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Sports Massage With or Without Ice Packs After Plyometric Exercise in Male Combat Athletes: A Three-Period Crossover Study

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Abstract

Whether local cooling adds to the recovery effects of sports massage after strenuous exercise remains uncertain. This study compared sports massage alone (SM), sports massage followed by ice packs (SM+ICE), and passive rest after plyometric exercise in male combat-sport athletes. Thirty athletes completed three treatment periods with 14-day washouts: SM, SM+ICE, and passive rest. Initial condition allocation was randomized, but chronological treatment sequences were unavailable for analysis. After a standardized plyometric protocol, active conditions involved seven sessions over 72 h. Each session included 20 min of bilateral quadriceps massage; SM+ICE additionally included 10 min of simultaneous bilateral ice-pack application. Rectus femoris stiffness and pressure pain threshold (PPT) were primary outcomes. Assessments occurred before and immediately after exercise and at 24, 48, and 72 h; the 72-h assessment followed the final treatment session. Multivariate repeated-measures models evaluated within-participant changes with Holm adjustment. All participants completed all conditions. The primary SM+ICE-versus-SM comparison showed greater reductions in rectus femoris stiffness with SM+ICE (Holm-adjusted $p<0.001$), but no additional PPT benefit ($p=0.438$). At 72 h, the SM+ICE–SM difference in change from immediately post-exercise was −26.30 N/m for stiffness (95% CI, −28.24 to −24.36) and −1.14 N for PPT (95% CI, −2.81 to 0.54). Exploratory secondary analyses showed higher reactive strength index and perceived-recovery scores with SM+ICE, and lower creatine kinase fold changes at 24 and 48 h. Adding ice packs to sports massage was associated with larger short-term stiffness reductions, without demonstrated additional PPT benefit. Secondary findings require replication. Missing treatment-order data, unblinded participants, unequal treatment duration, and post-treatment assessment at 72 h limit causal and practical inference.

Keywords: *muscle stiffness, pressure pain threshold, creatine kinase, reactive strength index, perceived recovery*

Introduction

Recovery after demanding exercise is important for human performance, since it influences athletes' ability to withstand and adapt to repeated physical stress. Because combat-sport athletes integrate technical practice with strength and conditioning (Zhang et al., 2025), there is a practical requirement to clarify how functions needed for later exercise recover. Plyometric experimental protocols offer a controlled model of lower-limb loading that includes repeated eccentric and concentric movements. Among combat athletes, these protocols have been applied to study muscle mechanical characteristics, pain sensitivity, biochemical reactions, and jump performance (Trybulski et al., 2024, 2026). Although these measures describe specific loading-related responses, they do not replicate the complete physiological, tech-

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nical, and psychological demands of competition.

Because post-exercise responses are multidimensional (Rappelt et al., 2023), recovery should be evaluated across complementary domains. Rectus femoris (RF) stiffness describes a local mechanical property, pressure pain threshold (PPT) reflects sensitivity to a standardized mechanical stimulus, and reactive strength index (RSI) captures performance during a specific jumping task. Creatine kinase (CK) activity and perceived recovery provide additional biochemical and subjective information. These outcomes address different questions, and improvement in one cannot establish equivalent improvement in the others. Biochemical changes should not be interpreted as direct evidence of restored performance (Freitas, Nakamura, Miloski, Samulski, & Bara-Filho, 2014).

Sports massage offers a practical approach to managing post-exercise discomfort, but evidence for symptom relief should be distinguished from evidence for functional recovery. Hilbert, Sforzo, and Swensen (2003) found reduced soreness intensity 48 hours after eccentric exercise without improved peak torque or range of motion. A systematic review and meta-analysis similarly reported benefits for soreness and flexibility without clear improvement in strength, jumping, sprinting, or endurance performance (Davis, Alabed, & Chico, 2020). These findings support assessing several recovery domains and caution against using reduced discomfort alone to infer readiness for demanding exercise.

Local cooling may complement massage through sensory effects. Algafly and George (2007) demonstrated reduced nerve conduction velocity and increased pain threshold and tolerance after cryotherapy. However, this physiological rationale does not establish an incremental recovery benefit from adding cooling to massage. In a randomized crossover trial in male mixed martial arts athletes, dry massage during exercise breaks better preserved several mechanical and performance outcomes. In contrast, ice massage produced a more favorable PPT response (Trybulski et al., 2025). Ice massage during brief exercise intervals differs in application and timing from ice packs delivered after a completed massage session.

The specific unresolved comparison is therefore massage alone versus the same massage followed by ice packs. Previous research examined combined contrast heat and cold pressure therapy (Trybulski et al., 2024), alternative massage modalities during exercise breaks (Trybulski et al., 2025), and massage or lymphatic drainage during recovery (Trybulski et al., 2026). None of these comparisons isolated the addition of ice packs to an otherwise identical sports massage procedure. A passive-rest condition also provides a reference for recovery without either treatment.

This three-period crossover study compared sports massage, sports massage followed by ice packs, and passive rest over 72 hours in 30 male combat athletes. The principal question was whether adding ice packs altered recovery relative to massage alone, considering RF stiffness and PPT alongside CK, RSI, and perceived recovery. Repeated assessments characterized the time course of these responses within the same athletes.

Methods

Study design

This single-center, three-period crossover study was conducted at Provita Medical Center, Żory, Poland. Each intervention period was separated from the next by a 14-day washout. Of 35 athletes screened, five were excluded before enrolment for health-related reasons. The remaining 30 athletes completed all three conditions: sports massage (SM), sports massage followed by ice packs (SM+ICE), and passive rest (CON). Initial condition assignment was generated using randomizer.org. However, individual chronological treatment sequences were unavailable in the analysis dataset; therefore, period, sequence, and carryover effects could not be modeled. Participants and treating physiotherapists were not blinded. Physical assessors were independent of treatment delivery and were blinded to the current treatment condition. Assessments were performed before warm-up and exercise (T0), immediately after exercise (T1), and 24 h (T2), 48 h (T3), and 72 h (T4) after exercise.

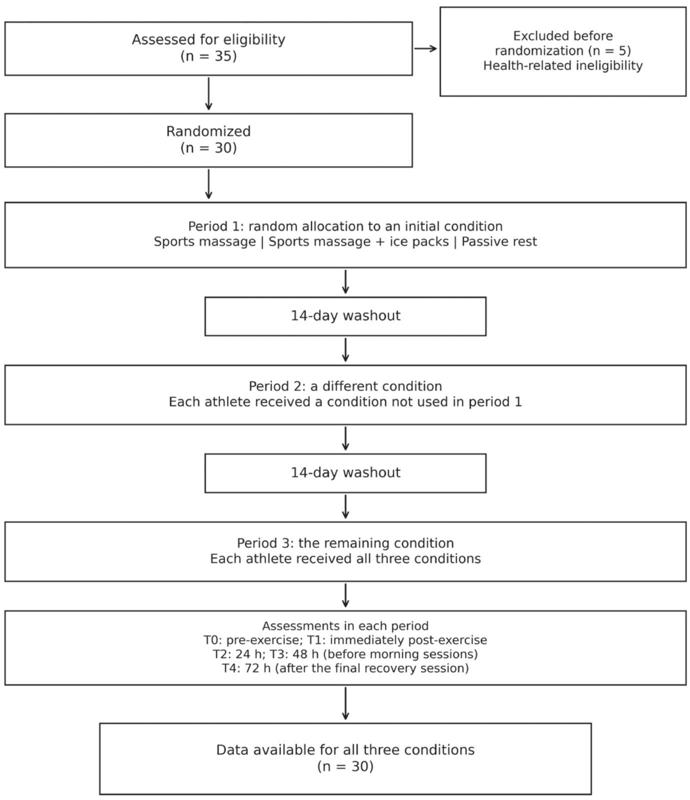

FIGURE 1. Participant flow and the three-period crossover schedule. SM, sports massage; SM+ICE, sports massage followed by ice packs; CON, passive rest.

The study was conducted under a broader muscle-relaxation research project approved by the Research Ethics Committee of the National Council of Physiotherapists, Poland (approval no. 24; 24 April 2023), and registered in the ISRCTN registry (ISRCTN10033645; 4 July 2023). Procedures complied with the Declaration of Helsinki, and all participants provided written informed consent. Figure 1 presents the participant flow and study schedule.

Participants

A sensitivity calculation in Python, using the noncentral t approach also implemented in G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), indicated that 30 paired observations provide 80% power for a standardized paired difference of dz = 0.59 at two-sided α = 0.025. This was not an a priori sample-size calculation or a power calculation for the multivariate comparison.

Participants were 30 male combat sports athletes classified as Tier 2 (trained/developmental) according to McKay et al. (2022). Inclusion criteria were male sex, age 18–40 years, good general health, at least three years of combat sports training, and at least three training sessions per week. Exclusion criteria were elevated blood pressure before testing (>140/90 mmHg), current injuries or ongoing treatment for musculoskeletal injuries, skin or myofascial lesions, and tattoos at the measurement sites. Extreme fatigue, fever, or infection also precluded participation, and athletes could withdraw at any time. All 30 participants had anthropometric and intervention measurements available. Table 1 presents their characteristics.

Table 1. Participant Characteristics (n = 30)

Characteristic	Mean (SD)	Minimum–maximum
Age (years)	28.7 (3.6)	21–34
Body mass (kg)	80.9 (7.8)	69–92
Height (cm)	175.7 (6.7)	167–189
Body mass index (kg/m^2)	26.33 (3.38)	20.83–32.27
Training experience (years)	6.5 (3.1)	3–12
Systolic blood pressure (mmHg)	123.1 (3.0)	119–129
Diastolic blood pressure (mmHg)	83.4 (2.9)	78–87
Resting heart rate (beats/min)	73.0 (6.6)	62–82
Male sex, n (%)	30 (100)	—

Note. SD, standard deviation.

Plyometric exercise protocol

Athletes performed five sets of bilateral jumps onto a 50-cm box, continuing until they could no longer sustain effort, with 1-min interset rests (adapted from Trybulski et al., 2024). Repetition counts were not fixed. Warm-up comprised 5 min of moderate cycling and 3 min of stretching the knee flexors/extensors, hip abductors/adductors, and triceps surae. Each jump involved a countermovement and arm swing, bilateral landing on the box, and a jump down with hip and knee flexion on landing (Figure 2). A paramedic supervised the task.

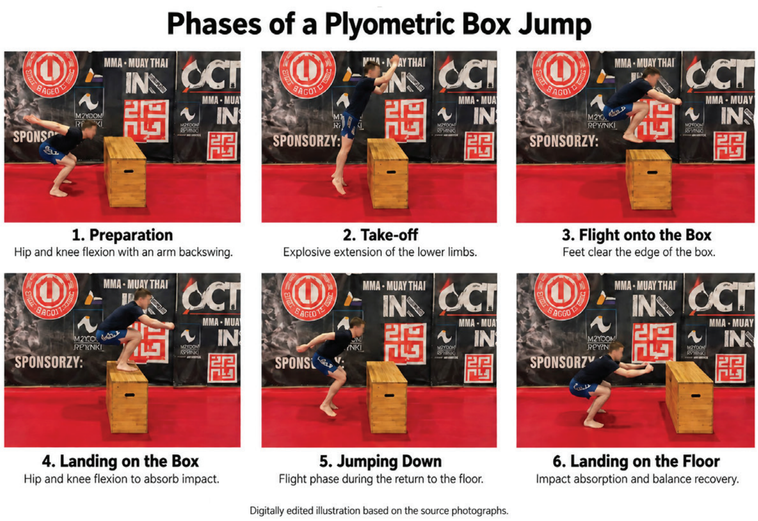

FIGURE 2. Phases of the plyometric box jump: preparation, take-off, flight onto the box, landing on the box, jumping down, and landing on the floor.

Recovery interventions

Seven sessions were administered in each SM and SM+ICE period: after T1 and that evening; after T2 and that evening; after T3 and that evening; and before T4. Thus, the immediate, 24-h, and 48-h assessments preceded the corresponding session, whereas the 72-h assessment followed the final session.

Physiotherapists with at least three years of experience applied sports massage to both quadriceps after reviewing a standardized sequence. Each thigh received approximately 1 min of effleurage and 3 min each of kneading, deep friction, and compression, totaling 10 min per thigh and 20 min per session (Figure 3A–D). Pressure elicited mild painful discomfort of 1–2/10. SM+ICE used the same massage, followed by simultaneous ice-pack application to both thighs for 10 min, for a total of 30 min per session (Figure

3E). Packs were removed from a freezer; their surface temperature was approximately 3–4°C, measured with a noncontact infrared thermometer before application.

In CON, athletes rested without treatment. During follow-up, other recovery modalities, including stretching, massage, cooling, and therapeutic procedures, were prohibited; adherence was assessed by questionnaire and verbal declaration. Participants and treating physiotherapists were unblinded.

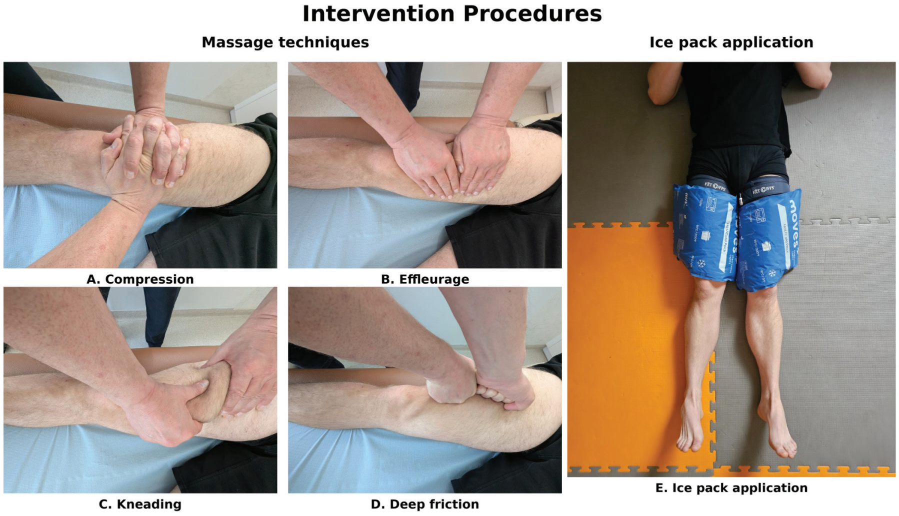

FIGURE 3. Recovery procedures. Massage techniques: (A) compression, (B) effleurage, (C) kneading, and (D) deep friction. (E) Simultaneous application of ice packs to both thighs after completion of the 20-min massage.

Outcome measures

For the present study, RF stiffness and pressure pain threshold (PPT) were designated as primary outcomes. Secondary outcomes were creatine kinase (CK), reactive strength index (RSI), perceived recovery, and rating of perceived exertion (RPE). All outcomes were assessed at T0–T4, except RPE, which was recorded only at T1.

Blinded physical assessments were carried out by experienced physiotherapists who were independent from intervention delivery. Qualified personnel collected and analyzed the blood samples, while unblinded participants provided the subjective outcomes. RF stiffness and PPT were evaluated separately for both thighs. The measurement procedures were based on Trybulski et al. (2024). Further details on the measurements, along with external evidence of reliability and validity, are included in the Supplementary Materials.

Primary outcomes

RF stiffness was assessed with a MyotonPRO device (Myoton AS, Tallinn, Estonia) while participants were positioned supine, with the knee supported and the quadriceps kept relaxed. The measurement locations were determined at the midpoint between the anterior superior iliac spine and the superior border of the patella, then marked so they could be rechecked. For each thigh, three trials were collected; each trial consisted of five mechanical impulses, and the results were averaged for analysis. Earlier work has shown inter-rater intraclass correlation coefficients (ICCs) of 0.91–0.98 and between-day ICCs of 0.70–0.87 (Chen et al., 2019). Its association with ultrasound elastography was r=0.416 (Lee, Kim, & Lee, 2021).

At each designated location, PPT was measured with an FPIX algometer (Wagner Instruments, Greenwich, CT, USA) fitted with a 4-mm-radius probe. Force was then increased in a direction perpendicular to the site until the participant indicated pain for the first time. For each thigh, three measurements were collected, and the mean was used for analysis. Prior work has shown intra-rater ICCs of 0.92–0.96 and inter-rater ICCs of 0.94–0.96 (Koh et al., 2023). In addition, correlations between algometer and force-plate readings were reported to fall between 0.990 and 0.999 (Kinser, Sands, & Stone, 2009).

Secondary outcomes

After instruction and practice, athletes completed three drop jumps from a 50-cm box, rebounding vertically without delay on ForceDecks (VALD Performance, Australia). RSI was derived by dividing jump height by contact time, then averaged across the three attempts. Prior work has shown excellent reliability for RSI obtained from jump mats (ICC = 0.99; Markwick, Bird, Tufano, Seitz, & Haff, 2015). Compared with laboratory force platforms, ForceDecks demonstrated a vertical-force bias of under 2 N (Collings, Lima, Dutaillis, & Bourne, 2024).

CK. At each assessment, 8 mL of venous whole blood was collected in one seated antecubital draw and analyzed using point-of-care testing (POCT), reported in U/L. CK responds to training load but does not directly measure restored function (Freitas et al., 2014).

Perceived recovery was measured with the Total Quality Recovery scale (TQR; range, 6–20 points; Kenttä & Hassmén, 1998). Prior studies have found that TQR scores are inversely related to CK activity (r = −0.75; Osiecki et al., 2015) and that TQR is sensitive to training load (Freitas et al., 2014).

At T1, RPE was measured with the Borg 6–20 scale (Borg, 1982). Earlier treadmill studies found ICCs ranging from 0.75 to 0.82 (Lamb, Eston, & Corns, 1999). These reliability estimates are protocol-specific and were obtained from external studies, not from the present sample.

Statistical analysis

The analyses used Python version 3.12.14, SciPy version 1.17.0, and statsmodels version 0.14.5 (Seabold & Perktold, 2010). All data were complete, so none of the observations analyzed were omitted or imputed. Continuous outcomes were reported as mean (standard deviation [SD]), whereas ordinal outcomes were presented as median [quartiles].

Multivariate linear models for repeated measures incorporated condition, categorical time, and, in the case of RF stiffness and PPT, side, along with every interaction term. At the participant level, contrasts were evaluated with Hotelling's T^2 statistic, which was transformed into an F statistic and did not rely on any sphericity assumption (Hotelling, 1931). CK was examined on a logarithmic scale. Since data on the chronological order of treatment were not available, the models were unable to account for period, sequence, or carryover effects.

The main comparisons jointly tested SM+ICE versus SM changes from T1 to T2–T4, averaging both thighs. Holm correction covered two primary omnibus tests and, separately, six primary time-specific contrasts (Holm, 1979). Paired contrasts provided differences, pointwise 95% confidence intervals (CIs), and dz. CK estimates were ratios of follow-up/T1 fold changes. Other comparisons used separate Holm families. We used quantile–quantile plots, Shapiro–Wilk tests, and 49,999 participant-level sign flips to assess sensitivity.

TQR used Friedman and paired Wilcoxon tests; Borg RPE used the same tests at T1. Holm-adjusted pairwise results included rank-biserial correlations. We used correlations adjusted for participant and condition to explore T1-to-T3 associations, extending Bakdash and Marusich (2017), with 9,999 participant-bootstrap resamples for CIs and no confirmatory correlation tests.

All hypothesis tests used two-tailed significance, with $\alpha = 0.05$. The Supplementary Methods provide full details on contrast formation, multiplicity-adjustment families, software versions, and resampling procedures. T4 was evaluated following the last treatment session.

Results

All 30 athletes completed all three periods and contributed complete repeated-measures data. This comprised 900 thigh-level observations each for RF stiffness and PPT, 450 participant-period-time observations each for CK, RSI, and TQR, and 90 participant-period observations for Borg RPE. Participant characteristics are shown in Table 1, and outcome distributions and complete model results are provided in Tables S1–S3. Across treatment periods, the plyometric protocol was followed by increased stiffness and CK and by reduced PPT and RSI at T1 relative to T0 (Figure 4).

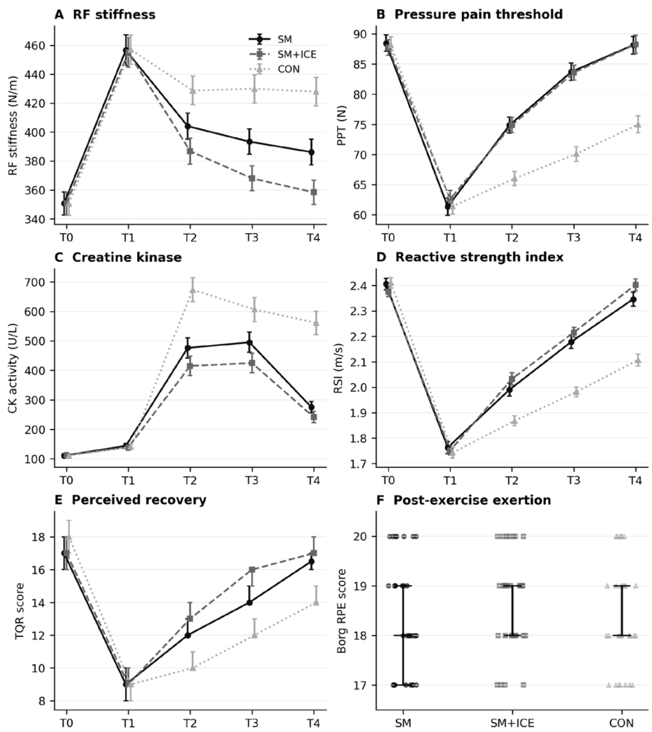

FIGURE 4. Outcomes across SM, SM+ICE, and CON. Panels A–D show means with 95% CIs; A and B average both thighs within each athlete. Panel E shows TQR medians and interquartile ranges. Panel F shows individual Borg ratings with medians and interquartile ranges. T0, before exercise; T1, immediately after; T2, 24 h; T3, 48 h; T4, 72 h, after the final recovery session. Time points are equally spaced for display.

Primary outcomes

The omnibus within-participant SM+ICE-versus-SM contrast differed significantly for RF stiffness, $F(3, 27) = 403.48$, Holm-adjusted $p < 0.001$, but not for PPT, $F(3, 27) = 0.93$, Holm-adjusted $p = 0.438$. Relative to SM, SM+ICE resulted in greater reductions in stiffness from T1 at 24 h (difference, −15.74 N/m; 95% CI, −18.04 to −13.44), 48 h (−23.82 N/m; 95% CI, −25.91 to −21.73), and 72 h (−26.30 N/m; 95% CI, −28.24 to −24.36; all Holm-adjusted $p < 0.001$). Differences in PPT changes between SM+ICE and SM were not statistically significant at any follow-up (all Holm-adjusted $p = 0.306$; Table 2). Relative to CON, both active conditions resulted in greater decreases in stiffness and greater increases in PPT at each follow-up (all adjusted $p < 0.001$; Table S4). Within-condition changes are presented in Table S5.

Laterality and secondary outcomes

Averaged across conditions and times, right-minus-left differences were −0.95 N/m (95% CI −1.19 to −0.72) for stiffness and −0.28 N (−0.34 to −0.23) for PPT. No side-related interactions remained statistically significant after multiplicity adjustment (Tables S3 and S6; Figures S1 and S2).

Compared with SM, SM+ICE was associated with lower CK follow-up-to-T1 fold-change ratios at 24 h (ratio, 0.903; 95% CI, 0.834–0.977; adjusted p=0.026) and 48 h (ratio, 0.890; 95% CI, 0.821–0.966; adjusted p=0.020), but not at 72 h (ratio, 0.909; 95% CI, 0.824–1.004; adjusted p=0.058). Changes in RSI from T1 were greater with SM+ICE at 24 h (difference, 0.054 m/s; 95% CI, 0.033–0.076), 48 h (0.049 m/s; 95% CI, 0.022–0.075), and 72 h (0.068 m/s; 95% CI, 0.041–0.096; all adjusted $p \leq 0.003$). TQR scores were higher with SM+ICE at all follow-ups (all adjusted p

Table 2. SM+ICE Versus SM at Follow-Up

Outcome	Time	Estimate (95% CI)	Adjusted p	Effect size
Stiffness (N/m)	T2	-15.74 (-18.04, -13.44)	<0.001	-2.55
Stiffness (N/m)	T3	-23.82 (-25.91, -21.73)	<0.001	-4.26
Stiffness (N/m)	T4	-26.30 (-28.24, -24.36)	<0.001	-5.06
PPT (N)	T2	-1.25 (-2.92, 0.43)	0.306	-0.28
PPT (N)	T3	-1.40 (-3.09, 0.30)	0.306	-0.31
PPT (N)	T4	-1.14 (-2.81, 0.54)	0.306	-0.25
CK (ratio)	T2	0.903 (0.834, 0.977)	0.026	-0.48
CK (ratio)	T3	0.890 (0.821, 0.966)	0.020	-0.54
CK (ratio)	T4	0.909 (0.824, 1.004)	0.058	-0.36
RSI (m/s)	T2	0.054 (0.033, 0.076)	<0.001	0.94
RSI (m/s)	T3	0.049 (0.022, 0.075)	0.003	0.69
RSI (m/s)	T4	0.068 (0.041, 0.096)	<0.001	0.92
TQR (points)	T2	1.0	<0.001	1.00
TQR (points)	T3	1.0	<0.001	1.00
TQR (points)	T4	1.0	<0.001	1.00

Note. Estimates are differences in change from T1 (stiffness, PPT, RSI), ratios of follow-up/T1 fold changes (CK), or median paired score differences (TQR). Stiffness and PPT average both thighs. Effect sizes are dz (CK log scale) or rank-biserial correlations (TQR). CIs are pointwise. Holm families: six primary, 30 additional continuous, and nine TQR contrasts. SM, sports massage; SM+ICE, SM followed by ice packs; PPT, pressure pain threshold; CK, creatine kinase; RSI, reactive strength index; TQR, Total Quality Recovery; CI, confidence interval. T1, immediately after exercise; T2, 24 h; T3, 48 h; T4, 72 h after exercise.

< 0.001; Table 2). Borg RPE scores at T1 did not differ between conditions, $\chi^2(2) = 0.27$, $p = 0.875$ (Table S7). Exploratory participant- and condition-adjusted correlations were 0.17 (95% CI, −0.11 to 0.43) for changes in log(CK) and RSI and 0.13 (95% CI, −0.17 to 0.42) for changes in PPT and TQR. Both CIs included zero (Table S8; Figure S3). Participant-level sign-flip sensitivity analyses yielded conclusions consistent with the primary contrast analyses (Table S9).

Discussion

This study examined whether adding ice packs to standardized sports massage altered selected post-exercise responses over 72 h after plyometric exercise in male combat athletes. Relative to SM, SM+ICE was associated with larger reductions in RF stiffness, whereas the primary comparison did not demonstrate an incremental effect on PPT. Secondary findings favored SM+ICE for RSI and perceived recovery, with lower CK fold changes at 24 and 48 hours. Thus, the results support an outcome-specific pattern rather than a uniform improvement in recovery. The primary outcomes did not converge, and neither the nonsignificant PPT comparison nor small laterality differences establish equivalence.

The stiffness and PPT findings require separate interpretation. Additional stiffness reductions with SM+ICE do not show that the combined procedure provided greater analgesia, because PPT did not demonstrate an incremental benefit in the joint comparison. Conversely, the absence of a statistically significant PPT difference is not evidence that both treatments have identical sensory effects. Confidence intervals, the outcome scale, and the recovery interval remain relevant when judging plausible differences. The observed separation between these domains supports reporting each outcome independently rather than describing a single global recovery effect.

The distinction between symptom relief and performance is consistent with massage research. Hilbert et al. (2003) observed reduced soreness without improved torque, while Davis et al. (2020) found benefits for soreness and flexibility but no clear improvement in performance. Our RSI findings therefore warrant replication rather than a general claim that massage or cooling restores athletic performance. Differences in exercise loading, repeated treatment exposure, and assessment timing may contribute to divergent findings.

In combat athletes, ice massage during brief exercise breaks favored PPT, whereas dry massage better preserved several mechanical and performance outcomes (Trybulski et al., 2025). Those findings do not transfer directly to ice packs applied after massage over three days. Similarly, a parallel trial reported improved PPT with massage and lymphatic drainage relative to passive rest, but tested different treatments and dosing (Trybulski et al., 2026). The present comparison addresses the incremental contribution of the combined protocol, not the efficacy of cooling alone.

Mechanisms remain uncertain. Cooling can modify sensory conduction (Algafly & George, 2007), but we did not measure nerve activity, tissue temperature, or inflammation. A human biopsy study found no clear reduction in muscle inflammatory responses with cold-water immersion relative to active recovery (Peake et al., 2017). Lower CK therefore cannot establish an anti-inflammatory mechanism or accelerated repair; CK also reflects biological and analytical variability (Radišić Biljak et al., 2025). Resting myotonometric stiffness is a local mechanical measure, not direct evidence of contractile recovery. The imprecise exploratory correlations likewise do not establish common mechanisms.

Practical implications

For practitioners already using massage, adding ice packs may be considered an optional adjunct with expectations limited to the measured short-term responses. Additional pain-threshold benefit was not demonstrated. Seven combined sessions required 210 minutes per athlete, compared with 140 minutes for massage alone, so uncertain functional relevance should be weighed against 70 additional minutes. Lower stiffness, CK, or perceived fatigue should not independently determine return to demanding training. Decisions should also consider task-specific performance and athlete tolerance. Routine long-term cooling cannot be recommended from these data: attenuated training adaptations reported after repeated cold-water immersion (Roberts et al., 2015) concern a different modality and do not establish either harm or safety for this ice-pack protocol.

Limitations

The main design limitation was the absence of chronological treatment-order data in the analysis dataset. Although initial condition assignment was randomized, period, sequence, and carryover effects could not be estimated. Crossover reporting requires these distinctions (Dwan, Li, Altman, & Elbourne, 2019). A 14-day washout may not fully exclude altered responsiveness to repeated eccentric exercise, as protective responses have been reported to persist for months after elbow-flexor eccentric exercise (Nosaka, Sakamoto, Newton, & Sacco, 2001), although the magnitude and duration of such effects cannot be extrapolated directly to these trained athletes. Similar baseline values would not rule out altered responsiveness. Consequently, some observed differences may reflect period-related influences rather than treatment effects alone.

The overarching registration also differs from this report in intervention details, outcome hierarchy, and follow-up, including classification of PPT as secondary and assessments through 48 hours. It does not independently verify prospective specification of the present 72-hour protocol or statistical contrasts. No separately archived analysis plan was available. These discrepancies limit protection against selective reporting and make confirmatory interpretation inappropriate.

Participants and therapists were unblinded, and no sham or attention-matched condition was included. Blinded assessors reduce some measurement bias but cannot remove expectations affecting subjective ratings or voluntary jumping effort. Placebo-controlled immersion research demonstrates that expectations can influence recovery outcomes (Broatch, Petersen, & Bishop, 2014); it does not quantify their contribution here. The extra treatment time and absence of an ice-only condition prevent separation of cooling-specific effects, contextual effects, and massage–cooling interactions.

T4 followed treatment, whereas T1–T3 preceded the corresponding session. Consequently, the 72-hour difference may combine cumulative recovery with an immediate treatment response; the interval between treatment and assessment was not recorded in the analysis dataset. Pack surface temperature is not tissue temperature. Adipose thickness influences cooling depth and duration (Otte, Merrick, Ingersoll, & Cordova, 2002), and unmeasured local thermal exposure limits dose interpretation. The protocol cannot establish an optimal temperature or treatment frequency.

Measurement reliability was drawn from external populations, anatomical sites, and devices. Within-study measurement error and smallest worthwhile differences were not established, limiting individual interpretation despite statistically detectable group differences. The dataset retained outcome summaries rather than raw Myoton impulses or individual jump trials. POCT analyzer identification and analytical quality-control data were unavailable, limiting assessment of CK measurement uncertainty. Exercise repetitions and concurrent training, sleep, nutrition, and medication exposure were not available for adjustment; adherence to restrictions relied on self-report.

Thirty men from one center limit precision and generalizability to women, other training levels, injured athletes, and competitive settings. The sensitivity calculation cannot replace prospective sample-size planning. Multiple testing was addressed within separate families, not across every analysis; secondary and correlational findings remain exploratory. Large paired effect sizes do not establish clinical importance and require independent replication. Follow-up ended at 72 hours, with no direct assessment of tissue repair, competition performance, or long-term adaptation. Systematic adverse-event data were unavailable, so tolerability and safety cannot be inferred from complete follow-up.

Future research

Independent, prospectively registered replication studies should prespecify the outcome hierarchy, primary contrast, clinically meaningful effect threshold, and multiplicity strategy before recruitment. A parallel design could avoid exercise carryover; a crossover design should retain treatment sequences and justify washout using the exercise model. Adding ice-only and credible attention-control conditions would help separate treatment components. Measurements immediately before and after each session, plus a later treatment-free follow-up, could distinguish transient effects from sustained recovery. Tissue-temperature monitoring, standardized exercise volume, analytical quality control, adverse-event recording, and objective adherence data would improve interpretation. Larger, more diverse samples should test whether laboratory changes translate into sport-specific performance and whether repeated use influences training adaptation.

Conclusions

Massage followed by ice packs showed larger short-term stiffness reductions than massage alone, without demonstrated additional PPT benefit. Secondary functional and perceptual findings are promising but provisional. The study does not establish accelerated tissue repair, readiness for competition, or a general recommendation for routine cooling.

Author Contributions

Conceptualization: RT, VA, RC; methodology: RT, VA, RC; investigation, including measurements and recovery interventions: RT, BR, RC; data curation: RT, RC, VA; formal analysis: RT, VA; visualization: RT, RC, BR; writing, original draft: RT, BR, VA, VG; writing, review and editing: RT, RC, BR, VA; supervision: RT, VA; project administration: RC, VG.

RT: Robert Trybulski; BR: Beata Borecka; VG: Vlad Adrian Geantă; RC: Robert Çitozi; VA: Viorel Petru Ardelean.

References

Algafly, A. A., & George, K. P. (2007). The effect of cryotherapy on nerve conduction velocity, pain threshold and pain tolerance. *British Journal of Sports Medicine, 41*(6), 365–369. I: 10.1136/bjsm.2006.031237

Bakdash, J. Z., & Marusich, L. R. (2017). Repeated measures correlation. *Frontiers in Psychology, 8*, Article 456. doi: 10.3389/fpsyg.2017.00456

Borg, G. A. V. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise, 14*(5), 377–381. doi: 10.1249/00005768-198205000-00012

Broatch, J. R., Petersen, A., & Bishop, D. J. (2014). Postexercise cold water immersion benefits are not greater than the placebo effect. *Medicine & Science in Sports & Exercise, 46*(11), 2139–2147. doi: 10.1249/MSS.0000000000000348

Chen, G., Wu, J., Chen, G., Lu, Y., Ren, W., Xu, W., . . . Qiu, B. (2019). Reliability of a portable device for quantifying tone and stiffness of quadriceps femoris and patellar tendon at different knee flexion angles. *PLOS ONE, 14*(7), Article e0220521. doi: 10.1371/journal.pone.0220521

Collings, T. J., Lima, Y. L., Dutaillis, B., & Bourne, M. N. (2024). Concurrent validity and test–retest reliability of VALD ForceDecks' strength, balance, and movement assessment tests. *Journal of Science and Medicine in Sport, 27*(8), 572–580. doi: 10.1016/j.jsams.2024.04.014

Davis, H. L., Alabed, S., & Chico, T. J. A. (2020). Effect of sports massage on performance and recovery: A systematic review and meta-analysis. *BMJ Open Sport & Exercise Medicine, 6*(1), Article e000614. doi: 10.1136/bmjsem-2019-000614

Dwan, K., Li, T., Altman, D. G., & Elbourne, D. (2019). CONSORT 2010 statement: Extension to randomised crossover trials. *BMJ, 366*, Article l4378. doi: 10.1136/bmj.l4378

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. doi: 10.3758/BF03193146

Freitas, V. H., Nakamura, F. Y., Miloski, B., Samulski, D., & Bara-Filho, M. G. (2014). Sensitivity of physiological and psychological markers to training load intensification in volleyball players. *Journal of*

Sports Science and Medicine, 13(3), 571–579. https://www.jssm.org/jssm-13-571.xml%3EFulltext

Hilbert, J. E., Sforzo, G. A., & Swensen, T. (2003). The effects of massage on delayed onset muscle soreness. *British Journal of Sports Medicine, 37*(1), 72–75. doi: 10.1136/bjsm.37.1.72

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics, 6*(2), 65–70. https://www.jstor.org/stable/4615733

Hotelling, H. (1931). The generalization of Student's ratio. *The Annals of Mathematical Statistics, 2*(3), 360–378. doi: 10.1214/aoms/1177732979

Kenttä, G., & Hassmén, P. (1998). Overtraining and recovery: A conceptual model. *Sports Medicine, 26*(1), 1–16. doi: 10.2165/00007256-199826010-00001

Kinser, A. M., Sands, W. A., & Stone, M. H. (2009). Reliability and validity of a pressure algometer. *Journal of Strength and Conditioning Research, 23*(1), 312–314. doi: 10.1519/JSC.0b013e31818f051c

Koh, R. G. L., Paul, T. M., Nesovic, K., West, D., Kumbhare, D., & Wilson, R. D. (2023). Reliability and minimal detectable difference of pressure pain thresholds in a pain-free population. *British Journal of Pain, 17*(3), 239–243. doi: 10.1177/20494637221147185

Lamb, K. L., Eston, R. G., & Corns, D. (1999). Reliability of ratings of perceived exertion during progressive treadmill exercise. *British Journal of Sports Medicine, 33*(5), 336–339. doi: 10.1136/bjsm.33.5.336

Lee, Y., Kim, M., & Lee, H. (2021). The measurement of stiffness for major muscles with shear wave elastography and Myoton: A quantitative analysis study. *Diagnostics, 11*(3), Article 524. doi: 10.3390/diagnostics11030524

Markwick, W. J., Bird, S. P., Tufano, J. J., Seitz, L. B., & Haff, G. G. (2015). The intraday reliability of the reactive strength index calculated from a drop jump in professional men's basketball. *International Journal of Sports Physiology and Performance, 10*(4), 482–488. doi: 10.1123/ijspp.2014-0265

McKay, A. K. A., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., . . . Burke, L. M. (2022). Defining training and performance caliber: A participant classification framework. *International Journal of Sports Physiology and Performance, 17*(2), 317–331. doi: 10.1123/ijspp.2021-0451

Nosaka, K., Sakamoto, K., Newton, M., & Sacco, P. (2001). How long does the protective effect on eccentric exercise-induced muscle damage last? *Medicine & Science in Sports & Exercise, 33*(9), 1490–1495. doi: 10.1097/00005768-200109000-00011

Osiecki, R., Rubio, T. B. G., Coelho, R. L., Novack, L. F., Conde, J. H. S., Alves, C. G., & Malfatti, C. R. M. (2015). The total quality recovery scale (TQR) as a proxy for determining athletes' recovery state after a professional soccer match. *Journal of Exercise Physiology Online, 18*(3), 27–32. https://www.asep.org/asep/asep/JEPonlineJUNE2015_Coelho.pdf

Otte, J. W., Merrick, M. A., Ingersoll, C. D., & Cordova, M. L. (2002). Subcutaneous adipose tissue thickness alters cooling time during cryotherapy. *Archives of Physical Medicine and Rehabilitation, 83*(11), 1501–1505. doi: 10.1053/apmr.2002.34833

Peake, J. M., Roberts, L. A., Figueiredo, V. C., Egner, I., Krog, S., Aas, S. N., . . . Raastad, T. (2017). The effects of cold water immersion and active recovery on inflammation and cell stress responses in human skeletal muscle after resistance exercise. *The Journal of Physiology, 595*(3), 695–711. doi: 10.1113/JP272881

Radišić Biljak, V., Lazić, A., Nikler, A., Pekas, D., Saračević, A., & Trajković, N. (2025). Post-exercise creatine kinase variability: A literature review. *Biochemia Medica, 35*(2), Article 020502. doi: 10.11613/BM.2025.020502

Rappelt, L., Javanmardi, S., Heinke, L., Baumgart, C., & Freiwald, J. (2023). The multifaceted nature of recovery after exercise: A need for individualization. *Sports Orthopaedics and Traumatology*, *39*(4), 359-367. https://doi.org/10.1016/j.orthtr.2023.10.006

Roberts, L. A., Raastad, T., Markworth, J. F., Figueiredo, V. C., Egner, I. M., Shield, A., . . . Peake, J. M. (2015). Post-exercise cold water immersion attenuates acute anabolic signalling and long-term adaptations in muscle to strength training. *The Journal of Physiology, 593*(18), 4285–4301. doi: 10.1113/JP270570

Seabold, S., & Perktold, J. (2010). Statsmodels: Econometric and statistical modeling with Python. In S. van der Walt & J. Millman (Eds.), *Proceedings of the 9th Python in Science Conference* (pp. 92–96). doi: 10.25080/Majora-92bf1922-011

Trybulski, R., Stanula, A., Vovkanych, A., Muracki, J., Wang, H.-K., & Kużdżał, A. (2025). Immediate effect of ice and dry massage during rest breaks on recovery in MMA fighters: A randomized crossover clinical trial study. *Scientific Reports, 15*(1), Article 12323. doi: 10.1038/s41598-025-97194-x

Trybulski, R., Wang, H.-K., Hagner-Derengowska, M., Kawczynski, A., Olaniszyn, G., & Kuždzał, A. (2026). Effects of lymphatic drainage and intense sports massage on muscle properties, damage, and function after eccentric plyometric training: A randomized controlled parallel trial. *European Journal of Applied Physiology, 126*(5), 2765–2778. doi: 10.1007/s00421-025-06101-9

Trybulski, R., Żebrowska, A., Bichowska-Pawęska, M., Kuźdżał, A., Ryszkiel, I., Silva, R. M., . . . Kawczyński, A. (2024). The effects of combined contrast heat cold pressure therapy on post-exercise muscle recovery in MMA fighters: A randomized controlled trial. *Journal of Human Kinetics, 94*, 127–146. doi: 10.5114/jhk/190220

Zhang, S., Huang, W., Soh, K. G., Luo, S., Li, L., & Wang, X. (2025). Effects of core strength training on the technical skill performance of striking combat sport players: a systematic review. *PeerJ*, *13*, e19615. https://doi.org/10.7717/peerj.19615