Comparative efficacy of active recovery and cold water immersion as post-match recovery interventions in elite youth soccer.

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KEYWORDS: Football, Rehabilitation, Sport Performance, Cold Water Immersion, Muscle Damage.

WORD COUNT: 5,390

Abstract

The current study compared cold-water immersion (CWI) and active recovery (AR) to static stretching (SS) on muscle recovery post-competitive soccer matches in elite youth players (n=15).

In a controlled crossover design, participants played a total of nine competitive soccer games, comprising three 80 minute games for each intervention (SS, CWI and AR). Muscle oedema, creatine kinase (CK), countermovement jump performance (CMJA) and perceived muscle soreness (PMS) were assessed pre-, immediately post-, and 48 hours post-match and compared across time-intervals and between interventions.

Following SS, all markers of muscle damage remained significantly elevated ($P<0.05$) compared to baseline at 48 hours post-match. Following AR and CWI, CMJA returned to baseline at 48 hours post-match, whilst CK returned to baseline following CWI at 48 hours post-match only. Analysis between recovery interventions revealed a significant improvement in PMS ($P<0.05$) at 48 hours post-match when comparing AR and CWI to SS, with no significant differences between AR and CWI observed ($P>0.05$). Analysis of %change for CK and CMJA revealed significant improvements for AR and CWI compared to SS.

The present study indicated both AR and CWI are beneficial recovery interventions for elite young soccer players following competitive soccer matches, of which were superior to SS.

Introduction

To allow for the greatest opportunity for success in an elite sporting career, athletes are required to train and compete at exceptionally high physical, technical, and psychological intensities, resulting in high stress loads being placed on their bodies (Reilly & Ekblom, 2005). In order to maintain or enhance training and performance levels, athletes require sufficient time to recover from the training stimulus and allow muscular adaptations to take place (Peake, Neubauer, Della Gatta, & Nosaka, 2017). Consequently, athletes and their coaches will seek recovery interventions that will reduce time taken to recover upon cessation of exercise exposure. As such, optimal recovery interventions following training and competition in elite sport are commonly sought (Kinugasa & Kilding, 2009).

Static stretching (SS) is a historically recommended recovery intervention, said to minimise muscle soreness following exercise via the dispersion of post-exercise muscle oedema, reducing the potential damaging effects of reactive oxygen species, neutrophils, lymphocytes and pro-inflammatory cytokines (Cheung, Hume, & Maxwell, 2003). This intervention has been implemented with varying levels of success, with studies in basketball (Delextrat, Hippocrate, Leddington-Wright, & Clarke, 2014) reporting significant improvements on perceived muscle soreness (PMS) and countermovement jump performance, whilst research involving adult semi-professional soccer players suggest improvements in peak power (Dawson, Cow, Modra, Bishop, & Stewart, 2005). However, these positive findings focused on non-elite participants, and therefore research concerning elite young soccer players must be considered. Pooley, Spendiff, Allen and Moir (2017) monitored elite young soccer players and found SS to be ineffective. As Pooley et al. (2017) focused only on the effects of SS, further research on the alternative recovery interventions used in elite youth soccer must also be considered.

Within elite soccer, a number of interventions are frequently used, with two of the most prevalent being active recovery (AR) and hydrotherapy techniques such as cold water immersion (CWI) and contrast water therapy (CWT) (Nédélec, et al., 2013). AR – a low intensity 'cool down' (Peake, et al., 2017) - has been suggested to aid in the recovery process by facilitating in the removal of metabolic by-products from skeletal muscles post-exercise (Reilly & Ekblom, 2005). Low intensity exercise completed following the cessation of intense physical activity is reported to increase cardiac output and muscle blood flow (Peake, et al., 2017), accelerating the clearance of exercise by-products (Martin, Zoller, Robertson & Lephart, 1998) reducing the potential pooling effects of pro-inflammatory cytokines, ultimately preventing further cell damage (Chazaud, 2016).

Difficulties arise when comparing findings between AR interventions, as the aim of increasing blood flow to respiring muscles can be achieved through various modes of exercise (Darani, Abedi, & Fatolahi, 2018; Bahnert, Norton, & Lock, 2013; Tessitore, Meeusen, Cortis, & Capranica, 2007; Gill, Beaven, & Cook, 2006). Tessitore et al. (2007) compared the effects of an AR intervention comprising 8 minutes walking, 8 minutes jogging, 4 minutes dynamic stretching to passive recovery (PR), electrostimulation and water-based aerobic exercise following soccer training of elite young soccer players with no significant improvements in recovery markers identified as a result of any recovery intervention. However, findings of Tessitore et al. (2007) contradict those of Gill et al. (2006), reporting significant improvements in CK following elite competitive rugby matches using a cycle ergometer AR intervention when compared to PR. Limitations on the transferability of the findings of Tessitore et al (2007), and Gill et al. (2006) to elite young soccer players are evident. Although using elite young soccer players within their sample population, Tessitore et al. (2007) implement recovery interventions around pre-season training events potentially producing lower physical outcomes and exertion in comparison to soccer matches, therefore limiting the amount of muscle damage inflicted. In comparison, Gill et al. (2006) utilise elite adult rugby players within their sample population, again affecting the transferability of findings between adult and youth athletes, and rugby and soccer players. As a result, further research on the effects of AR in elite youth soccer players following competitive soccer matches is required.

Hydrotherapy techniques, including CWT, CWI, and aerobic water-based exercise have shown significant improvements in muscle recovery when compared to alternative recovery techniques (Stephens, Malson, Miller, Slater & Askew, 2016; Elias, Wyckelsma, Varley, McKenna, & Aughey, 2013; Vaile, Halson, & Graham, 2010). CWI is suggested to aid in the recovery process by assisting in the removal of metabolic by-products following exercise by improving venous return via vasoconstriction as a result of exposing muscle to cold water (Stephens, et al., 2016) dampening the potentially harmful effects of pro-inflammatory cytokines involved in the removal of damaged muscle tissue (Peake, Nosaka, & Suzuki, 2005). As with AR, numerous CWI protocols have been implemented throughout research, with literature of Machado et al. (2016) supporting its use suggesting protocols using water temperatures between 11 and 15^{o}C with submersion times between 10 and 15 minutes were most effective for both immediate and delayed recovery effects. Despite the extensive research of CWI interventions showing significant improvements in muscle recovery (Machado, et al., 2016; Elias, et al., 2013; Ascensão, Leite, Rebelo, Magalhäes, & Magalhäes, 2011; Rowsell, Coutts, Reaburn, & Hill-Hass, 2009; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009), there is a dearth of evidence supporting the use of CWI following competitive matches concerning elite young soccer players when compared to alternative recovery interventions, and therefore this area requires further research.

To date, no clearly defined recovery protocol has been identified and compared across recovery modalities demonstrating its effectiveness on improving recovery following elite youth soccer matches, and as such, coaches and athletes must rely on past research from nonspecific sports or incomparable participant age and training statuses when implementing recovery interventions. It has been demonstrated that the use of traditional SS as a recovery intervention was ineffective for the elite young sample population (Pooley, et al., 2017), and therefore this study aimed at determining the efficacy of alternative recovery interventions when compared to SS following competitive soccer matches of elite youth soccer players.

Methods

Participants

Fifteen elite young soccer players (mean [± SD]: age 16 [1] years, stature 176.4 [5.1] cm, mass 64.9 [5.6] kg) from a professional football academy in the English Premier League voluntarily participated in this study. Prior to participating in the study, participants were informed of any risks that may occur, and player and parental consent was obtained. All procedures were conducted in accordance with the Declaration of Helsinki, and the study was ethically approved by the Faculty of Science, Engineering and Computing Ethics Committee (Kingston University London, UK).

Experimental Design

Participants were required to complete three 80-minute competitive soccer matches (2x40min per match) for each recovery intervention [static stretching (SS), cold water immersion (CWI) and active recovery (AR)], where interventions were implemented in a cross-sectional fashion upon completion of the respective soccer matches. In order to assess the extent of muscle damage elicited from matches, markers of muscle damage via muscle oedema, creatine kinase (CK), countermovement jump with arms (CMJA) and perceived muscle soreness (PMS) were measured before (pre), immediately after (post), and 48-hours after (48-hours post) each competitive soccer match. All indicators of muscle damage are commonly used markers in the assessment of muscle damage and recovery (Darani, et al., 2017; Gill, et al., 2006; Ingram, et al., 2009; Ascensão, et al., 2011; Kinugasa & Kilding, 2009; Bahnert, et al., 2013).

Experimental Protocol

Physical Assessments

Upon arrival to the match facility, participant stature and mass were recorded, immediately followed by the recording of PMS at 2.5 hours prior the match commencing. PMS was indicated on a 10-point visual analogue scale (VAS) from 0.5 to 5 with 0.5 increments.

Immediately following PMS assessment, muscle oedema was taken using a constant-tension tape measure to assess muscle circumference (Pooley, et al., 2017) using three sites of the lower body; the two sites on the lower leg were identified by 1/3 (OedemaG1) and 2/3 (OedemaG2) of the lower leg length calculated by the distance from the medial condyle of the Tibia to the Calcaneus. The site on the upper leg (OedemaQ) was identified by the midpoint of the distance from the Patella to the anterior superior iliac spine. Following these initial assessments, CK levels were assessed using fingertip whole blood samples, and analysed using the i-STAT 1 Analyser (Abbott Point of Care, Abbott Park, Illinois, USA). Two hours prior to exercise, CMJA was recorded using the Smart Speed Jump Mat (Fusion Sport), with participants completing three maximal jumps with peak jump performance recorded for analysis.

Recovery Intervention

Prior to any participation in matches, a physical and technical preparation warm-up was conducted by a sport scientist and UEFA qualified coach respectively. Warm-ups remained consistent throughout the duration of the study, comprising 15 minutes physical preparation involving muscle activation, movement preparation, dynamic stretching and mobility, and 15 minutes of positional and technical football work. For consistency, the warm-ups were conducted by the same sport scientist and coach prior to all competitive games.

Immediately following completion of the competitive 'home' fixtures, participants were randomly assigned to either the CWI [10 minutes submersion to the point of the illiac crest in cold water set to 14 ±0.8°C (Machado, et al., 2016)] or AR [10 minutes low intensity exercise on a cycle ergometer at 80-100rpm ~80 Watts (Gill, et al., 2006)] intervention, or the SS protocol (Pooley, et al., 2017) performed following 'away' fixtures (two 15 second stretches to the gastrocnemius, hamstrings, quadriceps, glutes, hip flexors, adductors and abductors). Upon completion of the recovery protocols, participants were required to repeat the assessment of muscle damage markers in the same order as taken pre-match. Post-match assessments were undertaken within 30 minutes of completing the match. The same assessments of muscle damage were recorded at 48 hours post-exercise. On every occasion, the assessments were carried out in the same order and by the same sport scientist. The time intervals of assessments (pre-, post- and 48 hours post-match) were consistent with those used throughout literature (Pooley, et al., 2017; Ascensão, et al., 2011; Magal, et al., 2010; Brown, Child, Day, & Donnelly, 1997).

Player Exclusions

For the purpose of control, and for the monitoring of physical outcomes of competitive soccer matches, Global Positioning Systems (GPS) units fitted with accelerometers were worn by all participants when competing in games. The GPS units (STATSports Apex) reported movement variables across all axes, as well as reporting heart rate data. Individual thresholds based on these movement parameters were set according to the average of the combined variables for all full competitive matches completed. As a result, match percentages were calculated, with the average of dynamic stress load (fatigue score calculated using player movements, steps and collisions), metres per minute, speed intensity, high metabolic power distance, high speed running distance (distance covered above 65% of an individual's maximum speed), accelerations, decelerations, heart rate minutes above 85% of max., and heart rate exertion over all full games amounting to a match percentage of 100%. This match percentage determined the individual intensity of matches completed for all players. To ensure the intensity of each competitive football match remained consistent throughout the study, any participant whose match percentage for any particular game was ± 10% of their average match percentage for all completed matches were excluded from the data collection for that specific competitive match. Furthermore, participants were excluded from data collection for individual games if they failed to complete a minimum of 80% of the 80 minute match whilst goalkeepers were excluded from the study due to the inability to control consistency in physical loading for matches. Of a potential squad of 24, seven players were excluded for not completing a minimum of 80% of match play and two were goal keepers. As such a total of 15 players were include in the final analysis.

Statistical Analysis

Data are presented as mean ± standard deviation (SD) unless otherwise stated. Analysis of indicators of muscle damage commenced following assessment for normality in all data, verified using the Shapiro-Wilk test. To analyse differences in assessment markers (CK, CMJA, PMS) a two way within-subjects repeated measures analysis of variance (ANOVA) was used comparing [conditions SS, CWI and AR] x time points (pre, post-, and 48-hours post-exercise) using statistical software SPSS 23 (SPSS Inc., Chicago, IL, USA). Data of assessment markers were also transformed to indicate percentage change from pre-match baseline values to indicate the percentage of recovery achieved (Pooley, et al., 2017; Duffield, Cannon & King, 2010; Howatson, Goodall & van Someren, 2009; Ingram, et al., 2009; Goodall & Howatson, 2008; Montgomery, et al., 2008; Gill, et al., 2006). A Bonferroni statistical test was used for post-hoc analysis. Effect sizes were calculated using partial ETA^2 (η^2) where 0.01 = small; 0.06 = medium; and 0.14 = large effect (Field, 2009) and 95% bootstrap confidence intervals were used to detect differences in trends in the data, where negative/positive values indicate negative/positive relationships respectively, and intervals crossing zero indicate no effect (Field, 2009). Statistical significance was accepted at $p < 0.05$.

Results

All analysis of all pre-match markers of muscle damage between SS, AR and CWI revealed no significant differences suggesting that for all three conditions, participant pre-match physical conditions' were similar allowing an accurate comparison of post-match and 48 hours post-match data.

Analysis of data within conditions across time intervals (pre-, post-, 48 hours post-) revealed a significant increase in PMS immediately following (post-) competitive soccer matches when compared to pre-match measures ($p < 0.001$, η^2: 0.961, 95% CI 2.373 to 2.767) and was significant for all conditions (SS: $p < 0.001$, η^2: 0.981, 95% CI 2.558 to 3.162, AR: $p < 0.001$, η^2: 0.960, 95% CI 2.156 to 2.944, CWI: $p < 0.001$, η^2: 0.961, 95% CI -1.950 to 2.650; Table 1). PMS collected at 48 hours post-match was significantly elevated in comparison to pre-match values for all recovery interventions (SS: $p < 0001$, η^2: 0.956, 95% CI 1.450 to 1.970, AR: $p = 0.003$, η^2: 0.643, 95% CI 0.328 to 1.172, CWI: $p = 0.013$, η^2: 0.514, 95% CI 0.122 to 0.798), with all three interventions significantly reduced from post-match values (SS: $p < 0.001$, η^2: 0.956, 95% CI 0.965 to 1.335, AR: $p < 0.001$, η^2: 0.967, 95% CI 1.550 to 2.050, CWI: $p < 0.001$, η^2: 0.923, 95% CI 1.438 to 2.242). CMJA (cm) performance was significantly reduced immediately post-match when compared to pre-match values for all recovery interventions (SS: $p < 0.001$, η^2: 0.847, 95% CI 4.019 to 7.803, AR: $p < 0.001$, η^2: 0.896, 95% CI 2.811 to 4.757, CWI: $p < 0.001$, η^2: 782, 95% CI 2.431 to 5.649). At 48 hours post-match, CMJA following SS intervention remained significantly reduced, ($p < 0.001$, η^2: 0.784, 95% CI 1.944 to 4.496) however no significant differences were observed between pre- and 48 hour post-match CMJA performance following AR and CWI interventions (Table 1).

**** Table 1 near here****

A significant increase in CK (ng/mL) was observed between pre- and post-match measure within all conditions (SS: $p < 0.001$, η^2: 0.944, 95% CI 3.782 to 5.478, AR: $p < 0.001$, η^2: 0.918, 95% CI 3.502 to 5.538, CWI: $p = 0.001$, η^2: 0.734, 95% CI 2.276 to 6.064), with a significant reduction in CK observed between post- and 48 hour post-match measures taken following all recovery interventions (SS: $p < 0.001$, η^2: 0.814, 95% CI 1.280 to 2.700, AR: $p < 0.001$, η^2: 0.857, 95% CI 2.594 to 4.906, CWI, $p < 0.001$, η^2: 0.829, 95% CI 2.770 to 5.650), however no significant difference between pre- and 48 hour post-match CK was observed following CWI intervention. No significant differences in muscle oedema were identified between any time intervals, for all recovery interventions.

Analysis of data between conditions across time intervals produced no significant differences ($p > 0.05$) between any interventions pre-match, and immediately post-match when assessing CK (ng/mL), CMJA (cm), muscle oedema (cm) and PMS, however at 48 hours post-match, PMS significantly reduced following AR ($p = 0.003$, η^2: 0.644, 95% CI 0.281 to 0.999) and CWI ($p < 0.001$, η^2: 0.766, 95% CI 0.478 to 1.162) when compared to SS. Assessments of CK at 48 hours post-match significantly reduced following AR ($p = 0.020$, η^2: 0.468, 95% CI 0.334 to 3.066), and CWI ($p = 0.031$, η^2: 0.430, 95% CI 0.255 to 4.205) when compared to SS.

In order to determine the effects of recovery interventions on the percentage change of CK, CMJA and PMS, further statistical analysis was conducted. This analysis, consistent with previous research (Pooley, et al., 2017; Duffield, et al., 2010; Howatson, et al., 2009; Ingram, et al., 2009; Goodall & Howatson, 2008; Montgomery, et al., 2008; Gill, et al., 2006), also eliminated the potential inter-individual variability of CK. Results showed a significant reduction in CK following AR ($p = 0.014$, η^2: 0.507, 95% CI 20.106% to 135.634%), and CWI ($p < 0.001$, η^2: 0.794, 95% CI 67.572% to 151.769%) when compared to SS at 48 hours post-match (Figure 1). A significant reduction in CK values following CWI recovery intervention at 48 hours post-match was also reported ($p = 0.049$, η^2: 0.366, 95% CI 0.217% to 62.383%) when compared to AR. Percentage change from pre-competition levels at immediately post- and 48 hours post-match between conditions were also analysed for CMJA and PMS, with results showing significant differences were identified between SS and AR ($p = 0.016$, η^2: 0.494, 95% CI 1.530% to 11.390%), and SS and CWI ($p = 0.001$, η^2: 0.693, 95% CI 3.811% to 11.509%) at 48 hours post-competition (Figure 2) when assessing CMJA, whilst significant differences at 48 hours post-match between SS and AR ($p = 0.005$, η^2: 0.605, 95% CI 33.284% to 137.016%), and SS and CWI ($p = 0.001$, η^2: 0.725, 95% CI 57.452% to 157.208%) were identified when assessing PMS (Figure 3).

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Discussion

The main findings from the present study showed CWI and AR significantly attenuate markers of muscle damage over a 48 hour period in comparison to conventional SS.

Immediately post-match, no significant differences between recovery intervention groups were identified for all markers of muscle damage, suggesting the exposure to soccer matches elicited a consistent level of muscle damage allowing for an accurate comparison of the effects of recovery interventions at 48 hours post-match. All indicators of muscle damage (CK, PMS, CMJA) revealed a significant increase immediately post-match when compared to pre-match values, demonstrating that competitive youth soccer matches significantly induce muscle damage, which further supports the findings of previous research (Pooley, et al., 2017), and highlights a demand for the use of effective recovery interventions to assist in returning athletes to their pre-competition status.

When considering the effects of SS and AR on the attenuation of CK, markers of CK taken at 48 hours post-match were significantly reduced in comparison to post-match values, however were also significantly elevated when compared to pre-match values. This would suggest that full recovery hadn't occurred at 48 hours post-match, although when analysing the effects of CWI on CK, data collected 48 hours post-match showed a significant reduction in comparison to that collected immediately post-match, with no significant difference between pre-match and 48 hours post-match with CK values returning to baseline. These findings contradict those of Ascensão et al. (2011) who, although presenting significant differences in CK values following CWI and thermoneutral recovery interventions, found CK remained elevated at 24-, and 48-hours post-match in comparison to pre-match data, therefore not returning to baseline. The differences in findings may be attributed to the use of a one-off soccer match by Ascensão and coworkers for sample collection – potentially exposing participants to physical outcomes of soccer matches that are outside an average range, therefore affecting the validity of their findings. The present study showed no such limitations and so adds to the existing evidence for support of CWI as a recovery intervention following elite youth soccer matches. Further research comparing the changes in CK levels following recovery interventions can be compared to the present study. Gill et al. (2006) report a recovery percentage of CK at 36 hours post-match at ~60% following an AR intervention, with the recovery percentage improving to 88% at 84 hours post-match. Although time intervals used by Gill and others differ from those used in the present study, the recovery trends are complementary, with both interventions having a positive effect on CK following exposure to game situations at 48 hours post-match in the present study and 36 and 84 hours post-match in the study of Gill et al. (2006). Furthermore, Goodall and Howatson (2008) report a significant reduction in CK at 48 hours post-eccentric exercise when compared to values taken at 24 hours post-exercise following CWI, again supporting the findings of the present study. It has been suggested that exposure to CWI following exercise may elicit a reduction in capillary permeability (Broatch, 2015), as a result attenuating the efflux of CK from damaged muscle fibres. This theory may provide an explanation for the reduction in CK at 48 hours post-match following CWI intervention, and the return of CK to baseline measure seen in the present study. Although capillary permeability was not measured in the present study, this may be an area for further investigation in future studies.

A comparison of CMJA performance across time intervals showed a significant increase in jump height at 48 hours post-match when compared to values recorded immediately post-match in all three conditions suggesting muscle recovery had occurred, however when comparing values recorded at 48 hours post-match to pre-match measures following the SS intervention, jump heights remained significantly lower. In comparison AR and CWI interventions showed no significant differences between pre-match and 48 hour post-match jump heights suggesting that performance indicators of muscle damage have returned to baseline, and participants had fully recovered (Table 1; Figure 2). These results support the findings of Elias et al. (2013) who reported a return to baseline in performance markers (CMJA and sprint time) at 48 hours post-match following a CWI intervention (14 min submersion at

12˚C) when monitoring male professional soccer players. Additionally, Ascensão et al. (2011) reported a significant reduction in CMJA performance at 24 hours post-match when compared to baseline values, however no significant differences between baseline and CMJA performance at 48 hours post-match were found, suggesting the AR intervention assisted in returning performance markers to baseline values, and supporting the findings of the present study. As described by Peake et al. (2017), one potential mechanism that may explain muscle damage is the 'popping sarcomere theory', whereby muscle damage is caused following eccentric muscle contractions, where sarcomeres are overstretched beyond the point of filament overlap and is likely to result in a reduction in force production, as seen in the present study with reduced CMJA heights immediately post-match. It may be possible that the use of SS as a recovery mechanism exacerbates muscle damage by stretching further sarcomeres beyond the point of filament overlap. Peake and others (2017) also suggested that stretching of sarcomeres may open stretch-activated channels allowing calcium to enter the cytosol through these open channels of the sarcolemma which may in turn stimulate Calpain enzymes to degrade contractile proteins, providing further reductions in force production. The stimulation of Calpain enzymes and degradation of contractile proteins was not measured in the present study, however may be an area for consideration in future studies.

When considering PMS, measurements of all three recovery interventions at 48 hours post-match demonstrated a significant improvement from values recorded immediately post-match, however all remained significantly elevated compared to pre-match data. This would suggest that although perceived soreness had improved, the recovery process was yet to be completed. These findings support those of Pooley et al. (2017) who demonstrated PMS remained elevated at 48 hours post-match when comparing SS to passive recovery. The findings of the present study suggests that even with the addition of AR or CWI interventions, perceived soreness remains elevated. These findings may be of benefit to coaches to recognise that although some physiological and performance markers of muscle damage suggest muscle recovery has occurred, athletes perceptions suggest otherwise and therefore may demonstrate a reduced exertion resulting in reduced performance in sessions in the days immediately following competitive soccer matches, potentially as a protective mechanism for the prevention of injury or further damage. These findings should be taken in to consideration by coaches, alongside the technical and tactical aims of training sessions.

When comparing the effects of recovery interventions on PMS at 48 hours post-match, AR and CWI demonstrated significantly lower values than SS, suggesting these interventions provide a superior recovery benefit, however no differences between AR and CWI were identified which may imply both interventions provide similar levels of recovery effects. It has been suggested that the use of CWI as a recovery intervention may assist in reducing perceived soreness (Broatch, 2015) due to reduced firing rate of pain sensory receptors in the skin after cooling and therefore reducing the pain sensation. Furthermore, Broatch (2015) suggests CWI induced vasoconstriction may reduce perceived pain via reduced inflammation and the osmotic pressure of exudate, therefore decreasing pressure exerted on pain signalling nociceptors.

Analysis of the effects of SS, AR and CWI on CMJA revealed no significant differences between any recovery interventions, suggesting AR and CWI provided no greater recovery benefit than SS. As such, analysis was undertaken using a recovery percentage, aligning baseline values. When analysing data in the form of percentage change, pre-match values were set to 100%. The purpose of this was to remove the inter-individual variance of markers of muscle damage, whilst determining the recovery percentage at 48 hours post-match in comparison to baseline figures to establish intervention effectiveness. PMS percentage change revealed a significant reduction for AR and CWI when compared to SS at 48 hours post-match. Furthermore, a significant improvement between 48 hour post-match and immediate post-match data was identified for all recovery conditions, with no significant differences identified between pre-match and 48 hour post-match PMS for AR and CWI suggesting an improved recovery effect in comparison to SS. The significant reduction in PMS following CWI when compared to SS may be supported by the findings of Elias et al. (2013) who reported CWI interventions the most effective for reducing perceived muscle soreness following a practice match of professional male soccer players. As aforementioned, these findings may be attributed to CWI dampening the neural signalling, reducing the firing rate of pain sensory receptors in the skin after cooling resulting in reduced sensation of pain (Broatch, 2015).

Analysis of CK data in the form of percentage change at 48 hours post-match also shows a significant reduction in AR and CWI values when compared to SS, suggesting both interventions provide a significant recovery benefit. Again these findings support those of previous research – Ascensão et al. (2011) report a significant improvement in CK at 48 hours post-match following CWI when compared to a thermoneutral intervention, suggesting the vasoconstriction effects of the CWI protocol assisted in the removal of waste products and inflammatory cytokines (Broatch, Petersen, & Bishop, 2018) following soccer match exposure. Similar findings were made by Gill et al. (2006), reporting a significant improvement in CK as a result of AR when compared to a passive recovery intervention, however this was found at 84 hours post-match. The AR intervention utilised in the present study was based on that of Gill et al. (2006) and with such positive findings would suggest a similar outcome would have been witnessed by Gill and others had measures been taken at 48 hours post-match. Interestingly, the present study found a significant reduction in CK following CWI when compared to AR, suggesting CWI may be a superior recovery intervention for elite young soccer players.

A significant improvement in 48 hour post-match CMJA performance in the form of percentage change was identified when comparing AR and CWI to SS. The findings of this study support previous research conducted by Gill and co-workers (2006) stating a significantly improved recovery effect when comparing AR to PR assessments of elite adult rugby players. However, the significant improvement in markers of muscle damage following the AR intervention have been conflicted by findings of more recent research on elite youth soccer players produced by Tessitore et al. (2007), with no significant differences between recovery interventions being identified. The differences in these results may be due to the AR intervention that was implemented, as that used by Tessitore and others (2007) consisted of 8 minutes walking, 8 minutes jogging and 4 minutes of dynamic movements – a protocol that, although longer in duration, may have been lower in intensity, resulting in a lower systemic blood flow than the AR intervention of the present study, potentially limiting the removal of blood toxins in skeletal muscles and allowing for possible further damage to be caused by pro-inflammatory cytokines (Chazaud, 2016), although further research to confirm these suggestions and compare the effectiveness of both AR interventions may be required. Positive findings for the CWI intervention may be attributed to reduced fluctuations of limb blood flow as demonstrated by Fiscus, Kaminski, and Powers (2005). Pieffer, Abbiss, Nosaka, Peake, and Laursen, (2009) report a reduction in femoral venous diameter following cold water immersion post-exercise (20 minutes submersion at 14.3˚C) which remain for up to 45min post-intervention at which point, sample collection was terminated. This may suggest CWI interventions provide an enhanced recovery benefit due to a continued reduced muscle temperature and femoral venous diameter in the time following intervention termination, potentially providing an enhanced recovery when compared to alternative interventions.

In conclusion, the results of this study showed CWI and AR significantly attenuate markers of muscle damage over a 48 hour period in comparison to conventional SS. The findings of the present study support previous research (Elias, et al., 2013; Ascensão, et al., 2011; Ingram, et al., 2009; Gill, et al., 2006), suggesting AR and CWI significantly improve indicators of muscle damage following competitive sporting matches, whilst providing new evidence to support the use of AR and CWI as recovery interventions for elite young soccer players following competitive soccer matches. The findings of 48 hour post-match values of CK and CMJA returning to pre-performance measures following the CWI intervention may indicate this is a superior recovery intervention over AR, however this would require further investigation. Owing to the mode of AR protocol used in the present study, the practicality of a soccer team completing a CWI intervention may be advantageous, along with the superior significant findings when deciding the intervention of choice.

Practical Implications

In light of the current findings, it may be advised that CWI and AR interventions provide an enhanced recovery effect when compared to SS. Additionally, there would appear to be limited differences in recovery benefit between CWI and AR, suggesting use of either protocol would provide similar and significant improvements in muscle recovery, however it is feasible to predict that a combination of both AR and CWI may provide superior recovery benefits than either alone, although the order of intervention use must be considered. The findings of this study would suggest that, in the absence of CWI (in cases such as away fixtures), the use of AR would provide a significant recovery benefit similar to that of CWI, however again mode of intervention must be considered for practicality, as the AR protocol used in the present study requires cycle ergometers. Should similar recovery results be found using little or no equipment, AR on away fixtures may be advised for improving markers of muscle damage at 48 hours post-match. It must also be considered that PMS remains elevated at 48 hours post-match, regardless of the effectiveness of recovery intervention, potentially resulting in reduced physical exertion of athletes in subsequent training sessions or possible injury should coaches chose to ignore perceived soreness and plan sessions based on physiological markers of muscle damage. In applied settings such as elite academy football it may be recommended that recovery interventions are sought after all competitive soccer matches (home and away) to assist in reducing muscle damage at 48 hours post-match.

Limitations

It must be noted that, whilst this study compared the effects of SS, AR and CWI, the SS recovery intervention was implemented upon completion of away soccer matches only, whilst AR and CWI recovery interventions were implemented following home soccer matches only. Although the muscle damage inflicted from competitive game did not differ significantly between conditions therefore allowing for comparisons between recovery interventions, this study did not account for the potential effects of uncontrollable factors, such as the travel to and from games.

Acknowledgements

The authors wish to thank all the participants who volunteered their time for this study and in doing so made the completion of this research possible.

Competing Interests/Funding

The authors confirm they have no financial interests related to any of the material in this manuscript. No financial support was sought. No conflicts of interest are declared.

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Table 1. Comparison of mean (+ SD) physiological, psychological and performance markers of muscle damage at pre-, post- and 48hrs post-competitive soccer matches in recovery interventions (n=15).

	Assessment time point		
	Pre	**Post**	**48hrs Post**
PMS (0.5-5)			
SS	1.2 (0.2) [b]	4.1 (0.3) [a]	3.0 (0.3) [a] [b]
AR	1.6 (0.5) [b]	4.1 (0.2) [a]	2.3 (0.3) [a] [b]*
CWI	1.7 (0.5) [b]	4.0 (0.5) [a]	2.1 (0.4) [a] [b]*
CK (ng/mL)			
SS	2.8(1.7) [b]	7.4(2.2) [a]	5.5 (2.4) [a] [b]
AR	3.0(1.0) [b]	7.5(1.3) [a]	3.8 (1.0) [a] [b]*
CWI	3.2(1.2) [b]	7.4(2.9) [a]	3.2 (1.2) [b]*
CMJA (cm)			
SS	46.6 (6.4) [b]	40.7 (8.0) [a]	43.4 (7.2) [a] [b]
AR	44.8 (5.0) [b]	41.1 (4.1) [a]	44.4 (4.1) [b]
CWI	44.2 (5.3) [b]	40.2 (4.7) [a]	44.4 (5.2) [b]
OedemaG1(cm)			
SS	26.2 (2.6)	26.5 (2.6)	26.9 (2.7)
AR	25.2 (1.5)	25.7 (1.4)	25.6 (1.5)
CWI	25.0 (1.7)	25.6 (1.5)	25.9 (2.0)
OedemaG2 (cm)			
SS	35.7 (2.1)	35.5 (2.0)	35.6 (1.9)
AR	34.7 (1.9)	35.2 (1.9)	34.9 (2.0)
CWI	34.6 (2.0)	35.0 (1.7)	34.3 (1.8)
OedemaQ (cm)			
SS	49.2 (4.0)	50.1 (4.1)	49.9 (4.0)
AR	49.7 (2.6)	50.3 (2.7)	50.0 (2.8)
CWI	49.3 (2.9)	50.3 (3.0)	49.6 (2.7)

[a] $p < 0.05$ = significantly different from Pre; [b] $p < 0.05$ = significantly different from Post;
* $p < 0.05$ = significantly different from SS, ▪ $p < 0.05$ = significantly different from AR

SS, static stretching; AR, active recovery; CWI, cold water immersion

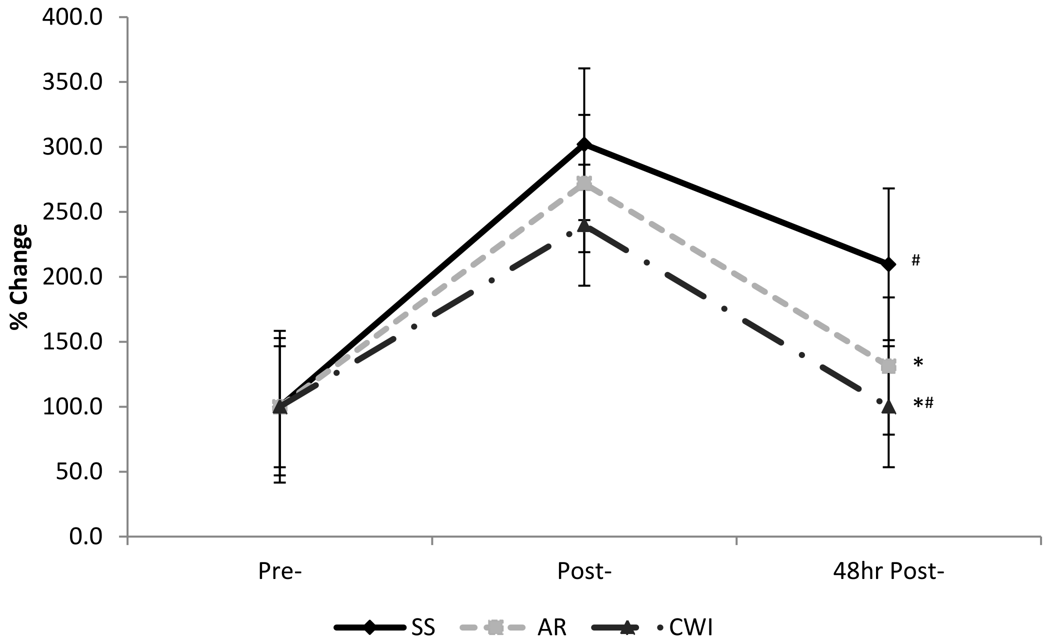

Figure 1. Percentage change in CK (ng/Ml) levels between pre-exercise, immediately post-exercise and 48 hours post-exercise, grouped by condition (SS, static stretching; AR, active recovery; CWI, cold water immersion). Error bars represent SE at respective time points. *$p < 0.05$, significantly different from SS. $^{\#}p < 0.05$, significantly different from AR (n=15).

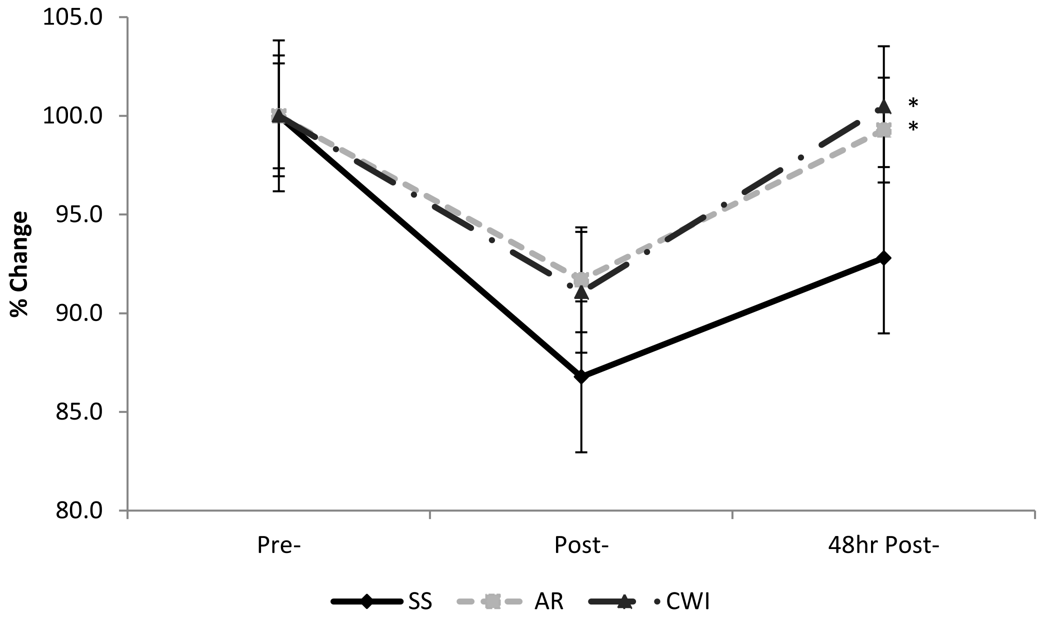

Figure 2. Percentage change in CMJA (cm) performance between pre-exercise, immediately post-exercise and 48 hours post-exercise, grouped by condition (SS, static stretching; AR, active recovery; CWI, cold water immersion). Error bars represent SE at respective time points. *$p < 0.05$, significantly different from SS (n=15).

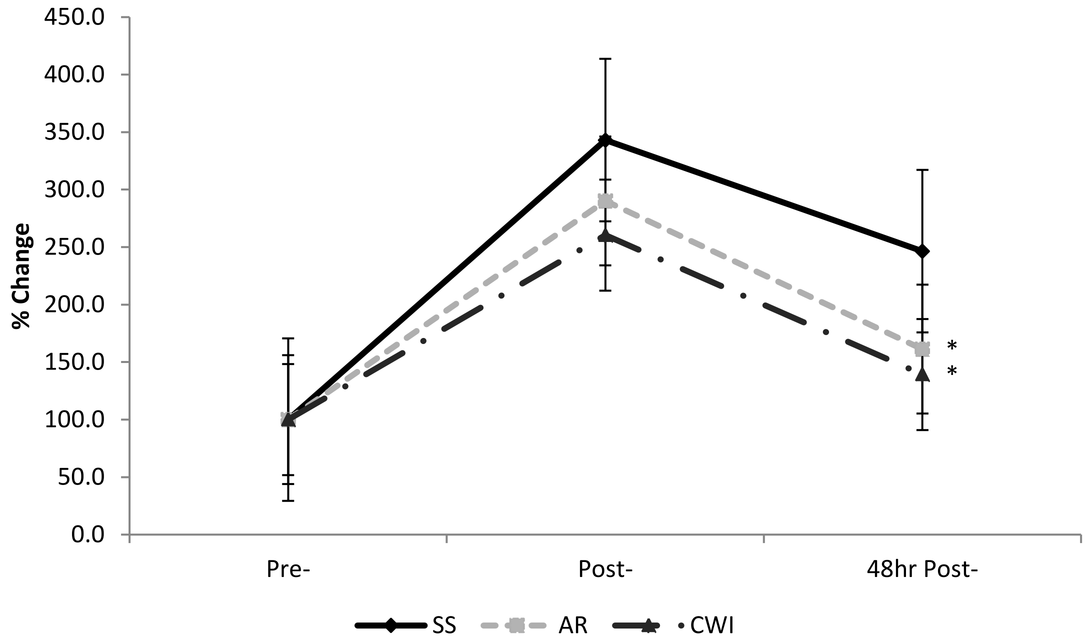

Figure 3. Percentage change in PMS between pre-exercise, immediately post-exercise and 48 hours post-exercise, grouped by condition (SS, static stretching; AR, active recovery; CWI, cold water immersion). Error bars represent SE at respective time points. *$p < 0.05$, significantly different from SS (n=15).