Title: Cryotherapy re-invented: application of phase change material for recovery in elite soccer

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Authors: Tom Clifford[1, 5], Will Abbott[2, 3], Susan Y. Kwiecien[4, 5], Glyn Howatson[5, 6], Malachy P. McHugh[4, 5].

[1]School of Biomedical Sciences, Newcastle University, United Kingdom; [2]School of Sport and Service Management, Brighton University, UK; [3]Brighton and Hove Albion F.C, American Express Elite Performance Centre, Lancing, UK; [4]Nicholas Institute of Sports Medicine and Athletic Trauma, Lenox Hill Hospital, New York, NY; [5]Department of Sport, Exercise and Rehabilitation, Northumbria University, Newcastle, United Kingdom; [6]Water Research Group, School of Environmental Sciences and Development, Northwest University, Potchefstroom, South Africa.

Corresponding author:

Tom Clifford, Newcastle University, Faculty of Medical Sciences, School of Biomedicine Newcastle-upon-Tyne, NE2 4HH, UK Tel: +44 0192 088 311

Running head: Cryotherapy and recovery in elite soccer

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Abstract

Purpose: This study examined 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, eleven elite-soccer players from the reserve squad of a team in the 2nd highest league in England wore PCM cooled to 15°C (PCM_{cold}) or left at ambient temperature (PCM_{amb}) for 3 h after a soccer match. To assess recovery, countermovement jump (CMJ) height, maximal isometric voluntary contraction (MIVC), muscle soreness (MS), and the adapted Brief Assessment of Mood Questionnaire (BAM+) were measured before, 12, 36 and 60 h after each match. Pre and post intervention, a belief questionnaire (BFQ) was completed to determine perceived effectiveness of each garment.

Results: Results are comparisons between the two conditions at each time point post-match. MIVC at 36 h post was greater with PCM_{cold} vs. PCM_{warm} (P=0.005; ES=1.59; 95% CI=3.9 to 17.1%). MIVC also tended to be higher at 60 h post (P=0.051; ES=0.85; 95% CI= −0.4 to 11.1%). MS was 26.5% lower in PCM_{cold} vs. PCM_{warm} at 36 h (P=0.02; ES=1.7; 95% CI= −50.4 mm to −16.1 mm) and 24.3% lower at 60 h (P=0.039; ES=1.1; 95% CI= −26.9 mm to −0.874 mm). There were no between condition differences in post-match CMJ height or BAM+ (P>0.05). The BFQ revealed that players felt the PCM_{cold} was more effective than the PCM_{amb} after the intervention (P=0.004).

Conclusions: PCM cooling garments provide a practical means of delivering prolonged post-exercise cooling and thereby accelerating recovery in elite soccer players.

Key words: Recovery, cryotherapy, soccer, muscle damage, exercise.

Introduction

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 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 aetiology 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 non-contractile 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], where adaptation to an exercise stimulus is of secondary importance during periods of competition or fixture congestion.

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 recovery will be facilitated [10]. Such effects are purported to reduce tissue temperature and increase hydrostatic pressure, leading to a reduction in inflammation and oxidative stress [10-13]. Nonetheless, it remains equivocal as to whether cooling the muscles does actually reduce inflammation [14]. Additionally, the effectiveness of CWI as a recovery aid has been questioned, with large meta-analyses suggesting small to moderate benefits [12 15]. There are, however, some studies reporting that CWI can assist recovery in the days following intermittent exercise or competitive soccer matches that was summarised in a narrative review [1].

In addition to the limited benefits of CWI in exercise recovery [12], 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 [16]. 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 [17]. 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. The potential benefits of local PCM application for exercise recovery have recently been explored, and indicate that wearing PCM (15°C) can aid recovery following muscle-damaging exercise in untrained individuals [18].

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 hypothesised that PCM would attenuate muscle soreness 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 h 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 Faculty of Health and Life Sciences, Northumbria University. Eleven elite male, outfield soccer players (Age, 19 ± 1 yrs; height, 1.80 ± 0.57 m; mass, 75.9 ± 7.2 kg; bodyfat, 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 (i.e., CWI) or form of compression was prohibited throughout testing.

Experimental design

This study employed a crossover design. After two league matches between the period of Jan – March 2017, players wore, in a randomized fashion, PCM (Glacier Tek, USDA BioPreferred PureTemp, Plymouth, MN, USA) that were either cooled in a freezer to 15° C (intervention; PCM_{cold}) or left at ambient (~22° C) temperature (control; PCM_{amb}). PCM blocks were worn on the quadriceps muscles inside compression shorts for 3 h in total from approximately 45 mins post-match. They were worn while travelling back from the matches on the team bus, which had an air temperature between 18-21°C. During their application, the players sat 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 which 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 h after the match to monitor recovery.

These variables were all recorded prior to training (between 09:00 – 10:30) and in the following order: an adapted Brief Assessment of Mood (BAM+), muscle soreness (MS), counter movement jump (CMJ) height, and maximal isometric voluntary contraction (MIVC). Participants were familiarized with the above procedures prior to the main data collection. Players wore GPS units (Catapult, Leeds, UK) 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, UK) 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 s Three maximal efforts were performed, each separated by 60 s of passive, seated recovery, with the mean value (N) used for analysis. The inter-day coefficient of variation (CV) 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 s of standing recovery; the mean of the 3 jumps was used for analysis. The CV for this protocol was <5%.

Muscle soreness

Muscle soreness (MS) was rated by marking a vertical line on a 200 mm visual analogue (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 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, muscle soreness and sleep quality[20]. For each of the 10 questions, players drew a vertical line on a 100 mm visual analogue scale (VAS), which has “not at all” and “extremely” at opposing ends. The lines were measured with a ruler and recorded and an overall score calculated with the following equation: positively associated questions (x4) − the negatively associated questions (x6 from the BAM). Further details of the BAM+ and its development are available in[22].

Data analysis

All data are expressed as mean ± SD and statistical significance was set at $P < 0.05$ prior to analyses. MIVC, CMJ, MS and BAM+ values were analysed using a repeated measures ANOVA with 2 treatment levels (PCM_{cold} vs. PCM_{amb}) and 4 repeated measures time points (PRE, 12 h, 36 h, 60 h). If the ANOVA 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 post-match (e.g., MIVC at 36 h post with PCM_{warm} vs. PCM_{cold}). In the event of a significant violation of spherecity, Greenhouse-Geisser adjustments were used. External load data was analysed with paired student t-tests. The BFQ was analysed using the Wilcoxon signed-rank test. All data were analysed using IBM SPSS Statistics 23 for Windows (Surrey, UK). 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 two conditions ($P < 0.01$). The requirement for being included in the intervention was that 60 minutes of the match had to be completed; no players had to be excluded on this criterion. In terms of treatment order, 8 players used PCM_{cold} first and 3 players $PCM_{warm.}$

Muscle function

As shown in Figure 1, MIVC was reduced after both treatments (time effect; $P = 0.0001$) but recovery was faster with PCM_{cold} (treatment*time effect; $P = 0.001$) at 36 h ($P = 0.005$; large ES = 1.59; 95% CI = 3.9 to 17.1%). MIVC also tended to be higher at 60 h after PCM_{cold} treatment ($P = 0.051$; 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; $P = 0.032$), with losses peaking at 36 h (Figure 2). PCM_{cold} tended to increase CMJ performance after the match vs. PCM_{warm} but this did not reach statistical significance (treatment effect; $P = 0.064$; treatment*time effect; $P = 0.095$).

Muscle soreness

A time effect for increased MS was observed ($P = 0.0001$; Figure 3); however, MS was lower after PCM_{cold} (treatment effect; $P = 0.02$; treatment*time effect; $P = 0.010$; Figure 3). At 36 h post, MS was, on average, 26.5% lower after PCM_{cold} vs. PCM_{amb} ($P = 0.02$; large ES = 1.70; 95% CI = −50.4 mm to −16.1 mm) and, at 60 h, 24.3% lower in the PCM_{cold} ($P = 0.039$; large ES = 1.10; 95% CI = −26.9 mm to −0.874 mm).

Readiness to play, as measured by the BAM+ questionnaire, was reduced after wearing both garments post-match (time effect; $P = 0.0001$); however, no treatment ($P = 0.438$) or treatment*time effects were observed ($P = 0.164$; Figure 4).

Before the intervention, there was no difference in the player's perception of how effective they felt each treatment would be ($P = 0.480$), suggesting that the PCM_{amb} served as a good control, and limited the possibility of a placebo effect at the outset. In contrast, at post-intervention, it was felt that PCM_{cold} was more effective than PCM_{amb} (Table 2; $P = 0.004$).

Discussion

The main finding of this study was that donning PCM garments for 3 h after a competitive soccer match enhanced functional recovery; more specifically, both isometric strength loss and MS were significantly attenuated 2-3 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 aid functional recovery in elite soccer players.

The enhanced recovery of MIVC and reduction in MS with PCM_{cold} is consistent with recent findings [18], which showed that applying PCM_{cold} for 6 h following 120 isolated eccentric knee extensions attenuated MIVC loss and MS for up to 4 days' post-exercise. 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 h 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 h 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 h post-match. As to why the PCM_{cold} was not beneficial at 12 h post-match is unclear and difficult to explain. However, given the loss in MIVC and MS peaked at this time point, one 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 h post-exercise [7 23]. Additionally, in terms of MIVC, at this time point a greater proportion of the strength loss was probably more attributable to mechanisms which are not postulated to be amenable to cryotherapy (e.g., 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 h post-exercise [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 (e.g., 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 remodelling. Although such effects remain equivocal with acute CWI (10 min) [14], a more prolonged cooling intervention (6 h) was shown to reduce phagocyte adherence and desmin loss 24 h after muscle damage in mice[13], 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 non-discriminate manner, can degrade both damaged and healthy cells, inhibiting recovery[11 13 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 contraction[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, while 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 h post-match in the present study, with 9 of the 11 players scoring higher relative to their baseline values after PCM_{cold} at 36 h, revealing a large effect size (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 two treatments. This could be interpreted to suggest that the PCM_{cold} was more effective for aiding physiological/biomechanical recovery rather than the psychological/wellbeing aspects of recovery. Indeed, these two could represent distinct aspects of recovery, given the recent suggestion 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. Firstly, we were unable to measure local tissue temperature between the two conditions to confirm that the PCM_{cold} was having the desired effect. However, because in previous work the same PCM_{cold} reduced skin temperature to 22° C [18], —similar to that reported after CWI [30],we are confident that the skin temperature was similarly decreased 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 pre-conceived belief about how cold exposure might benefit there 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 1). 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, can be applied to large groups of athletes, and allow 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. While 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 h after a soccer match lowers MS and improves the recovery of MIVC. Studies examining the effects of these garments in other sporting populations (e.g., rugby) along with the potential mechanisms involved, are warranted.

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Table 1. A comparison of external load during match-play for the two conditions (PCM_{cold} vs. PCM_{amb}). Total distance is the total distance covered during the match; explosive distance refers to the distance travelled accelerating at ≥2 m·sec^{-1} and decelerating at ≤2 m·sec^{-1}; sprint distance is the distance travelled at ≥60% of maximum speed (km·h^{-1}); and duration is the total number of minutes spent on the field of play.

	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

There were no differences between conditions for any variable ($P > 0.05$).
Values are mean ± SD; $n = 11$.

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*	2.55 ± 1.04

* PCM_{cold} perceived to be more effective than PCM_{amb} post intervention ($P = 0.004$).

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*	2.55 ± 1.04

* PCM_{cold} perceived to be more effective than PCM_{amb} post intervention (P = 0.004).

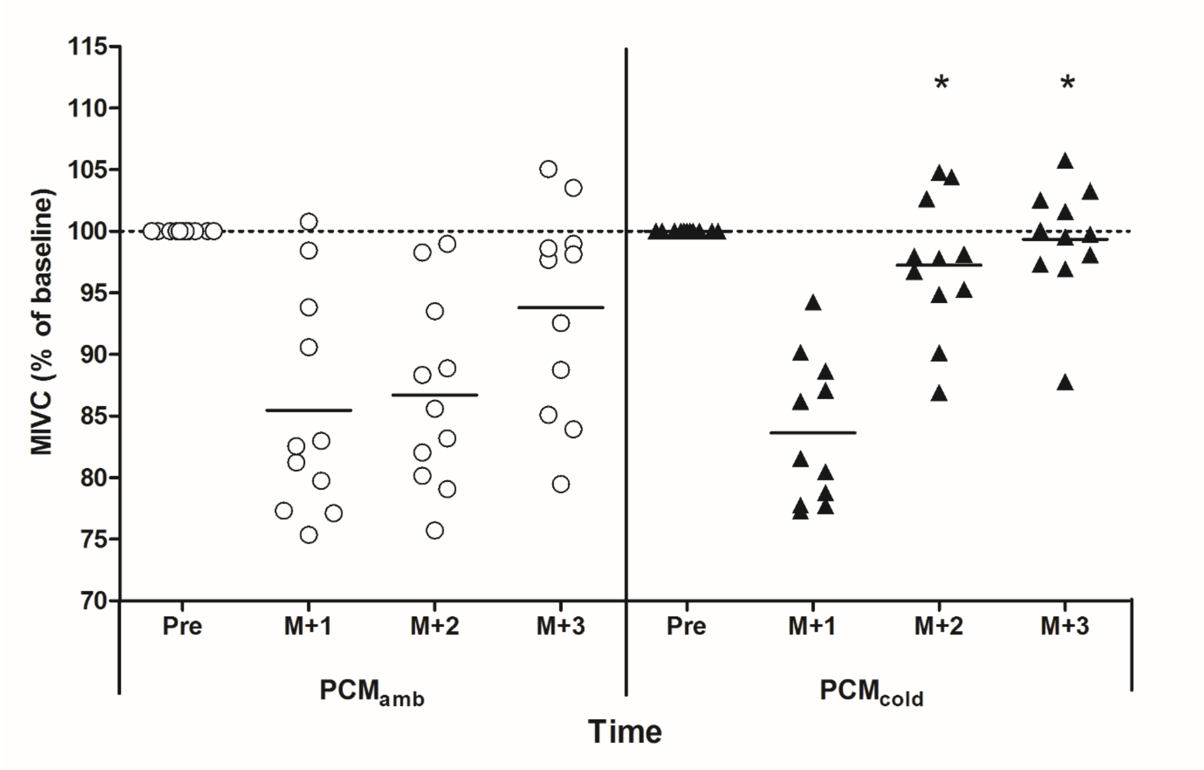

Figure 1. Percentage changes in MIVC before and up to 3 days after a match (M+3). *MIVC recovered quicker after PCM$_{cold}$ vs. PCM$_{amb}$ $P < 0.05$). Values are mean ± SD ($n = 11$).

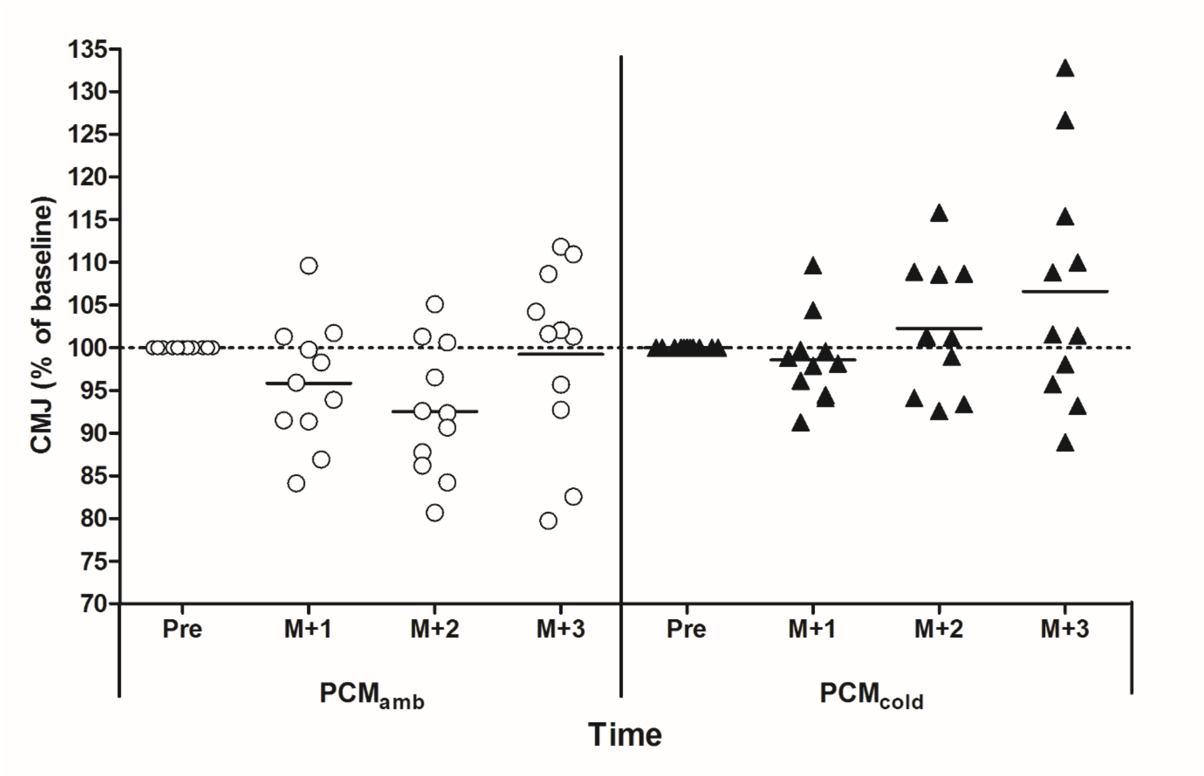

Figure 2. Percentage changes in CMJ height before up to 3 days after each match (M+3). Values are mean ± SD (n = 11).

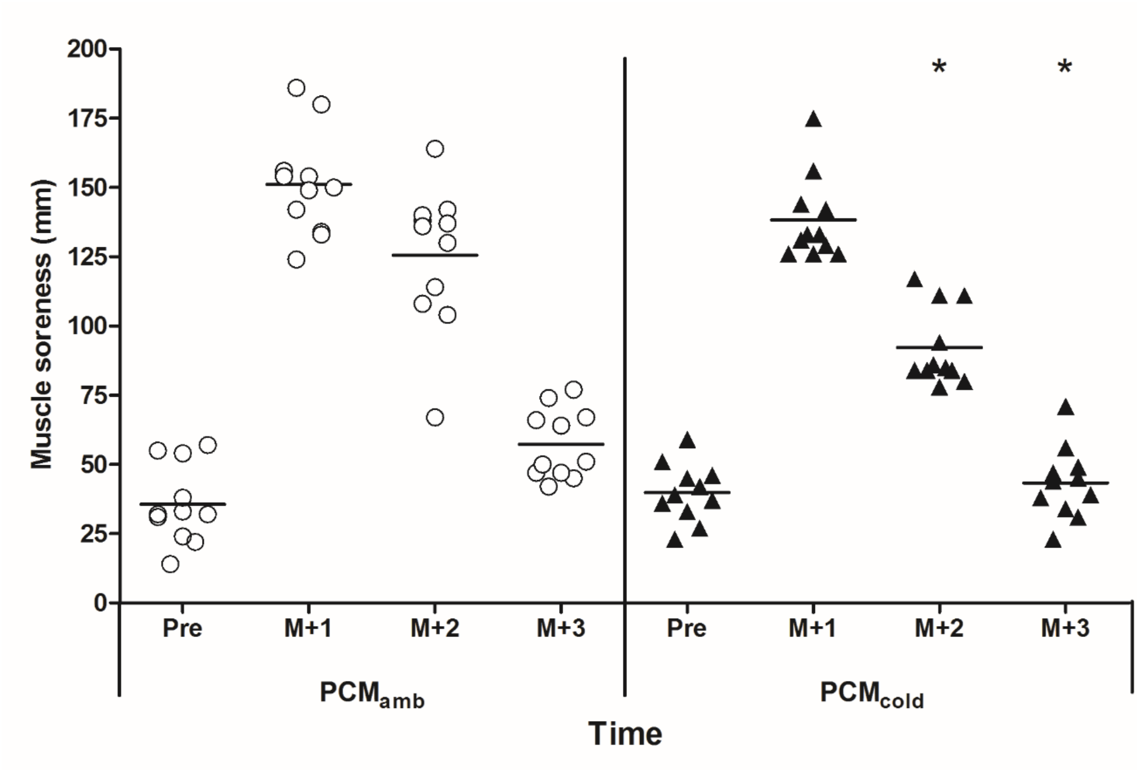

Figure 3. Muscle soreness before up to 3 days after a match (M+3). *Muscle soreness lower after PCM_{cold} vs. PCM_{amb}; $P < 0.05$. Values are mean ± SD ($n = 11$).

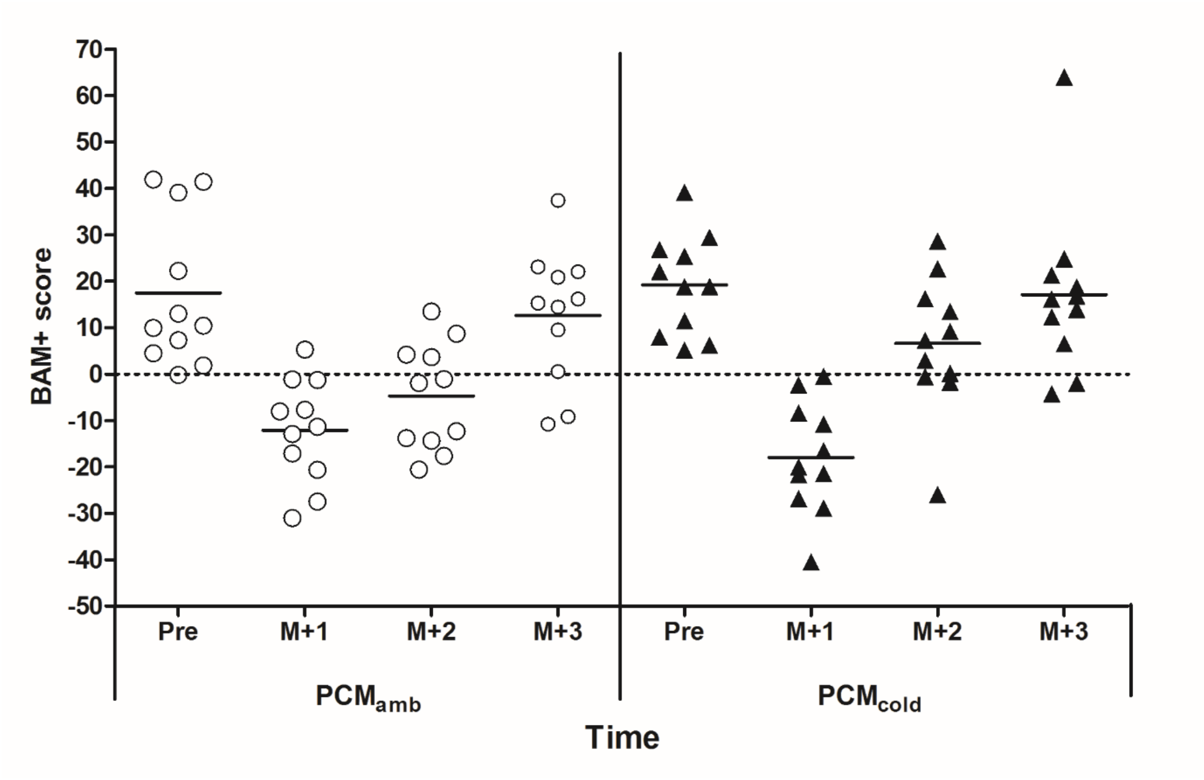

Figure 4. Changes in BAM+ score for each condition before up to 3 days after a match (M+3). Values are mean ± SD (n = 11).