
Acute Effects of Nutritional and Physical Recovery Strategies on Exercise Performance, Muscle Damage, and Fatigue In Elite Basketball Players: A Randomized Crossover Trial

[Alberto Marín-Galindo](#) , [Alejandro Perez-Bey](#) , Juan Manuel Escudier-Vázquez , [Daniel Velázquez-Díaz](#) * , [Julio Calleja-González](#) , [Carmen Vaz-Pardal](#) , [Juan Corral-Pérez](#) , [Jesus G Ponce-Gonzalez](#)

Posted Date: 20 January 2026

doi: 10.20944/preprints202601.1434.v1

Keywords: cold-water immersion; recovery strategies; nutrition; team sports; exercise-induced muscle damage



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a [Creative Commons CC BY 4.0 license](#), which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Article

Acute Effects of Nutritional and Physical Recovery Strategies on Exercise Performance, Muscle Damage, and Fatigue In Elite Basketball Players: A Randomized Crossover Trial

Alberto Marín-Galindo ¹, Alejandro Perez-Bey ², Juan M Escudier-Vázquez ³, Daniel Velázquez-Díaz ^{1,*}, Julio Calleja-González ⁴, Carmen Vaz-Pardal ⁵, Juan Corral-Pérez ¹ and Jesús G Ponce-Gonzalez ¹

¹ ExPhy Research Group, Department of Physical Education, Instituto de Investigación e Innovación Biomédica de Cádiz (INiBICA), Universidad de Cádiz, Cádiz, Spain

² GALENO Research Group, Department of Physical Education, Instituto de Investigación e Innovación Biomédica de Cádiz (INiBICA), Universidad de Cádiz, Cádiz, Spain

³ Fundación para la Gestión de la Investigación Biomédica de Cádiz, Hospital Puerta del Mar, 9^a planta, Unidad de Investigación, Cádiz, Spain

⁴ Physical Education and Sport Department, Faculty of Education and Sport, University of the Basque Country (UPV/EHU), Vitoria-Gasteiz, Spain

⁵ Andalusian Center of Sport Medicine, Junta de Andalucía, Cádiz, Spain

* Correspondence: daniel.velazquez@uca.es

Abstract

Background: Due to the congested competition calendar and the high physical demands of elite basketball, the selection of effective recovery strategies is essential to optimize performance and reduce exercise-induced fatigue and muscle damage. This study aimed to examine the acute effects of different nutritional and physical recovery strategies on exercise performance, muscle damage, and perceived fatigue and exertion in elite basketball players. **Method:** Fifteen elite male basketball players participated in a randomized crossover trial and completed four recovery conditions: cold-water immersion (CWI), active recovery (ACT), protein-carbohydrate supplementation (SUP), and placebo (PLA). Following a basketball-specific fatigue protocol, creatine kinase, countermovement jump performance, isometric strength, 10 m sprint, and 4 × 10 m shuttle run test were assessed at baseline, immediately post-exercise, and 24 h post-exercise. Perceived fatigue and rate of perceived exertion were measured at baseline, immediately post-exercise, immediately after the recovery intervention, and 24 h post-exercise. **Results:** The three recovery methods prevented the 24h exercise-induced CK increase observed in the PLA condition ($p > 0.05$). The CWI, SUP and ACT decreased fatigue and RPE immediately after their application ($p < 0.05$), while the PLA kept them elevated. CWI significantly improved 4x10mSRT time ($p = 0.027$) 24h. **Conclusion:** Nutritional supplementation and physical recovery strategies effectively attenuated exercise-induced muscle damage and fatigue in elite basketball players. However, CWI demonstrated the most pronounced acute benefits for physical performance recovery.

Keywords: cold-water immersion; recovery strategies; nutrition; team sports; exercise-induced muscle damage

1. Introduction

Basketball is one of the most popular sports in the World[1]. It is a team sport in which five players face off against five others, with an indefinite number of changes that can be made when the

coach deems it appropriate. It is a sport where the anaerobic metabolism predominates and where the execution of technical actions at a high intensity is essential, as well as the ability to repeat these maximum efforts many times[2–4]. Basketball includes sports skills such as changes of direction, accelerations, jumps or strong collisions and contacts with opponents[2]. These high intensity actions which cause great fatigue to accumulate, both central and peripheral, in a short period of time[5].

In recent years, the elite basketball sport calendar has become condensed[6], even having to play matches every two or three days, between national and international matches[6]. Therefore, this can have consequences for both physiological and psychological status and has the potential to impair performance[7]. Both the frequency of training sessions and matches, as well as the physical demand that is required in high performance, increase the risk of injury, despite the measures carried out during training to prevent these injuries[8].

These circumstances make recovery between training sessions and games essential[9]. Recovery must be effective, as fast as possible and without negatively interfering with the desired adaptations in the athlete or, at least, minimizing these interferences[10]. In that way, there are many studies that have investigated the effects of different recovery methods and strategies in many sports and training types[4,11,12]. Specifically, in basketball some of the most studied recovery strategies include cold water immersion, carbohydrates-protein supplements, and active recovery, the most used method in basketball[4]. Besides these mentioned methods has been presented high level of evidence and are the most used related to recovery effect. These recovery strategies have been shown to quickly recover physical performance and muscle damage[4]. However, for the best of the author's knowledge, no previous studies have analyzed the potential effect of these previous mentioned combined methods at the same time with basketballers.

Thus, the main aim of this study was examine the acute effects of different nutritional (carbohydrate-protein supplementation (SUP)) and physical recovery strategies (cold-water immersion (CWI) and active recovery (ACT)) on exercise performance, muscle damage, and perceived fatigue and exertion in elite basketball players.

2. Materials and Methods

2.1. Participants

A total of 15 elite male basketball players (mean \pm Standard Deviation, age 23 ± 4 years) participated in the study. All players competed in the Spanish Amateur Basketball League (EBA league) of the Spanish Basketball Federation (FEB), specifically, in the CB Cimbis team (San Fernando, Spain) and were classified to play the promotion phase to the Silver Spanish Basketball League (LEB SILVER The 3th Division). The general characteristics of the participants were described in Table 1.

Table 1. Descriptives statistics of the sample (n=15) of elite male basketball players.

| Variable | Mean (SD) | Minimum | Maximum |
|------------------------------|---------------|---------|---------|
| Age (years) | 22.13 (3.66) | 18.00 | 32.00 |
| Body mass (kg) | 93.35 (16.31) | 72.50 | 125.30 |
| Height (cm) | 192.99 (5.93) | 183.40 | 205.50 |
| BMI (kg/cm ²) | 25.01 (3.82) | 19.14 | 32.29 |
| Body fat percentage (%) | 10.14 (3.50) | 5.98 | 19.09 |
| VO ₂ max (ml/min) | 45.83 (4.72) | 40.40 | 54.80 |
| Heart Rate max (bpm) | 184.87 (9.73) | 172.00 | 201.00 |

Abbreviations: BMI = body mass index; bpm = beats per minute; SD = standard deviation

The inclusion criteria were: 1) not having recently suffered injuries, 2) having at least 10 years of sports practice, 3) having been training during the season a minimum of four times a week, and 4) having competed and trained regularly in the previous season. The exclusion criteria were: 1) suffering an injury during the study period or 2) not having gone through all the treatment groups (CWI, SUP, ACT and PLA).

To minimize potential interference from dietary changes or the use of other nutritional supplements, participants were instructed to maintain their usual dietary intake throughout the study period and avoid the consumption of any dietary supplements that could potentially provide ergogenic benefits. Also, there were any restrictions (e.g., no exercise 24h before the protocol visit, no caffeine for 8h prior), prior to the study visits. The study visits occurred two day after the first training. To track their training activities, participants completed a self-administered questionnaire detailing their weekly team practice duration and frequency of training.

The participants followed a similar diet established by the respective coaching staffs of each of the participating club. Before the start of the study, it was determined that the participants were ready to play and train with guarantees (i.e., that none had any injuries). None of the players had any injuries, allergies, or hormonal disturbances during data collection. In addition, none of the participants were to be under the influence of any type of illegal drugs or taking medication that affected body mass. The work performed during the training sessions was agreed on by the coaching staff and was therefore representative of the workload experienced during that period of the season [13].

2.2. Ethical Issues

After being informed about all the details of the experimental procedures and methods, including the potential risks of the study, each participant signed an informed consent. It must be noted that the obtained data were treated with the greatest confidentiality and scientific rigor, their use restricted by the guidelines for research projects following the scientific method required in each case, complying with the Organic Law 15/1999 of the 13th of December on the Protection of Personal Data (OLPPD); the proceedings used respected the ethic criteria of the Responsible Committee of Human Experimentation (established by law 14/2007, published in the Spanish Official State Gazette, n° 159). Ethical approval for the study was obtained from the ethical committee of University of Cádiz (Puerta del Mar University Hospital, Registration Number: PEIBA 2123-N-21: 11.22), and the study was in accordance with the Declaration of Helsinki [14].

2.3. Experimental Design and Procedures

This study is part of The Recovery Project (NCT05805540A). Briefly, body composition, maximal oxygen consumption (VO₂max) and maximal heart rate (HR_{max}) were determined prior the intervention. Then, a crossover design was used to examine the effects of 4 different recovery interventions on muscle damage and fatigue and physical performance after a fatigue exercise protocol in elite male basketball players, which included basketball-specific technical actions as changes of direction or jumps[15]. Thus, each athlete performed all the recovery methods that were included in the study, one week apart; including CWI (n=15), SUP (n=15), ACT (n=15), and placebo-control (PLA) (n=15) condition. The participants were randomized to four different groups by an independent statistician using OxMar open-source software. Physical performance and biochemical markers of muscle damage were measured at baseline (PRE), immediately after the fatigue protocol (POST) and 24 hours later (24h). Furthermore, perceived exertion and fatigue were obtained at PRE, POST, immediately after the applied recovery method (25min), and 24h. The study was carried out at the end of the season (one week after the last League competition match), the moment of the season when usually athletes have the highest level of fatigue and when more injuries are suffered[16], being able to focus completely on the study and thus avoid confounding variables of the practice and load of the match.

All participants kept two of their weekly team trainings and did not play any match during the intervention period. The weekly physical training session they had was replaced by the day they performed the study's fatigue protocol. Players were instructed to eat and perform activities similarly as they did during the first week of intervention.

2.3.1. Body Composition, Height and Cardiorespiratory Fitness

Before the beginning of the study, the participants were cited at the Andalusian Sports Medicine Center (CAMD) in San Fernando (Cádiz), where body composition, VO₂max and HRmax were determined.

Body composition and height were assessed using a Tanita MC780MA (Tanita®, Tokyo, Japan) and a wall-mounted stadiometer (Tanita Leicester Portable®, Tanita Corp., Barcelona, Spain), respectively.

Participants performed a maximal incremental test on a treadmill for VO₂max and HRmax assessment. Following a 3-minute warm-up period at a speed of 8 km/h, the speed was systematically increased by 1 km/h every three minutes until participants reached exhaustion. To simulate the physiological demands of outdoor running, a 1% gradient was applied to the treadmill [17] monitored with gas analyzer of open circuit, Jaeger MasterScreen CPX® (CareFusion, San Diego, USA), to determine their VO₂max and HRmax. All these tests had to be carried out without having consumed alcohol or stimulants in the previous 24 hours or having done vigorous physical exercise the day before.

2.3.2. Recovery Methods

In CWI condition, the participants were immersed, in a sitting position where legs were always covered, in cold water at 11 °C for 2 minutes and 2 minutes out of the water in a sitting position at room temperature (25 °C), repeating this process 5 times[4,18]. The SUP group consumed a mixed carbohydrate and protein beverage, composed of 0.3gr/kg of maltodextrin and 0.2gr/kg of neutral whey protein in 0.5 liters of water[4]. The ACT condition was carried out pedaling for 25 minutes at 50% of the HRmax on a cyclo-ergometer[19]. The PLA group drank a water-based drink and sweetener. Both the PLA and SUP groups were in double-blind condition in sitting position for 25 minutes until all recovery methods were completed.

2.3.3. Exercise Protocol

The participants performed a basketball-specific exercise protocol with maximal effort until fatigue, which included the following specific basketball circuit: a) Backward shift in defensive position, b) straight-line race with ball bounce and abrupt change of direction, c) entry to the basket, d) three jumps to the board, e) slalom with ball bounce, f) slalom without the ball, between spades, simulating direct block defense action (3 to the right and 3 to the left), g) backward sprint and h) frontal sprint. This exercise protocol was based on previous studies[15].

They performed 5 sets of 5 repetitions, with 30 seconds of rest between repetitions and 1 minute between sets. To avoid crowds in the rest areas and when performing post-effort tests, the start of the protocol was carried out in a staggered manner every 15 seconds. During the performance of the fatigue protocol, the heart rate of the athletes was monitored (Polar Team 2®, Polar, Kempele, Finland). In addition, after each series, to quantify the perceived exertion of participants the Borg Perceived Exertion Scale was used. Heart rate peak (HRpeak) and blood lactate concentration were measured to ensure that exercise protocol was performed to the maximum by the participants of all groups.

2.3.4. Outcomes

Creatine Kinase and Blood Lactate concentration. Blood lactate concentration was measured to examine the metabolic stress induced by the fatigue protocol. Blood samples were obtained from the

earlobe and collected into capillary tubes, and lactate was determined with Lactate Pro 2 (LT-1730, Arkray, Kyoto, Japan) and creatine kinase (CK) activity was analyzed with Reflotron® Plus – Roche (Roche Diagnostics ® SL, Barcelona) immediately after collection.

Fatigue and Rate of Perceived Exertion. Fatigue was assessed using its specific visual analogue scale on a scale from 1 to 10 (1 = no fatigue and 10 = extremely fatigued) and rate of perceived exertion (RPE) was also asked using the 0-10 Borg Scale in each participant. The players filled out the questionnaires evaluating fatigue and RPE before and immediately after the exercise, after the recovery method application and 24 hours later.

Performance Tests. Performance tests included a 10-m sprint test (10mST), 4x10m shuttle run test (4x10mSRT), countermovement jump (CMJ), and isometric strength in half squat exercise (IsoS). In the 10-mST, the players ran 10m maximally. In the 4x10mSRT, the subjects had to run as fast as possible between two cones 10 meters apart four times. The time of 10-mST and 4x10-mSRT were recorded with video analysis. In CMJ[20], the participants were asked to keep their hands on their hips and jump as high as possible. The flight time in jump height was used as a measure of jump performance and was measured on a force platform (Quattro Jump, Kristler). The jump height (h) was calculated from the flight time (t) by the formula: $h = t^2 \times g/8$, where $g = 9.81 \text{ m}\cdot\text{s}^{-2}$. For the IsoS, participants performed a maximal isometric contraction during 6 seconds in the half squat exercise, with 90° knee flexion, using a Smith machine (Nautilus NT 1800; Nautilus, Inc., Vancouver, WA, USA). The strength of the participants was measured with a force platform on which the exercise was performed. The players were asked to perform the maximal strength possible since the start and not to stop until a signal. The participants had 2 attempts of each test to achieve their best performance with 2-3 minutes of rest between trials. Only for CMJ test the participants had 3 attempts and we choose the best for the statistical analysis.

After the RPE, fatigue and CK measurements, and before the beginning of the physical performance tests, players performed 5 minutes of running warm-up and 5 minutes of light stretching. Players were familiar with the procedures during the preseason, and it was answered for their fatigue perception and RPE every day before training and competitive sessions.

2.4. Statistical Analysis

Data are expressed as mean \pm standard deviation (SD). Shapiro-Wilk test (<50) was used to check the normality of data distribution, and Levene test for homoscedasticity.

As the data followed a normal distribution, a 3x3 repeated measures analysis of variance (ANOVA) was used to compare the evolution over the time in physical performance variables. A 3x4 repeated measures ANOVA was used for the mean difference in perceived fatigue and exertion since they had an extra measure immediately after the recovery method application. The Bonferroni post hoc comparisons were applied. Effect size (ES) by partial eta squared was included and was classified as follows: higher than 0.90 was very large, from 0.75 to 0.90 was large, from 0.5 to 0.75 was moderate, and less than 0.25 was small. The 95% confidence intervals with corresponding p-values were included. The p-value <0.05 was considered statistically significant. All analyses were performed using SPSS Software (version 25; SPSS Inc, Chicago IL, USA).

3. Results

All exercise protocols performed in each recovery method showed the same fatigue, with similar blood lactate concentration, HR_{peak} and RPE levels (Table 2).

Table 2. Values of maximum effort and accumulated fatigue in the basketball-specific fatigue protocol for each recovery method.

| Variable | PLA (n=15) | CWI (n=15) | ACT (n=15) | SUP (n=15) | p |
|----------|------------|------------|------------|------------|---|
|----------|------------|------------|------------|------------|---|

| | | | | | |
|--------------------------------|------------------|------------------|------------------|------------------|-----------|
| Post Exercise Lactate (mmol/L) | 3.99 (1.58) | 3.88 (1.93) | 3.62 (2.08) | 4.19 (1.90) | 0.86 6 |
| RPE (0-10 scale) | 8.13 (1.88) | 8.47 (1.36) | 8.60 (1.40) | 8.40 (1.84) | 0.88 6 |
| Fatigue Protocol HRpeak (bpm) | 186.87 (8.65) | 188.93 (8.36) | 187.60 (8.16) | 188.40 (7.86) | 0.90 9 |

Data are presented as the mean (standard deviation at 95% CI). P-values indicate significant differences between conditions. Significance was set at $p < 0.05$. Abbreviations: PLA, placebo; CWI, cold water immersion; SUP, carbohydrates and protein co-ingestion; ACT, active recovery; RPE, rate of perceived exertion; HRpeak, heart rate peak

3.1. Time and Recovery Method Effects

A time main effect for CK ($F_{1,551}, 21.7 = 19.166$; $p < 0.001$; ES = moderate), fatigue ($F_{3, 42} = 41.471$; $p < 0.001$; ES = moderate), RPE ($F_{2,046}, 28.642 = 169,931$; $p < 0.001$; ES = very large), 4x10mSRT ($F_{2, 28} = 6.644$; $p = 0.004$; ES = small) and IsoS ($F_{2, 28} = 3,401$; $p = 0.048$; ES = small) was observed. There was a main effect of the recovery method for 10mST ($F_{3, 42} = 5.028$; $p = 0.005$; ES = small). There were no statistically significant interactions of the Recovery Method \times Time for any variable. The POST compared with PRE measurements of CK, fatigue and RPE showed statistically significant differences ($p < 0.05$). Bonferroni post-hoc comparisons are presented in Table 3.

3.1.1. Cold Water Immersion

For CK, there were differences PRE and 24h ($p = 0.003$), but not between POST and 24h ($p = 0.125$) when athletes used CWI. Fatigue values were significantly lower from POST to 25min ($p < 0.001$) with the use of CWI. 25min levels were not significantly different to PRE ($p = 0.082$) and 24h ($p = 0.103$). For RPE there were significant decrements in 25min compared with POST ($p < 0.001$), and 24 hours after RPE was significantly lower than 25min ($p = 0.035$). The time in 4 \times 10 agility test improved significantly ($p = 0.027$) in 24h compared with POST when CWI was used. There were no significant differences in CMJ height between measurement moments, but we observed a trend ($p = 0.067$) to improve 24h after the CWI application. There were no differences between moments ($p > 0.05$) for 10mST, or IsoS.

3.1.2. Protein + Carbohydrate Supplement

For CK, there were differences between PRE and POST ($p < 0.001$) and PRE and 24h ($p = 0.014$), but not between POST and 24h ($p = 0.100$) when athletes used SUP. Fatigue values were significantly higher from PRE to POST ($p < 0.001$), and 25min were significantly lower ($p = 0.044$) than POST with the use of SUP. 25min levels were not significantly different to PRE ($p = 0.067$) and 24h ($p = 0.072$). RPE values in POST were significantly higher ($p < 0.001$) than PRE in SUP condition. There were significant decrements in 25min compared with POST ($p = 0.001$), and in 24h compared with 25min ($p = 0.004$) when SUP was used. There were no significant differences in IsoS between measurement moments, but we observed a trend ($p = 0.078$) to improve 24h after the SUP application. There were no differences between moments ($p > 0.05$) for 10mST, 4x10mSRT, or CMJ when SUP was used.

3.1.3. Active Recovery

For CK, there were differences between PRE and POST ($p = 0.001$) and PRE and 24h ($p = 0.004$), but not between POST and 24h ($p = 0.075$) when athletes used ACT. Fatigue values were significantly higher from PRE to POST ($p = 0.004$), and 25min were significantly lower ($p = 0.015$) than POST with the use of ACT. 25min levels were not significantly different to PRE ($p = 0.157$) and 24h ($p > 0.05$). The RPE values in POST were significantly higher ($p < 0.001$) than PRE in ACT condition. There were

significant decrements in 25min compared with POST ($p < 0.001$), and in 24h compared with 25min ($p = 0.001$) when ACT was used. There were no differences between moments ($p > 0.05$) for 10mST, 4x10mSRT, CMJ, or IsoS when ACT was used.

Table 3. Post-recovery changes in rate of perceived exertion, fatigue, muscle damage and neuromuscular and physical performance.

| Variable | PLACEBO (n = 15) | COLD-WATER IMMERSION (n = 15) | ACTIVE RECOVERY (n = 15) | CHO-PRO SUPPLEMENT (n = 15) |
|----------------------------|---------------------|----------------------------------|--------------------------------|-----------------------------------|
| CK (mmol/L) | | | | |
| PRE | 85.09 (71.73) | 61.00 (18.25) | 72.29 (30.18) | 68.41 (30.77) |
| POST | 110.50 (85.51)* | 85.93 (27.03)* | 95.89 (34.74)* | 94.09 (36.27)* |
| 24hP | 163.11 (85.18)& | 122.68 (57.91)* | 142.11 (71.51)* | 136.15 (77.54)* |
| RPE (0- 10 scale) | | | | |
| PRE | 0.53 (1.36) | 0.13 (0.52) | 0.47 (1.25) | 0.07 (0.26) |
| POST | 8.13 (1.89)* | 8.60 (1.40)* | 8.47 (1.36)* | 8.40 (1.84)* |
| 25minP | 3.13 (2.42)& | 2.07 (2.66) | 4.13 (2.64)& | 3.67 (3.13)& |
| 24hP | 0.67 (1.35)# | 0.40 (1.06)# | 0.60 (0.91)# | 0.53 (1.19)# |
| Fatigue (0-10 scale) | | | | |
| PRE | 1.35 (1.59) | 1.72 (1.65) | 1.92 (1.95) | 1.59 (1.83) |
| POST | 4.95 (1.79)* | 5.97 (2.01)* | 4.51 (2.61)* | 5.12 (2.58)* |
| 25minP | 3.85 (2.04) | 3.04 (1.39)\$ | 2.93 (1.92)\$ | 3.49 (2.15)\$ |
| 24hP | 1.93 (1.81)# | 1.85 (2.19)\$ | 2.73 (2.30)\$ | 1.94 (1.83)\$ |
| 10mST (s) | | | | |
| PRE | 2.019 (0.195) | 2.047 (0.169) | 2.103 (0.159) | 1.980 (0.134) |
| POST | 2.049 (0.157) | 2.077 (0.193) | 2.111 (0.156) | 1.999 (0.133) |
| 24hP | 2.055 (0.129) | 1.990 (0.136) | 2.136 (0.143) | 1.973 (0.132) |
| 4x10mS RT (s) | | | | |
| PRE | 10.103 (0.450) | 10.065 (0.486) | 10.123 (0.455) | 10.063 (0.507) |
| POST | 10.139 (0.518) | 10.131 (0.540) | 10.139 (0.474) | 10.142 (0.561) |

| | | | | | |
|-----------------------------------|------|-------------------|-----------------|----------------|----------------|
| | 24hP | 10.021 (0.459) | 9.960 (0.497)\$ | 10.047 (0.458) | 10.054 (0.556) |
| CMJ | | | | | |
| Height (cm) | | | | | |
| | PRE | 33.31 (4.13) | 34.18 (3.64) | 32.97 (5.21) | 33.34 (3.61) |
| | POST | 34.23 (3.71) | 32.35 (3.41) | 32.94 (4.48) | 32.92 (3.47) |
| | 24hP | 33.65 (5.66) | 33.42 (3.59) | 33.81 (4.62) | 32.49 (3.74) |
| Isometri c strength (kg) | | | | | |
| | PRE | 208.46 (50.51) | 208.61 (41.44) | 213.69 (44.93) | 212.80 (35.98) |
| | POST | 195.45 (35.04) | 189.91 (69.41) | 203.78 (48.95) | 200.96 (35.10) |
| | 24hP | 203.37 (42.10) | 188.05 (37.03) | 187.97 (71.32) | 212.30 (33.24) |

Data are presented as the mean (standard deviation at 95% CI). Abbreviations: ACT, active recovery; CK, creatine kinase; CMJ, countermovement jump; CWI, cold water immersion; NA, no data available; RPE, rate of perceived exertion; 10mST, 10m Sprint Test; 4x10mSRT, 4x10m Shuttle Run Test; 25minP, immediately post recovery method measurement; 24hP, 24h post-exercise values * significant differences versus pre-exercise values; \$ significant differences versus post-exercise values; & significant differences versus pre-exercise and post-exercise values; # significant differences versus post-exercise and 25' post-exercise values

3.1.4. Placebo

For CK, there were significant differences among all moments ($p < 0.05$) when athletes used PLA. Fatigue values were significantly higher from PRE to POST ($p < 0.001$). 25min were not significantly different ($p = 0.159$) than POST with the use of PLA. 25min levels were significantly higher than PRE ($p = 0.006$) and 24h ($p = 0.017$). The RPE values in POST were significantly higher ($p < 0.001$) than PRE in PLA condition. There were significant decrements in 25min compared with POST ($p < 0.001$), and in 24h compared with 25min ($p = 0.008$) when PLA was used. PRE rate of perceived exertion levels was similar than 24h ($p > 0.05$).

4. Discussion

The main findings of this study were that CWI could be the best recovery method of those included. This method presents the effectiveness to attenuate the increase of blood CK after 24 hours of recovery, with a positive effect when ACT and SUP were used. In addition, all three recovery methods (CWI, SUP, and ACT) were effective in immediately improving perceived fatigue and RPE condition, while the PLA condition did not show this improvement. The CWI also showed an improving trend in the 10mST and CMJ, and it was the only effective recovery method that significantly reduce the time in the 4x10mSRT 24 hours later. The SUP use showed a positive trend in the 24h recovery of IsoS.

The positive effects of CWI on CK have been observed in previous studies performed on male athletes of different team sports[21,22]. Specifically, CWI may improve recovery from muscle damage in professional basketball players during a regular season[23]. Cold exposure decrease edema by decreasing the incoming blood flow, facilitating the clearance of accumulated metabolites in the peripheral fluid. Besides, the vasoconstriction produced by cold increase blood volume, increasing venous pressure, and facilitating the elimination of metabolites derived from muscle damage. In addition, the decrease in temperature reduced intramuscular metabolism, minimizing external damage[24]. However, there is evidence against CWI being effective in reducing CK concentration after 24 hours of intense exercise[25,26]. Against this, it should be considered that there are other scientific articles[12] in which they observed that although there are no significant effects after 24 hours, these were detected after 48 hours of recovery. The time from exercise to CK measurement seems to clarify the effects that CWI could have on CK. Therefore, more research should be carried out comparing the effects of this recovery method in the evolution of CK at 24, 48, and 72 hours, specifically in basketball.

The SUP use has been shown to attenuate the release of CK into the blood after physical exercise in our study. In line with these results, a study which included strength and power athletes observed this attenuation of the release of CK using SUP compared with PLA[27]. Furthermore, a recent review[28] concluded that, in the long term, sustained consumption of SUP could decrease the release of CK into the bloodstream. Nevertheless, researchers also concluded that there is evidence that shows how protein-based supplements, including mixtures with carbohydrates[29], decrease the increase in blood CK after intense exercise in the short term[28]. In this same study, the authors observed that these effects of SUP on CK would not be related to a significant improvement in physical performance[28].

There are conflicting results regarding the effect of ACT on post-exercise blood CK levels. Some studies show that performing low-intensity exercise after training or games improves CK clearance[30]. A recent systematic review with meta-analysis[21], which includes 43 studies, concluded that ACT is an effective method to reduce CK release 24h after the exercise, and therefore, to reduce exercise-derived muscle damage. However, there are several studies that show the low effectiveness of ACT on the clearance of CK[31,32]. We still find some controversy about the effectiveness of ACT to alleviate the increased CK in blood derived from exercise-induced muscle damage. To contrast this controversy, future studies should compare the effects of different types and doses of active recovery and examine whether these variables are key for this recovery method to be effective.

Concerning fatigue and RPE variables, in our study, we observed that CWI, SUP, and ACT were effective to recover fatigue perception and RPE, being CWI the recovery method that reduce the fatigue and RPE to basal values more quickly (immediately after application). There is strong scientific evidence supporting our results regarding the effects of CWI use on the perception of fatigue and RPE[33,34]. However, there are conflicting results related to the effects on perceived fatigue when ACT is used. The use of ACT may not be the best post-exercise strategy to reduce the perception of fatigue[21]. In particular, most studies show that the use of ACT does not have positive effects on the perception of fatigue, however, this method could be better than passive recovery[35]. In this study, the best or worst response of ACT versus passive recovery depends on the athletes' level. Concretely, for amateur athletes, making an ACT involves extra effort and they understand it as doing more physical exercise, while for professional athletes, ACT seems to be better than passive recovery. In line with these results, a systematic review[36] concluded that the only ACT format that is effective to improve the perception of fatigue or recovery is the one performed for a short period of time (6-10 min), being the time of exposure to ACT from our study far superior (25 min).

To our knowledge, our study is the first to specifically investigate the effects of SUP on the subjective perception of fatigue in basketball. Therefore, although these results provide us with new knowledge and strategies on how to improve our athletes' perception of fatigue, more studies are needed to contextualize our results in basketball.

Regarding the physical performance variables of the present study, the CWI improved the performance on 4x10mSRT test and showed a trend to improve the 10mST, without significant effects of the consumption of SUP, ACT and PLA for these variables. Although there were no significant differences in 10mST time between moments of measurement for any recovery method ($p > 0.05$), when PLA and ACT were used the 10mST time showed clinical increments 24 hours later, while using CWI and SUP this time decreased. The effectiveness of recovery using CWI on sprints performance has been seen in some studies and there are few studies performed in team sports (some of them in basketball players) in which the effects of CWI recovery were examined on agility performance[33,34,37]. Related to these tests, we found that the use of CWI after intense exercise is effective in accelerating the recovery of leg power[18], which theoretically would favor performance in the sprint and agility tests[38], two predominant physical skills in elite basketball players[2].

For the recovery of the CMJ performance, CWI was the only recovery method that showed a positive trend, showing a trend to significant differences after 24 hours with the use of CWI. The trend shown by our results is consistent with current evidence, which shows that CWI is effective in reducing performance losses derived from muscle fatigue in the CMJ in team sports players[22,33,34] and specifically in basketball players[37]. In line with our results, another study[22] showed that there are no differences in this regard between ACT and CWI, although the effectiveness of ACT on performance recovery in CMJ is not entirely clear. A review[35] observed that the effects of the use of ACT on the CMJ performance the day after were small or moderate. In our study, SUP had no beneficial effects on CMJ recovery after 24 hours, without differences with the PLA condition, something that had already been seen in previous studies performed in different team sports[28].

For the IsoS, no statistically significant positive effects of any recovery method were seen after 24 hours. In the case of CWI, the results of other studies showed results like ours[18,39]. Although it did not show a statistically significant improvement, the use of SUP showed a tendency to improve IsoS performance 24 hours after exercise to fatigue. No studies were found specifically investigating the effects of SUP after 24 hours on maximal strength. In high-intensity efforts, the availability of carbohydrates in the body is a key factor to obtain maximum performance[40]. We know that the SUP after intense physical exercise is effective in restoring the body's glycogen stores[41]. Therefore, in line with our results, the use of SUP could have positive short-term effects on the recovery of strength, but more well-designed studies are needed to clarify this issue. Regarding the effects of ACT on strength, there is evidence that this recovery method is not effective in improving muscle strength 24 hours after strenuous exertion. This may be due to which it was observed that this method was effective to accelerate the recovery at the central level but not the contractile properties of the muscle, without beneficial effects on the maximum voluntary contraction [37]. Furthermore, it was observed that ACT is not effective in improving physical performance in general, and strength particularly, 24 hours after its application. More studies are needed to see the effects of this recovery method after different periods of time (24h, 48h, 72h, at least), based on individualization [42].

Our study is not free of limitations and, therefore, other studies are needed to complement the results provided. Our study did not include female basketball players, and we know that there are biological and physiological differences related to sports performance. Similarly, recovery methods could affect men and women differently, so it is necessary to evaluate the methods used by us in professional female basketball players. In addition, our study was carried out on high-performance players, so we could not extrapolate the results to basketball players in other categories or to other sports in which there are different physical and physiological demands. It should be noted that it is difficult to obtain larger samples in athletes, as not many have the availability to comply with the training and supplementation instructions required by the study. Moreover, sampling using a convenient, non-probabilistic sampling procedure may produce results that are not representative of the rest of the population. These limitations may underrepresent the results and may affect study outcomes. Nevertheless, the purpose of this study is not to transfer information to the general population.

In addition to these limitations, our study has several strengths. The randomized crossover design of this study increases the internal validity. The inclusion of a placebo condition as a control also increases the internal validity, being able to compare the recovery methods with this group. Another strength of our study is the double-blind of the design, in which the evaluators did not know the recovery method that had been applied to each participant, and participants were unaware if they were taking SUP or PLA, avoiding bias in this regard.

5. Conclusions

Findings suggest that nutritional supplementation and physical recovery strategies effectively attenuated exercise-induced muscle damage and fatigue in elite basketball players. However, our results mainly showed that cold-water immersion is the most effective method in our study for reducing exercise-derived muscle damage, measured by creatine kinase, which can lead to a significant improvement in sprint, agility, and countermovement jump performance. Furthermore, this method can also lead to a quick recovery of low levels of perceived fatigue. Additionally, consuming a carbohydrate supplement mixed with protein and utilizing active recovery after physical exertion could have beneficial effects on perceived fatigue and positively impact isometric strength recovery.

Author Contributions: JPG, AMG and JCG participated in the design of the study and contributed to data collection; AMG participated in the data collection and data reduction/analysis; AMG wrote the first draft of the manuscript; AMG, APB, DVD, and JME contributed to data collection. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

Funding: AMG was supported by a predoctoral grant from the Spanish Ministerio de Educación (Ministry of Education) [grant number FPU20/03649]. DVD was funded by from the Junta de Andalucía and the European Social Fund Plus [grant number DGP_POST_2024_00864].

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethical Committee of Puerta del Mar University Hospital, Cádiz, Spain (Registration Number: PEIBA 2123-N-21: 11.22).

Informed Consent Statement: After being informed about all the details of the experimental procedures and methods, including the potential risks of the study, each participant signed an informed consent to participate in this study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: This study was undertaken with the collaboration of the Andalusian Center of Sport Medicine and the Sports Delegation of San Fernando (Cádiz). The authors thank the following for their assistance and contribution to the development and achievement of this research.

Conflicts of Interest: The author declare that they have no competing interests.

References

1. Ostojic SM, Mazic S, Dikic N (2006) Profiling in basketball: Physical and physiological characteristics of elite players. *J Strength Cond Res* 20:740–744
2. Puente C, Abián-Vicén J, Areces F, López R, Del Coso J (2017) Physical and Physiological Demands of Experienced Male Basketball Players During a Competitive Game. *J Strength Cond Res* 31:956–962
3. Gottlieb R, Shalom A, Calleja-Gonzalez J (2021) Physiology of Basketball – Field Tests. Review Article. *J Hum Kinet* 77:159
4. Calleja-González J, Terrados N, Mielgo-Ayuso J, Delextrat A, Jukic I, Vaquera A, Torres L, Schelling X, Stojanovic M, Ostojic SM (2015) Evidence-based Post-Exercise Recovery Strategies in Basketball. *Physician Sport Med* 44:74–78

5. Petway AJ, Freitas TT, Calleja-González J, Leal DM, Alcaraz PE (2020) Training load and match-play demands in basketball based on competition level: A systematic review. *PLoS One*. <https://doi.org/10.1371/JOURNAL.PONE.0229212>
6. Sánchez RP, Navarro Barragán RM, Calleja-González J, Gómez-Ruano MÁ, Jiménez Sáiz SL (2022) Physical Persistency across Game Quarters and during Consecutive Games in Elite Junior Basketball Players. *Int J Environ Res Public Health*. <https://doi.org/10.3390/ijerph19095658>
7. Calleja-Gonzalez J, Marques-Jimenez D, Jones M, et al (2020) What Are We Doing Wrong When Athletes Report Higher Levels of Fatigue From Traveling Than From Training or Competition? *Front Psychol*. <https://doi.org/10.3389/FPSYG.2020.00194/FULL>
8. Alaphilippe A, Mandigout S, Ratel S, Bonis J, Courteix D, Duclos M (2012) Longitudinal Follow-Up of Biochemical Markers of Fatigue Throughout a Sporting Season in Young Elite Rugby Players. *J Strength Cond Res* 26:3376–3384
9. Pernigoni M, Conte D, Calleja-González J, Boccia G, Romagnoli M, Ferioli D (2022) The Application of Recovery Strategies in Basketball: A Worldwide Survey. *Front Physiol* 13:1–7
10. Bishop PA, Jones E, Woods AK (2008) Recovery From Training: A Brief Review. *J Strength Cond Res* 22:1015–1024
11. Calleja-González J, Mielgo-Ayuso J, Sánchez-Ureña B, Ostojic SM, Terrados N (2019) Recovery in Volleyball. *J Sports Med Phys Fitness* 59:982–993
12. Altarriba-Bartes A, Peña J, Vicens-Bordas J, Milà-Villaroel R, Calleja-González J (2020) Post-competition recovery strategies in elite male soccer players. Effects on performance: A systematic review and meta-analysis. *PLoS One*. <https://doi.org/10.1371/JOURNAL.PONE.0240135>
13. Paulauskas H, Kreivyte R, Scanlan AT, Moreira A, Siupsinskas L, Conte D (2019) Monitoring Workload in Elite Female Basketball Players During the In-Season Phase: Weekly Fluctuations and Effect of Playing Time. *Int J Sports Physiol Perform* 14:941–948
14. (2013) World Medical Association declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA* 310:2191–2194
15. Hülka K, Lehnert M, Bělka J (2017) Reliability and validity of a basketball-specific fatigue protocol simulating match load. *Acta Gymnica* 47:92–98
16. Kofotolis N, Kellis E (2007) Ankle Sprain Injuries: A 2-year Prospective Cohort Study in Female Greek Professional Basketball Players. *J Athl Train* 42:388–394
17. Jones AM, Doust JH (1996) A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *J Sports Sci* 14:321–327
18. Leeder J, Gissane C, Someren K Van, Gregson W, Howatson G (2012) Cold Water Immersion and Recovery From Strenuous Exercise: A Meta-Analysis. *Br J Sports Med* 46:233–240
19. Vanderthommen M, Makrof S, Demoulin C (2010) Comparison of active and electrostimulated recovery strategies after fatiguing exercise. *J Sport Sci Med* 9:164–169
20. Markovic, G., D. Dizdar, I. Jukic and MC (2004) Reliability and Factorial Validity of Squat and Countermovement Jump Tests. *J Strength Cond Res* 18:551–555
21. 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. *Front Physiol* 9:403
22. Pooley S, Spendiff O, Allen M, Moir HJ (2020) Comparative efficacy of active recovery and cold water immersion as post-match recovery interventions in elite youth soccer. *J Sports Sci* 38:1423–1431
23. Seco-Calvo J, Mielgo-Ayuso J, Calvo-Lobo C, Córdova A (2020) Cold Water Immersion as a Strategy for Muscle Recovery in Professional Basketball Players During the Competitive Season. *J Sport Rehabil* 29:301–309
24. Ihsan M, Watson G, Abbiss CR (2016) What are the Physiological Mechanisms for Post-Exercise Cold Water Immersion in the Recovery from Prolonged Endurance and Intermittent Exercise? *Sport Med* 46:1095–1109
25. Pointon M, Duffield R, Cannon J, Marino FE (2012) Cold water immersion recovery following intermittent-sprint exercise in the heat. *Eur J Appl Physiol* 112:2483–2494

26. Hohenauer E, Taeymans J, Baeyens JP, Clarys P, Clijsen R (2015) The effect of post-exercise cryotherapy on recovery characteristics: A systematic review and meta-analysis. *PLoS One* 10:1–22
27. Hoffman JR, Ratamess NA, Tranchina CP, Rashti SL, Kang J, Faigenbaum AD (2010) Effect of a proprietary protein supplement on recovery indices following resistance exercise in strength/power athletes. *Amino Acids* 38:771–778
28. Poulouis A, Georgakouli K, Draganidis D, et al (2019) Protein-Based Supplementation to Enhance Recovery in Team Sports: What is the Evidence? *J Sport Sci Med* 18:523–536
29. Koopman R, Wagenmakers AJM, Manders RJF, Zorenc AHG, Senden JMG, Gorselink M, Keizer HA, Van Loon LJC (2005) Combined ingestion of protein and free leucine with carbohydrate increases postexercise muscle protein synthesis in vivo in male subjects. *Am J Physiol - Endocrinol Metab* 288:645–653
30. Gill ND, Beaven CM, Cook C (2006) Effectiveness of Post-Match Recovery Strategies in Rugby Players. *Br J Sports Med* 40:260–264
31. Andersson H, Raastad T, Nilsson J, Paulsen G, Garthe I, Kadi F (2008) Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. *Med Sci Sports Exerc* 40:372–380
32. Suzuki M, Umeda T, Nakaji S, Shimoyama T, Mashiko T, Sugawara K (2004) Effect of incorporating low intensity exercise into the recovery period after a rugby match. *Br J Sports Med* 38:436–440
33. Higgins TR, Greene DA, Baker MK (2017) Effects of Cold Water Immersion and Contrast Water Therapy for Recovery From Team Sport: A Systematic Review and Meta-analysis. *J Strength Cond Res* 31:1443–1460
34. Ahokas EK, Ihalainen JK, Kyröläinen H, Mero AA (2019) Effects of Water Immersion Methods on Postexercise Recovery of Physical and Mental Performance. *J strength Cond Res* 33:1488–1495
35. Van Hooren B, Peake JM (2018) Do We Need a Cool-Down After Exercise? A Narrative Review of the Psychophysiological Effects and the Effects on Performance, Injuries and the Long-Term Adaptive Response. *Sport Med* 48:1575–1595
36. Ortiz Jr RO, Sinclair Elder AJ, Elder CL, Dawes JJ (2019) A Systematic Review on the Effectiveness of Active Recovery Interventions on Athletic Performance of Professional-, Collegiate-, and Competitive-Level Adult Athletes. *J Strength Cond Res* 33:2275–2287
37. Montgomery PG, Pyne DB, Hopkins WG, Dorman JC, Cook KK, Minahan CL (2008) The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *J Sports Sci* 26:1135–1145
38. Behm DG, Young JD, Whitten JHD, et al (2017) Effectiveness of traditional strength vs. power training on muscle strength, power and speed with youth: A systematic review and meta-analysis. *Front Physiol*. <https://doi.org/10.3389/fphys.2017.00423>
39. De Freitas VH, Ramos SP, Bara-Filho MG, Freitas DGS, Coimbra DR, Cecchini R, Guarnier FA, Nakamura FY (2019) Effect of cold water immersion performed on successive days on physical performance, muscle damage, and inflammatory, hormonal, and oxidative stress markers in volleyball players. *J Strength Cond Res*. <https://doi.org/10.1519/JSC.0000000000001884>
40. Mata F, Valenzuela PL, Gimenez J, Tur C, Ferreria D, Domínguez R, Sanchez-Oliver AJ, Sanz JMM (2019) Carbohydrate availability and physical performance: physiological overview and practical recommendations. *Nutrients*. <https://doi.org/10.3390/nu11051084>
41. Kerksick CM, Wilborn CD, Roberts MD, et al (2018) ISSN exercise & sports nutrition review update: Research & recommendKerksick, C. M., Wilborn, C. D., Roberts, M. D., Smith-Ryan, A., Kleiner, S. M., Jäger, R., ... Kreider, R. B. (2018). ISSN exercise & sports nutrition review update: Research & recommendat. *J Int Soc Sports Nutr* 15:1–57
42. Schelling X, Calleja-González J, Torres-Ronda L, Terrados N (2015) Using testosterone and cortisol as biomarker for training individualization in elite basketball: A 4-year follow-up study. *J Strength Cond Res* 29:368–378

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.