral condyle, in the anterolateral region.¹⁹ All images were 17 18 captured with the quadriceps at rest, with participants in the supine position and the lower limbs in a neutral position.¹⁹ To ensure proper transducer coupling during each 19 measurement, excessive pressure on the assessed region was avoided.¹⁹ 20 - Echo intensity: this refers to the amount of US waves reflected by muscle tissue, quantified 21 on a grayscale histogram ranging from 0 (black) to 255 (white).²⁰ Higher echo intensity 22 23 values reflect a greater presence of non-contractile components, including intramuscular fluid content, ²⁰ which may be influenced by massage interventions.¹¹ Image analysis was 24

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1 performed using ImageJ Software 1.42q (National Institute of Health, Bethesda, USA), with the region of interest defined within the vastus lateralis muscle.²⁰ To minimi 2 overestimation of echo intensity due to US attenuation by subcutaneous fat 3 normalized based on adipose layer thickness.²⁰ This thickness was defined as 4 5 between the superficial aponeurosis of the vastus lateralis and the superficial the adipose layer.²⁰ Corrected echo intensity was calculated by adjusting the 6 value obtained from the region of interest according to the measured adipos 7 using a validated correction formula.²⁰ For each participant, the average of t 8 expressed in arbitrary unit (a.u.), was used for analysis. Prior to data collecti 9 was assessed on 20 images, reporting high reliability (intraclass correlation of 10 $(ICC_{3,1}) = 0.96 - 0.98).$ 11 - Elastography: shear-wave elastography quantifies tissue stiffness by measure 12 of shear waves propagated through the muscle.²¹ For the measurement, a re 13 region of interest was placed in the belly of the vastus lateralis, between the 14 deep aponeuroses.¹⁹ Within each US image, 10 regions of interest were place 15 longitudinally along the muscle fibers to obtain shear modulus values, which 16 expressed in kilopascals (kPa).¹⁹ Higher values in kPa indicate greater muscle 17 18 reflecting increased resistance to deformation, which may be modulated by interventions.¹¹ These values were used to generate an elastogram, a color-19 map in which red indicates higher stiffness and blue indicates lower stiffness 20 21 (Supplementary Material C). Muscle stiffness was calculated as the average across three

images, totaling 30 regions of interest. This method has been reported as a reliable

23 assessment.²¹

24 Statistical Analysis

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1	The sample size was calculated to ensure 80% statistical power (β = 0.20) and a 5%
2	significance level (α = 0.05), accounting for a potential 15% dropout rate. The calculation
3	indicated that a minimum of 42 participants would be required to detect a 2-point
4	difference in pain (SD = 3 points) ²² and a 1-point difference in fatigue (SD = 1.5 points), ²³
5	using the NRS. The calculation was performed using the G*Power software.
6	An intention-to-treat approach was employed for all analyses, with participants
7	analyzed according to their initial randomization. Missing data were addressed using the
8	multiple imputation method, ²⁴ generating 20 imputed datasets based on all available
9	variables to predict missing values. ²⁴
10	All data are presented as mean and standard deviation. Data normality was
11	evaluated using the Shapiro-Wilk test. To evaluate the effect of massage therapy across
12	time points, a mixed linear model analysis of variance (ANOVA) was conducted for pain,
13	fatigue, muscle stiffness and intramuscular fluid content. Differences from baseline (A2)
14	were considered in the analysis of acute effects (A3), as well as after 24h (A4), 48h (A5), and
15	72h (A7) post-fatigue induction. The efficacy of the second massage therapy, applied 48h
16	after induced fatigue, was assessed using an independent t-test, comparing the change in
17	outcomes from pre- to post-intervention (A6 minus A5). For each comparison, mean
18	difference (MD) and 95% confidence interval (CI) were calculated. Additionally, effect sizes
19	(Cohen's d) were computed for significant comparisons and interpreted as small (d=0.2),
20	moderate (d=0.5), or large (d≥0.8). ²⁵ Statistical analyses were conducted using IBM SPSS
21	Statistics, version 26.0.

22 Mediation analyses were performed to investigate whether the acute effects of the 23 massage (A3 minus A2) on pain and fatigue were mediated by changes in muscle stiffness 24 and intramuscular fluid content. This statistical approach assesses whether the effect of an 1 independent variable (massage) on an outcome (pain or fatigue) occurs directly, or

- 2 indirectly through one or more mediating variables. In this context, direct effects represent
- 3 the portion of the intervention's impact not explained by changes in the mediators (muscle
- 4 stiffness or intramuscular fluid content), while indirect effects quantify the portion
- 5 mediated by them. Analyses followed the framework outlined by MacKinnon et al.,²⁶ using
- 6 1000 bootstrapped simulations to estimate the total, direct, and indirect effects, with
- 7 corresponding 95% CI. All mediation analyses were conducted using the R software

8 (package "mediation"), with statistical significance set at $p \le 0.05$ for all analyses.

- 9 **RESULTS**
- 10 Participants Flow

Of the 86 participants initially enrolled in the study, 10 were lost to follow-ups after the A5 assessment. Consequently, 37 participants in the experimental group and 39 in the control group completed the study protocol. Baseline characteristics were comparable between the experimental and control groups, including age, body mass, height, and gender distribution (Supplementary material D).

16 Protocol Adherence

All randomized participants met the eligibility criteria. The assessors remained
 blinded throughout the study to ensure unbiased evaluations. All participants received the
 assigned intervention, and data were analyzed according to their original group allocation,
 adhering to the intention-to-treat principle.

- 21 Massage Effects
- 22 Descriptive statistics (means and standard deviations) for pain, fatigue, muscle
- 23 stiffness, and intramuscular fluid content across all assessments are provided in
- 24 Supplementary Material E. Massage was associated with a reduction in pain levels

1 immediately post-intervention compared to sham mobilization (Table 1). Specifically, the

2 experimental group presented a mean pain reduction of 1.4 points (95% CI 0.1 to 2.8)

3 relative to the control group, corresponding to a moderate effect size (d = 0.59). No

4 significant differences between groups were observed for pain at subsequent time points.

- 5 Similarly, no significant between-group differences were detected for fatigue, muscle
- 6 stiffness, or intramuscular fluid content across any assessments (Table 1). Following the

7 second massage application, conducted 48 hours after fatigue induction, there were no

8 significant between-group differences for any of the outcomes analyzed (Table 2).

9 Mediation Analysis

Mediation analyses did not identify significant mediating effect of muscle stiffness or intramuscular fluid content on the immediate post-intervention changes in pain and fatigue (Table 3). Muscle stiffness accounted for approximately 4% of the total effect on both pain and fatigue, while intramuscular fluid content contributed about 1% of the total effect on pain and 5% of the total effect on fatigue. These effects were minor and not statistically significant, indicating that the interventions primarily exert direct effects on pain and fatigue, independent of changes in muscle stiffness or intramuscular fluid content.

17 DISCUSSION

The findings indicated that massage reduced pain levels immediately after the intervention compared to the sham technique group. However, no significant differences in pain outcomes were observed between groups during subsequent follow-up assessments. Furthermore, massage had no impact on fatigue, muscle stiffness (elastography), or intramuscular fluid content (echo intensity) at any assessment point. The reapplication of massage 48 hours post-fatigue induction also did not affect any of the measured outcomes. In terms of potential mechanisms, the results suggest that changes in muscle stiffness or
 intramuscular fluid content do not mediate the observed decreases in pain or fatigue.

3 The pain-relieving effects of massage in fatigued athletes aligns with prior literature.^{2,5} This confirms massage as an effective and clinically relevant intervention for 4 5 supporting post-exercise recovery in athletes. Despite these benefits, the magnitude of the 6 effect should be carefully considered in clinical decision-making. This study reported a 1.4point reduction in pain, which may be an arguable magnitude. Additionally, the lower bound 7 8 of the confidence interval suggests that, for some athletes, the actual effect of massage could be close to null effect, consistent with previous studies.^{8,10} Nonetheless, massage 9 remains a low-cost, non-invasive, and well-accepted intervention with no reported adverse 10 effects, justifying its use for immediate pain relief in appropriate cases. Clinicians are 11 encouraged to assess each case individually, considering not only pain modulation but also 12 other potential benefits, such as psychological and relaxation effects. 13 The current findings refute previous theories suggesting that pain reduction caused 14 by massage after strenuous activity is mediated by reductions in muscle stiffness or 15 intramuscular fluid content.¹¹ To understand these results, some points must be considered. 16 In the context of muscle fatigue, muscle stiffness was reduced following fatigue, consistent 17 with prior literature.²⁷ Thus, pain reduction from massage cannot be attributed to 18 decreased stiffness if stiffness was not elevated. Although some studies suggest massage 19 reduces muscle stiffness measured via elastography,^{13,14} these findings were observed in 20 non-fatigued individuals. Furthermore, massage did not alter muscle stiffness but remained 21 22 effective for pain reduction, suggesting that the effects of massage in fatigue conditions are 23 likely unrelated to stiffness. Regarding intramuscular fluid content, the fatigue protocol did 24 not significantly impact echo intensity, preventing conclusions about the influence of

massage on intramuscular fluid levels. Massage effects on fluid mobility might be more 1 2 pronounced in cases of fluid accumulation, such as inflammation, lymphatic alterations, or post-exercise situations involving extreme exertion. Overall, these results suggest that the 3 analgesic effects of massage in fatigued athletes are not explained by mechanical or 4 5 vascular factors. Instead, neurophysiological mechanisms may play a role. Rapid pain 6 reduction may be linked to massage-induced mechanoreceptor activation through pleasant tactile stimulation,²⁸ which modulates pain.²⁹ Massage may also increase oxytocin, an 7 endogenous mediator with antinociceptive and analgesic properties³⁰ However, these are 8 theoretical suggestions, and further research is needed to elucidate the mechanisms of 9 10 massage. Massage did not reduce fatigue compared to the sham technique. This finding 11 supports existing evidence that the effect of massage on fatigue may be influenced by the 12 initial level of fatigue, with its benefits potentially being more pronounced in situations of 13

severe fatigue.^{8–10} Although out fatigue induction protocol increased participants' perceived 14 fatigue by nearly seven points, this level of fatigue and the duration of fatigue state may not 15 have been sufficient to trigger a metabolic response that could be modulated by massage. 16 This could also explain the absence of significant subacute effects of massage on pain and 17 fatigue at 24, 48, and 72 hours post-intervention. Similarly, the reapplication of massage at 18 48 hours did not yield significant reductions in pain or muscle fatigue. One possible 19 explanation for this lack of effect is that the fatigue induction protocol was designed to 20 simulate typical levels of fatigue experienced by athletes, without inducing muscle damage. 21 22 As a result, the protocol may not have caused delayed onset muscle soreness or elevated 23 fatigue levels throughout the procedure. Consequently, participants reported relatively low 24 pain, and fatigue scores the following day, which may have reduced the magnitude of the

massage intervention's effect. This suggests that the protocol employed was not able to
induce persistent pain or fatigue symptoms. While previous studies have demonstrated
positive effects of massage in reducing delayed onset muscle soreness,¹² the current
findings imply that the therapeutic benefits of massage are most effective in acute pain
scenarios and may be dependent on the intensity and physiological impact of the exertion
involved.

7 Limitations

8 This study was conducted with healthy university athletes who were accustomed to high training loads. As such, the findings may be limited to populations with similar 9 characteristics. Although we included a sham technique, this did not guarantee the blinding 10 of the participants. As a result, individuals with prior knowledge of massage therapy may 11 have been biased in their responses, despite the use of a sham technique. Additionally, 12 while the fatigue protocol was effective in impacting performance and simulating a 13 strenuous sports condition, it involved only concentric contraction and did not precisely 14 replicate the movements and loads typically encountered by athletes during their sport-15 specific training and competition. 16

Therefore, this study demonstrated that quadriceps massage reduces pain in 17 university athletes immediately after intervention compared to sham technique but has no 18 effect on pain at later time points (24–72 hours post-fatigue induction). Massage also 19 showed no significant effects on perceived fatigue, muscle stiffness, or intramuscular fluid 20 21 content at any time point. Reapplication of massage at 48 hours post-fatigue had no 22 additional effect. Moreover, changes in muscle stiffness (elastography) and intramuscular 23 fluid content (echo intensity) did not mediate acute changes in pain and fatigue caused by 24 massage.

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1 FIGURE LEGENDS

- 2 Figure 1. Study design and flow of participants.
- 3 Figure 2. Normalized muscle torque during the fatigue protocol (the black line represents
- 4 mean values, and red shaded area indicates standard deviations).
- 5 **Figure 3**. A Massage therapy; B Sham knee mobilization; C Sham hip mobilization.









TABLES

	Difference within groups ^a								Difference between groups ^b			
	Post minus		nus 24h mir		ninus 48h minus		72h minus		Post minus	24h minus	48h minus	72h minus
Outcomes	Baseline		Baseline		Baseline		Baseline		Baseline	Baseline	Baseline	Baseline
	-	Com	D	Car	Exp	Com	Exp	G	Exp minus	Exp minus	Exp minus	Exp minus
	Ехр	Con	Ехр	Con		Con		Coll	Con	Con	Con	Con
Pain	-2.7	-1.3	-3.6	-3.9	-3.8	-4.0	-4.1	-4.3	-1.4	0.3	0.2	0.2
(points)	(2.5)	(2.2)	(3.5)	(3.3)	(3.5)	(3.7)	(3.2)	(3.7)	(-2.8; -0.1)	(-1.0; 1.7)	(1.1; 1.6)	(-1.2; 1.5)
Fatigue	-3.8	-3.5	-6.4	-5.7	-7.0	-6.7	-7.3	-7.0	-0.3	-0.7	-0.3	-0.3
(points)	(2.4)	(2.4)	(2.8)	(2.3)	(2.2)	(1.9)	(2.2)	(2.1)	(-1.3; 0.7)	(-1.6; 0.4)	(-1.3; 0.7)	(-1.3; 0.7)
Stiffness	-0.9	-0.2	na	na	-0.4	0.0	na	na	-0.7		-0.4	na
(kPa)	(3.6)	(4.1)	na	na	(3.6)	(3.7)			(-2.2; 0.9)	na	(-2.0; 1.2)	na
Echo Intensity	3.1	3.5	20	20	-0.9	-0.8	20		-0.4	20	-0.1	20
(a.u.)	(5.4)	(5.4)	na	na	(5.1)	(4.6)	na	IId	(-2.5; 1.9)	na	(-2.3; 2.1)	na

Table 1. Between-group comparisons across the study protocol.

Abbreviations: Exp = experimental group, Con = control group, na = not applicable.

*Number in bold indicate significant difference. ^amean (SD), ^bmean difference (95% CI)



	Difference v	Difference between		
	(Post minus Pre-i	groups ^b		
	Exp	Exp minus Con		
Pain (points)	-0.1 (0.5)	0.0 (0.3)	-0.1 (-0.3; 0.1)	
Fatigue (points)	-0.2 (0.6)	-0.1 (0.6)	-0.1 (-0.4; 0.2)	
Stiffness (kPa)	-0.1 (2.7)	0.4 (3.0)	-0.5 (-1.7; 0.8)	
Echo Intensity (a.u.)	1.3 (4.3)	1.9 (3.4)	0.6 (-2.2; 1.1)	

Table 2. Between-group comparisons for intervention reapplication at 48 hours.

Abbreviations: Exp = experimental group, Con = control group.

^amean (SD), ^bmean difference (95% CI)

ifference (95% CI)

	Average Causal	Average	Average		
	Mediation Effect	Direct Effect	Total Effect		
For Pain					
- Stiffness	0.1 (-0.2; 0.3); p=0.60	-1.4 (-2.5; -0.5); p<0.01	-1.4 (-2.4; -0.4); p<0.01		
- Echo Intensity	0.0 (-0.2; -0.2); p=0.99	-1.4 (-2.5; -0.5); p<0.01	-1.4 (-2.5; -0.5); p<0.01		
For Fatigue					
- Stiffness	0.0 (-0.2; 0.1); p=0.76	-0.3 (-1.3; 0.8); p=0.61	-0.3 (-1.3; 0.8); p=0.56		
- Echo Intensity	0.0 (-0.2; 0.2); p=0.88	-0.3 (-1.3; 0.7); p=0.59	-0.3 (-1.3; 0.7); p=0.57		

Table 3. Estimates (95% CI) for mediation analysis

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CONFIRMATION OF ETHICAL COMPLIANCE: Ethical approval was obtained from the Federal University of Santa Maria Human Research Ethics Committee (registration number CAAE 67652823.0.0000.5346), and the trial was prospectively registered in the Brazilian Registry of Clinical Trials (RBR-10wr9c7d).



SUPPLEMENTARY MATERIAL

Supplementary Material A. Impact of the fatigue protocol	
Supplementary Material B. TIDieR checklist	03
Supplementary Material C. Sample of the shear-wave elastography analysis	
Supplementary Material D. Characteristics of participants	
Supplementary Material E. Descriptive analyses for the outcome	
Supplementary Material F. CONSORT checklist	07



Variables mean (SD)	Pre-Fatigue	Pre-Fatigue Post-Fatigue		p-value ^a
Pain (points)	0.4 (1.1)	4.6 (3.1)	-4.2 (-4.9 to -3.5)	< 0.01
Fatigue (points)	1.1 (1.7)	7.8 (1.6)	-6.7 (-7.2 to -6.2)	< 0.01
Stiffness (kPa)	13.3 (3.3)	11.9 (5.0)	1.3 (0.3 to 2.4)	0.01
Echo Intensity (a.u.)	46.6 (15.2)	46.8 (15.7)	-0.2 (-1.2 to 0.8)	0.69
Quadriceps strength (%)	184 (56) ^b	108 (36) ^c	76 (65 to 86)	< 0.01

Supplementary Material A. Impact of the fatigue protocol (mean (SD).

^aresults from paired-t tests; ^bfirst five repetitions of the first set of the fatigue protocol, ^clast five repetitions of the fourth set of the fatigue protocol.

Supplementary material B. TIDieR checklist

A. Experimental intervention

Brief name: Massage therapy

Why: To recover physical parameters after induced fatigue.

What:

Materials: A neutral, soap-based foam.

Procedures: 1-minute superficial effleurage, during which the therapist performed gentle gliding movements from distal to proximal along the muscle fibers of the quadriceps; 3-minute deep effleurage, which involved the same technique but with increased pressure; 3-minute petrissage, in which the therapist used the palms to compress, lift, and knead the tissue sequentially; 1-minute tapotement, where the therapist applied rhythmic, oscillatory movements to the thigh using cupped hands; and 2-minute superficial effleurage.

Who provided: Physiotherapist.

How: Face-to-face and individually.

Where: Laboratory

When and how much: In a single session for 10 minutes, and the same procedure was repeated 48 hours after the fatigue protocol.

Tailoring: none.

Modifications: none.

How well: not applicable.

B. Control intervention

Brief name: Sham joint mobilisation.

Why: To provide tactile sensation without inducing actual joint movement.

What:

Materials: Inelastic belt.

Procedures: For the sham hip joint mobilization, the belt was positioned across the participant's inguinal region and around the therapist's lower back. For the sham knee joint mobilization, the belt was placed around the proximal tibial region of the participant and secured around the therapist's lower back. In both cases, the therapist applied a slight, oscillatory movement by shifting the body away from the participant.

Who provided: Physiotherapist.

How: Face-to-face and individually.

Where: Laboratory

When and how much: In a single session for five minutes in each mobilisation, and the same procedure was repeated 48 hours after the fatigue protocol.

Tailoring: none.

Modifications: none.

How well: not applicable.



Supplementary Material C. Sample of the shear-wave elastography analysis.

Characteristic	Experimental $(n = 43)$	Control $(n = 43)$
Age (yr), mean (SD)	22 (2)	22 (2)
Gender, males/females	25/18	27/16
Height (m), mean (SD)	1.74 (0.11)	1.74 (0.12)
Weight (Kg), mean (SD)	73 (14)	72 (14)

Supplementary Material D. Characteristics of participants

0	Baseline (A2)		Post (A3)		24h (A4)		48h (A5)		48h (A6)		72h (A7)	
Outcomes	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con
Pain (points)	4.5 (3.0)	4.7 (3.3)	1.8 (2.0)	3.4 (2.2)	0.9 (1.3)	0.8 (1.3)	0.7 (1.3)	0.7 (1.6)	0.6 (1.0)	0.7 (1.5)	0.4 (0.8)	0.5 (1.4)
Fatigue (points)	7.8 (1.7)	7.8 (1.5)	4.0 (2.3)	4.3 (2.2)	1.4 (1.8)	2.0 (1.9)	0.8 (1.4)	1.0 (1.4)	0.6 (1.1)	0.9 (1.4)	0.5 (1.1)	0.7 (1.5)
Stiffness (kPa)	11.3 (3.7)	12.6 (6.1)	12.5 (3.7)	13.0 (4.6)	na	na	13.0 (2.9)	13.2 (3.8)	12.9 (4.1)	13.6 (3.5)	na	na
Echo Intensity (a.u.)	48.2 (16.9)	45.5 (14.5)	51.3 (16.4)	48.9 (15.4)	na	na	47.3 (16.1)	44.7 (13.8)	48.6 (18.2)	46.5 (15.4)	na	na

Supplementary Material E. Descriptive analyses for the outcome [mean (SD)].

Abbreviations: Exp = experimental group; Con = control group; na = not applicable.

Supplementary Material F. CONSORT checklist

Section/topic	No	CONSORT 2025 checklist item description	Reported
Title and abstract			on page no. S
Title and structured abstract	10	Identification as a randomized trial	1 1
The and structured abstract	1a		
	lb	Structured summary of the trial design, methods, results, and conclusions	1-2 7
Open science	2		. ht
I rial registration	2	Name of trial registry, identifying number (with URL) and date of registration	<u> </u>
Protocol and statistical analysis plan	3	Where the trial protocol and statistical analysis plan can be accessed	4 prin
Data sharing	4	Where and how the individual de-identified participant data (including data dictionary), statistical code and any other materials can be accessed	NA -pd
Funding and conflicts of interest	5a	Sources of funding and other support (eg, supply of drugs), and role of funders in the design, conduct, analysis and reporting of the trial	Title page
	5b	Financial and other conflicts of interest of the manuscript authors	Title page
Introduction			
Background and rationale	6	Scientific background and rationale	3-4 prin
Objectives	7	Specific objectives related to benefits and harms	4
Methods			
Patient and public	8	Details of patient or public involvement in the design conduct and reporting of the trial	1. pc
involvement	0	Details of parton of public intervention in the data git, conduct and reporting of the data	5 05
Trial design	9	Description of trial design including type of trial (eg, parallel group, crossover), allocation ratio, and framework (eg, superiority, equivalence, non-inferiority, exploratory)	4 ctory.
Changes to trial protocol	10	Important changes to the trial after it commenced including any outcomes or analyses that were not prespecified, with reason	NA 9
Trial setting	11	Settings (eg, community, hospital) and locations (eg, countries, sites) where the trial was conducted	5 1
Eligibility criteria	12a	Eligibility criteria for participants	5 2
	12b	If applicable, eligibility criteria for sites and for individuals delivering the interventions (eg, surgeons, physiotherapists)	NA G
Intervention and comparator	13	Intervention and comparator with sufficient details to allow replication. If relevant, where additional materials describing the intervention and comparator (eg, intervention manual) can be accessed	7-9
Outcomes	14	Prespecified primary and secondary outcomes, including the specific measurement variable (eg, systolic blood pressure), analysis metric (eg, change from baseline, final value, time to event), method of aggregation (eg, median, proportion), and time point for each outcome	9-10 tree
Harms	15	How harms were defined and assessed (eg, systematically, non-systematically)	NA g
Sample size	16a	How sample size was determined, including all assumptions supporting the sample size calculation	10-11
	16b	Explanation of any interim analyses and stopping guidelines	NA
Randomisation:	4 -		
Sequence generation	17a	Who generated the random allocation sequence and the method used	4-5

Allocation concealment	17b 18	Type of randomisation and details of any restriction (eg, stratification, blocking and block size) Mechanism used to implement the random allocation sequence (eg, central computer/telephone; sequentially numbered,	4-5
mechanism		opaque, sealed containers), describing any steps to conceal the sequence until interventions were assigned	4-5
Implementation	19	Whether the personnel who enrolled and those who assigned participants to the interventions had access to the random allocation sequence	4-5
Blinding	20a	Who was blinded after assignment to interventions (eg, participants, care providers, outcome assessors, data analysts)	9
	20b	If blinded, how blinding was achieved and description of the similarity of interventions	5-6
Statistical methods	21a	Statistical methods used to compare groups for primary and secondary outcomes, including harms	11
	21b	Definition of who is included in each analysis (eg, all randomised participants), and in which group	11
	21c	How missing data were handled in the analysis	11
	21d	Methods for any additional analyses (eg, subgroup and sensitivity analyses), distinguishing prespecified from post hoc	NA
Results			
Participant flow, including flow diagram	22a	For each group, the numbers of participants who were randomly assigned, received intended intervention, and were analysed for the primary outcome	12
	22b	For each group, losses and exclusions after randomisation, together with reasons	12
Recruitment	23a	Dates defining the periods of recruitment and follow-up for outcomes of benefits and harms	5
	23b	If relevant, why the trial ended or was stopped	NA
Intervention and comparator	24a	Intervention and comparator as they were actually administered (eg, where appropriate, who delivered the	NIA
delivery		intervention/comparator, how participants adhered, whether they were delivered as intended (fidelity))	INA
	24b	Concomitant care received during the trial for each group	NA
Baseline data	25	A table showing baseline demographic and chrical characteristics for each group	12
Numbers analysed,	26	For each primary and secondary outcome, by group:	
outcomes and estimation		• the number of participants included in the analysis	
		• the number of participants with available data at the outcome time point	12-14
		• result for each group, and the estimated effect size and its precision (such as 95% confidence interval)	
		• for binary outcomes, presentation of both absolute and relative effect size	
Harms	27	All harms or unintended events in each group	NA
Ancillary analyses	28	Any other analyses performed, including subgroup and sensitivity analyses, distinguishing pre-specified from post hoc	NA
Discussion			
Interpretation	29	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	13-15
Limitations	30	Trial limitations, addressing sources of potential bias, imprecision, generalisability, and, if relevant, multiplicity of analyses	15

Citation: Hopewell S, Chan AW, Collins GS, Hróbjartsson A, Moher D, Schulz KF, et al. CONSORT 2025 Statement: updated guideline for reporting randomised trials. BMJ. 2025; 388:e081123. https://dx.doi.org/10.1136/bmj-2024-081123

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*We strongly recommend reading this statement in conjunction with the CONSORT 2025 Explanation and Elaboration and/or the CONSORT 2025 Explanated Checklist for important clarifications on all the items. We also recommend reading relevant CONSORT extensions. See www.consort-spirit.org.