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Human Kinetics
ORIGINAL INVESTIGATION

Cryotherapy Reinvented: Application of Phase Change Material for Recovery in Elite Soccer

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Purpose: To examine whether donning lower-body garments fitted with cooled phase change material (PCM) would enhance recovery after a soccer match. ***Methods:*** In a randomized, crossover design, 11 elite soccer players from the reserve squad of a team in the second-highest league in England wore PCM cooled to 15°C (PCM_{cold}) or left at ambient temperature (PCM_{amb}; sham control) for 3 h after a soccer match. To assess recovery, countermovement jump height, maximal isometric voluntary contraction (MIVC), muscle soreness, and the adapted Brief Assessment of Mood Questionnaire (BAM+) were measured before 12, 36, and 60 h after each match. A belief questionnaire was completed preintervention and postintervention to determine the perceived effectiveness of each garment. ***Results:*** Results are comparisons between the 2 conditions at each time point postmatch. MIVC at 36 h postmatch was greater with PCM_{cold} versus PCM_{warm} ($P = .01$; ES = 1.59; 95% CI, 3.9–17.1%). MIVC also tended to be higher at 60 h postmatch ($P = .05$; ES = 0.85; 95% CI, –0.4% to 11.1%). Muscle soreness was 26.5% lower in PCM_{cold} versus PCM_{warm} at 36 h ($P = .02$; ES = 1.7; 95% CI, −50.4 to −16.1 mm) and 24.3% lower at 60 h ($P = .04$; ES = 1.1; 95% CI, −26.9 to −0.874 mm). There were no between-conditions differences in postmatch countermovement jump height or BAM+ ($P > .05$). The belief questionnaire revealed that players felt the PCM_{cold} was more effective than the PCM_{amb} after the intervention ($P = .004$). ***Conclusions:*** PCM cooling garments provide a practical means of delivering prolonged postexercise cooling and thereby accelerate recovery in elite soccer players.

Keywords: muscle damage, exercise, strength, muscle soreness

It is well established that a soccer match can induce muscle damage that persists for several days.[1–3] Typically, this muscle damage manifests as increased feelings of muscle soreness (MS) and a reduced force-generating capacity, both of which can increase the risk of injury[4] and negatively affect the ability to perform the explosive movements integral to soccer performance, such as sprinting, jumping, accelerating, and changing direction.[2,5,6]

The etiology of muscle damage after a soccer match is multifactorial and complex, but, broadly speaking, it is likely to be initiated by direct mechanical stress to the contractile and noncontractile muscle apparatus, and then followed by a cascade of immunological-mediated processes that orchestrate repair and recovery.[5–7] Indeed, there is now a growing body of evidence that this inflammatory response is crucial to muscle regeneration after muscle-damaging exercise.[8] With that said, because of the secondary damage that inflammation can provoke in the initial aftermath of the damaging insult, it is also postulated that an intervention that might temporarily reduce inflammation might help to expedite the recovery process.[9] This could be particularly beneficial when adaptation to an exercise stimulus is of secondary importance during periods of competition or fixture congestion.[10]

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One of the most popular recovery interventions used in soccer is cold water immersion (CWI).[1] Following a soccer match or training, players often use CWI applied to the lower body in the belief that it will facilitate recovery.[11] Such effects are purported to reduce tissue temperature and increase hydrostatic pressure, leading to a reduction in inflammation and oxidative stress.[11–14] Nonetheless, it remains equivocal as to whether cooling the muscles actually does reduce inflammation.[15] Additionally, the effectiveness of CWI as a recovery aid has been questioned, with a large meta-analysis suggesting small to moderate benefits.[13] There are, however, some studies reporting that CWI can assist recovery in the days following intermittent exercise or competitive soccer matches that was summarized in a narrative review.[1]

In addition to the limited benefits of CWI in exercise recovery,[13] its use also comes with logistical challenges, such as facilities to cater for its use immediately following a soccer match. Also, some players might be put off by the thermal discomfort associated with CWI.[10] With these limitations in mind, alternative approaches for muscle cooling are necessary. One such approach is the use of temperature-controlled phase change material (PCM). To date, PCM has principally been used in clothing to reduce thermal stress in occupational settings.[16] An attractive feature of PCM is that while absorbing heat from the body; for example, when the PCM is set at 15°C, it maintains this constant temperature until the material has changed from a solid to a liquid, which takes approximately 3 hours.[17] It has been shown that during a 3-hour application, the PCM can maintain skin temperature at 22°C, but temperature changes beyond 3 hours are unclear.[17] In the same study, the potential benefits of local PCM application for exercise recovery were explored, and indicate that wearing PCM (15°C) can aid recovery following muscle-damaging exercise in untrained individuals.[17]

The clear advantage of PCM over CWI and other cytotherapeutic methods, at least from a practical perspective, is that they are extremely portable, easy to apply to entire squads, and can be worn for an extended period of time with minimal thermal discomfort or obstruction, thereby allowing athletes to freely move around during application. Such advantages could be particularly useful in elite team sports like soccer, where access to CWI might not be available when traveling for away matches or at tournaments. In this study, we hypothesized that PCM would attenuate MS and restore muscle function in the 3 days following a soccer match. Accordingly, the aim was to examine if PCM garments (with a 15°C freeze-thaw temperature), worn for 3 hours after a soccer match, could accelerate functional and perceived recovery in elite soccer players after a competitive league match.

Methods

Participants

This study received ethical approval from the Faculty of Health and Life Sciences, Northumbria University. Eleven elite males, outfield soccer players (age, 19 [1] y; height, 1.80 [0.57] m; mass, 75.9 [7.2] kg; body fat, 7.9% [1.3%]) were recruited from the under-23 squad of a professional soccer team playing in the Sky Bet Championship in England. Players were given a detailed outline of the study procedures before providing written informed consent and completing a health history questionnaire. The use of any other cytotherapeutic interventions (ie, CWI) or form of compression were prohibited throughout testing.

Experimental Design

This study employed a cross-over design. After 2 league matches between the period of January and March 2017, players wore, in a randomized fashion, PCM (Glacier Tek; USDA BioPreferred PureTemp, Plymouth, MN) that were either cooled in a freezer to 15°C (intervention; PCM_{cold}) or left at ambient (~22°C) temperature (PCM_{amb}), which served as our sham control. The PCM material is derived from vegetable oils, and each block is 32 cm in length and 13 cm in width. Two PCM blocks were worn on the quadriceps muscles inside compression shorts (worn up to the knee) for 3 hours in total from approximately 45 minutes post-match. The 3-hour application time was chosen, as we knew from our previous work[17] that a reduced skin temperature of ~22°C could be maintained for this period, whereas we could not guarantee that without changing them—which would have been logistically more challenging—that they would have able to maintain our desired skin temperature. In terms of the pressure exerted by the intervention, in a pilot study with 14 subjects wearing the shorts fitted with the PCM packs (unpublished data), the average compression pressure as measured by the Kikuhime pressure monitor (Kikuhime; TT, 160 Medi Trade, Søleddet, Denmark) was 5.0 mm Hg, which is negligible compared with the pressure needed to influence recovery through compression garments.[18] One block was worn on the medial part of the thigh and the other on the lateral part of the thigh. They were worn while traveling back from the matches on the team bus that had an air temperature between 18°C and 22°C. During their application, the players' activity was not restricted; however, they largely remained sitting upright on the bus, only moving to use the bathroom. For blinding purposes, prior to the intervention, players were informed that both the PCM_{cold} and PCM_{amb} were equally effective for recovery and that we were only interested in what they preferred in terms of comfort. The order of randomization for the garments was performed using an online generator (www.randomizer.org) by an individual not involved in data collection. A range of dependent variables were collected before the matches (PRE: ~84 h after their last match and ~84 h prior to their next match), and 12, 36, and 60 hours after the match, to monitor recovery. These variables were all recorded prior to training (between 9 and 10.30 AM) and in the following order: an adapted Brief Assessment of Mood (BAM+), MS, countermovement jump (CMJ) height, and maximal isometric voluntary contraction (MIVC). Participants were familiarized with the above procedures prior to the main data collection. Players wore Global Positioning System units (Catapult, Leeds, United Kingdom) to track their external load during each match.

Maximal Isometric Voluntary Contraction

As in previous studies,[19,20] MIVC of the right knee extensors was measured with a portable strain gauge (MIE Medical Research Ltd, Leeds, United Kingdom) at an approximately 70° angle of knee flexion. Players were seated upright on a physio bench and had a plinth (attached to the strain gauge) placed just above the malleoli of the right ankle. Players were asked to push against the plinth maximally and hold the contraction for 3 seconds Three maximal efforts were performed and each was separated by 60 seconds of passive, seated recovery, with the mean value (N) used for analysis. The interday coefficient of variation for this protocol was calculated as <8%.

Countermovement Jump

CMJ height was measured in cm with an Optojump system (Bolzano, Italy). Participants started the movement upright with hands fixed to their hips and after a verbal cue, descended into a squat prior to performing a maximal effort vertical jump. Participants performed 3 maximal efforts, separated by approximately 60 seconds of standing recovery; the mean of the 3 jumps was used for analysis. The coefficient of variation for this protocol was <5%.

Muscle Soreness

MS was rated by marking a vertical line on a 200-mm visual analog scale (VAS). At one end read "no soreness" and the other "unbearably painful;" the marked line was measured with a ruler and recorded.

Questionnaires

As in a previous study,[21] before and after the intervention, participants rated how effective they felt the interventions were going to be for recovery (PRE) and how effective they felt they were for recovery (60 h). They completed a Likert scale from 1 "not effective at all" to 5 "extremely effective" for each condition. The aim of this was to gauge the player's perception of how effective they felt the interventions were before and after using them. On each day (PRE—60 h), players also completed a recently developed questionnaire for qualitatively assessing the athlete's mood, recovery status, and overall performance readiness.[20] The questionnaire, known as the BAM+, contains 6 items from The Brief Assessment of Mood (BAM) and 4 questions relating to confidence, motivation, MS, and sleep quality.[20] For each of the 10 questions, players drew a vertical line on a 100-mm visual analog scale, which has "not at all" and "extremely" at opposing ends. The lines were measured with a ruler and recorded, and an overall score was calculated with the following equation: positively associated questions (×4) – the negatively associated questions (×6 from the BAM). Further details of the BAM+ and its development are available in Shearer et al.[22]

Data Analysis

All data are expressed as mean (SD), and statistical significance was set at $P < .05$ prior to analyses. MIVC, CMJ, MS, and BAM+ values were analyzed using a repeated-measures analysis of variance with 2 treatment levels (PCM_{cold} vs PCM_{amb}) and 4 repeated-measures time points (PRE, 12 h, 36 h, and 60 h). MS did not follow a normal distribution (according to $P < .05$ on the Kolmogorov–Smirnov test and inspection of histograms), so it was log transformed prior to analysis. If the analysis of variance indicated a significant interaction effect (treatment × time), Bonferroni post hoc analysis was performed to locate where the differences lie. The post hoc comparisons refer to a difference in conditions at a specific time point postmatch (eg, MIVC at 36 h post with PCM_{warm} vs PCM_{cold}). In the event of a significant violation of sphericity, Greenhouse–Geisser adjustments were used. External load data were analyzed with paired student *t* tests. The BFQ was analyzed using the Wilcoxon signed-rank test. All data were analyzed using IBM SPSS Statistics 23 for Windows (Surrey, United Kingdom). To estimate the magnitude of the treatment effects, Cohen's *d* effect sizes (ES) were calculated with the magnitude of effects considered either small (0.20–0.49), medium (0.50–0.79), and large (>0.80).

Results

External Load

As shown in Table 1, there were no differences in any of the external load variables, including time on the field, between the 2 conditions ($P < .01$). The requirement for being included in the intervention was that 60 minutes of the match had to be completed; no players were excluded on this criterion. In terms of treatment order, 8 players used PCM_{cold} first and 3 players used PCM_{warm}.

Muscle Function

As shown in Figure 1, MIVC was reduced after both treatments (time effect; $P < .001$), but recovery was faster with PCM_{cold} (treatment × time effect; $P = .001$) at 36 hours ($P = .01$; large ES = 1.59; 95% CI, 3.9%–17.1%). MIVC also tended to be higher at 60 hours after PCM_{cold} treatment ($P = .05$; large ES = 0.85; 95% CI, –0.4% to 11.1%). Although, to a smaller extent, CMJ performance also decreased after both treatments (time effect; $P = .03$), with losses peaking at 36 hours (Figure 2). PCM_{cold} tended to increase CMJ performance after the match versus PCM_{warm}, but this did not reach statistical significance (treatment effect; $P = .06$; treatment × time effect; $P = .10$).

Table 1 A Comparison of External Load During Match Play for the 2 Conditions (PCM_{cold} vs PCM_{amb})

	PCM_{cold}	PCM_{amb}
Total distance, m	9414 (2142)	9742 (1365)
Explosive distance, m	628 (149)	637 (78)
Sprint distance, m	330 (129)	339 (85)
Duration, min	81 (18)	83 (11)

Abbreviation: PCM, phase change material. Note: Total distance refers to the distance covered during the match; explosive distance refers to the distance traveled accelerating at ≥2 $m \cdot s^{-1}$ and decelerating at ≤2 $m \cdot s^{-1}$; sprint distance refers to the distance traveled at ≥60% of maximum speed ($km \cdot h^{-1}$); duration refers to the total number of minutes spent on the field of play. There were no differences between conditions for any variable ($P > .05$). Values are mean (SD); N = 11.

Muscle Soreness

A time effect for increased MS was observed ($P < .001$; Figure 3); however, MS was lower after PCM_{cold} (treatment effect; $P = .02$; treatment × time effect; $P = .01$; Figure 3). At 36 hours postmatch, MS was, on average, 26.5% lower after PCM_{cold} versus PCM_{amb} ($P = .02$; large ES = 1.70; 95% CI, −50.4 to −16.1 mm) and, at 60 hours, 24.3% lower in the PCM_{cold} ($P = .04$; large ES = 1.10; 95% CI, −26.9 to −0.874 mm).

Readiness to play, as measured by the BAM+ questionnaire, was reduced after wearing both garments postmatch (time effect;

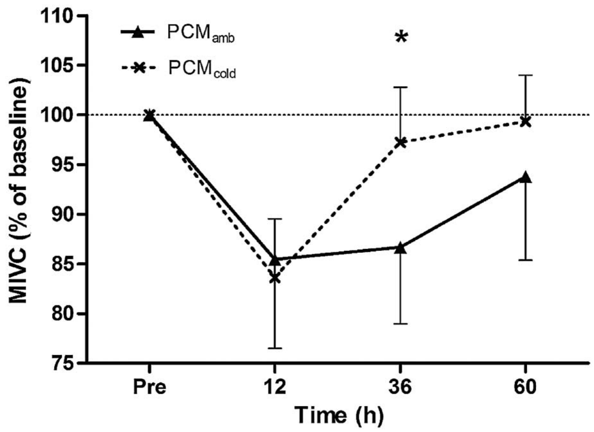

Figure 1 — Percentage changes in MIVC before and up to 60 hours after the match. MIVC was reduced after both matches (time effect; $P < .001$). *MIVC recovered more quickly after PCM_{cold} versus PCM_{amb}; treatment × time effect, $P = .001$. Values are mean (SD); N = 11. PCM indicates phase change material; MIVC, maximal isometric voluntary contractions.

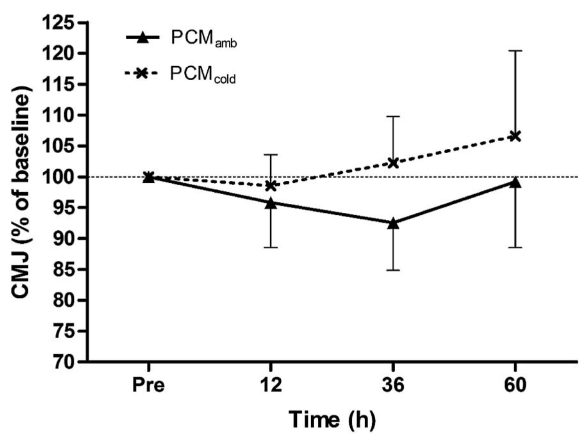

Figure 2 — Percentage changes in CMJ height before up to 60 hours after the match. CMJ was changed after both matches (time effect; $P = .03$) but tended to recover quicker with PCM_{cold} (treatment × time effect $P = .10$). Values are mean (SD); N = 11. PCM indicates phase change material; CMJ, countermovement jump.

$P < .001$); however, no treatment ($P = .44$) or treatment × time effects were observed ($P = .16$; Figure 4).

Before the intervention, there was no difference in the player's perception of how effective they felt each treatment would be ($P = .48$), suggesting that the PCM_{amb} served as a good control, and limited the possibility of a placebo effect at the outset. In contrast, at postintervention, it was felt that PCM_{cold} was more effective than PCM_{amb} (Table 2; $P = .004$).

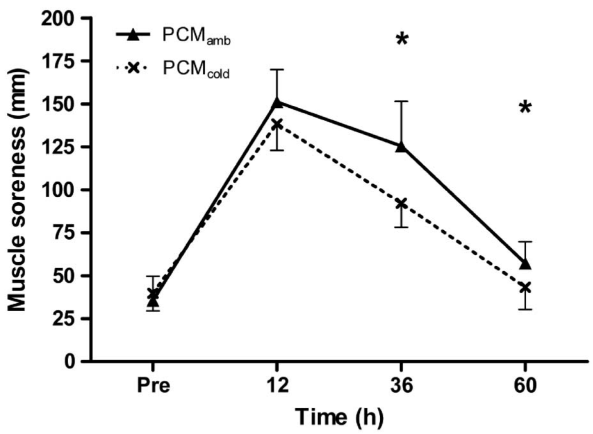

Figure 3 — Muscle soreness before up to 60 hours after the match. Muscle soreness increased after both matches (time effect; $P < .001$). *Muscle soreness lower after PCM_{cold} versus PCM_{amb}; treatment × time effect, $P = .010$. Values are mean (SD); N = 11. PCM indicates phase change material.

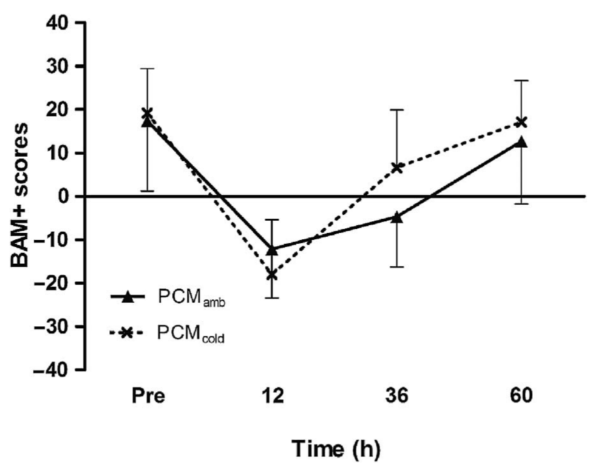

Figure 4 — Changes in the adapted Brief Assessment of Mood Questionnaire (BAM+) score for each condition before and up to 60 hours after the match. BAM+ scores fell after both matches (time effect; $P < .001$), but no treatment × time effects were evident; $P = .16$. Values are mean (SD); N = 11. PCM indicates phase change material.

Table 2 Perceived Effectiveness of the PCM Garments for Recovery Before and After the Intervention

	PCM_{cold}	PCM_{amb}
Pre	3.55 (0.69)	3.36 (0.50)
Post (M + 3)	4.18 (0.60)[a]	2.55 (1.04)

Abbreviation: PCM, phase change material.
[a]PCM_{cold} perceived to be more effective than PCM_{amb} postintervention ($P = .004$).

Discussion

The main finding of this study was that donning PCM garments for 3 hours after a competitive soccer match enhanced functional recovery; more specifically, both isometric strength loss and MS were significantly attenuated 2 to 3 days after the match. In line with these findings, the players felt the cooled garments were more effective than the ambient garments after the intervention (Table 2). This study provides the first evidence that the application of these novel cooling garments aids functional recovery in elite soccer players.

The enhanced recovery of MIVC and reduction in MS with PCM_{cold} is consistent with recent findings,[17] which showed that applying PCM_{cold} for 6 hours following 120 isolated eccentric knee extensions attenuated MIVC loss and MS for up to 4 days postexercise. The present study, however, expands upon these findings, indicating that: (1) the beneficial effects of these garments are not just limited to recreationally active individuals, but also extend to elite-level soccer players; and (2) a ~3-hour application is sufficient for accelerating functional recovery—at least in this population and under these very applied conditions. Of course, it is unclear if a 6-hour application would have further augmented the effects in the present study; however, the optimal application time for these garments does require further investigation.

Interestingly, the beneficial effects of PCM_{cold} on MIVC and MS only became evident at 36 and 60 hours postmatch. Why the PCM_{cold} was not beneficial at 12 hours postmatch is unclear and difficult to explain. However, given the loss in MIVC and MS peaked at this time point, 1 plausible explanation is that the magnitude of damage was simply too large for the PCM_{cold} to have any discernible effects. Alternatively, the discrepancy could be related to how soon this measure was collected after the end of the match. Indeed, it is possible that the changes in MIVC and MS at this time point were more a reflection of lingering physiological and mental fatigue rather than muscle damage per se, which is generally more evident ≥24 hours postexercise.[7,23] Additionally, in terms of MIVC, at this time point, a greater proportion of the strength loss was probably more attributable to mechanisms that are not postulated to be amenable to cryotherapy (eg, a loss of Ca^{2+} homeostasis and failure of the excitation–contraction coupling system[24]). Instead, muscle cooling is thought to affect the immunological responses associated with secondary damage; most notably local inflammation and oxidative stress, which develop more gradually following the initial muscle-damaging stimulus, generally peaking 24–96 hours postexercise.[25,26] Thus, given the time course of events, it would be reasonable to assume that the benefits of PCM_{cold} would become more apparent at later stages in the recovery process when functional recovery (eg, MIVC loss and MS) are more likely to be hindered by secondary processes. Following this logic, a possible mechanism by which the PCM_{cold} application could have accelerated recovery was by reducing the number of inflammatory cells, especially phagocytes, that adhere to the vascular endothelium and infiltrate the damaged tissues for remodeling. Although such effects remain equivocal with acute CWI (10 min),[15] a more prolonged cooling intervention (6 h) was shown to reduce phagocyte adherence and desmin loss 24 hours after muscle damage in mice,[14] lending some support to this theory. Such effects are, in turn, likely to blunt the neutrophil-mediated release of reactive oxygen species, which, in a nondiscriminate manner, can degrade both damaged and healthy cells, inhibiting recovery.[12,14,27] There is, indeed, evidence in humans that have shown a link between exercise-induced inflammation and isometric strength loss,[25] and some in animals showing that attenuating inflammation enhances the recovery of muscle function after muscle lengthening contractions,[27] which would support this proposition. Nonetheless, it is important to note that not all studies have found a link between inflammation and muscle function after muscle-damaging exercise.[28] Thus, although such effects are plausible, without measuring inflammation, this is somewhat speculative; this postulation needs to be tested experimentally to confirm this idea.

Another interesting finding from this study is that despite the benefits of PCM_{cold} on MIVC recovery, CMJ performance was not significantly altered. This could be largely due to the fact that the magnitude of CMJ loss after the match was only small; thus, there was not a large enough impairment to detect a significant treatment effect. With that said, CMJ height did tend to be greater at 36 and 60 hours postmatch in the present study, with 9 of the 11 players scoring higher relative to their baseline values after PCM_{cold} at 36 hours, revealing a large ES (1.2). Therefore, these findings might be interpreted as practically meaningful by a practitioner or coach working in elite soccer.

In contrast to the functional measures, the BAM+ was not different between the 2 treatments. This could be interpreted to suggest that the PCM_{cold} was more effective for aiding physiological/biomechanical recovery rather than the psychological/well-being aspects of recovery. Indeed, these 2 could represent distinct aspects of recovery, given the recent suggestion that they do not tend to correlate well using a number of measures.[29] Notwithstanding, the BAM+ is a new tool and is yet to be validated as a recovery marker, so perhaps this measure is not sensitive enough for detecting significant changes between treatments.

It is important to acknowledge the limitations of this work. First, we were unable to measure local tissue temperature between the 2 conditions to confirm that the PCM_{cold} was having the desired effect. However, because the same PCM_{cold} reduced skin temperature to 22°C in previous work,[17] not dissimilar to that reported after CWI was applied post a heavy bout of plyometric exercise (24.5°C),[30] we are confident that the skin temperature will similarly decrease in the present study. Another limitation, which is inherent in all cryotherapy-based research, is our inability to rule out that these results were largely a result of a placebo effect due to the players' preconceived belief about how cold exposure might benefit their recovery. However, it is important to note that at the outset of the study, the players did not believe that the PCM_{cold} would be more beneficial than the PCM_{warm} (Table 2). Finally, again, due to the practical constraints of working with elite athletes, the potential underlying mechanisms could not be determined. These are important questions that need to be examined in future work.

Practical Applications

The phase change garments used in this study are also easily portable and can be applied to large groups of athletes for an extended period of time, while allowing the athletes to move freely during use; consequently, they offer a highly practical means of applying cryotherapy to enhance recovery following competitive team-sport matches. Although it remains to be seen if the phase change material garments used in this study are more efficacious than other forms of cryotherapy from a practical perspective, at the very least, these garments offer an attractive alternative method of enhancing recovery when access to CWI is not available, perhaps in away competition or tournament scenarios.

Conclusions

In conclusion, the present findings showed, for the first time, that applying cooled PCM to the quadriceps for 3 hours after a soccer match lowers MS and improves the recovery of MIVC. Studies examining the effects of these garments in other sporting populations (eg, rugby), along with the potential mechanisms involved, are warranted.

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