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Research article

Post-Match Recovery in Soccer with Far-Infrared Emitting Ceramic Material or Cold-Water Immersion

Tiago M. Coelho [1]✉, Renan F. H. Nunes [1], Fabio Y. Nakamura [2], Rob Duffield [3], Marília C. Serpa [1], Juliano F. da Silva [1], Lorival J. Carminatt [4], Francisco J. Cidral-Filho [5], Mariana P. Goldim [6], Khiany Mathias [5], Fabricia Petronilho [6], Daniel F. Martins [5] and Luiz G. A. Guglielmo [1]
[1] Physical Effort Laboratory, Department of Physical Education, Federal University of Santa Catarina, Florianópolis, SC, Brazil; [2] Associate Graduate Program in Physical Education UPE/UFPB, João Pessoa, Paraíba, Brazil; [3] Sport & Exercise Discipline Group, University of Technology (UTS), Moore Park, Sydney, Australia; [4] Human Performance Research Laboratory, Health Sciences and Sports Center, University of the State of Santa Catarina, Florianópolis, SC, Brazil; [5] Laboratory of Experimental Neurosciences and Graduate Program in Health Sciences, University of Southern Santa Catarina, Palhoça, SC, Brazil; [6] Laboratory of Neurobiology of Inflammatory and Metabolic Processes, University of Southern Santa Catarina, Tubarão, SC, Brazil

Abstract
We investigated the effects of two common recovery methods; far-infrared emitting ceramic materials (Bioceramic) or cold-water immersion on muscular function and damage after a soccer match. Twenty-five university-level soccer players were randomized into Bioceramic (BIO; n = 8), Cold-water immersion (CWI; n = 9), or Control (CON; n = 8) groups. Heart rate [HR], rating of perceived exertion [RPE], and activity profile through Global Positioning Satellite Systems were measured during the match. Biochemical (thiobarbituric acid reactive species [TBARS], superoxide dismutase [SOD], creatine kinase [CK], lactate dehydrogenase [LDH]), neuromuscular (countermovement [CMJ] and squat jump [SJ], sprints [20-m]), and perceptual markers (delayed-onset muscle soreness [DOMS], and the perceived recovery scale [PRS]) were assessed at pre, post, 24 h, and 48 h post-match. One-way ANOVA was used to compare anthropometric and match performance data. A two-way ANOVA with post-hoc tests compared the timeline of recovery measures. No significant differences existed between groups for anthropometric or match load measures ($P > 0.05$). Significant post-match increases were observed in SOD, and decreases in TBARS in all groups ($p < 0.05$), without differences between conditions ($p > 0.05$). Significant increases in CK, LDH, quadriceps and hamstring DOMS ($p < 0.05$), as well as decreases in 20-m, SJ, CMJ, and PRS were observed post-match in all groups ($p < 0.05$), without significant differences between conditions ($p > 0.05$). Despite the expected post-match muscle damage and impaired performance, neither Bioceramic nor CWI interventions improved post-match recovery.

Key words: Soccer, intermittent exercise, muscle damage, inflammation, recovery.

Introduction

During soccer matches, players cover a distance of ~10km per game in a variety of intensities and actions (Anderson et al., 2016). The high mechanical loads performed throughout the 90-min can induce significant fatigue (Robineau et al., 2012), muscle damage (Ascensão et al., 2011), and reduced neuromuscular function (Ascensão et al., 2011; Robineau et al., 2012). Furthermore, the timeline of post-match suppression of performance and existence of damage, perceptual fatigue, and delayed-onset muscle soreness (DOMS) may last for 48-72 h in soccer players (Ascensão et al, 2011; Elias et al, 2013). Accordingly, implementation of recovery strategies to counter the deleterious effects of fatigue is popular to accelerate recovery (Robineau et al., 2012; Rupp et al., 2012). Amongst various recovery interventions, cold-water immersion (CWI) has become ubiquitous in many professional sports and is commonly accepted as a valid recovery technique despite ongoing questions regarding logistical use in soccer (Ascensão et al., 2011; Rupp et al., 2012; Rowsell et al., 2009). Conversely, the role of passive heating through the use of bioceramic materials, also called Far-Infrared Emitting Ceramic Materials (cFIR) therapy, is more recent and is suggested as an effective recovery method in soccer (Loturco et al., 2016) and futsal (Nunes et al., 2020), providing increased muscle temperature for longer periods, with less intrusion. These interventions represent contrasting methods of post-match recovery i.e., short-term large application of cold with high logistical demand vs prolonged application of warmth via easily worn apparel. Understanding the efficacy of these methods may guide practitioners in their approach and use of post-match recovery interventions to aid player preparation.

Recently, Machado et al. (2016) in a systematic review and meta-analysis, concluded that CWI is marginally better than passive recovery in the management of muscle soreness; reporting water temperature of 11-15°C and immersion duration of 11-15 min to provide the best outcomes. However, research on the effects of CWI on systemic markers of inflammation (e.g., oxidative stress, creatine kinase [CK], and lactate dehydrogenase [LDH]) and neuromuscular performance (jumps and sprints) in soccer players has produced inconsistent findings (Rupp et al., 2012; Rowsell et al., 2009). Thus, further evidence on the efficacy of the post-match use of CWI for soccer players is required.

Alternatively, cFIR is a recently introduced methodology for post-exercise recovery, able to reduce pain (Loturco et al., 2016) and improve physical performance

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(Nunes et al., 2020; Leung et al., 2013). The cFIR materials are produced from a combination of different oxides (Vatansever and Hamblin, 2012), which emit heat and radiation to produce anti-oxidative, anti-inflammatory, and analgesic activities observed in *in vitro* and animal model studies (Leung et al., 2013; Lin et al., 2013). This evidence has led to the assumption that cFIR may induce performance enhancement and recovery benefits in competitive sports. Recently, Nunes et al. (2020) demonstrated that daily use of cFIR during overnight sleep provided *likely* and *possibly* higher performance in jump heights and 5-m sprinting speed, as well as reduced perceived training load and DOMS during a 2-week preseason training period in elite futsal players. Conversely, the daily use of cFIR materials worn as Bioceramic pants for 2 hours over three days did not facilitate recovery after maximal eccentric exercise in moderately active men (Nunes et al., 2019a). In addition, other studies reported a decrement in DOMS after an intense plyometric (jump) session in professional soccer players (Loturco et al., 2016), and improved balance/posture in athletes (Cian et al., 2015), and resistance to fatigue (Leung et al., 2013) with the use of this material. Hence, further evidence is required to support the use of cFIR as a post-match recovery method in soccer.

To date, only Hausswirth et al. (2011) have compared the efficacy of cFIR (lamps) and cryotherapy (whole-body) on recovery of markers of muscle damage (i.e., maximal isometric muscle strength and CK) and perceived sensations (i.e., pain, tiredness, and well-being) in highly-trained endurance runners; showing that cryotherapy sessions performed within 48 h post-exercise accelerated recovery compared to cFIR or passive modalities. These recovery interventions were performed according to commonly performed protocols, that provide different post-match durations, exposures, and logistical demands. For example, the prolonged use of cFIR during sleep to increase exposure time and ambient conditions is more appropriate; yet contrasts with the short-duration and immediacy of CWI (Machado et al., 2016). Given the lack of current data, understanding the specificity of respective recovery interventions could inform the practical applications to be used by coaches and support staff to assist player preparation. Therefore, the aim of this study was to determine the effectiveness of cFIR during overnight sleep or post-exercise CWI to improve functional and biochemical markers of muscle damage after a friendly soccer match.

Methods

Twenty-five university-level soccer players participated in the study. The sample size was determined using G*Power software (V.3.0.10), with 80% power at the 0.05 level of significance, demonstrating that 8 participants were needed in each group. The inclusion criteria were: completion of 75% of match time and all physical testing sessions (goalkeepers excluded), being free from chronic diseases, not taking any medication (e.g., painkillers, anti-inflammatory), nutritional supplements with intracellular buffers (i.e., beta alanine and creatine), or illegal substances, and abstinence from other recovery methods during one week before the start of the study. Each player gave written informed consent after receiving the explanation of the study. All procedures performed in this study were approved by a local Institutional Ethics Committee and followed the ethical guidelines of the Declaration of Helsinki.

Participants were separated by playing position (defender, midfielder, and forward) and randomly allocated to bioceramic (BIO; n = 8), cold-water immersion (CWI; n = 9), or control groups (CON; n = 8), to one of two different friendly matches conducted within two weeks (i.e., with the first [1st week] and second match [2nd week] including 13 [i.e., CWI; n = 5; BIO; n = 4; CON; n = 4; defender = 4; midfielder = 6; forward = 3] and 12 [CWI; n = 4; BIO; n = 4; CON; n = 4; defender = 4; midfielder = 6; forward = 2] players, respectively), and to one of two different teams by random permute block (available at www.randomization.com). Due to the stratification based on playing position, match, and team, each group was homogenous, equally balanced in the variables described above. In addition, some athletes participated solely in the friendly match and did not take part in any other experimental test. These athletes trained together 3 days a week and were at the same competitive level.

Biochemical markers of muscle damage and inflammation, neuromuscular performance, and perceptual markers were assessed before, immediately after, (excluding jump and recovery scale), as well as 24 and 48 h after the one-off friendly soccer match. One week prior to the experiment, players undertook anthropometric measurements, were familiarized with the physical tests and rating scales to be used, and performed the intermittent field Carminatti's test (T-CAR) as a measure of aerobic fitness (Dittrich et al., 2011).

Environmental temperature during the match was 22.5 ± 0.8°C and humidity 55.7 ± 1.5 %. On the match day, the players arrived at the University's facilities between 4:00-5:00 p.m. A blood sample was obtained after the participants had rested for approximately 15 min., after which they consumed a light meal and drink and rested for 2 h. The suggested meal consisted of 1.7 g white bread and 0.3 g of low-fat spread per kilogram of body mass (Thompson et al, 2003). Subsequently, perceptual markers and neuromuscular performances were assessed before the beginning of the match (~7-h p.m.). All players completed 100% of match time. Additionally, at 24 h and 48 h following the match, players returned to the University laboratory at the same time of day to repeat the measure procedures (Figure 1). Furthermore, although the players were instructed on how to adapt their meal calorie intake (approximately 60% carbohydrates, 15% proteins, and 25% lipids), no food diaries were kept, which can be assumed as a limitation of the study. Moreover, the consumption of water during the game was *ad libitum*, while other kinds of drinks (e.g., hypotonic or drinks containing carbohydrates) were not allowed.

Height, body mass, and skinfolds (triceps, subscapular, supra iliac, and abdominal) were measured as anthropometric indicators (single evaluator). Height was measured using a stadiometer with a precision of 1 mm (SANNY®), and body mass using a scale with a precision of 0.1 kg (TOLEDO®) and skinfolds with a scientific

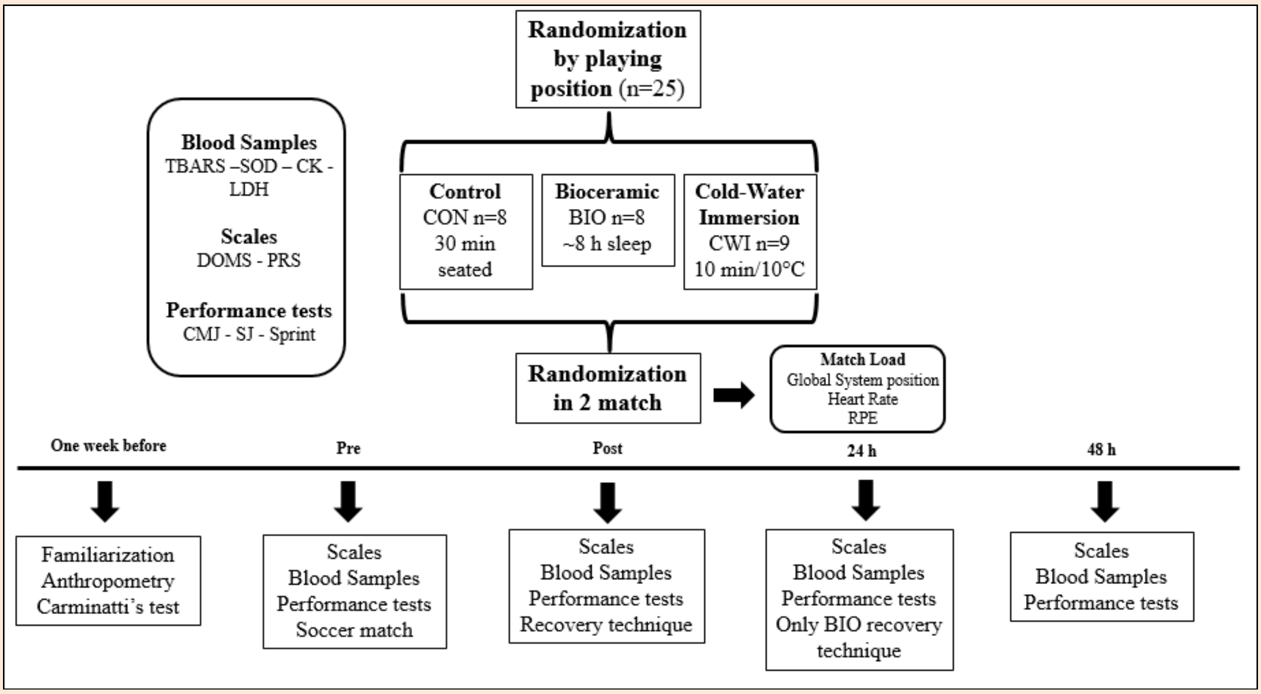

Figure 1. Experimental protocol. TBARS= thiobarbituric acid reactive species; SOD= superoxide dismutase; CK = creatine kinase; LDH= lactate dehydrogenase; CMJ= countermovement jump; SJ= squat jump; DOMS= delayed-onset muscle soreness; PRS= perceived recovery status; RPE= rating of perceived exertion. CON: Control group; BIO: Bioceramic group; CWI: cold-water immersion group.

adipometer accurate to 1 mm (CESCORF®). Body density was estimated by the Faulkner equation (1968) and application of this value to estimate the percentage of fat through the Siri equation (1961).

The Carminatti's test (T-CAR) requires participants to perform repeated bouts of 5 x 12-s shuttle runs at progressively faster speeds, dictated by prerecorded audio cues until volitional exhaustion (Dittrich et al., 2011). The 12-s bouts were separated by 6-s recovery periods, making each stage 90-s in duration. The initial running distance was set at 15-m and was increased by 1-m at each stage (90-s). Peak running velocity in the T-CAR ($PV_{T\text{-}CAR}$) was calculated from the distance in the last set completed by the athlete, divided by the time to complete the stage repetition (Dittrich et al., 2011). Heart rate (HR) was monitored at 5-s intervals throughout all the tests using a commercially available telemetry system (Polar S610; Polar Electro Oy, Kempele, Finland).

Blood samples (5-ml) were drawn from an antecubital arm vein using a standard venipuncture technique with an ethylene diamine tetra acetic acid (EDTA) tube. Samples were centrifuged for 10-min at 1,500-rpm to obtain the plasma. To determine oxidative damage to lipids, we measured the formation of Thiobarbituric acid reactive species (TBARS) during an acid-heating reaction (Draper and Hadley, 1990). The intra- and inter-assay coefficients of variation (CVs) were 3.9% and 5.9%. Superoxide dismutase (SOD) activity was determined in erythrocytes according to the method described by Bannister and Calabrese (1987). Specific activity was expressed as units per milligram (U·mg–1) of protein. One unit is estimated by 50% inhibition of adrenaline autoxidation, read at 480 nm using a spectrophotometer (Hitachi U-1900; Tokyo, Japan). The intra- and inter-assay CVs were 7.7% and 8.2%, respectively. CK activity was determined with a spectrophotometer using a commercially available kit (Cobas Mira Plus, Roche, Basel, Switzerland). LDH activity was determined with a spectrophotometer by means of a commercial diagnostic test kit (Sigma Diagnostics, St. Louis, MO). The CK and LDH intra- and inter-assay CVs were 3.8% and 2.8%, and 3.2% and 1.6% respectively.

Each participant was asked to complete a delayed-onset muscle soreness (DOMS) questionnaire for the lower limbs, in which they were required to rank their perception of soreness on a scale from 0 (''absence of soreness'') to 10 (''very intense soreness'') (Vaile et al., 2007), and a perceived recovery status scale (PRS), which consists of values between 0 ("very poorly recovered") and 10 ("very well recovered") (Laurent et al., 2011).

The countermovement jump (CMJ) and squat jump (SJ) were performed to assess jumping height using a QUATTRO JUMP device (model 9290AD, Winterthur, Swiss). In the SJ, subjects were required to remain in a static position with a 90° knee flexion angle for 2-s prior to jumping, without any preparatory movement. In the CMJ, the players were instructed to execute a downward movement followed by complete extension of the legs and were free to determine the highest countermovement amplitude and avoid changes in jumping coordination. Three attempts were allowed for each jump. Successive attempts in the same jump mode were interspersed by ~15-s intervals, and hands remained in the supra-iliac region in both types of jumps.

Subsequently, athletes performed three maximal sprints of 20-m, with a 90-s passive rest interval between each sprint. All sprinting tests were conducted in an outdoor court, time was recorded using a photocell system (CEFISE®, Speed Test 4.0, São Paulo, Brazil), and the best two results were averaged and used for analysis.

During the official soccer match, the players wore an integrated Global Positioning Satellite System (GPS) and HR monitoring device (SPI Elite, GPSports Systems, Canberra, Australia). Speed was reported directly from the GPS sensor; proprietary software rules are applied to filter the data to improve the accuracy of the GPS Software (Team AMS v2015.3). The distance was calculated from GPS derived speed data. The relative distance covered (m/min^{-1}) and high-speed running (speed >19.8 $km \cdot h^{-1}$) were reported during the match. Furthermore, after the end of the match (~15-30 min), the players were required to report the intensity using the session rating of perceived exertion (s-RPE method) by means of a modified 10-point RPE scale, multiplied by the total match duration (Foster et al., 2001).

After the post-match measures, players in the CWI group submerged their lower limbs up to the iliac crest in a stirred ~10°C cold-water bath for 10 min (Bailey et al., 2007; Nunes et al., 2019b), following which they underwent testing at 30 min post (Bailey et al., 2007; Nunes et al., 2019b). The CON group remained seated for 30 min post-match in a controlled environment (22-23°C, 50 - 60% humidity) with no other external recovery method before undertaking testing (Nunes et al., 2019b). The BIO group continuously wore the pants during two overnight sleep periods (~8 h each) (Nunes et al., 2020). The bioceramic formulation used in this study was composed of microscopic particles produced from various cFIR ingredients (Patented Formulation by M.E.T. LLC, USA). A radiant power emission analysis in the infrared region in the range between 9 and 11 microns was conducted with a Scientech calorimeter (Boulder, CO, USA), Astral model (S AC2500S series), which reported the following values: 1) Fabric with bioceramic emissivity 0.91; 2) Fabric without bioceramic emissivity 0.83. The pants were made of polyester (81%) and spandex (19%) and came in three different sizes (M, L, and XL) and the size of the bioceramic pants worn by any given participant was always the same. Of note, the use of cFIR in interventions during two overnights was deemed appropriate from an ecological perspective for athletes, although it has been previously demonstrated that acute exposure to FIR improved indirect markers of EIMD (Nunes et al., 2020). Whilst it is appreciated that the respective interventions present different post-match durations and temporal exposure, these are deemed the most appropriate practices based on relevant literature and ecological context. They also represent contrasting methods to approach recovery (i.e., immediate with high logistical need vs prolonged with minimal demands).

The Shapiro-Wilk and Levene's tests were used to verify normality and homogeneity of the data, respectively. One-way ANOVA was used to compare anthropometric data, T-CAR performance, and match load between groups. A two-way mixed-model ANOVA (group×time) followed by the Bonferroni post-hoc test was used to compare blood-based measures, performance tests, and perceptual markers between groups. Significance was assumed at $P < 0.05$ a priori. Delta changes (Δ) from pre measures were used for analysis to reduce bias arising from uniformity errors (i.e., Delta change = Post-values (immediately post, 24 h and 48 h) - Pre). The statistical analyses were performed using SPSS20.0 for Windows (SPSS Inc., Chicago, USA). Values are reported as mean ± standard deviation (SD).

Results

The anthropometric, T-CAR performance, and match load data are shown in Table 1 and Table 2. No significant differences were evident between groups for any anthropometric or performance measures ($p > 0.05$), or measures of match load ($p > 0.05$).

Table 1. Anthropometric and physiological performance variables determined from the Carminatti's test.

Variables	CON (n = 8)	BIO (n = 8)	CWI (n = 9)
Age (years)	20.8 ± 3.2	22.63 ± 4.2	22.63 ± 3.2
Height (m)	1.77 ± 0.04	1.78 ± 0.08	1.79 ± 0.08
Bodymass (kg)	72.99 ± 11.27	71.96 ± 10.57	75.93 ± 9.20
% Body fat	12.9 ± 4.8	12.89 ± 2.7	13.05 ± 1.9
$PV_{T\text{-}CAR}$ ($km \cdot h^{-1}$)	15.19 ± 0.77	15.53 ± 0.99	15.33 ± 0.87
HR_{max} (bpm)	192 ± 8	195 ± 7	190 ± 9

CON: Control group; BIO: Bioceramic group; CWI: cold-water immersion group; cm: centimeters; kg: kilogram; %: percentage; $PV_{T\text{-}CAR}$: Peak velocity; HR_{max}: maximal heart rate.

Table 2. Internal and external load during the match play.

Variables	CON (n = 8)	BIO (n = 8)	CWI (n = 9)
HR_{mean} (bpm)	162 ± 9	173 ± 7	158 ± 17
s-RPE (a.u)	585 ± 117	765 ± 124	562 ± 223
Relative distance covered ($m \cdot min^{-1}$)	91.05 ±15.6	105.06 ± 11.4	91.01 ± 18.4
Nº sprints	15 ± 5	20 ± 10	19 ± 13
Sprints (m)	232.8 ± 92.6	293.0 ± 184.4	293.4 ± 216.9

CON: Control group; BIO: Bioceramic group; CWI: cold-water immersion group; HR_{mean}: mean heart rate; s-RPE: session rating of perceived exertion (arbitrary units); Nº *Sprints*: number of sprints performed in the match (≥20 km/h); *Sprints* = Distance covered performed ≥20 km/h (meters). Values are presented as means ± standard deviation.

A decrease was reported in ΔTBARS at post, 24 h, and 48 h compared to pre ($F = 12.362$; $p = 0.002$; $p = 0.001$; $p = 0.001$), 24 h compared to post ($F = 12.362$; $p = 0.001$), and 48 h compared to 24 h ($F = 12.362$; $p = 0.003$) (Figure 2). Percentage changes for TBARS at post, 24 h, and 48 h were -13%, -67%, and -94% for CON; -48%, -82%, and -89% for BIO; and -23%, -59%, and -86% for CWI. ΔSOD increased significantly at post, 24 h, and 48 h compared to pre ($F = 5.583$ $p = 0.001$; $p = 0.001$; $p = 0.001$), 24 h compared to post ($F = 5.583$ $p = 0.004$), and 48 h compared to 24 h ($F = 5.583$; $p = 0.007$) (Figure 2). Percentage changes for SOD at post, 24h, and 48h were +14%, +26%, and +32% for CON; +9%, +33%, and +26% for BIO; and +13%, +29%, and +29% for CWI.

Significantly increased values were observed in ΔCK ($F = 21.216$, $p = 0.021$; $p = 0.000$; $p = 0.001$) and ΔLDH ($F = 11.649$, $p = 0.001$; $p = 0.000$; $p = 0.002$) at post, 24 h, and 48 h compared to pre, respectively, in all groups. However, no significant differences were observed between groups ($p > 0.05$; Figure 3A and Figure 3B). Percentage changes for CK at post, 24 h, and 48 h were +39%, +71%, and +54% for CON; +28%, +80%, and +72% for BIO; and +57%, +79%, and +62% for CWI. For LDH the percentage changes were +35%, +25%, and +14% for CON; +35%, +42%, and +32% for BIO; and +38%, +42%, and +3% for CWI at post, 24 h, and 48 h respectively.

Significant performance decline was found in sprint Δ20-m (F = 6.613; p = 0.001; p = 0.002; p = 0.002), ΔSJ (F = 13.327; p = 0.002; p = 0.001), and ΔCMJ (F = 4.876; p = 0.003; p = 0.001) at post (sprint), 24 h, and 48 h compared to pre, respectively, in all groups, without differences between groups (Figure 4A, Figure 4B and Figure 4C). Percentage changes for 20-m at post, 24 h, and 48h were -2.4%, -2.9%, and -1.4% for CON; -7.6%, -3.1%, and -2.5% for BIO; and -2.2%, -1.8%, and -1.8% for CWI. For SJ the percentage changes were -6.1% and -4.3% for CON; -7.1% and -3.4% for BIO; and -3.9% and -3.4% for CWI at 24 h and 48 h respectively. CMJ percentage changes were -7.4% and -4.6% for CON; -4.3% and -0.7% for BIO; and -0.8% and -1.8% for CWI at 24 h and 48 h respectively.

DOMS increased significantly both in quadriceps (F = 3.793; p = 0.023; p = 0.022; p = 0.017) and hamstring (F = 21.387, p = 0.022; p = 0.021; p = 0.014), whereas the PRS scale (F = 74.191; p = 0.002; p = 0.001) decreased throughout recovery in all groups, as compared to pre values. However, no group interactions were observed between groups (Figure 5A, Figure 5B and Figure 5C).

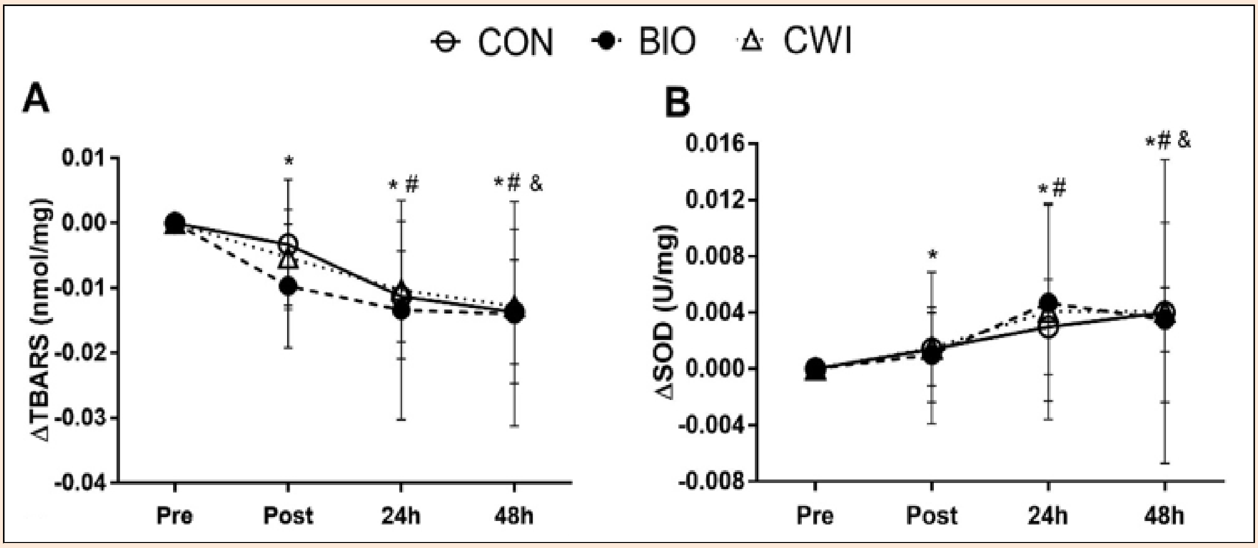

Figure 2. Delta change from pre for each interventions throughout the 48 h recovery period for (A) TBARS and (B) SOD. * p < 0.05 in relation to pre for all groups; # p < 0.05 in relation to post for all groups; & p < 0.05 in relation to 24-h for all groups. CON: Control group; BIO: Bioceramic group; CWI: cold-water immersion group.

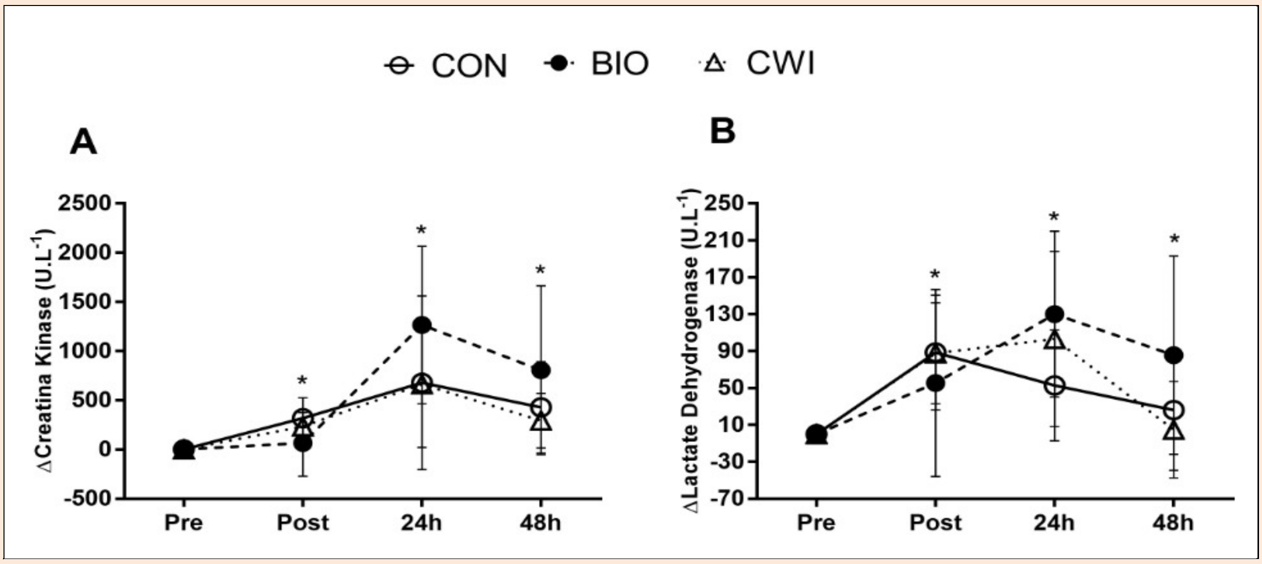

Figure 3. Delta change between interventions throughout the 48 h recovery period for (A) creatine kinase and (B) lactate dehydrogenase. * p < 0.05 in relation to pre for all groups. CON: Control group; BIO: Bioceramic group; CWI: cold-water immersion group.

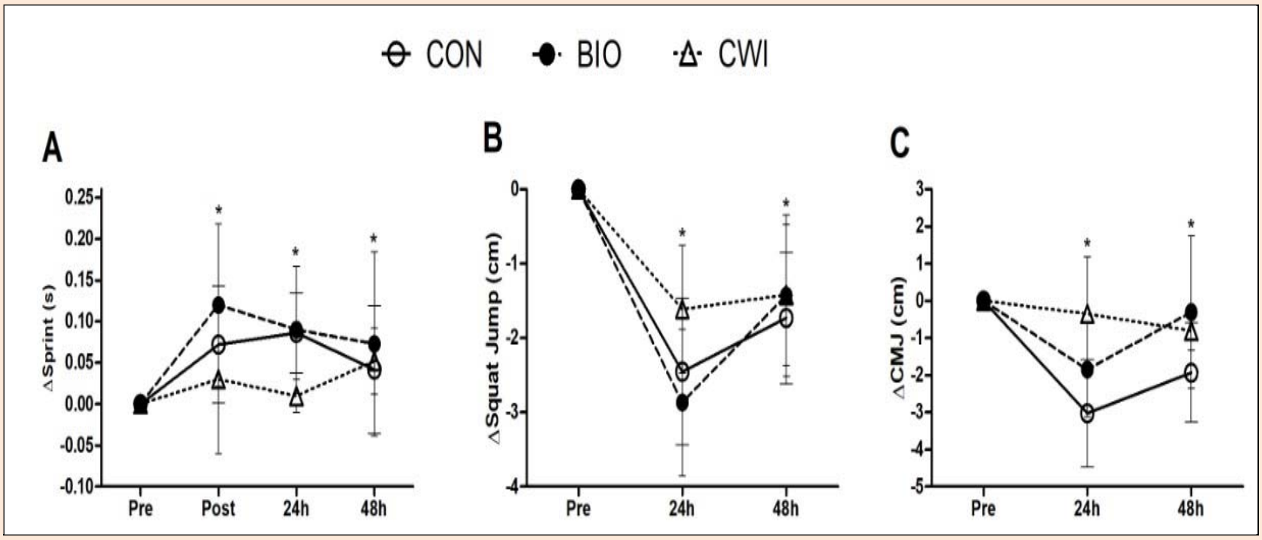

Figure 4. Delta change between interventions throughout the 48 h recovery period for (A) sprint, (B) squat jump, and (C) countermovement jump. * $p < 0.05$ in relation to pre for all groups. CON: Control group; BIO: Bioceramic group; CWI: cold-water immersion group.

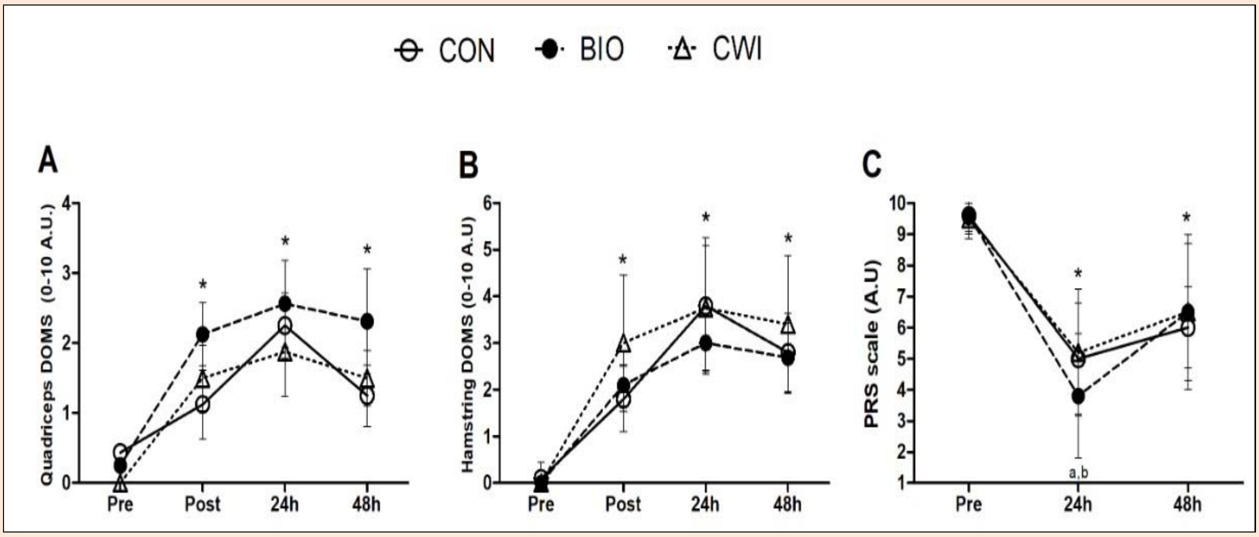

Figure 5. Change in mean between interventions throughout the 48 h recovery period for (A) quadriceps DOMS, (B) hamstring DOMS, and (C) PRS scale. * $p < 0.05$ when comparing pre to all other groups; # $p < 0.05$ in relation to 24 h for all groups. CON: Control group; BIO: Bioceramic group; CWI: cold-water immersion group.

Discussion

The present study compared the effects of cFIR emitting clothing and CWI on post-match recovery of neuromuscular performance, and biochemical and perceptual markers in Brazilian university-level soccer players. As expected, blood-based markers (i.e., CK and LDH), neuromuscular performance, and perceptual indices were negatively affected for at least 48 h post-match; although, no significant differences existed between treatments and control. On the other hand, TBARS decreased and SOD increased during the 48 h recovery period in all groups. Thus, despite the contrasting approaches to recovery and the popularity of these interventions, limited effects of BIO or CWI interventions were evident to suggest improved post-match recovery outcomes.

The effects of CWI on physiological recovery in soccer continue to be debated, and the current study adds to this by showing no effect on any of the biochemical markers of muscle damage or inflammation examined. Previously, Ascensão et al. (2011) showed that 10-min of CWI at 10°C was capable of reducing CK (30-min, 24 h, and 48 h), myoglobin (30-min), and C-reactive protein (30-min, 24 h, and 48 h) when applied immediately after a one-off soccer match compared to thermoneutral water immersion. Conversely, Rowsell et al. (2009) reported no changes over time for any post-match inflammatory markers during a 4-day simulated soccer tournament with either cold or thermoneutral water immersion. This discrepancy between the findings of the aforementioned research likely relates to the combination of the methods used and physical demands encountered during the matches. For example, although Ascensão et al. (2011) reported improvements in biochemical markers after using CWI compared to thermoneutral water, no internal or external load data were reported during the respective matches, as was reported in the current study. In the study of Rowsell et al. (2009) although the same water temperature was used during the CWI, the exposure was half the duration (5-min) and undertaken in an intermittent fashion (60-s immersion, 60-s thermoneutral condition). In other sports or exercise models, previous findings are equivocal regarding the effects of CWI on inflammatory or oxidative stress markers. Recently, De Freitas et al. (2019) demonstrated no effects on oxidative stress or inflammatory markers after daily CWI in volleyball players, as well as on TNF-α (Townsend et al., 2103; Tseng et al., 2013) and IL-6 (Tseng et al., 2013; Roberts et al., 2014) at post-exercise recovery. These data suggest that CWI therapy, a commonly used sports recovery intervention, seems to have limited effects on recovery kinetics of oxidative stress or inflammatory markers.

The use of cFIR in athletic populations has recently been reported to assist recovery of physiological markers of post-exercise fatigue and damage (Nunes et al., 2020; Loturco et al., 2016). In this regard, Loturco et al. (2016) reported no effect of cFIR clothing on male soccer players during a 10-h sleeping period over three successive nights after 100 drop-jumps on CK activity compared with the placebo group. This finding is in agreement with previous studies that demonstrated that an FIR sauna and cFIR clothing pants applied on three consecutive days did not decrease CK levels in highly-trained endurance runners (Hausswirth et al. 2011) and in moderately active men after eccentric muscle damage (Nunes et al., 2019a), respectively. Of note, our results showed decreased TBARS activity during the 48 h recovery period in all groups, which in part can be explained by the increase in the antioxidant activity of SOD (Kozioł et al., 2020), chronic adaptations of this system to this type of exercise in athletes (ESCOBAR et al, 2009), and diet (Figure 2A). Similarly, Nunes et al. (2020) demonstrated impairment in oxidative stress markers (i.e., TBARS, protein carbonyl, SOD, and CAT) throughout a 2-week preseason training period in futsal players, whilst no effects of cFIR clothing worn daily were observed compared to a placebo group. However, cFIR induced greater increases in pro- and anti-inflammatory markers (i.e., TNF-α and IL-10) in both weeks. Whilst speculative, within the scope of the current literature, the explanations of our findings may be due to the insufficient emissivity of the clothing to reflect/emit FIR rays into human tissues, or its insufficiency to promote biological effects and improve recovery in the current individuals. However, these mechanisms were not investigated in the present study. Furthermore, a longer time lapse between the end of the exercise protocol and the time the participants started wearing the cFIR pants could prevent acute effects of cFIR on neutrophil migration (Loturco et al., 2016), considering that in this study, the athletes started wearing the BIO pants approximately 2-3 h after the game.

As expected, sprint and jump performance outcomes were reduced at 48 h post-match (Figure 4), and no interventions showed any improvement in recovery compared to control. Previously, Ascensão et al. (2011) reported that CWI following a soccer match transiently increased quadriceps maximal voluntary contractions (MVC) at 24 h compared to thermoneutral water, but without differences for sprint and jump height. Thus, strength tests appear to be more sensitive to a more contractile-dependent muscular performance than sprints and jumps (Bailey et al., 2007). In the current study, no effect of CWI was evident to improve post-match recovery of peak power from CMJ. Similarly, Rupp et al. (2012) reported that CWI performed immediately and 24 h after volitional fatigue did not affect subsequent anaerobic power in collegiate soccer players. In line with these findings, other studies did not observe any treatment effect of CWI against decrements in neuromuscular performance caused by one-off or successive soccer matches (Rowsell et al., 2009; Kinugasa and Kilding, 2009). Recently, Nunes et al. (2019b) suggested that it is important to use more neuromuscular fatigue markers (e.g., rate of force development and peak power output from jumps) compared with those usually reported in other studies (e.g., MVC, sprint abilities and jump height) to measure the effects of CWI post-match.

Given that cFIR has not been extensively explored, previous studies have suggested its feasibility as a post-exercise recovery method (Leung et al., 2013). However, Loturco et al. (2016) did not demonstrate any positive effects of cFIR clothing in male soccer players who performed damaging drop jumps and used FIR for ten hours sleeping over three successive nights on vertical jumps or maximal dynamic strength performance. Similarly, Nunes et al. (2019a) performed an eccentric protocol to induce muscle damage in physically active men (i.e., three sets of 30 maximal isokinetic contractions of the quadriceps at $60°\cdot s^{-1}$), and applied bioceramic or placebo pants immediately 2 h, 24 h, 48 h, and 72 h post-exercise. The results showed that the use of two hours of cFIR treatment in the lower limbs, did not facilitate recovery of MVC over three days. Conversely, Hausswirth et al. (2011) performed a running protocol to induce muscle damage in runners, and applied FIR (via lamps) immediately, 24 h, and 48 h post-exercise, showing that trained runners exposed to 30-min of FIR in the whole body were able to recover knee extensor MVC by 48 h post, although these findings may be partially biased due to the absence of blinding. Nunes et al. (2020) demonstrated quantitative positive changes in SJ (*likely* higher in Week-2), CMJ (*possibly* higher on Week-1), and 10-m sprint time (*likely* faster in Week-1) in the BIO compared to the PL group; however, the effect size was considered small in these cases. Other research has suggested that cFIR contributes to increased grip strength and hand dexterity (Ko and Berbrayer, 2002), besides improving standing posture and handstand stability in expert gymnasts (Cian et al., 2015). However, it appears not to be effective in recovering muscular contractile performance after a soccer match.

No differences were reported in DOMS and perceptual recovery between treatments. Different studies have been found regarding the acute effects of cold therapies on perceptual markers (Ascensão et al, 2011; Rowsell et al., 2009; Kinugasa and Kilding, 2009; Pointon and Duffield, 2012). For example, Ascensão et al. (2011) showed lower DOMS in hip adductors at 30-min, and in calf and quadriceps at 24 h in the CWI condition than in thermoneutral immersion. Corroborating these findings, Rowsell et al. (2009) demonstrated that cold-water was more effective than thermoneutral immersion for reducing the perception of leg soreness during a 4-day soccer tournament. In fact, close examination of the literature suggests that solely perceived recovery is positively influenced by CWI (Kinugasa and Kilding, 2009; Broatch et al., 2014). This is in line with the suggestion that the majority of the effects of CWI are mediated by the placebo effect (Broatch et al., 2014).

Previous studies in clinical trials have also demonstrated that FIR reduced pain (Ko and Berbrayer, 2002; Bagnato et al., 2012). However, few studies have investigated the cFIR effect on perceptual markers, such as DOMS and PRS in athletes. Loturco et al. (2016) were the first to report that FIR emitting clothes over three successive nights may have contributed to reduced DOMS within 72 h (moderate and large effect sizes, respectively) after a plyometric (jump) exercise bout. The authors suggested that FIR clothes may be used to accelerate muscle pain recovery after eccentrically-biased exercises in soccer players. This is in agreement with previous studies that demonstrated that cFIR treatment *likely* lowered DOMS in seven training sessions (35% of the preseason) and perceived internal training load during the first week in futsal players (Nunes et al., 2020). Hausswirth et al. (2011) observed that the perception of muscle pain was significantly reduced after 48 h in relation to the non-treatment condition. However, in the present study, DOMS and PRS recovery did not differ between group conditions, corroborating with Nunes et al. (2019a), who did not observe any positive effects on the same perceptual scales using cFIR treatments.

Future studies should test the advantages of BIO during recovery from matches and training sessions. It is necessary to understand the biological mechanisms on human tissues, and additionally to evaluate the required time for their use. A further need exists to understand the effects associated with different protocols, populations, and recovery strategies. In this line, concerning CWI therapy, multicentric studies are necessary (i.e., large number of participants) to clarify this issue as a potential recovery strategy, due to the wide numbers of conflicting studies in the literature.

Finally, our study has limitations regarding the absence of dietary monitoring, which may have been a factor that contributed to the decrease in TBARS activity due to the effects of the non-enzymatic antioxidant system (VASCONCELOS et al., 2007), and for not having been a crossover study.

Conclusion

In conclusion, for the 48 h recovery of muscle damage, BIO and CWI do not provide conclusive evidence that they can be used as techniques to enhance functional and perceptual recovery after a soccer match. Especially, BIO requires further research in order to be accepted as an effective recovery modality.

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Key points

- The effectiveness of CWI to improve post-exercise recovery remains unclear in soccer players.
- cFIR treatment suggests that the use of this material during short periods does not facilitate recovery, but further investigations into its chronic effects are warranted.

AUTHOR BIOGRAPHY

Tiago M. COELHO
Employment
Professor at Avantis University Center, Santa Catarina, Brazil
Degree
Msc
Research interests
Performance and assessment in soccer and futsal, exercise physiology and recovery strategies
E-mail: tiago_coelho_5@yahoo.com.br

Renan F. H. NUNES
Employment
Sport Scientist Associação Ferroviária de Esportes soccer team
Degree
PhD
Research interests
Recovery strategies, training load and methods for improving performance on sports.
E-mail: nunesrenan85@hotmail.com

Fabio Y. NAKAMURA
Employment
Federal University of Paraíba
Degree
PhD
Research interests
Sports performance, heart rate variability, physiological monitoring
E-mail:
fahoy_nakamura@yahoo.com.br

Rob DUFFIELD
Employment
Associate Professor, University of Technology Sydney.
Degree
PhD
Research interests
Performance and recovery in sport
E-mail: Rob.Duffield@uts.edu.au

Marília C. SERPA
Employment
Center of Sport - Federal University of Santa Catarina
Degree
MSc
Research interests
Caffeine supplementation focused on sports performance (neuromuscular, perceptual, and biomechanical factors). Also working on research related to exercise physiology. In this sense, it still develops a work with focused on sport and rehabilitation
E-mail: mariliacserpa@hotmail.com

Juliano F. da SILVA
Employment
Research Group for Development of Football and Futsal, Sports Center, Federal University of Santa Catarina
Degree
PhD
Research interests
Performance and assessment in soccer and futsal
E-mail: juliano.fernandes@ufsc.br

Lorival J. CARMINATT
Employment
Assistant professor, Center for Health and Sport Sciences, State Uniersity of Santa Catarina, Brazil.
Degree
PhD
Research interests
Sport Science, soccer, exercise physioligy
E-mail: carminattilj@gmail.com

Francisco J. CIDRAL FILHO
Employment
Director of Research and Development at Multiple Energy Technologies (Washington, PA - USA)
Degree
PhD
Research interests
Integrative Medicine, Low Level Light Therapy (LLLT), acupuncture, and neurobiology of pain and inflammation.
E-mail: cidral@gmail.com

Mariana P. GOLDIM
Employment
Assistant professor at University Center Barriga Verde-UNIBAVE, Brazil.
Degree
PhD.
Research interests
Inflammation and oxidative stress.
E-mail: marigoldim@gmail.com

Khiany MATHIAS
Employment
University of Southern Santa Catarina
Degree
Graduated
Research interests
Exercise physiology, sepsis, neuroinflammation, neuroscience
E-mail: khianymathias@hotmail.com

Fabricia PETRONILHO
Employment
Professor at University of South Santa Catarina, Brazil
Degree
PhD.
Research interests
Sepsis, neuroinflammation and oxidative stress.
E-mail:
fabriciapetronilho@yahoo.com.br

Daniel F. MARTINS
Employment
Permanent professor, Postgraduate Program in Health Sciences, University of Southern Santa Catarina, Brazil
Degree
PhD.
Research interests
Exercise physiology, exercise analgesia, Chronic pain
E-mail: danielmartinsfisio@hotmail.com

Luiz G. A. GUGLIELMO
Employment
Assistant professor, Centre of Sport, Federal University of Santa Catarina, Brazil
Degree
PhD
Research interests
Exercise physiology, sport science, and sport performance
E-mail: luiz.guilherme@ufsc.br

✉ **Tiago Martins Coelho**
Physical Effort Laboratory, Department of Physical Education, Federal University of Santa Catarina, Florianópolis, SC, Brazil