Efficacy of recovery strategies on pain pressure thresholds in basketball players

Eficacia de estrategias de recuperación en umbrales de presión del dolor en jugadores de baloncesto

Authors

Marcin Janusiak [1]
Rui Miguel Silva [2,3]
Francisco Tomás González Fernández [4]
Małgorzata Smoter [5]
Aleksandra Kisilewicz [6]
Sebastian Klich [7]

[1] Śląsk Wrocław Basketball, Physiology Department, Wrocław, (Poland)
[2] Research Center in Sports Performance, Recreation, Innovation and Technology (SPRINT), 4960-320 Melgaço, (Portugal)
[3] Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, (Portugal)
[4] University of Granada, (Spain)
[5] Gdansk University of Physical Education and Sport, Gdańsk, (Poland)
[6] Gdansk University of Physical Education and Sport, Gdańsk, (Poland)
[7] University of Health and Sport Sciences, Wrocław, Poland

Corresponding author:
Rui Miguel Silva
rui.s@ipvc.pt

How to cite in APA

Janusiak, M., da Silva, R. M., González Fernández, F. T., Smoter, M., Kisilewicz, A., & Klich, S. (2025). Efficacy of recovery strategies on pain pressure thresholds in basketball players. *Retos*, *65*, 569–578. https://doi.org/10.47197/retos.v65.110201

Abstract

Objective: This study assessed the effects of active recovery training, cold-water immersion, contrast-water immersion, and no intervention on pain pressure thresholds in the quadriceps, triceps, and full leg. Following these recovery strategies, it also examined the relationships between creatine kinase, myoglobin, and pain pressure thresholds.
Methods: Twenty basketball players from the Śląsk Wrocław team, aged 18 to 35, participated in a randomized controlled trial. They were divided into four groups: active recovery training, cold-water immersion, contrast-water immersion, and control. The interventions were applied post-match, and pain pressure thresholds were measured in the quadriceps, triceps, and full leg using a Somedic Algometer type 2. Blood samples were collected for analysis of creatine kinase and myoglobin levels.
Results: Active recovery training significantly improved pain pressure thresholds across all muscle groups compared to cold-water immersion, contrast-water immersion, and control ($p=0.001$, $d = 0.87$ to 6.12). Cold-water immersion showed significant benefits in the triceps and full leg muscles compared to contrast-water immersion and control ($p=0.001$, $d = -2.90$ to 5.56). Contrast-water immersion did not differ significantly from the control in any muscle group. No significant correlations were found between pain pressure thresholds and creatine kinase and myoglobin levels.
Conclusion: Active recovery training was the most effective strategy for improving pain pressure thresholds in basketball players, with cold-water immersion offering additional benefits for specific muscle groups. The lack of correlation between pain pressure thresholds and muscle damage biomarkers suggests that pain pressure thresholds alone may not be a reliable indicator of muscle damage.

Keywords

Pain sensitivity; sports recovery; sports training; team sports.

Resumen

Objetivo: Este estudio evaluó los efectos del entrenamiento de recuperación activa, la inmersión en agua fría, la inmersión en agua contrastada y la no intervención sobre los umbrales de dolor en los cuádriceps, tríceps y pierna completa. También se examinaron las relaciones entre la creatina quinasa, la mioglobina y los umbrales de dolor tras estas estrategias de recuperación.
Métodos: Veinte jugadores de baloncesto del equipo Śląsk Wrocław, de entre 18 y 35 años, participaron en un ensayo controlado aleatorio. Los participantes fueron divididos en cuatro grupos: entrenamiento de recuperación activa, inmersión en agua fría, inmersión en agua contrastada y control. Las intervenciones se aplicaron después del partido, y los umbrales de dolor se midieron en los cuádriceps, tríceps y pierna completa utilizando un algómetro Somedic tipo 2. Se recogieron muestras de sangre para el análisis de los niveles de creatina quinasa y mioglobina.
Resultados: El entrenamiento de recuperación activa mejoró significativamente los umbrales de dolor en todos los grupos musculares en comparación con la inmersión en agua fría, la inmersión en agua contrastada y el control ($p=0.001$, $d = 0.87$ a 6.12). La inmersión en agua fría mostró beneficios significativos en los músculos tríceps y pierna completa en comparación con la inmersión en agua contrastada y el control ($p=0.001$, $d = -2.90$ a 5.56). La inmersión en agua contrastada no mostró diferencias significativas respecto al control en ningún grupo muscular. No se encontraron correlaciones significativas entre los umbrales de dolor y los niveles de creatina quinasa y mioglobina.
Conclusión: El entrenamiento de recuperación activa fue la estrategia más efectiva para mejorar los umbrales de dolor en los jugadores de baloncesto, con la inmersión en agua fría ofreciendo beneficios adicionales para grupos musculares específicos. La falta de correlación entre los umbrales de dolor y los biomarcadores de daño muscular sugiere que los umbrales de dolor por sí solos pueden no ser un indicador fiable del daño muscular.

Palabras clave

Deportes de equipo; entrenamiento deportivo; recuperación deportiva; sensibilidad al dolor.

Introduction

Basketball is a team sport characterized by intermittent bursts of high-intensity actions, where players are required to tolerate a variety of locomotor demands such as sprinting, shuffling, jumping, accelerations, decelerations, and changes of direction at different angles throughout the game (Pernigoni et al., 2021). As previously shown, the external load associated with these high-intensity actions varied depending on the type of activity (e.g., sprints, jumps, or high-intensity specific movements), their duration, and whether they were performed with or without the ball (Pernigoni et al., 2021). Maintaining a good level of anaerobic power is of utmost importance to cope with high-intensity locomotor demands. Conversely, aerobic capacity in basketball is essential for sustaining multiple short bursts of high-intensity activity throughout the game (Gottlieb et al., 2021; Stojanović et al., 2018). Furthermore, basketball players participate in intense training sessions to meet the match demands, leaving insufficient time for complete recovery between sessions (Williams et al., 2021).

Biomarkers of muscle damage such as CK, myoglobin, lactate dehydrogenase, aldolase, troponin, aspartate aminotransferase, and carbonic anhydrase indicate disruption, stress, and inflammation (Brancaccio et al., 2010; Kellmann et al., 2018). Notably, CK has demonstrated its reliability as a biomarker for assessing recovery-fatigue status in team sport athletes (Pérez-Castillo et al., 2023; Reichel et al., 2020). Indeed, a previous systematic review showed that in team sports, the most monitored serum markers for match-induced muscle injury were CK followed by myoglobin concentrations (Silva et al., 2018). Moreover, CK and myoglobin can be increased for above 72 hours post-match in different team sports (Doeven et al., 2018; Silva et al., 2018), acknowledging the fact that although some measures of physical performance can return more rapidly to pre-match values, the muscles need more time to recover from muscle damage biomarkers (Doeven et al., 2018). Also, it was noticed that there is a significant increase in the acute magnitude of perceived delayed onset muscle soreness (DOMS) in the post-match (Silva et al., 2018). This delayed recovery and increased DOMS highlight the role of muscle damage biomarkers in understanding post-match recovery and their relationship with pain perception.

Pain pressure threshold (PPT), defined as the minimum force required to elicit pain, provides a complementary assessment of recovery through its association with DOMS and mechanosensitive nociceptor excitability (Thornton et al., 2024). Athletes often exhibit higher pain thresholds and tolerances compared to non-athletes, and they tend to perceive pain as less intense (Thornton et al., 2024). On the other hand, it was previously reported that women had significantly lower pre-exercise PPT values (24.1±6.1 N/cm^2) compared to men (48.9±13.8 N/cm^2) (Silva et al., 2021). In the same study, post-exercise PPT values remained relatively stable in women across all time points (24.7±9.9 N/cm^2 immediately post-exercise, 24.1±6.4 N/cm^2 at 48 hours post-exercise) (Silva et al., 2021). In contrast, men exhibited an increase in PPT immediately post-exercise (49.9±16.1 N/cm^2), followed by a significant decrease at 48 hours post-exercise (48.3±15.5 N/cm^2). Furthermore, post-exercise DOMS appears to be associated with heightened excitability of mechanosensitive nociceptors, showing that PPT may be used as a measure for assessing the magnitude of DOMS (Fleckenstein et al., 2017).

Current evidence suggests potential recovery benefits from active recovery strategies and water immersion protocols at varying temperatures (Dupuy et al., 2018; Moore et al., 2023). A previous systematic review has highlighted the positive impact of active recovery sessions on physical performance (Ortiz et al., 2019). Nevertheless, determining the optimal intensity level for active recovery remains inconclusive, and the reliability of blood biomarkers for fatigue clearance rate is uncertain (Ortiz et al., 2019). Cold water immersion (CWI) protocols aim to decrease tissue temperatures and blood flow, thereby resulting in diminished swelling, inflammation markers, and pain perception (Machado et al., 2016). CWI was previously shown to be effective in reducing the circulating creatine kinase (CK) and myoglobin concentrations after strenuous exercise (Ihsan et al., 2016).

In contrast to active recovery, the utilization of CWI demonstrated reduced myoglobin concentrations following high-intensity exercise (Roberts et al., 2014). Also, it was previously revealed that CWI immediately after exercise and delayed CWI (3 hours post-exercise) significantly improved next-day performance (Brophy-Williams et al., 2011) Furthermore, the PPT is reduced after a CWI protocol immediately after exercise (Pinto et al., 2020). However, there is a lack of evidence reporting the effects of other recovery strategies on PPT (Klich et al., 2018). Contrast water immersion alternates CWI with hot water immersion, and it previously showed positive effects for CK 48h and 72h after exercise (Bieuzen et al.,

2013). On the other hand, only 48h after exercise, significantly lower myoglobin concentrations after contrast water therapy (Bieuzen et al., 2013).

Given that PPT and DOMS may be correlated, and that DOMS is a perceived measure of muscle damage, it may be hypothesized that PPT can be influenced by the presence of blood concentrations of CK and myoglobin and that such relationships may differ between different recovery strategies. Investigating the possible associations between biomarkers of muscle damage and PPT after different recovery interventions can give great insights regarding the use of PPT to infer muscle damage. For all the above, the present study aimed (i) to assess the effects of ART, CWI, and COWI on PPT in the quadriceps, triceps, and full leg muscles; and (ii) to analyze the correlations between CK, Mb, and PPT following different recovery interventions.

Method

Participants

A total of 20 basketball players affiliated with the Śląsk Wrocław team, aged 18 to 35 years, were recruited for this study. The mean age of the participants was 24.75 years, with an average height of 194.7 cm, body mass of 91.62 kg, and BMI of 23.96. All players were actively involved in top-tier league competitions and were enlisted for participation by the team's physiotherapist. A post hoc power analysis was conducted to determine the achieved power for the study. Using G* Power software (version 3.1.3; University of Trier, Trier, Germany) the effect size (f) for the one-way ANOVA was calculated from Cohen's d values. For the most relevant and largest effect observed (d = 3.98 for ART vs. CWI in quadriceps), the corresponding effect size (f) was calculated to be 2.89, which corresponds to a very large effect based on Cohen's conventions. The alpha level was set at 0.05, and the total sample size was 20 participants, distributed across 4 groups (active recovery, cold-water immersion, contrast-water immersion, and control), with 5 participants per group. The results of the power analysis indicated that the study had an achieved power of 0.83 (83.4%), which is above the commonly accepted threshold of 0.80. This suggests that the study was adequately powered to detect significant differences among the groups.

Procedure

This study followed a randomized controlled trial design, aimed to assess the impact of various recovery interventions on pain sensitivity thresholds and blood markers associated with muscle damage in basketball players. Participants were randomly allocated to one of four groups: a control group with no recovery intervention, a contrast baths group, an active recovery training group, and an ice baths group. Randomization was carried out using a random number generator in Microsoft Excel. Before the study, a list of participant identifiers was generated, and each participant was assigned an ID number. In Microsoft Excel, the [=RAND()] function was used to generate a random number between 0 and 1 for each participant. This function produces a random decimal value, which is then used to sort the participants in ascending order. The first 5 participants were allocated to the contrast baths group, the next 5 to the active recovery training group, the following 5 to the ice baths group, and the remaining 5 to the control group. The allocation sequence was concealed from the researchers conducting the intervention to ensure unbiased assignment. Group assignments were revealed only after the completion of participant enrollment. The study spanned three days post-match: match day, 24 hours post-match, and 48 hours post-match. Each group underwent specific recovery interventions or control conditions according to the assigned protocol.

Interventions

The cold-water immersion group underwent cold water immersion, with participants immersed in water maintained at temperatures between 1°C and 5°C for 5 minutes, utilizing pools provided by the ICOOLSPORT company. The contrast water immersion group received contrast immersion, which involved alternating cycles of hot and cold baths administered for 20 minutes. The active recovery training group engaged in post-match jogging and structured training sessions with a duration of 45 minutes, aimed at reducing delayed onset muscle soreness (DOMS), conducted 24- and 48-hours post-match. Participants in the control group did not participate in any recovery strategies and abstained from any training session after the match. Participants in the control group, also completed the measurements for

PPT and blood markers at three time points: match day (immediately post-match), 24 hours post-match, and 48 hours post-match. These measurements were conducted at the same time of day (around 10:00 AM) for all participants to minimize the effect of diurnal variations on the results.

Measurements/Outcomes

Pain Pressure Thresholds

Pain pressure thresholds were measured using a Somedic Algometer type 2, applied to three specific muscle points: (i) quadriceps; (ii) calves; and (iii) triceps. Participants were positioned comfortably, and clothing obstructing access to target muscle points was removed. Anatomical landmarks were marked for consistent measurement. The algometer, with a rubber-covered tip, was gently pressed against muscles at a standardized pressure rate of 30 kPa/s. Participants signaled pain perception, and measurements were repeated across muscle regions. Thresholds were recorded before and after matches and during recovery periods. Data were analyzed to evaluate changes in pain sensitivity and recovery intervention effectiveness in managing DOMS in basketball players.

Blood Analysis

Blood analysis procedures were performed to evaluate creatine kinase (CK) activity and myoglobin concentration. Venous blood samples were obtained from participants at three time points: before the match, and 24- and 48 hours post-match. Approximately 5 milliliters of blood were collected from the dominant elbow fossa using standard venipuncture techniques and stored in vacutainer tubes to prevent contamination. Following collection, samples were centrifuged at 3000 rpm for 10 minutes at room temperature to separate the serum from other blood components. The serum was then carefully extracted, labeled, and stored at -80°C to maintain stability. Samples were thawed to room temperature before analysis. CK activity was measured using an automated clinical chemistry analyzer (Model 7080, Hitachi, Co., Ltd., Tokyo, Japan) with commercially available test kits (Roche Diagnostics, Indianapolis, IN, USA). Mb concentration was measured using an automated clinical chemistry analyzer (Model Elecsys 2010, F. Hoffmann-La Roche Ltd., Tokyo, Japan). Each sample was analyzed in duplicate to minimize variability, and quality control measures were implemented to ensure accuracy. Statistical analysis was performed to evaluate changes in CK activity and Mb concentration over the study period and assess the impact of recovery interventions on muscle recovery in basketball players.

Data analysis

To analyze the data, descriptive statistical methods were utilized to determine percentages as well as measures of central tendency and dispersion, specifically the mean and standard deviation. Tests for normal distribution and homogeneity of variances were conducted using the Kolmogorov–Smirnov test and Levene's test, respectively. First, one-way analysis of variance (ANOVA) was employed to analyze the differences between groups in each recovery strategy: i) Active Recovery Training Group, ii) Cold-water immersion Group, iii) Contrast-water immersion Group, and iv) Control groups focused on three specific sites: i) quadriceps, ii) triceps, and iii) the full leg. The effect size (*d*) was calculated through Cohen's d (Cohen, 1988). The interpretation of the d regardless of the sign, followed the scale: very small (0.01), small (0.20), medium (0.50), large (0.80), very large (1.20), huge (2.0) as initially suggested by Cohen (1992) and expanded by Sawilowsky (2009). Pearson's correlation coefficient (r) was employed to explore the relationship between PPT CK and Mb for each group, with interpretation criteria based on the magnitude of the correlation coefficient. Statistical analyses were performed using SPSS v.27.0 for Windows (SPSS Inc., Chicago, IL).

Results

Descriptive statistics were calculated for each PPT variable. See Table 1, for more information.
Descriptive statistics were calculated for CK and Mb levels (Table 2).
Different one-way ANOVAs were conducted to analyze the differences between groups in each recovery strategy: i) Active Recovery Training Group, ii) Cold-water immersion Group, iii) Contrast-water immersion Group, and iv) Control groups focused on three specific sites: i) quadriceps, ii) triceps, and iii) the full leg. First, a one-way ANOVAs with mean quadriceps data revealed significant differences between ART Group and CWI Group, p=0.001, d=3.98, ART Group and COWI Group, p=0.001, d=0.87, ART Group

and C Group, *p*=0.001, *d*=1.24, CWI Group and COWI Group, *p*=0.001, *d*=1.22, CWI Group and C Group, *p*=0.001, *d*=-2.40. However, the same analysis realized between COWI Group and C Group, did not reveal significant differences, *p*=0.721, *d*=-0.10. (See Figure 1 and Table 3, for more information).

Table 1. Pressure points for each group recovery strategy (mean±SD).

	Quadriceps	Triceps	Full leg
ART Group	982.11±30.66 LCI= 968.67 CI=13.44 UCI= 995.55	995.60±29.22 LCI= 982.79 CI=12.81 UCI= 1008.40	999.35±25.05 LCI= 988.37 CI=10.98 UCI= 1010.33
CWI Group	880.04±19.45 LCI= 871.51 CI=8.53 UCI= 888.56	842.36±25.82 LCI= 831.05 CI=11.31 UCI= 853.67	861.20±19.76 LCI= 852.54 CI=8.66 UCI= 869.86
COWI Group	938.10±64.24 LCI= 909.94 CI=28.15 UCI= 966.25	909.09±61.50 LCI= 882.14 CI=26.95 UCI= 936.04	923.59±60.13 LCI= 897.24 CI=26.35 UCI= 949.95
C Group	943.41±31.86 LCI= 929.44 CI=13.96 UCI= 957.37	935.90±37.54 LCI= 919.44 CI=16.45 UCI= 952.35	939.65±29.26 LCI= 926.82 CI=12.83 952.48

ART Group: Active Recovery Training Group; CWI Group: Cold-water immersion Group; COWI Group: Contrast-water immersion and C Group: Control Group; LCI: Lower Confidence Interval; CI: 95% Confidence Interval and, UCI: Upper Confidence Interval.

Table 2. Creatine kinase and myoglobin levels across recovery interventions

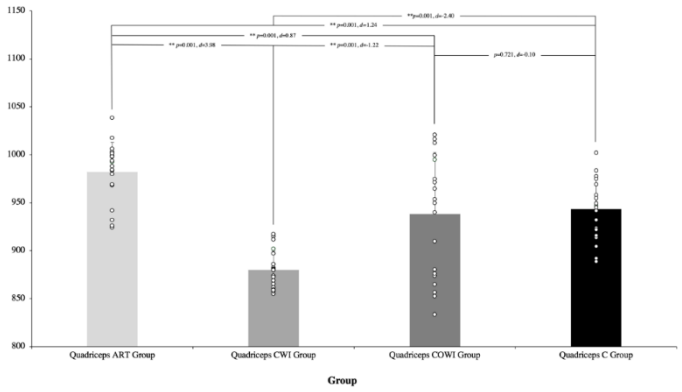
Creatine kinase (U/L)				
	Active Recovery Training Group	Cold-water immersion Group	Contrast-water immersion Group	Control Group
Immediately after match	349.84±89.38	269.98±62.59	302.99±86.31	293.13±84.63
24h after match	453.91±116.09	398.75±84.86	393.27±109.60	392.73±107.05
48h after match	337.96±88.24	299.84±59.51	292.89±83.34	241.19±67.42
Myoglobine (ng/mL)				
	Active Recovery Training Group	Cold-water immersion Group	Contrast-water immersion Group	Control Group
Immediately after match	48.08±2.88	51.78±14.23	45.73±8.09	50.04±3.92
24h after match	32.95±2.08	38.72±11.47	31.19±5.05	26.17±2.05
48h after match	30.88±1.93	34.20±10.22	28.93±4.73	14.62±1.13

Table 3. Between groups differences between the Active Recovery Training Group, Cold-water immersion Group, Contrast-water immersion Group, and Control groups for quadriceps, triceps, and full leg.

				One-way ANOVA					
Quadriceps ART Group	Quadriceps CWI Group	Quadriceps COWI Group	Quadriceps C Group	ART Group Vs CWI Group	ART Group Vs COWI Group	ART Group Vs C Group	CWI Group Vs COWI Group	CWI Group Vs C Group	COWI Group Vs C Group
982.11±30.66 LCI= 968.67 CI=13.44 UCI= 995.55	880.04±19.45 LCI= 871.51 CI=8.53 UCI= 888.56	938.10±64.24 LCI= 909.94 CI=28.15 UCI= 966.25	943.41±31.86 LCI= 929.44 CI=13.96 UCI= 957.37	*p*=0.001** *d*=3.98	*p*=0.001** *d*=0.87	*p*=0.001** *d*=1.24	*p*=0.001** *d*=-1.22	*p*=0.001** *d*=-2.40	*p*=0.721 *d*=-0.10
Triceps ART	Triceps CWI	Triceps COWI	Triceps Control	ART Vs CWI	ART Vs COWI	ART Vs Control	CWI Vs COWI	CWI Vs Control	COWI Vs Control
995.60±29.22 LCI= 982.79 CI=12.81 UCI= 1008.40	842.36±25.82 LCI= 831.05 CI=11.31 UCI= 853.67	909.09±61.50 LCI= 882.14 CI=26.95 UCI= 936.04	935.90±37.54 LCI= 919.44 CI=16.45 UCI= 952.35	*p*=0.001** *d*=5.56	*p*=0.001** *d*=1.80	*p*=0.001** *d*=1.77	*p*=0.001** *d*=-1.41	*p*=0.001** *d*=-2.90	*p*=0.05* *d*=-0.53
Full leg ART	Full Leg CWI	Full Leg COWI	Full leg Control	ART Vs CWI	ART Vs COWI	ART Vs Control	CWI Vs COWI	CWI Vs Control	COWI Vs Control
999.35±25.05 LCI= 988.37 CI=10.98 UCI= 1010.33	861.20±19.76 LCI= 852.54 CI=8.66 UCI= 869.86	923.59±60.13 LCI= 897.24 CI=26.35 UCI= 949.95	939.65±29.26 LCI= 926.82 CI=12.83 952.48	*p*=0.001** *d*=6.12	*p*=0.001** *d*=1.64	*p*=0.001** *d*=2.19	*p*=0.001** *d*=-1.39	*p*=0.001** *d*=-3.14	*p*=0.229 *d*=-0.34

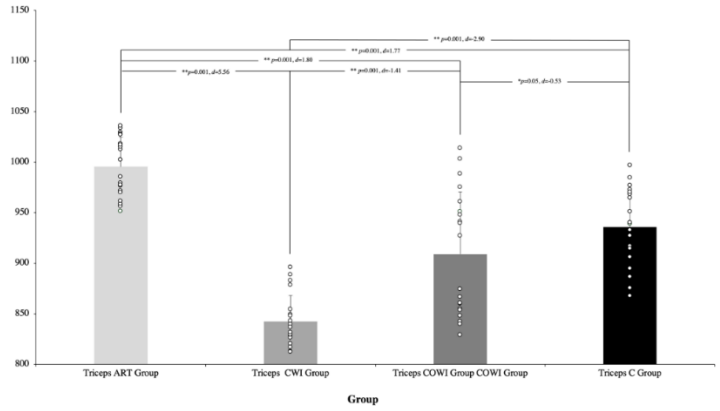
ART Group: active recovery training group; CWI Group: cold-water immersion group; COWI Group: contrast-water immersion; LCI: lower confidence Interval; CI: 95% confidence Interval and, UCI: upper confidence interval.

Figure 1. Mean quadricep's pressure points (mean± SD) for each group recovery strategy.



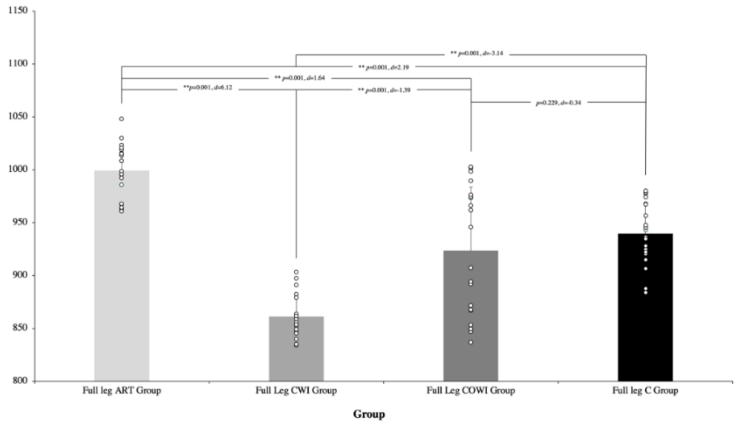
Second, another one-way ANOVAs with mean triceps data showed significant differences between ART Group and CWI Group, p=0.001, d=5.56, ART Group and COWI Group, p=0.001, d=1.80, ART Group and C Group, p=0.001, d=1.77, CWI Group and COWI Group, p=0.001, d=-1.41, CWI Group and C Group, p=0.001, d=-2.90, and COWI Group and C Group, p=0.05, d=-0.53. (See Figure 2 and Table 3, for more information).

Figure 2. Mean tricep's pressure points (mean± SD) for each group recovery strategy.



Last, one-way ANOVAs with mean full leg data revealed significant differences between ART Group and CWI Group, p=0.001, d=6.12, ART Group and COWI Group, p=0.001, d=1.64, ART Group and C Group, p=0.001, d=2.19, CWI Group and COWI Group, p=0.001, d=-1.39, CWI Group and C Group, p=0.001, d=-3.14. Crucially, the one-way ANOVA performed between COWI Group and C Group, did not show significant differences, p=0.229, d=-0.34. (See Figure 3 and Table 3, for more information).

Figure 3. Mean full leg pressure points (mean± SD) for each group recovery strategy.



Lastly, a correlation analysis was conducted to explore the relationships between PPT CK and Mb for each group. No significant correlations were reported.

Discussion

This study aimed to assess the impact of ART, CWI, and COWI on PPT in the quadriceps, triceps, and full leg muscles. Additionally, it aimed to investigate the correlations between CK, Mb, and PPT following different recovery interventions. The main findings revealed that ART was the most effective recovery strategy, demonstrating significantly higher PPTs across all muscle groups compared to CWI, COWI, and control. Furthermore, CWI showed significant efficacy in the triceps and full leg muscles, whereas COWI did not significantly outperform the control group in any muscle group. Notably, no significant correlations were found between PPT CK and Mb.

ART demonstrated superior effectiveness in improving PPT across all studied muscle groups. This finding aligns with previous research highlighting the benefits of low-intensity exercise in maintaining muscle activation, promoting blood flow, and facilitating the removal of metabolic waste products, which collectively improve muscle recovery and reduce DOMS (Dupuy et al., 2018; Michaelson et al., 2019). For instance, a previous systematic review showed that different forms of ART were superior to passive controls that were exposed to passive rest in decreasing DOMS (Fares et al., 2022). The significant differences observed between the ART group and all other groups (CWI, COWI, and control) suggest that ART might offer the greatest benefits for recovery, particularly in sports like basketball that require high-intensity, intermittent activities.

CWI showed significant benefits in reducing muscle pressure points, particularly in the triceps and full leg muscles. The effectiveness of CWI is likely due to its ability to decrease tissue temperature and blood flow, thereby reducing inflammation, swelling, and pain perception (Li et al., 2023; Roonkiani et al., 2020). The significant reduction in PPT for the triceps and full leg muscles in the CWI group, compared to other recovery strategies, supports its potential use as an effective method for managing muscle soreness and accelerating recovery post-exercise (Brophy-Williams et al., 2011; Tavares et al., 2019). These findings are consistent with previous studies demonstrating the benefits of CWI in reducing biomarkers of muscle damage and improving performance recovery (Li et al., 2023; Moore et al., 2023). For instance, a previous study that examined the impact of a CWI protocol on muscle pain sensitivity found that immersing in 5°C water for 5 minutes effectively reduced PPT one hour following repeated maximal sprint sessions (Klich et al., 2018). For such reasons, CWI may serve as a valuable strategy when combined with ART protocols for improved pain sensitivity.

Moreover, COWI did not show significant benefits over the control group in enhancing PPT. This finding suggests that alternating between hot and cold water may not provide substantial recovery benefits, or its effects might be less consistent compared to other recovery methods. This is in contrast with previous research that has indicated some positive effects of COWI on DOMS and reduced muscle strength loss from 6 to 96 hours after exercise in comparison to passive recovery (Bieuzen et al., 2013). However, a previous systematic review found that only CWI 24 hours after exercise improved neuromuscular recovery and fatigue perception (Higgins et al., 2017). In the same study (Higgins et al., 2017), neither CWI nor COWI was found to enhance the recovery of perceived muscle soreness following team sports. These differences between study findings can be explained by the often included participants with varying training statuses and physiological stressors, as reported by other systematic reviews on hydrotherapy and recovery (Bieuzen et al., 2013). Furthermore, the lack of significant improvement in PPT in this study highlights the need for further investigation into the optimal protocols and timing for COWI to maximize its recovery benefits. The lack of significant improvement in PPT in the present study may also reflect individual variability in response to hydrotherapy. Factors such as differences in muscle damage severity, baseline physiological state, or adaptation to recovery methods could contribute to the null findings for COWI (Bieuzen et al., 2013). Additionally, the short duration of exposure to hot and cold cycles in the protocol might have limited its effectiveness. Exploring longer or more intense COWI protocols could provide greater responses for improving recovery outcomes.

The present study found no significant correlations between PPT and the biomarkers CK and Mb across all recovery strategies. This lack of correlation suggests that PPT might not be directly influenced by the concentrations of these muscle damage biomarkers. While CK and Mb are well-established indicators of

muscle damage and recovery status (Nowakowska et al., 2019), PPT is a subjective measure of pain sensitivity and might be influenced by other factors such as individual pain tolerance, psychological state, and the specific nature of exercise-induced muscle damage (Fleckenstein et al., 2017). The disparity between these measures could also reflect the multifactorial nature of recovery processes, wherein pain perception and biochemical markers may operate through distinct pathways or be modulated differently by recovery interventions (Doeven et al., 2018). For instance, CK and Mb are primarily indicative of structural muscle damage and the extent of myocyte leakage, while PPT reflects nociceptive input and the central processing of pain signals, which can be affected by psychological factors such as stress, anxiety, or an athlete's previous experiences with pain (Brancaccio et al., 2010; Kellmann et al., 2018). Furthermore, the lack of correlation may indicate a temporal disconnect between biochemical markers and pain sensitivity. Biomarker levels such as CK and Mb may peak at different times relative to changes in pain thresholds (Fleckenstein et al., 2017), suggesting that the time points used for assessment in this study might not have captured the associations between these variables. Future studies should consider longitudinal measurements to better understand how these markers evolve and interact with pain perception. Additionally, it is possible that the magnitude of changes in CK and Mb was not sufficient to influence nociceptive pathways in this study, and that other inflammatory mediators, such as interleukins or prostaglandins, played a more critical role in modulating pain sensitivity (Brancaccio et al., 2010).

Given the promising effectiveness of ART in enhancing muscle recovery, it should be prioritized in post-exercise recovery protocols. CWI can be used as a supplementary recovery method, particularly for its benefits in improving pain sensitivity in specific muscle groups such as in the triceps and full leg. The limited efficacy of COWI observed in this study suggests that its use should be carefully considered, and further research is needed to optimize its application. This study has several limitations, including the small sample size. Additionally, investigating the long-term effects of these recovery strategies on muscle performance and exploring other potential biomarkers of muscle damage and recovery would provide valuable insights. Future research should explore larger and more diverse populations to generalize the findings and examine the psychological aspects of recovery and pain perception.

Conclusions

The present study showed that active recovery seems to be the most effective strategy for improving PPT across muscle groups, with CWI providing supplementary benefits for the triceps and full leg, while COWI showed no significant improvements over the control group. The lack of correlation between PPT, CK, and Mb suggests that PPT should not be used to infer muscle damage biomarkers. These findings highlight the value of active recovery for optimizing muscle recovery and pain sensitivity, with CWI as a potential supplementary method. Future research should explore long-term effects, individual variability, and additional biomarkers to improve recovery strategies and their practical applications.

Financing

The authors declare no funding.

References

Bieuzen, F., Bleakley, C. M., & Costello, J. T. (2013). Contrast Water Therapy and Exercise Induced Muscle Damage: A Systematic Review and Meta-Analysis. *PLoS ONE*, *8*(4). https://doi.org/10.1371/journal.pone.0062356

Brancaccio, P., Lippi, G., & Maffulli, N. (2010). Biochemical markers of muscular damage. *Clinical Chemistry and Laboratory Medicine*, *48*(6), 757–767. https://doi.org/10.1515/CCLM.2010.179

Brophy-Williams, N., Landers, G., & Wallman, K. (2011). Effect of immediate and delayed cold water immersion after a high-intensity exercise session on subsequent run performance. *Journal of Sports Science and Medicine*, *10*(4), 665–670. https://doi.org/10.1016/j.jsams.2011.11.238

da Silva, W., Machado, Á. S., Lemos, A. L., de Andrade, C. F., Priego-Quesada, J. I., & Carpes, F. P. (2021). Relationship between exercise-induced muscle soreness, pain thresholds, and skin temperature

in men and women. *Journal of Thermal Biology*, *100*(June), 1–8. https://doi.org/10.1016/j.jtherbio.2021.103051

Doeven, S. H., Brink, M. S., Kosse, S. J., & Lemmink, K. A. P. M. (2018). Postmatch recovery of physical performance and biochemical markers in team ball sports: A systematic review. *BMJ Open Sport and Exercise Medicine*, *4*(1). https://doi.org/10.1136/bmjsem-2017-000264

Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugué, B. (2018). An evidence-based approach for choosing post-exercise recovery techniques to reduce markers of muscle damage, Soreness, fatigue, and inflammation: A systematic review with meta-analysis. *Frontiers in Physiology*, *9*, 1–15. https://doi.org/10.3389/fphys.2018.00403

Fares, R., Vicente-Rodríguez, G., & Olmedillas, H. (2022). Effect of Active Recovery Protocols on the Management of Symptoms Related to Exercise-Induced Muscle Damage: A Systematic Review. *Strength and Conditioning Journal*, *44*(1), 57–70. https://doi.org/10.1519/SSC.0000000000000654

Fleckenstein, J., König, M., Vogt, L., & Banzer, W. (2017). The pain threshold of high-threshold mechanosensitive receptors subsequent to maximal eccentric exercise is a potential marker in the prediction of DOMS associated impairment. *PLoS ONE*, *12*(10), 1–17. https://doi.org/10.1371/journal.pone.0185463

Gottlieb, R., Shalom, A., & Calleja-Gonzalez, J. (2021). Physiology of Basketball-Field Tests. Review Article. *Journal of Human Kinetics*, *77*(1), 159–167. https://doi.org/10.2478/hukin-2021-0018

Higgins, T. R., Greene, D. A., & Baker, M. K. (2017). Effects of cold water immersion and contrast water therapy for recovery from team sport: A systematic review and meta-analysis. *Journal of Strength and Conditioning Research*, *31*(5), 1443–1460. https://doi.org/10.1519/JSC.0000000000001559

Ihsan, M., Watson, G., & Abbiss, C. R. (2016). What are the Physiological Mechanisms for Post-Exercise Cold Water Immersion in the Recovery from Prolonged Endurance and Intermittent Exercise? *Sports Medicine*, *46*(8), 1095–1109. https://doi.org/10.1007/s40279-016-0483-3

Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A. J., Duffield, R., Erlacher, D., Halson, S. L., Hecksteden, A., Heidari, J., Wolfgang Kallus, K., Meeusen, R., Mujika, I., Robazza, C., Skorski, S., Venter, R., & Beckmann, J. (2018). Recovery and performance in sport: Consensus statement. *International Journal of Sports Physiology and Performance*, *13*(2), 240–245. https://doi.org/10.1123/ijspp.2017-0759

Klich, S., Krymski, I., Michalik, K., & Kawczyński, A. (2018). Effect of short-term cold-water immersion on muscle pain sensitivity in elite track cyclists. *Physical Therapy in Sport*, *32*, 42–47. https://doi.org/10.1016/j.ptsp.2018.04.022

Li, J., Soh, K. G., Loh, S. P., Luo, S., Bashir, M., & Yu, X. (2023). Effect of post-activation potentiation on the sports performance of athletes: a systematic review. *Journal of bodywork and movement therapies*, 39, 243–250. https://doi.org/10.1016/j.jbmt.2024.02.006

Machado, A. F., Ferreira, P. H., Micheletti, J. K., de Almeida, A. C., Lemes, Í. R., Vanderlei, F. M., Netto Junior, J., & Pastre, C. M. (2016). Can Water Temperature and Immersion Time Influence the Effect of Cold Water Immersion on Muscle Soreness? A Systematic Review and Meta-Analysis. *Sports Medicine*, *46*(4), 503–514. https://doi.org/10.1007/S40279-015-0431-7

Michaelson, J. V., Brilla, L. R., Suprak, D. N., McLaughlin, W. L., & Dahlquist, D. T. (2019). Effects of Two Different Active Recovery Modes During High-intensity Interval Training. *Translational Journal of the American College of Sports Medicine*, *4*(4), 23–27. https://doi.org/10.1249/01.mss.0000494345.81598.90

Moore, E., Fuller, J. T., Bellenger, C. R., Saunders, S., Halson, S. L., Broatch, J. R., & Buckley, J. D. (2023). Effects of Cold-Water Immersion Compared with Other Recovery Modalities on Athletic Performance Following Acute Strenuous Exercise in Physically Active Participants: A Systematic Review, Meta-Analysis, and Meta-Regression. *Sports Medicine*, *53*(3), 687–705. https://doi.org/10.1007/s40279-022-01800-1

Nowakowska, A., Kostrzewa-Nowak, D., Buryta, R., & Nowak, R. (2019). Blood biomarkers of recovery efficiency in soccer players. *International Journal of Environmental Research and Public Health*, *16*(18). https://doi.org/10.3390/ijerph16183279

Ortiz, R. O., Sinclair Elder, A. J., Elder, C. L., & Dawes, J. J. (2019). A systematic review on the effectiveness of active recovery interventions on athletic performance of professional-, collegiate-, and

competitive-level adult athletes. *Journal of Strength and Conditioning Research*, *33*(8), 2275–2287. https://doi.org/10.1519/JSC.0000000000002589

Pérez-Castillo, Í. M., Rueda, R., Bouzamondo, H., López-Chicharro, J., & Mihic, N. (2023). Biomarkers of post-match recovery in semi-professional and professional football (soccer). *Frontiers in Physiology*, *14*(April), 1–21. https://doi.org/10.3389/fphys.2023.1167449

Pernigoni, M., Ferioli, D., Butautas, R., La Torre, A., & Conte, D. (2021). Assessing the External Load Associated With High-Intensity Activities Recorded During Official Basketball Games. *Frontiers in Psychology*, *12*(April), 1–8. https://doi.org/10.3389/fpsyg.2021.668194

Pinto, J., Rocha, P., & Torres, R. (2020). Cold-Water Immersion Has No Effect on Muscle Stiffness After Exercise-Induced Muscle Damage. *Clinical Journal of Sport Medicine : Official Journal of the Canadian Academy of Sport Medicine*, *30*(6), 533–538. https://doi.org/10.1097/JSM.0000000000000682

Reichel, T., Boßlau, T. K., Palmowski, J., Eder, K., Ringseis, R., Mooren, F. C., Walscheid, R., Bothur, E., Samel, S., Frech, T., Philippe, M., & Krüger, K. (2020). Reliability and suitability of physiological exercise response and recovery markers. *Scientific Reports*, *10*(1), 1–11. https://doi.org/10.1038/s41598-020-69280-9

Roberts, L. A., Nosaka, K., Coombes, J. S., & Peake, J. M. (2014). Cold water immersion enhances recovery of submaximal muscle function after resistance exercise. *American Journal of Physiology - Regulatory Integrative and Comparative Physiology*, *307*(8), R998–R1008. https://doi.org/10.1152/ajpregu.00180.2014

Roonkiani, S. K., Ebrahimi, M., & Majelan, A. S. (2020). Effect of cold water immersion on muscle damage indexes after simulated soccer training in young soccer players. *Biomedical Human Kinetics*, *12*(1), 236–241. https://doi.org/10.2478/bhk-2020-0030

Silva, J. R., Rumpf, M. C., Hertzog, M., Castagna, C., Farooq, A., Girard, O., & Hader, K. (2018). Acute and Residual Soccer Match-Related Fatigue: A Systematic Review and Meta-analysis. *Sports Medicine*, *48*(3), 539–583. https://doi.org/10.1007/s40279-017-0798-8

Stojanović, E., Stojiljković, N., Scanlan, A. T., Dalbo, V. J., Berkelmans, D. M., & Milanović, Z. (2018). The Activity Demands and Physiological Responses Encountered During Basketball Match-Play: A Systematic Review. *Sports Medicine*, *48*(1), 111–135. https://doi.org/10.1007/s40279-017-0794-z

Tavares, F., Beaven, M., Teles, J., Baker, D., Healey, P., Smith, T. B., & Driller, M. (2019). Effects of chronic cold-water immersion in elite rugby players. *International Journal of Sports Physiology and Performance*, *14*(2), 156–162. https://doi.org/10.1123/ijspp.2018-0313

Thornton, C., Baird, A., & Sheffield, D. (2024). Athletes and Experimental Pain: A Systematic Review and Meta-Analysis. *Journal of Pain*, *xxx*(xxx), 104450. https://doi.org/10.1016/j.jpain.2023.12.007

Williams, M. N. C., Dalbo, V. J., Fox, J. L., O'Grady, C. J., & Scanlan, A. T. (2021). Comparing weekly training and game demands according to playing position in a semiprofessional basketball team. *International Journal of Sports Physiology and Performance*, *16*(6), 772–778. https://doi.org/10.1123/ijspp.2020-0457

Authors' and translators' details:

Marcin Janusiak	katzurin2001@gmail.com	Author
Rui Miguel Silva	rui.s@ipvc.pt	Author
Francisco Tomás González Fernández	ftgonzalez@ugr.es	Author
Małgorzata Smoter	m.h.smoter@gmail.com	Author
Aleksandra Kisilewicz	ruimiguelfps@gmail.com	Author
Sebastian Klich	sebastian.klich@awf.wroc.pl	Author
Rui Miguel Silva	rui.s@ipvc.pt	Translator