Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

Preedee Khaniyo

Effects of post-match cold water immersion on next day recovery in professional soccer players

Master's thesis in Physical Activity and Health (Exercise Physiology)
Supervisor: Ulrik Wisløff
Co-supervisor: Arnt Erik Tjønna
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NTNU
Kunnskap for en bedre verden

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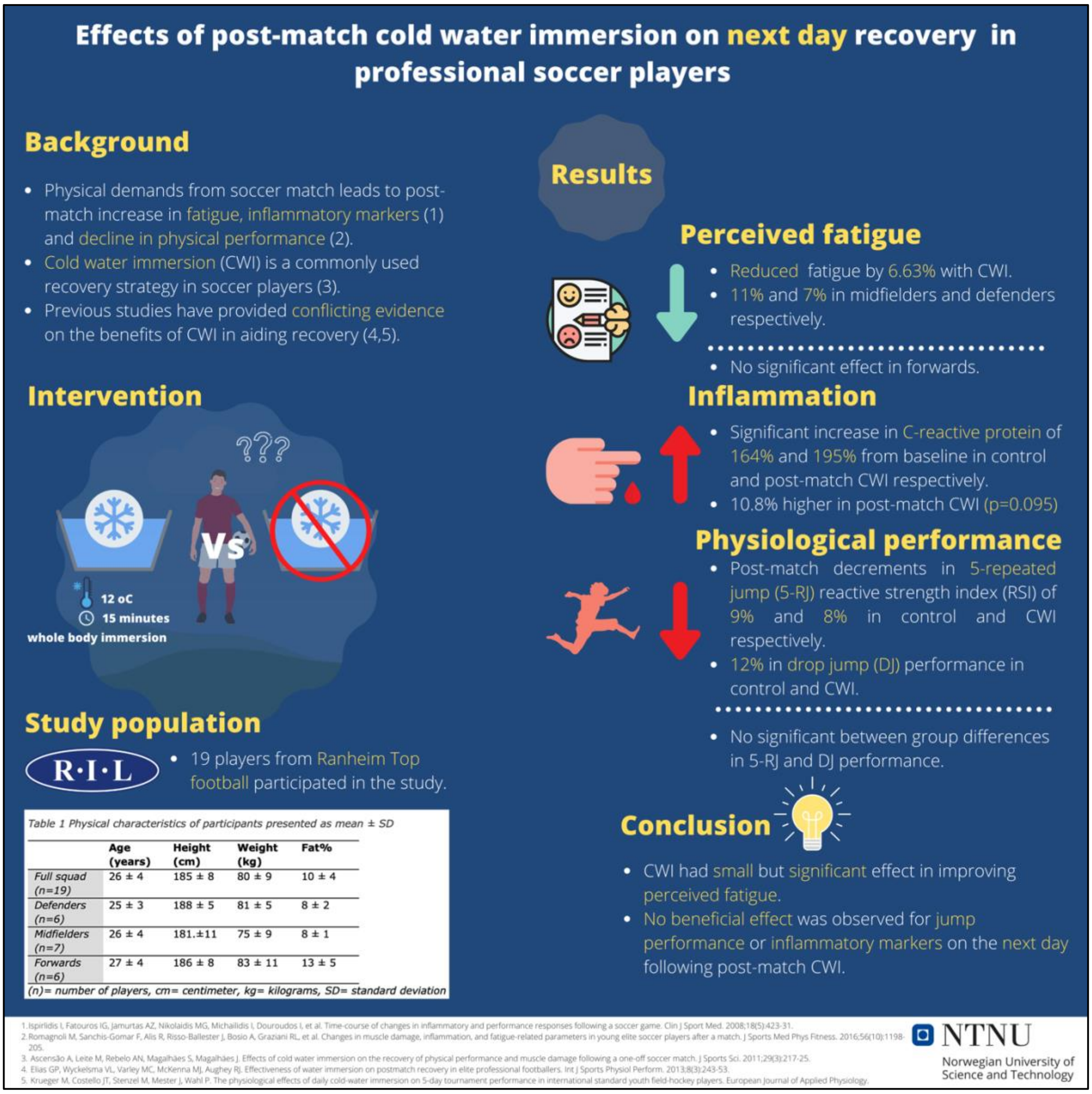
Infographic



Abstract

Introduction: Physical demands from a soccer match results in decline of physiological performance and disturbances in biochemical markers. Cold water immersion (CWI) is a recovery strategy commonly used among soccer players to accelerate recovery process. The aim of this study was to investigate effects of post-match CWI on perceived fatigue, inflammation, and physical performance in elite soccer players.

Methods: 19 male soccer players from Ranheim Top football participated in the study. Post-match CWI (experimental) at 12°C for 15 minutes was used as a recovery strategy for home matches while on away matches participants received no CWI (control). Next day perceived fatigue was measured using rating of fatigue (ROF) scale, C-reactive protein (CRP) was measured to quantify inflammatory response as well as 5-repeated jump (5-RJ) test and drop jump (DJ) test as assessment of recovery of physical performance

Results: Post-match CWI reduced perceived fatigue by 6.63% (p=0.003) compared to control. Most noticeable effect were observed in defenders (-7.20%, p=0.04) and midfielders (-11.08%, p=0.013). Post-match CWI resulted in a trend towards higher rise in CRP levels from baseline compared to the no CWI (195% vs 164%, p=0.095). No significant differences were observed for post-match CWI ability in limiting decrements in jump performance in either 5-repeated jump or drop jump test compared to no CWI.

Conclusion: Our findings indicate that CWI was more effective than control in improving perceived fatigue. No beneficial effect was observed for jump performance or inflammatory markers on the next day following post-match CWI.

Keywords: soccer, recovery, cold water immersion, fatigue, inflammation, jump performance

1. Introduction

Soccer matches imposes a huge physiological demand on the body of the players. Throughout the game, players cover a total distance of around 10 000 meters while performing game skills such as jumping, tackling, sprinting, turning, kicking, and maintaining balance (1). An elite level competitive season include up to as many as 60 matches. The high number of matches may require a team to play 2 games per week. Participation in competitive matches every 4 days can increase the risk of overuse injury up to six times when compared to being given >6 days for recovery (2, 3). Due to the COVID-19 pandemic the duration of the 2020 season was shortened and leading to that most weeks included two official matches per week. Therefore, it is important to restore the athletes to pre-match levels as quickly as possible. Decline in physical performance following a 90-minute soccer match has been reported by numerous studies. This decline in performance can last for 48h to 96h (hours) depending on the physical variables assessed (4-6). Noticeable decrease in performance can be observed in skills such as repeated sprint ability, jumps and maximal strength. In a study by Rampinini et al, significant decline of 11% and 3% from baseline values in physical skill performance such as maximal voluntary contraction (MVC) and sprint performance respectively, were observed post-match in elite soccer players. Recovery of physical performance to pre-match values were observed after 48h (5). In another study by Romagnoli et al, countermovement jump (CMJ) height was recorded 30 minutes pre-match. The pre-match values were compared to 24h and 48h post-match. The CMJ height remained lower at both time intervals. CMJ height did not recover to pre-match values at 48h post-match. Another study also revealed similar findings. The jump performance remained lower than pre-match values for up to 72h (6). Other physical variables such as 20m sprint ability and lower extremity strength measures of the quadriceps and hamstring using knee extension and flexion remained significantly lower compared to pre-match values (4).

Physical demands from a competitive match have been shown to alter biochemical markers of athletes. Markers for exercise-induced muscle damage (EIMD), inflammation and hormonal parameters are the most relevant biomarkers for recovery process (7). Creatine kinase (CK) is a marker of muscle damage. In soccer players, increased levels of CK have been observed following a competitive match. Numerous studies point to CK reaching its highest values at 24, 48 and 72h post-match (8-10). CK concentrations has been shown to be physical load dependent. In a weekly micro-cycle, first division football players exhibited highest concentrations during the beginning of the week and lowest on the last day of the micro-cycle, corresponding to the trend of a gradual decrease in physical load observed throughout the week (11). Muscle damage caused by the physical demands of the competition initiates an inflammation process involving the release of inflammatory cytokines. Muscle repair and regeneration lasts for up to 72h during which the levels of cytokines remains elevated (7). C-reactive protein (CRP) is a highly sensitive protein and a biomarker of inflammation. CRP levels can be elevated due to conditions like infection, cardiovascular disease, and cancer. Elevated CRP levels has also been shown following strenuous exercise (12). Peak values for CRP were observed 24h post-match for both male and female soccer players. The values returned to pre-match levels at 48h following a soccer match (10). Studies showed that increase in CRP from pre-match levels can reach up to 120-150% at 24h post-match (10, 13). Immediate post-match CRP response to physical stress has been shown to be up to 66% increased (13). Ongoing elevated levels of these biomarkers can lead to increased risk of overuse injury (14). Therefore, recovery interventions accelerating the process of recovery may provide a competitive advantage and decrease the risk for injury.

Recovery plays a significant role in athletic success. Numerous recovery strategies have been used to accelerate the process of recovery to pre-match levels. Cold water immersion (CWI) is one of the most used recovery strategies among soccer players (15-17). Temperature in cold water immersion is defined as temperature less than 15°C (18). CWI promotes recovery by exerting compressive forces through hydrostatic pressure which increase with the depth of immersion. Vasoconstriction due to cold temperature limits blood flow to the periphery leading to decreased oedema and inflammation (18). Numerous physiological alterations promoting recovery have been reported following post-exercise CWI. CWI promotes recovery through both acute and long-term mechanism. Some notable mechanism includes removal of local metabolic by-products and reductions in EIMD (9, 18, 19). CWI has also been shown to be effective in improving perception of fatigue and soreness following competition (15-17, 20). According to a review by Broatch et al, studies have shown that post-exercise CWI provides benefits towards improved recovery of muscle strength, aerobic exercise performance, inflammation, and muscle soreness. There is no evidence regarding CWI having detrimental effect on athletes (21). Moreover, CWI has been shown to be more effective compared to other immersion techniques such as contrast water therapy (CWT) and thermoneutral water immersion (TWI) (15, 22). A study by Elias et al showed that CWI 12°C for 14 minutes effectively restored sprinting performance close to baseline levels at 24h and complete restoration at 48h. Static jumps and countermovement jump (CMJ) performance improved significantly compared to CWT and passive recovery in Australian professional footballers (22). Ascensão et al showed that post-match CWI was more effective than TWI in recovery of perceptual marker of delayed onset muscle soreness at 24h, and inflammatory response and squat jump performance at 48h in soccer players (15). A study in male junior soccer players showed that post-match CWI during a 4 day soccer tournament was effective in limiting decrements in match running performance during subsequent matches compared to TWI (16). Post-exercise CWI has also been shown to improve performance in trained athletes. In a study by Vaile et al, male endurance trained cyclist receiving CWI following 105 minutes of fatigue inducing cycling protocol which included 66 maximal effort intervals of 5-15s improved cycling sprint and time trial performance compared to passive recovery on day 4 and 5 of testing (23). Variations of immersion depth has been used among studies on post-exercise CWI. A meta-analysis has shown that whole body immersion protocol was more effective compared to partial body (legs or arms only) immersion protocol in terms of performance recovery (24). Despite numerous reported benefits of CWI on recovery, data on professional soccer players and its application in a competitive season is still lacking.

On the contrary there are studies showing CWI to be ineffective in improving physical performance, perceived fatigue, and biochemical markers of recovery (20, 25). Recent study has shown that daily whole body post-exercise CWI at 6°C for 5 minutes in German youth hockey players did not improve the match performance during a five-day tournament. Moreover, markers of muscle damage, CMJ and repeated sprint ability were indifferent when compared to passive recovery (20). Similar findings was reported by Rupp et al, that lower body post-exercise CWI at 12°C for 15 minutes did not improve yo-yo intermittent recovery test performance, perceived fatigue and CMJ performance compared to control in collegiate soccer players (25). Furthermore, Kositsky et al, showed that improvement in jump performance following CWI was accompanied by impaired jumping biomechanics. This suggests that the jumps were performed at less efficiency due to decreased ankle joint stiffness (26). The conflicting result among studies challenges the idea of implementing post-match CWI as a recovery strategy for professional soccer players in a competitive season.

The purpose of this study was to investigate the effects of post-match CWI in professional soccer players on perceived fatigue measure, biochemical and physical performance markers of recovery on training session next day. We hypothesize that post-match CWI will be more effective in improving the perceived fatigue score compared to control. Post-match CWI will be more effective in limiting the decrements in jump performance compared to control. Post-match CWI will be more effective in limiting increased inflammatory response compared to the control on next day training session.

2. Materials and Method

2.1 Subjects

The population included was professional soccer players from a local club in Trondheim, Norway. Ranheim Top football competes in the Norwegian First Division league (OBOS Ligaen). A total of 19 players (physical characteristics represented in Table 1) were involved in the study. The study was registered and approved by the Norwegian Centre for Research Data (NSD). Players were informed about the study protocol and the players gave written consent to participate in the study. Defenders, midfielders, and forwards were involved in the study, whereas goal keepers were excluded.

2.2 Experimental design

The study took place during the OBOS League 2020 season from July 3, 2020 to December 19, 2020. The participants were informed about the study protocol and underwent a familiarization session during the first week of the season. The study is a within subject experimental design study. The participants underwent CWI after home match and no CWI following away match. The data were collected on the training session the following day. Data were collected for players that played at least 60 minutes during the match. Data for home matches was then compared with away matches to see the effect of post-match CWI on next day perceived fatigue, inflammation, and restoration of physical performance. Figure 1 depicts the experimental design for this study. Immersion protocol and tests for recovery are described in the following sections.

2.3 Immersion protocol

The players were exposed to CWI approximately 20 minutes after every home game. The players followed the protocol that included whole body immersion (up to shoulder level) at 12^{o}C ± 1^{o}C for 15 minutes. The water temperature was maintained using crushed ice. The room temperature was maintained in the range of 20-24^{o}C.

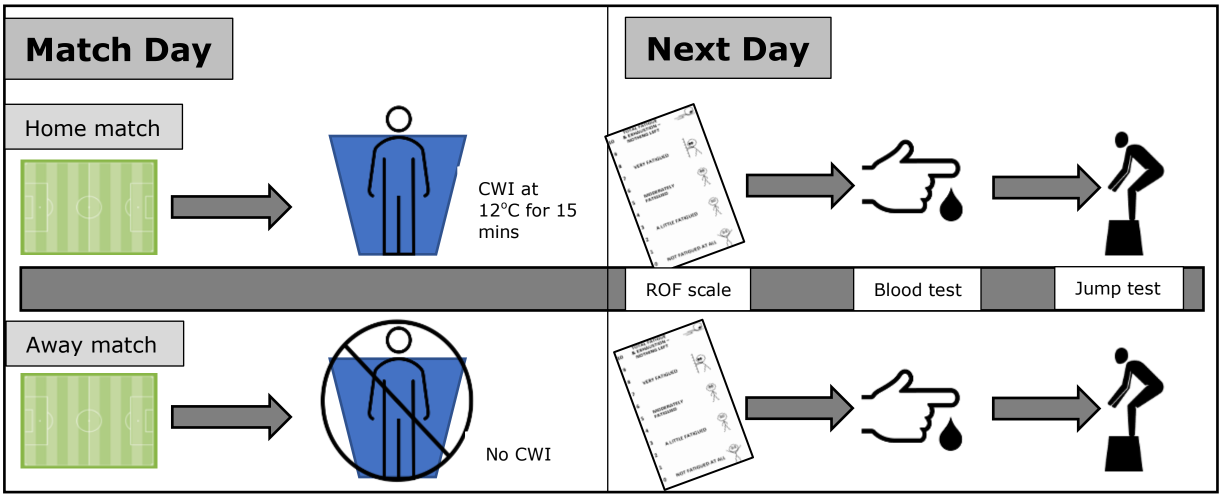


Figure 1 Illustration representing experimental design. Rating of fatigue (ROF) scale by Micklewright et al 2017 (27).

2.4 Perceived marker of fatigue

Perceived fatigue on the day after each match were evaluated using the rating of fatigue (ROF) scale (Appendix A, Figure 2). The easy-to-understand scale has 11 numerical points and 5 diagrams that represent fatigue at various levels. The scale ranges from 0 (no fatigue at all) to 10 (complete exhaustion). Guidelines for reporting perceived fatigue were provided verbally by test leader to the participants as described by Micklewright et al (27). Participants were explained fatigue level at various diagrams and numerical points from 0 to 10. Participants were instructed to report by only using numerical value on the ROF scale. Participants were instructed to avoid reporting two numbers for example, "I feel between six or seven today"(27).

2.5 Biochemical marker of inflammation (CRP - C-reactive protein)

The capillary blood sample collection was performed using the fingerpick method. The index and middle finger were used depending on the softness of the fingertips which would allow easy puncture of the finger and limiting the finger squeeze as much as possible. The blood sample were analyzed using *QuikRead go® easy CRP kit (Aidian Oy, Espoo, Finland)*. The instrument measures CRP levels in the blood ranging from 1-200 mg/L.

Sample collection were made according to protocol described in the *QuikRead go® easy CRP kit* manual. The blood sample was collected using a 10µl blood collection tube placed horizontally against blood avoiding contact with the skin surface. Blood sample tube was then transferred into the cuvette containing the buffer. The cuvette was closed tightly using *easy CRP reagent cap*. The cuvette was then inserted into the *QuikRead go® instrument* ensuring the side of the barcode faces the front of the instrument. The instrument then displays the result within 3 minutes.

2.6 Physiological Performance marker

SMARTJUMP system (Fusion sport, Nottingham, United Kingdom) was used to quantify the jump performance data. The kit involved *SMARTJUMP jump mat (Fusion sport, Nottingham United Kingdom)* and companion application on iOS device *SMARTSPEED (Fusion sport, Nottingham, United Kingdom)*, on which real time results were obtained. Reactive strength index (RSI) was the output obtained from jump tests. RSI (meters · second^{-1}) is derived from jump height (meters) divided by ground contact time (seconds). RSI has been used to measure performance and training progress, further uses of RSI tests involves neuromuscular fatigue monitoring in competitive team sports (28).

2.6.1 5-repeated jump (5-RJ) test

5-repeated jump test was used to measure athlete's ability to transition quickly from eccentric to concentric contraction. The test serves to replicate the demands of movements performed in sports. In this jump test the athlete assumed a flat-footed position with feet set at shoulder width apart on the jump mat. The athlete was instructed to have the hands on their hips during the jump to eliminate contribution from the force generated by the arms. Athletes were instructed to limit the ground contact time while maximizing jump height over 5 jumps. The athlete was also instructed to land as close as possible on the same spot from which they took off. The RSI recording for the first jump were discarded due to the absence of rebound jump. The RSI of the remaining 4 jumps were averaged and recorded (29).

2.6.2 Drop jump (DJ) test

DJ test measures reactive capacity of an athlete when dropping from a set height. In our study, a 30 cm-box was used as set height from which the participants initiated the jump. In this test the participants first stand on the 30 cm-box facing towards the jump mat with their arms on their hips. Then the athletes were instructed to step-off the box with their dominant leg extended over the mat first before dropping off with both legs. The athlete was instructed to minimize ground contact time and maximize jump height. The athlete was also instructed to land on the same spot on the jump mat from which they took off (30). RSI was then recorded for the jump of each participant.

2.7 Statistical analysis

The data are represented as means ± standard deviations (SD) if not otherwise stated. The data were analyzed using IBM Statistical Package of Social Sciences (IBM Corp. Released 2019. IBM SPSS Statistics for Mac, Version 26.0. Armonk, NY: IBM Corp). The dependent variables were tested for normality using Kolmogorov-Smirnov test. The perceptual, biochemical, and physical performance data were analyzed using Mann-Whitney U test. Cohen's d Effect size (ES) was assessed to indicate the magnitude of changes within the different variables. The changes were categorized into the following: <0.2 = trivial, 0.2-0.6 = small, 0.6-1.2 = moderate, 1.2-2.0 = large. The relationship between marker of inflammation, physical performance and perceptual marker were assessed using Spearman's correlation. Data were deemed to be statistically significant if $p<0.05$.

3. Results

3.1 Physical characteristics

The anthropometric measurements for participants are provided in Table 1.

Table 1 Physical characteristics of participants presented as mean ± SD

	Age (years)	Height (cm)	Weight (kg)	Fat%
Full squad (n=19)	26 ± 4	185 ± 8	80 ± 9	10 ± 4
Defenders (n=6)	25 ± 3	188 ± 5	81 ± 5	8 ± 2
Midfielders (n=7)	26 ± 4	181.±11	75 ± 9	8 ± 1
Forwards (n=6)	27 ± 4	186 ± 8	83 ± 11	13 ± 5

(n)= number of players, cm= centimeter, kg= kilograms, SD= standard deviation

3.2 Perceived fatigue (Rating of fatigue (ROF) score)

Mean ROF score (Table 2) was 6.63% lower after CWI compared with no CWI (p=0.003). CWI had small effect on alleviating perceived fatigue (effect size, ES=0.42). Position specific mean ROF score (Table 2) data analysis showed that midfielders and defenders reported lower perceived fatigue score by 11.08% (p=0.013, ES=0.75) and 7.20% (p=0.04, ES=0.48) accounting for moderate and small changes respectively when exposed to CWI after match. However, despite decrease in mean ROF score for players in the forward position when exposed to CWI, no improvement in fatigue score were detected (p=0.334, ES=0.20).

Table 2 Mean rating of fatigue score. Score ranges from 0 - 10. 0 = not fatigue at all, 5 = moderately fatigue, 10 = complete exhaustion.

	No CWI	CWI	Cohen's d Effect Size
Full Squad (n)	6.49 ± 0.97 (83)	6.06 ± 1.06 * (127)	0.42
Defenders (n)	6.81 ± 0.99 (37)	6.32 ± 1.02 * (47)	0.48
Midfielders (n)	6.5 ± 0.8 (22)	5.78 ± 1.12 * (32)	0.75
Forwards (n)	6.08 ± 0.9 (23)	5.89 ± 0.96 (37)	0.20

**significant decrease in CWI(p<0.05)*
(n) = number of observations, CWI – cold water immersion

3.3 Biochemical marker of recovery (CRP- C-reactive protein)

Mean CRP increased from baseline by 164% in control (p=0.0001) and 195% in post-match CWI (p=0.0001) for full squad (Table 3). Despite higher increase when participants received CWI, there were no significant differences. Post-match CWI elicited close to negligible response in CRP levels on the day following a competitive match (ES=0.13). Position specific analysis showed similar trends for all positions in that there was significant increase from baseline when the participants received post-match CWI and no CWI (Table 3). However, significant differences between CWI and no CWI were not detected.

Table 3 Mean CRP response to post-match CWI and no CWI on the next day.

	Baseline ($mg{\cdot}L^{-1}$)	**No CWI ($mg{\cdot}L^{-1}$)**	**CWI ($mg{\cdot}L^{-1}$)**	**Cohen's d Effect Size**
Full Squad (n)	1.42 ± 0.70 (19)	3.76 ± 3.68 * (73)	4.19 ± 2.7 * (74)	0.13
Defenders (n)	1.37 ± 0.29 (6)	4.72 ± 4.91 * (33)	4.64 ± 2.62 * (31)	0.02
Midfielders (n)	1.63 ± 1.14 (7)	3.41 ± 2.37 * (19)	3.97 ± 2.65 * (18)	0.22
Forwards (n)	1.23 ± 0.1 (6)	2.60 ± 1.37 * (21)	3.88 ± 2.83 * (25)	0.61

**significant change from baseline (p<0.05),*
#significant difference between CWI and Control (p<0.05)
(n) = number of observations, CWI – cold water immersion, CRP – C-reactive protein

3.4 Physiological markers of recovery

3.4.1 5-repeated Jump (5-RJ) Test

Post-match decrements in reactive strength index (RSI) of 9.14% (p=0.042) and 8.12% (p=0.036) for repeated jumps performance of the full squad (Table 4) were observed for control and CWI respectively. Post-match CWI did not improve RSI for repeated jumps in full squad sample (p=0.804, ES= 0.06). Position specific analysis revealed that mean RSI for defenders decreased significantly from baseline values when not exposed to post-match CWI whereas, no significant decrease was detected in defenders receiving post-match CWI (Table 4). However, no significant difference in mean RSI were observed between post-match CWI and no CWI among defenders. No significant decrease in mean RSI from baseline were observed among midfielders and forwards. No significant difference between post-match CWI and no CWI were observed among midfielders and forwards.

3.4.2 Drop Jump (DJ) Test

We observed a 12% reduction in mean RSI during drop jump test after CWI (p=0.003) and control (p=0.012). No significant difference was observed in mean RSI after CWI compared to control situation (Table 5). Position specific comparison for all positions showed no significant decrease in mean RSI from baseline after receiving CWI and no CWI. No difference in mean RSI was observed between control and post-match CWI for all positions (defenders p=0.983, midfielders p=0.239. forwards p=0.575)

Table 4 Mean RSI (m·s⁻¹) for 5-repeated jump test

	Baseline (RSI)	No CWI (RSI)	CWI (RSI)	Cohen's d Effect Size
Full Squad (n)	1.97 ± 0.33 (19)	1.79 ± 0.33* (65)	1.81 ± 0.30* (68)	0.06
Defenders (n)	1.94 ± 0.21 (6)	1.7 ± 0.24 * (33)	1.74 ± 0.24 (28)	0.13
Midfielders (n)	2.0 ± 0.35 (7)	1.93 ± 0.34 (15)	1.83 ± 0.3 (16)	0.31
Forwards (n)	1.97 ± 0.44 (6)	1.86 ± 0.42 (17)	1.87 ± 0.37 (24)	0.01

**significant change from baseline (p<0.05),*
#significant difference between CWI and Control (p<0.05)
(n) = number of observations, RSI – reactive strength index, CWI – cold water immersion, $m \cdot s^{-1}$ - meter·seconds^{-1}

Table 5 Mean RSI ($m \cdot s^{-1}$) for drop jump test.

	Baseline (RSI)	No CWI (RSI)	CWI (RSI)	Cohen's d Effect Size
Full Squad (n)	1.84 ± 0.72 (19)	1.61 ± 0.30 * (64)	1.61 ± 0.32 * (70)	0
Defenders (n)	1.73 ± 0.29 (6)	1.51 ± 0.29 (33)	1.50 ± 0.29 (30)	0.03
Midfielders (n)	1.84 ± 0.38 (7)	1.7 ± 0.26 (14)	1.63 ± 0.33 (16)	0.24
Forwards (n)	1.95 ± 0.29 (6)	1.75 ± 0.33 (17)	1.74 ± 0.30 (24)	0.03

**significant change from baseline (p<0.05),*
#significant difference between CWI and Control (p<0.05)
(n) - number of observations, RSI- reactive strength index, CWI – cold water immersion, $m \cdot s^{-1}$ - meter·seconds^{-1}

3.5 Correlational Analysis

Spearman's correlations between CRP response, ROF score, DJ and 5-RJ test following post-match CWI is presented in Table 6. Significant positive correlation was observed between 5-RJ RSI and DJ RSI values. No other significant correlations were observed.

Table 6 Spearman's correlation between CRP response, Drop jump performance, 5-repeated jump performance and rating of fatigue score after post-match CWI

Correlations Analysis

			ROF	**CRP**	**DJ**	**5-RJ**
Spearman's correlations	*ROF score*	Correlation Coefficient	1.000	-.111	-.111	-.098
		Sig. (2-tailed)	.	.348	.361	.422
		N	118	74	70	69
	CRP (mg.ml-1)	Correlation Coefficient	-.111	1.000	.211	.146
		Sig. (2-tailed)	.348	.	.084	.239
		N	74	74	68	67
	DJ RSI (m.s-1)	Correlation Coefficient	-.111	.211	1.000	.730**
		Sig. (2-tailed)	.361	.084	.	.000
		N	70	68	70	69
	5-RJ RSI (m.s-1)	Correlation Coefficient	-.098	.146	.730**	1.000
		Sig. (2-tailed)	.422	.239	.000	.
		N	69	67	69	69

**Correlation significant at 0.01 (2-tailed)

N – number of observations, ROF – rating of fatigue, CRP – C-reactive protein, DJ – drop jump, 5-RJ – 5-repeated jumps, RSI – reactive strength index

4. Discussion

The main findings in the present study were that post-match CWI had small but significant improvement of recovery when compared to control situation for perceived fatigue score. There was no significant difference in recovery between the post-match CWI and control in biochemical and physiological performance markers of recovery. The purpose for using CWI as a recovery strategy is to limit the EIMD, inflammation and decline in performance (21). However, the results indicate that CWI was not effective in reducing the CRP levels and limiting the decline in jump performance in elite soccer players on the next day following the match. Our results are consistent with other studies conducted on team sport athletes which showed that despite improvement in perceived fatigue there was no beneficial effect in biomarkers of inflammation and physical performance (15-17). Interestingly, a study by Elias et al, with similar CWI protocol showed that post-match CWI in elite Australian footballers was effective in improving perceived fatigue and performance markers like squat jump (SJ), countermovement jump (CMJ) at 24h and 48h (hours) and repeated sprint ability at 48h post-match compared to passive recovery (22). In the present study, the players covered on average 114.9 to 136.3 meters·minute^{-1}, the lowest and highest distances per minute were covered by center backs and attacking midfielders respectively. In comparison Australian footballers in the study by Elias et al, covered an average of 107 meters·minute^{-1}, in addition the game was played for 75 minutes (22). Higher demands in soccer players may explain the differences in potential longer duration required for recovery in physiological performance. However, there are no evidence to support whether CWI may have superior effects on recovery in players accumulating lower physical load compared to players with higher physical load during the match. Further studies are needed to determine whether CWI may have a physical load dependent effect on physiological and biochemical recovery in professional athletes.

C-reactive protein (CRP)

According to systematic review by Kasapis et al, CRP levels consistently increases following strenuous exercise. The mechanism for increase of CRP has not been defined. However, muscle damage following exercise has been shown to trigger the release of interleukin-6 (IL-6). Increased production of IL-6 stimulates the production of CRP. The acute production of CRP is not only dependent on the expression of muscle damage marker creatine kinase (CK), but is also dependent on the muscle mass involved in the exercise (12). Following a soccer match peak value of CRP were observed after 24h (10), the elevated levels can be attributed to muscle mass involved (31) in performing various skill such as acceleration, deceleration, repeated sprints, tackling and jumping in a match (1). Repeated high intensity eccentric muscle contractions have been associated with increased expression of creatine kinase (32) thus leading to stimulation of inflammatory pathway and ultimately CRP synthesis (12, 33). The result in our study shows that following a competitive soccer match there is an increase in CRP of 164% from baseline value in the control. This finding was consistent with the studies from Souglis et al (10) and Ispirlidis et al (13). Contrary to our hypothesis, post-match CWI did not attenuate inflammation on the next day. CRP levels increased from baseline by 195% with post-match CWI, reaching a higher peak value compared to the control. Despite higher increase in CRP levels with post-match CWI, the between group difference of 10.82% was not statistically significant ($p=0.095$). Contrary to the results of the present study, Brophy-Williams et al, showed that immediate CWI at 15^{o}C for 15 minutes (up to mid sternum immersion) in trained male Australian footballers following high intensity exercise session was beneficial (-15%) in significantly attenuating the CRP response at 24h compared to control (4%) from baseline. This was accompanied by superior scores in totally quality recovery perception (TQRP) questionnaire and significantly more shuttles completed in yo-yo intermittent recovery (YIRT) test compared to control (37.9 vs 32.4 shuttles completed respectively) (34).However, other studies did not report significant beneficial effect of CWI at 24h post-exercise for relevant inflammatory markers following resistance exercise protocol in active young men (35) and high intensity sprint exercise protocol in recreationally active men (36). Conflicting results may be explained by the training status of subjects involved in the studies. Systematic review by Kasapis et al also, showed that following exercise training CRP levels were lower in trained compared to untrained subjects. Furthermore chronic physical activity has been associated with lower CRP levels compared to inactive counterparts (12). A study implementing lower body post-match CWI at 10^{o}C for 10 minutes as recovery strategy in soccer players reported elevated CRP levels (approximately 150%) from baseline at 24h post-match (15). Similarly, the present study reported 195% increase from baseline in CRP levels on the next day. However, in their study, post-match CWI did return the CRP levels to baseline at 48h and was more effective than thermoneutral water immersion (TWI) at 24h and 48h post-match indicating an important role of cold temperature in aiding recovery (15). This suggest that optimal recovery of CRP levels in soccer players can be expected at 48h.

Perceived Fatigue

Perceived fatigue measures have been used in numerous studies to assess the athletes' state of readiness and general fatigue (16, 17, 22, 25, 37). In our study post-match CWI was effective in reducing the perceived general fatigue compared to the control condition. Post-match CWI reduced general fatigue by 6.63% ($p=0.003$) for full squad with most noticeable reduction experienced by midfielders and defenders. There was no significant reduction in general fatigue for players at the forward position ($p=0.334$). According to an unpublished match load data for our sample population forwards had significantly higher distance (137.52% and 54.66% respectively) in sprint compared to attacking midfielders and full backs. Forwards also had higher number of accelerations (3.96% and 19.74% respectively) performed compared to attacking midfielders and full backs. Higher intensive physical match demands on the forwards may explain the limited effect of post-match CWI in improving perceived fatigue on the next day. However, there are no evidence suggesting that the effects of CWI on recovery is dependent on the amount of physical load accumulated. Further studies are needed to understand the relationship between accumulated physical load and the effects of CWI on recovery. The reduction in general fatigue with post-match CWI in the present study is consistent with findings in other studies (16, 17, 22, 37). Rowsell et al, reported in their findings that post-match CWI in junior soccer players was more effective compared to TWI in limiting general fatigue which was accompanied by lower rating for leg soreness compared to TWI (16). Similarly, a study by Elias et al, on elite Australian football players showed that CWI at 12°C for 14 minutes (up to xiphoid process immersion depth) was more effective compared to passive recovery in reducing general fatigue at 1h, 24, 48h post-match (22). CWI had a very large effect on reduction of perceived fatigue at 24h compared to passive recovery. This was accompanied by moderate effect in recovery of countermovement jump (flight time: contraction time) performance at 24h (22). However, a post-exercise CWI study employing yo-yo intermittent running test (YIRT) to induce fatigue did not show significant difference in perceived fatigue at 24h and 48h compared to passive recovery group in collegiate soccer players (25). The study employed similar CWI protocol to the present study at 12°C for 15 minutes however, the protocol was a lower body (up to umbilicus) immersion protocol (25), different from the present study which employed whole body immersion protocol. A meta-analysis by Poppendieck et al, showed that whole body immersion protocol was more effective in improving recovery compared to partial body immersion protocol (24). Mechanism regarding alleviation of fatigue through CWI is still unclear though the ability of CWI in reducing the body temperature has been shown to alleviate acute CNS fatigue as discussed by Ihsan et al (19). Moreover, parasympathetic re-activation following CWI has been shown to improve physical performance on the following day despite immediate decrease in performance (19, 38). Further studies are needed to understand the mechanism for improved perceived fatigue following post-match CWI.

Physiological performance markers of recovery

Physiological performance has been shown to be related with CNS fatigue. CNS fatigue is defined as the reduction in voluntary activation and neural drive to the muscle resulting in lowered force production thus impairing physical performance (19). CWI has been shown to improve maximal voluntary contraction (MVC) and jump performance following intense exercise (39) and sports match (22) respectively. CWI has also shown to be better alternative than other immersion methods such as contrast water immersion therapy (CWT) (17, 22) and TWI (9, 15). In this study, and despite improvements in perceived fatigue following post-match CWI, no beneficial effect was observed for either 5-RJ or DJ performance with post-match CWI compared to no CWI. Correlational analysis showed non-significant weak negative linear relationship between ROF score and 5-RJ and DJ RSI (Table 6). Minett et al reported immediate improvement in MVC 1h-post exercise in high heat conditions for CWI group but no difference was observed at 24h-post exercise between CWI and control group (39). On the contrary, Elias et al reported improved jump performance for both CMJ and SJ at 24h and 48h for post-match CWI group compared to passive recovery group in Australian football players (22). Given that the CWI protocol is similar between the present study and the study by Elias et al, improvements in jump performance may be explained by the demands of Australian football match which is played over 4 quarters for 75 minutes (22) compared to 2 halves for a total duration of 90 minutes in traditional soccer. Ascensão et al, reported that CMJ and SJ performance did not return to baseline at 24h post-match following CWI at 10°C for 10 minutes lower body (up to iliac crest) immersion however, in their study CWI was more effective than TWI for restoring SJ performance to baseline at 48h in soccer players (15). Similarly, De Nardi et al also reported that jump performance remained below baseline at 24h post-match however, decrements in jump performance for CWI group was lower compared to passive recovery (17). Results from the present study and other studies suggest that complete recovery of physiological performance following post-match CWI cannot be achieved at 24h post-match (15, 17, 22). However, studies have shown that at least 48h is needed for restoration of jump performance (15, 22). Moreover, repeated sprint ability was restored at 48h post-match in CWI group for Australian footballers (22). Romagnoli et al showed that jump performance in young elite soccer players remained below pre-match levels at 72h post-match (6). Post-match CWI may allow the players to resume high intensity training sessions sooner without the effect of residual fatigue from the previous match.

Previous studies have shown association between improvement in physical performance to lower muscle damage and inflammation biomarkers (15, 19). In our findings CRP response showed non-significant weak positive linear relationship with DJ and 5-RJ RSI (Table 6). Non-significant weak negative linear relationship was observed between CRP response and ROF score (Table 6). Despite non-significant findings, increase in jump performance and perceived fatigue did not show the tendency to correlate with the attenuation of inflammatory response on the next day. A study by Bouzid et al, also reported that recovery of physical performance following CWI did not correlate with lowered CK levels in soccer players (40). This suggest that other factors may be involved in the recovery of physical performance.

Strength and limitations of the study

Studies conducted on professional athletes during the competitive season is challenging. During the competitive season the team faces opponents with differing levels of difficulty. Some matches are more challenging than others thus resulting in differing physical demands. Due to technical limitations match demands/intensity for away matches (control) could not be quantified. Implementation of RPE may present a simple and viable option for quantifying the match intensity in future research. Furthermore, short, and long-distance travel during away games (control) may also have additional impact on perceived fatigue (ROF) compared to home games. To eliminate the additional fatigue factor of travelling and other stresses of away games, future research could be conducted entirely on home games for both post-match CWI and control. This will also help with being able to quantify match demands for both experimental and control situation. However, this would result in fewer CWI sessions in the season. The present study did not control for schedule of the testing sessions. The tests were conducted during different time of day because of variations in training schedule. Next day training schedule were dependent on the varied match schedule, the duration between which were spaced out accordingly. Moreover, the present study did not control for dietary intake.

It is important that data collection does not interrupt athletes' match preparation routine which may have an impact on match play. For example, in this study baseline values for CRP and jump performance were recorded early in the season prior to training session, when the players had 48h of rest. Other studies were able to obtain pre-match values at 30 minutes for CRP levels (15) and jump performance (15, 22). However, their studies were conducted on friendly matches (15, 22). The present study applied simple and non-exhaustive fatigue monitoring tests making it feasible and applicable in professional sport setting (41). Although the competitive season may not be the ideal environment to study the cause-and-effect relationship due to various uncontrollable factors, it does represent a real-world scenario which will help translate the data into real-world practice. Aforementioned considerations for future research will help design a more standardized cause-and-effect study in competitive professional soccer environment.

Conclusion

In conclusion, the present study showed that post-match CWI had small but significant effect in improving perceived fatigue on the next day. No improvements in next day physical performance and inflammatory markers were observed with post-match CWI. Furthermore, no significant correlations were found between perceived fatigue, biochemical and physiological performance markers of recovery.

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Appendix

A. Rating of fatigue (ROF) scale

Rating of Fatigue (ROF) scale (Figure 2) was used to determine the fatigue status of the participants on the following day after the match. The scale includes 11 numerical points from 0 – Not fatigued at all to 10 – total fatigue and exhaustion. The scale contains 5 diagrams for visual aid representing the fatigue at 5 different numerical points (27).

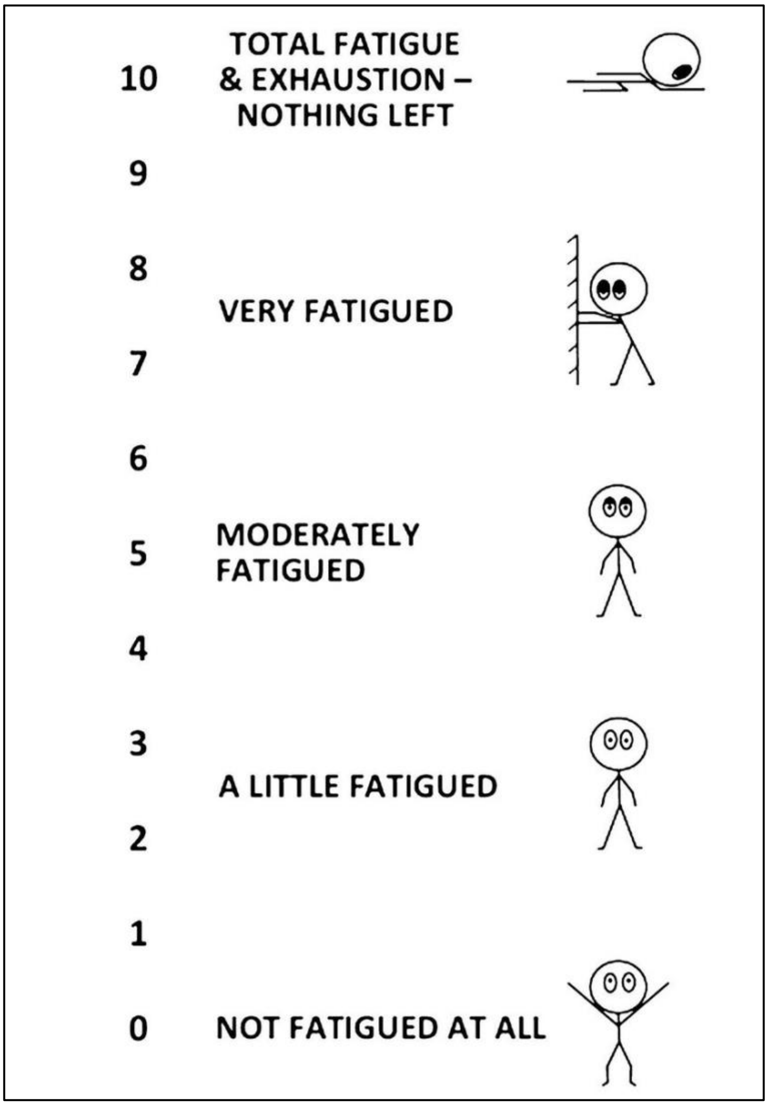

Figure 2 Rating of fatigue (ROF) scale (27)

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