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Short term effects of various water immersions on recovery from exhaustive intermittent exercise.

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Abstract

POURNOT, H., BIEUZEN, F., DUFFIELD, R., LEPRETRE, PM., COZZOLINO, C., HAUSSWIRTH, C. Short term effects of various water immersions on recovery from exhaustive intermittent exercise.

Purpose: To investigate the effectiveness of different techniques of water immersion recovery on maximal strength, power and the post-exercise inflammatory response in elite athletes. **Methods:** Forty one highly trained (Football, Rugby, Volleyball) male subjects (age = 21.5 ± 4.6 years, mass = 73.1 ± 9.7 kg and height = 176.7 ± 9.7 cm) performed 20min of exhaustive, intermittent exercise followed by a 15 min recovery intervention. The recovery intervention consisted of different water immersion techniques, including: temperate water immersion (36°C ; TWI), cold water immersion (10°C ; CWI), contrast water temperature ($10\text{-}42^{\circ}\text{C}$; CWT), and a passive recovery (PAS). Performances during a maximal 30-sec rowing test ($P_{30\text{sec}}$), a maximal vertical counter-movement jump (CMJ) and a maximal isometric voluntary contraction (MVC) of the knee extensor muscles were measured at rest (Pre-exercise), immediately after the exercise (Post-exercise), 1 hour after (Post 1h) and 24 hours later (Post 24h). Leukocyte profile and venous blood markers of muscle damage (creatine kinase (CK) and lactate dehydrogenase (LDH)) were also measured Pre-exercise, Post1h and Post24h. **Results:** A significant time effect was observed to indicate a reduction in performance (Pre-exercise vs. Post-exercise) following the exercise bout in all conditions ($p < 0.05$). Indeed, at 1 h post exercise, a significant improvement in MVC and $P_{30\text{sec}}$ was respectively observed in the CWI and CWT groups compared to pre-exercise. Further, for the CWI group, this result was associated with a comparative blunting of the rise in total number of leucocytes at 1h post and of plasma concentration of CK at 24h post. **Conclusions:** The results indicate that the practice of cold water immersion and contrast water therapy are more effective immersion modalities to promote a faster acute recovery of maximal anaerobic performances (MVC and 30'' all-out respectively) after an intermittent exhaustive exercise. These results may be explained by the suppression of plasma concentrations of markers of inflammation and damage, suggesting reduced passive leakage from disrupted skeletal muscle, which may result in the increase in force production during ensuing bouts of exercise.

Key words: INTERMITTENT EXERCISE, FATIGUE, MUSCLE DAMAGE, RECOVERY, WATER IMMERSION, PERFORMANCE, HIGH TRAINED ATHLETES.

Introduction

A common issue confronting most highly trained team sport athletes is the limited time available for full physiological recovery between training sessions and/or games. Excessive volumes of intense training and competition, particularly with minimal recovery time, can place great physiological constraints on the musculoskeletal system and potentially cause symptoms of overreaching, fatigue and result in the suppression of performance (Reilly and Ekblom 2005). Based on these observations, the need to maximize recovery periods and modalities appears to be important to speed performance restoration. Moreover, training or competition induced EIMD can result in a release of inflammatory mediators and myocellular enzymes into the plasma. Accordingly, serum creatine kinase (CK) has been reported to characterize muscle membrane disruption, and has been extensively measured within the literature as a biological marker of muscle damage (Brancaccio et al. 2008; French et al. 2008; Howatson et al. 2009; King and Duffield 2009; Reilly and Ekblom 2005). Indeed, *in situ* studies report peak plasma concentrations (*i.e.*, creatine (CK), lactate dehydrogenase (LDH), leukocytes) may be associated with the decline in performance during the 48 h following matches (Ispiridis et al. 2008; Rowsell et al. 2009). In addition, Rodenburg (1993) reported a significant positive correlation between percentage of torque loss during a maximal isometric voluntary contraction (MVC) and the level of plasma CK increases. As such, team sport athletes are often exposed to exhaustive and EIMD type activities during generic training and specific competitive bouts, and the use of recovery modes may be of importance to aid preparation for ensuing sessions.

Recovery is defined as the return of the muscle to its pre-exercise state following exercise (Tomlin and Wenger 2001). It is suggested that the use of recovery strategies ensures performance in subsequent exercise sessions (training and/or competition) are not unduly compromised by lingering muscle soreness or decrements in power or speed of movement (King and Duffield 2009). Among different methods of recovery interventions utilised following exercise, water immersion interventions, including, cold, temperate and contrast, are popular procedures used in many sports. Cold water immersion (CWI) is commonly used following acute musculoskeletal injuries to induce vasoconstriction and has recently been proposed to enhance both physiological and perceptual recovery (Bailey et al. 2007; Eston and Peters 1999; Gill et al. 2006). Further, in theory the effects of hydrostatic pressure associated with cold temperature or both hot and cold therapy may result in both muscular and vascular compression and therefore assist the reduction of early onset swelling and inflammation (Goodall and Howatson 2008). The technique of alternating hot-cold water or contrast water temperature therapy (CWT) is proposed to create a “vaso-pumping” action through alternating vasodilatation and vasoconstriction of the blood vessels due to temperature changes

(Cochrane 2004; Hing et al. 2008). The alterations in peripheral vessel constriction are proposed to increase blood flow and enhance the removal of metabolic by-products, consequently speeding recovery (Bailey et al. 2007; Vaile et al. 2008a, b). To date, such recovery interventions are being employed in field environments, despite limited scientific evidence regarding their potential benefits and/or mechanisms by which they may work (Vaile et al. 2008c). Further, treatment protocols vary with regard to the duration and frequency of immersions and the temporal relationship with exercise, possibly explaining the inconsistency in the collection of reported results regarding the recovery of strength and muscle soreness (Goodall and Howatson 2008; Sellwood et al. 2007). Indeed Gill et al. (2006) have reported an enhancement of the rate of CK clearance after an elite rugby match using CWT. Further, this study did not use muscular performance measures to explain the physiological relevance of the CK results to actual performance. In this context, Vaile et al. (2008b) demonstrated performance differences in time-trial cycling following use of either CWI or CWT recovery modes (in highly trained cyclists). Moreover, Ingram et al. (2009) used either CWI or CWT recovery; however, did not report any differences in the rate of CK release 24h post exercise.. Finally, Rowsell et al. (2009) demonstrated that both immersion in temperate water (TWI) (34°C) and CWI (10°C) did not improve performance in vertical jump and 20-m sprint performance in high-performance junior soccer players.

Despite these mixed findings, CWI and other forms of hydrotherapy are popular tools to enhance recovery following training and competition in elite athletes. To date, research on the use of post-exercise recovery using immersion therapy has been conducted on recreational athletes, whose body composition and physiological components may be vastly different from elite or high performance level athletes (Halson et al. 2008).. These results suggest that such immersion therapies applied to athletes of a greater capability may result in different time profiles of physiological and performance restoration (Ravier et al. 2006; Sellwood et al. 2007; Vaile et al. 2008b). In this context we hypothesized that a 24-h time of recovery after using CWI is more efficient against potentially harmful effects of inflammation and on the restitution of maximal anaerobic performance compared with passive recovery (PAS) or other hydrotherapy immersion (TWI, CWT). Therefore, to determine the impact of these recovery strategies on high performance athletes, the aim of this study was to consider the effectiveness of three hydrotherapy interventions (CWI, TWI and CWT) in comparison to PAS on anaerobic performance and removal of waste products.

Methods

SUBJECTS

A total of 41 elite athletes (21.5 ± 4.6 yr, 73.1 ± 9.7 kg, 176.7 ± 9.7 cm, $VO_2\text{max}$: 65.6 ± 3.2 ml.min⁻¹.kg⁻¹) volunteered to participate in this study. All subjects were high performance athletes who competed in National and International level competition for Football, Rugby or Volleyball, respectively. Participants trained six to ten times a week and competed at National and/or International level for at least five years. After being informed of all details of the experimental procedures and methods, the associated benefits and the potential risks of the investigation, each subject completed a written consent in accordance with ethics committee for the protection of individuals (Île-de-France XI, France; Ref. 09015). Ethics was approved by the Institutional Ethics committee. The day before and throughout the duration of the study, the subjects refrained from consumption of any anti-inflammatory pills and did not use any additional methods to aid recovery (i.e. stretching, massage or active recovery). Participants completed food and activity diaries to standardise hydration and nutrition during the week prior to each session and no caffeine was ingested before and throughout the duration of the tests.

EXPERIMENTAL DESIGN

An overview of the experimental protocol is presented in Figure 1. Prior to all testing sessions, subjects were randomly distributed in one of the following recovery groups: CWT, CWI, TWI and a control group (PAS). TWI, CWI, CWT & PAS were composed of 9, 13, 10 and 9 subjects, respectively. All subjects were previously habituated with each measure via normal sports specific testing and training procedures within the Institution. Subjects habitually use rowing ergometer after each game or training session as part of cool down procedures and regularly practice intermittent exhaustive exercise during conditioning sessions. Each respective recovery condition was conducted over two consecutive days of testing. All subjects completed an exhaustive intermittent exercise protocol involving counter-movement jump and rowing to invoke sufficient fatigue and muscle damage. Prior to and immediately, 1h and 24h following the exercise protocol, a series of maximal anaerobic power and strength assessment tests were performed. The maximal test dependent variables included a maximal isometric voluntary contraction (MVC) of the knee extensors, a maximal counter-movement jump (CMJ) and finally mean power during 30-sec all-out rowing test ($P_{30\text{sec}}$) to determine anaerobic capacity. Venous blood samples were collected to measure markers of (CK and LDH) and haematological profile were analyzed to reflect both muscle damages and inflammation prior to, 1h and 24h after the intermittent exercise protocol. All blood samples were obtained before the explosive strength and anaerobic capacity tests to avoid any potential acute effect of test performance on blood measures.

[Insert Figure 1]

INTERMITTENT ANAEROBIC FATIGUING EXERCISE

The exhaustive intermittent exercise protocol consisted of two bouts of 10 min, separated by a rest period of 10 min. Each bout consisted of a 10 min circuit consisting of alternating 30-sec of CMJ (frequency imposed: 0.7 Hz), and 30-sec rowing at power corresponding to 80% of $P_{30\text{sec}}$, each followed by a recovery period of 30 sec. This protocol generated both metabolic and local muscular fatigue comparable to the demands of training or competition (Magalhaes et al. 2010).

RECOVERY MODALITIES

Following the exercise protocol and post test measures, each recovery group was immersed underwater in a sitting position to the level of the iliac crest for 15 min in a dedicated bath, while the PAS group remained seated on a chair for 15 min. CWI and TWI were continuously immersed in water temperatures of 10 °C and 36 °C, respectively. The CWT group alternated immersion at 10 °C and 42 °C with 5 cycles of 1 min 30 sec in each bath.

PERFORMANCE

MVC was assessed using an isokinetic dynamometer (Biodex System 3, Biomedical Systems, Newark, CA, USA). The device was set-up according to the manufacturer's recommendations to exercise the knee extensors muscles of the non-dominant leg. The anatomical zero level was set at a knee angle of 0° (full extension). MVC was then determined by setting the joint angle at 70° of flexion and locked in place and marked to ensure consistency during subsequent testing sessions. Prior to the beginning of each test, the limb weight and moment acting upon the dynamometer power head were corrected for gravity. Three attempts of 3-sec were performed, each separated by a 60-sec rest period. The peak force obtained during the 3 sec effort was defined as the MVC.

The maximal jump height was measured during CMJ using an isoinertial dynamometer (Pro Myotest, Sion, Switzerland) and previously validated by Jidovtseff et al. (2008). Subjects were asked to place hands on their hips to prevent the influence of arm movement on vertical jump performance. Knee-bend during the CMJ was standardized based on the use of a goniometer to determine the degree of knee flexion prior to each jump. Subjects performed three maximal CMJ starting from a standing position, with a 1 min recovery period between respective jumps. Subjects were required to perform maximal efforts, with only the best jump height recorded for subsequent analyses.

$P_{30\text{sec}}$ was determined during a maximal 30 sec effort on a Concept II rowing ergometer (Morrisville, VT, USA). Subjects were harnessed to the rower's seat with a strap to the hips and instructed to perform a maximal 30 sec effort to reach and maintain the highest Wattage (W) output as fast as

possible. The average power output over 30 sec ($P_{30\text{sec}}$) was recorded. This value was used to determine the target to maintain the power output during the fatiguing exercise corresponding to 80% of the $P_{30\text{sec}}$. Power output values displayed by the ergometer for each stroke were calculated by the C2D system as previously described (Boyas et al. 2006) and recorded using the RowPro™ 1.7 software (Digital Rowing Inc., Boston, MA, USA).

BLOOD SAMPLING AND PROCESSING

Venous blood samples were collected pre-exercise and at two time points following exercise (Post 1h and Post 24h). Each blood sample (12-ml) was collected from a superficial forearm vein using standard venipuncture techniques. All samples were directly evacuated into serum separator (2 Vacutainer tubes lithium heparin = 4 ml and 1 Vacutainer tube EDTA = 4 ml) collection tubes (Greiner Bio-one; Frickenhausen, Germany).

ENZYMATIC ANALYSES – The blood contained within lithium heparin tubes was centrifuged at 3000 for 10 min $\text{rev}\cdot\text{min}^{-1}$, +4 °C to separate serum. Serum samples were frozen at -80°C until analysis. CK and LDH concentrations were then determined from serum using a Hitachi 911 automated clinical chemistry analyzer (Roche Diagnostics Corporation, Indianapolis, IN, USA) and commercially available reagents (Roche Diagnostics Corporation, Indianapolis, IN, USA).

LEUKOCYTE COUNT – Centrifuged Blood from EDTA tube were analysed for leukocyte count using an automated cell counter (Cell-Dyn® Ruby™, Abbott, IL, USA).

The inter- and intra- assay coefficients of variation in all assays performed were 2.2 to 6.2 and 3.0 to 6.5 respectively.

DELAYED ONSET MUSCLE SORENESS (DOMS)

DOMS was determined by a standardized half squat to ensure all subjects were experiencing the same movement/ sensation. Perceived soreness was then rated on a visual analogue scale (VAS). Subjects were required to rank their perception of soreness on a scale of 0 “normal” to 10 “extremely sore” at Pre-exercise, Post-exercise and 24h post exercise. This method has been used previously as non invasive way to monitor changes in perceived pain following muscle damaging protocols (Vaile et al. 2008c).

STATISTICAL ANALYSES

All variables were expressed as mean and standard deviation (Mean \pm SD). Differences in the measured variables among conditions and trials were analyzed with two-ways ANOVA for repeated measures (Recovery modality x Time, 4 x 4 or Recovery modality x Time, 4 x 3), using recovery modality as the between subject factor and time as the within-subjects factors. Newman-Keuls post hoc test was used to determine any difference among recovery modalities and over time. Data were analyzed using Statistica 7 for Windows (StatSoft, Inc. TULSA, Oklahoma, USA) and the level of significance was set at $p < 0.05$.

Results

EXPLOSIVE-STRENGTH AND HIGH INTENSITY EXERCISES

All subjects completed the exercise protocol with no significant differences in power observed between groups on Pre-exercise or Post-exercise measures for any performance variable ($P < 0.05$). As such, a similar performance and physiological state existed before and after the exercise protocol for all groups. Nevertheless, there was a significant main effect ($P < 0.05$) for time noted in the change in performance measures following the respective recovery interventions.

MVC, CMJ and $P_{30\text{sec}}$ values of all groups decreased significantly ($P < 0.05$) immediately after the exhaustive exercise bout in all groups (Post-exercise) (figure 2). Post-1h data indicated that a suppressed performance state remained evident for all groups except for the MVC and CMJ measures of CWI group and $P_{30\text{sec}}$ measure of CWT group, which were not significantly lower than Pre-exercise values. 24h post measures of MVC and $P_{30\text{sec}}$ indicated that a suppressed performance state remained evident for all groups except for the CWI and CWT groups, which were not significantly lower than Pre values (figure 2).

[Insert Figure 2]

BLOOD ANALYSES

ENZYMATIC ANALYSES – Compared with measures in pre-exercise condition, 24h post exercise the concentrations in plasma CK showed a significant increase ($P < 0.05$) for each group except CWI. No significant ($P > 0.05$) increase of LDH was measured at Post 1h and Post 24h compared to resting measures except for the CWT group at Post 1h.

[Insert Figure 3]

LEUKOCYTE COUNT – Post 1 h values of the PAS, TWI and CWT groups showed a significant ($p < 0.05$) rise in the total number leukocytes, neutrophils and monocytes from the resting measures. Conversely, CWI values have not changed ($P > 0.05$). However, 24 h following exercise, no significant differences ($P > 0.05$) were apparent either between conditions or to Pre-exercise testing measures (Table 1).

[Insert Table 2]

DOMS

Finally, perceived muscle soreness (DOMS) was significantly ($P < 0.05$) increased 24 hours post exercise in all groups (CWI, CWT, TWI and PAS) compared to Pre-exercise testing measures. No difference between groups were observed before or after fatiguing exercise ($P > 0.05$)

[Insert Figure 4]

1 Discussion

2 The purpose of this study was to investigate the effectiveness of four different recovery
3 modalities of cold water immersion (CWI), temperate water immersion (TWI) or contrast water
4 temperature (CWT) compared to passive (PAS) recovery on anaerobic performance and markers of
5 EIMD. We ventured the hypothesis that in the short term (24h), highly trained athletes (elite
6 International standard) immersed in cold water would show a speedier recovery of performance and
7 markers of EIMD. Indeed, in the present study, the following findings were evident; 1) CWI recovery
8 resulted in faster recovery of MVC and CMJ at 1 h post compared to Pre-exercise measures; 2) CWT
9 recovery resulted in faster recovery of P_{30sec} values at 1 h post compared to Pre-exercise measures; 3)
10 CWI resulted in a blunted CK 24 h response following exercise; 4) CWI also suppressed the rise in
11 neutrophil, monocyte and the total number of leukocyte count 1h post-exercise.

12

13 In the current study, CWT therapy resulted in an improved recovery of P_{30sec} 1 h after the
14 exhaustive exercise protocol, where in contrast, CWI and TWI showed minimal improvement in
15 recovery. These findings are in accordance with previous research on recreational subjects utilizing
16 CWT (Coffey et al. 2004; Versey et al. 2010) or CWI (Stacey et al. 2010) therapy following similar
17 exercise intensities and/or bouts. To the best of the authors knowledge, no previous research uses a
18 subject population of such international (elite) calibre, and accordingly, where the highly trained
19 status of the subject population may predispose them to a faster recovery than untrained
20 populations (Ravier et al. 2006). Similar to previous studies (Coffey et al. 2004; Versey et al. 2010),
21 the current findings highlight that CWT may promote the maintenance of performance during
22 maximal exercise in the short term (<1 h) compared to passive recovery or other immersion
23 therapies. While it must be noted that the change in performance between the groups was 28%, for
24 elite athletic populations, such improvements may be beneficial for continued training quality. The
25 observed suppression and recovery of the present MVC and CMJ data might reflect exercise-induced
26 skeletal muscle cell structure damages or disruption (Friden and Lieber 1992). The present data
27 demonstrated significant increases 1 h post exercise following the use of the CWI intervention
28 compared to other conditions; whereas CWT therapy data indicated that a suppressed performance
29 state for MVC was not evident 24h post exercise. The improvement of MVC with CWI at 24h post
30 exercise is in accordance with previous findings (Bailey et al. 2007; Vaile et al. 2008c) but, to the best
31 of our knowledge, is yet to be reported 1h post-exercise. Moreover, in contrast, Vaile et al. (2007)
32 reported CWT therapy did not attenuate any post-exercise force loss.

33

1 The aforementioned contrasting performance findings may be present due to the treatments
2 (CWT and CWI) and might suggest the importance of the duration of cold exposure for athletes.
3 Indeed, CWI protocols are suggested to require a longer period of immersion time in cold water
4 compared to CWT (Wilcock et al. 2006). It is possible that this might lead to more significant
5 physiological changes than CWT or CWI interspaced by PAS (Hing et al. 2008). Further, any CWI
6 induced vasoconstriction may require more time in water than 1-2 min and thus the difference in
7 immersion or exposure time and temperature (15°C-12 min vs. 10°C-15 min in the present study)
8 may explain the contrasting results of the aforementioned studies. Alternatively, the effect of
9 temperature per se as opposed to the induced hydrostatic pressure was tested with the use of the
10 TWI condition, which could cause a 'squeezing' and displacement of fluid from the lower extremities
11 into the thoracic region (Lollgen et al. 1981). Moreover, for mechanical effects of CWT, Cochrane
12 (2004) suggested that the significant skin temperature fluctuations from the hot-cold would cause
13 vasoconstriction and vasodilatation thereby initiating subcutaneous response and mechanical
14 shunting. Accordingly, the positive effect from CWT and the lack of positive effect from TWI or CWI
15 suggests that the recovery from a fatigued state may be mainly attributed to the localized cooling
16 effect to the periphery and possible effect on intra-muscular blood flow or contractile elements
17 (Cochrane 2004).

18
19 Previously, it has been suggested that lower MVC torque measured after maximal intensity
20 exercise is primarily a result of the presence of contractile trauma, in turn, which may present as
21 increased venous blood CK concentrations (Rodenburg et al. 1993). Further, contractile apparatus
22 disruption may also be evident by post-exercise elevations in inflammatory markers of white blood
23 cell counts (Smith et al. 2008). In regard to the present study, only in the CWI condition were the
24 changes in leucocyte and CK concentrations blunted at 1h and 24h respectively. The present findings
25 are consistent with those of similar investigations using cold water immersion therapy as a modality
26 to treat EIMD (Bailey et al. 2007). Importantly, the intensity and duration of exercise used to elicit
27 muscle damage resulted in severe muscle soreness and an associated period of muscular dysfunction
28 (*i.e.* MVC and CMJ), comparable to previously documented studies (Goodall and Howatson 2008;
29 Ispirlidis et al. 2008). Additionally, the overall increase in intracellular proteins (CK) present in venous
30 blood, reflecting the balance of the rate of clearance versus rate of appearance, was of a similar
31 volume and time course as observed in previous investigations on recreational athletes (French et al.
32 2008; Howatson et al. 2009; Ingram et al. 2009). Given the similar workload and exercise-induced
33 reductions in power between respective groups in the present study, the suppression of CK suggests
34 either a slower appearance or faster clearance following CWI. As highlighted earlier, local cooling is
35 likely to alter skeletal blood flow (Vaile et al. 2010), and may limit the passive leakage of intra-cellular

1 elements that are used as indirect markers of muscle damage. The corollary improvement in muscle
2 performance may represent a functional outcome of this reduced efflux of CK, or some other
3 mechanism yet to be determined.

4 Previous researchers postulated that the use of CWI post-exercise might attenuate the
5 induced muscle damage inflammatory response due to a decrease permeability of blood and lymph
6 vessels reducing the efflux of muscle damage markers from skeletal muscle (Eston and Peters 1999).
7 Thus, the lower CK concentrations via the reduction of cellular, lymphatic and capillary permeability
8 may be explain by localized vasoconstriction induced by the cooler temperature (Eston and Peters
9 1999) of CWI condition. Further, this reduced diffusion rate may assist in reducing acute
10 inflammation from muscle damage and immune activation (Coté et al. 1988; Stacey et al. 2010). In
11 turn, the reduced inflammation can reduce pain, swelling and the loss of force generation that is also
12 often associated with the inflammatory process (Goodall and Howatson 2008; Smith 1991). However,
13 in contrast to Vaile et al. (2007), we did not observe a significant effect of CWT to reduce post-
14 exercise CK values. These authors suggested that CWT causes alterations in the perfusion of the
15 muscle via alternating vasodilatation and vasoconstriction, which might attenuate the immune
16 response and therefore reduce myocellular damage. This result may be due to differences in the
17 CWT protocol, and in particular, on the duration exposure (90 sec for present study vs. 120 s). Unlike
18 the change in CK and considering the noted decrease in MVC torque, LDH was not elevated above
19 baseline in any group. This is consistent with work by Friden et al. (1983) who also found an elevation
20 in serum [CK] with no change in serum [LDH], although the fatiguing exercise was an eccentric bout
21 of the lower leg anterior muscle compartment. Thus, LDH response may be due to the size of the
22 muscle group affected by the fatiguing protocol. The differences in CK and LDH responses are most
23 likely due to the structurally different areas where they are sequestered within the muscle
24 sarcomere and are dependent on the site of primary mechanical muscle damage.

25 Classically, variations of CK are correlated with perceptions of soreness that could be
26 attenuated with cold therapy. In the present study, subjects tended not to report greater benefits for
27 DOMS with CWI when compared to other recovery interventions whereas performances and markers
28 of muscle damages were positively affected. In a similar way, although cooling has inhibitory
29 influences reporting beneficial effects on pain perception, some researchers reporting beneficial
30 effect of cryotherapy on EIMD have not observed a concomittant effect on muscle soreness
31 (Sellwood et al. 2007; Vaile et al. 2008c). Given the present athletes had prior familiarity with the
32 DOMS pain scale, and were not influenced by doing multiple conditions, the influence of a
33 comparative placebo condition may not factor in this study as it does in other studies (King and
34 Duffield 2009). IN addition, in the present study, recovery was followed for 24 h, whereas peak

1 tenderness is reported to occur around 48h post exercise and (Goodall and Howatson 2008) and as
2 such, the time course for peak DOMS may have been missed.

3

4 **Conclusion**

5 Elite team sports are often required to perform high intensity intermittent exercise on
6 consecutive days, and accordingly the use of recovery interventions between sessions may benefit
7 the recovery process. As such, CWI seems to be more effective than TWI, CWT and PAS respectively
8 on force loss restoration. It seems CWI offers the greatest restriction of the inflammatory process
9 following high intensity contraction or damage. On the contrary, acute 30'' all-out anaerobic
10 performance seems to be accordingly improved faster following CWT as opposed to other recovery
11 modes. That said, the improvements are only small and may not directly relate to all exercise bouts
12 or physical demands. In summary, this study demonstrated that cold water immersion in 10°C for 15
13 min, compared to the temperate immersion or passive recovery, offers greater benefit on
14 inflammation and subsequent performance 1 hours post exhaustive simulated team sports exercise
15 in high trained team sports athletes. Moreover, the enhancement of one component of the
16 anaerobic performances restoration may be attributed to a faster clearance of the metabolites with
17 CWT therapy.

18

19 **Practical applications**

20 The results of the present study suggest that CWI and CWT may be a beneficial recovery intervention
21 following and between training for team sports. In particular, where the task requires short maximal
22 efforts during prolonged continuous high-intensity efforts on successive days, these two therapies
23 may assist recovery to a greater degree than TWI interventions but must be used according to the
24 goal (muscular damage or metabolites clearance) and the period (close or distant from the fatiguing
25 exercise). However, particular attention must be paid on the exposure time and temperature of the
26 water

27

28

29

30

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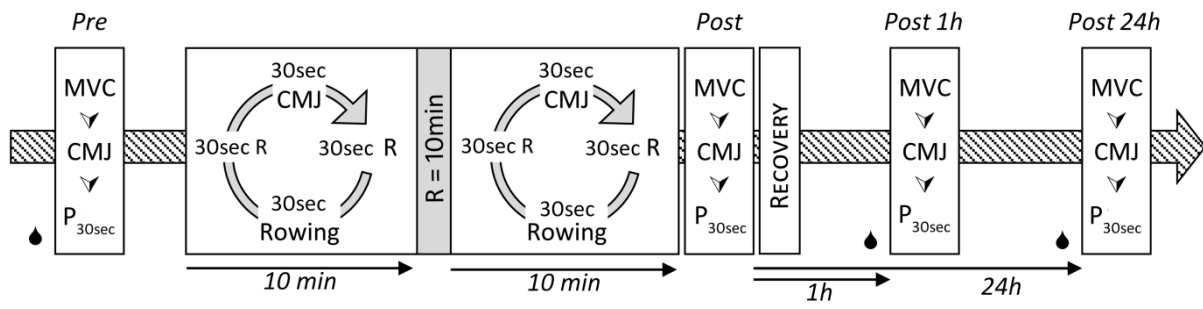
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40 **Figure and tables**

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1 **Figure 1:**



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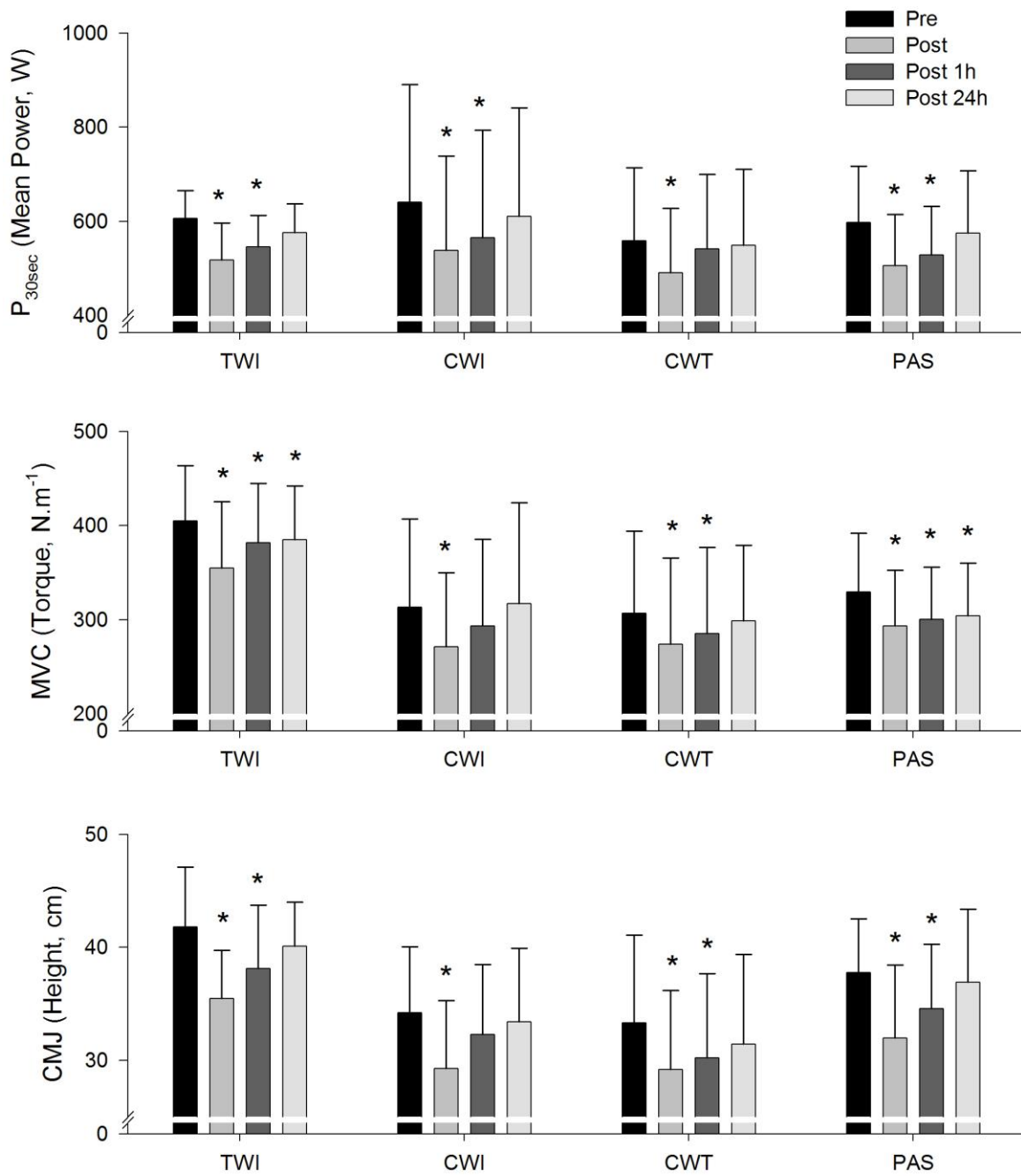
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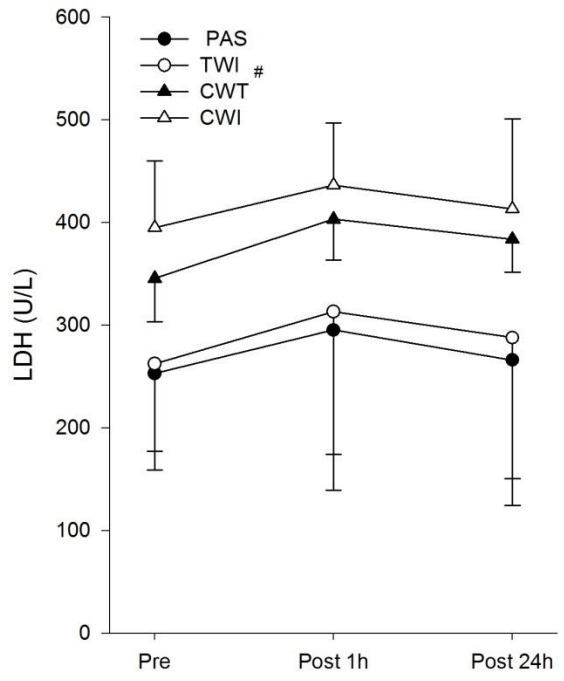
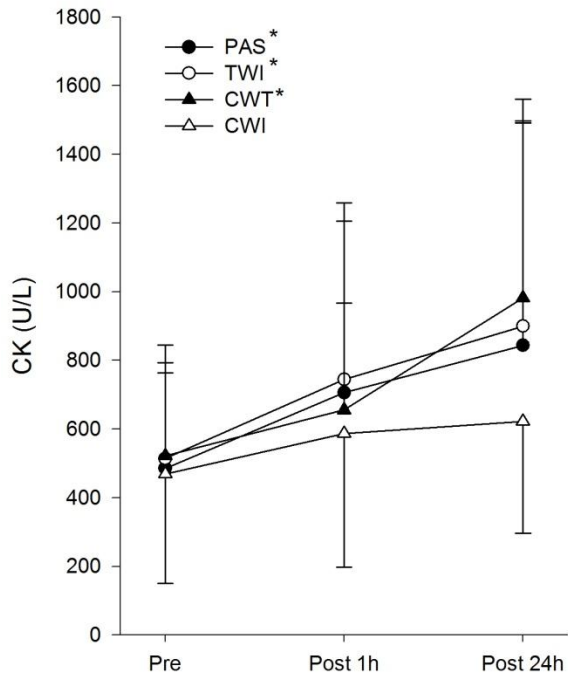
1 Figure 2:



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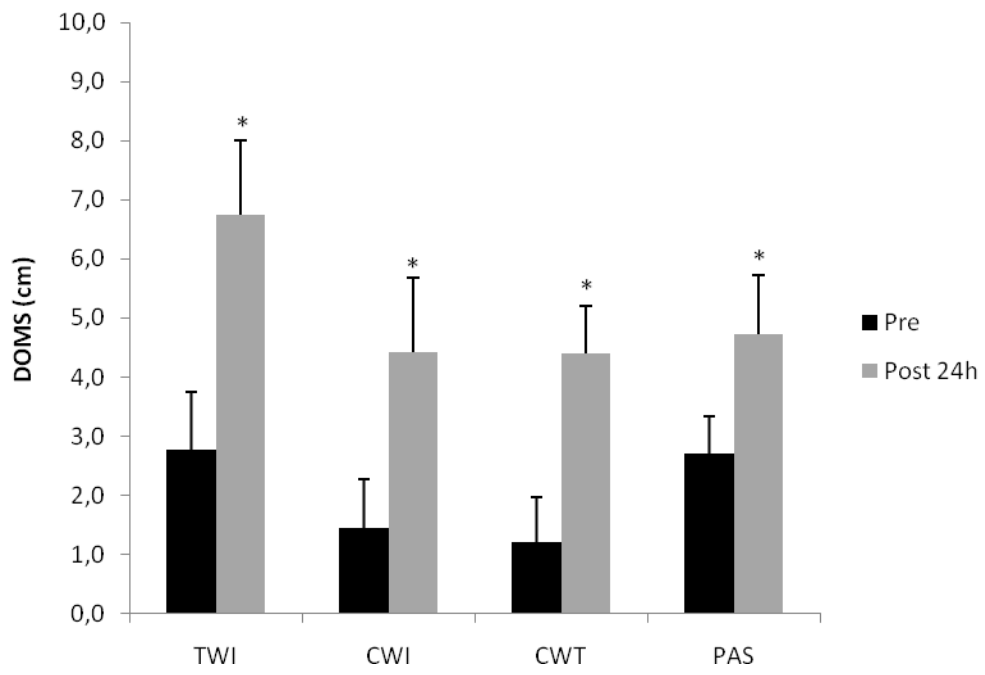
1 **Figure 3:**



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2 **Figure 4:**



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Table 2:

Analyse		Mean Values (range)		
		Pre-exercise	Post 1h	Post 24h
Leukocytes ($10^9.L^{-1}$)	PAS	5.5 (4.5-7.5)	7.6 (5.2-10.4)*	5.2 (3.2-8.2)
	CWI	7.2 (4.4-10.7)	9.4 (4.9-14.8)	7.4 (5.2-11.5)
	TWI	5.1 (2.8-7.9)	10.0 (4.3-14.6)*	5.7 (4-8.1)
	CWT	5.7 (4.1-8.2)	9.6 (4.5-17)*	6.2 (4.2-8)
Neutrophils ($10^9.L^{-1}$)	PAS	2.67 (1.61-4.17)	4.91 (2.10-7.98)*	2.67 (1.48-4.98)
	CWI	2.23 (0.99-3.80)	3.77 (1.32-7.95)	2.56 (1.39-4.74)
	TWI	1.06 (0.0-4.17)	2.24 (0.0-10.21)*	2.77 (0.0-5.08)
	CWT	3.31 (1.95-5.12)	7.73 (3.03-14.16)*	4.40 (3.29-5.98)
Lymphocytes ($10^9.L^{-1}$)	PAS	2.58 (1.57-7.46)	2.75 (0.90-10.41)	2.78 (1.34-8.17)
	CWI	4.36 (2.59-6.15)	5.06 (2.75-10.08)	4.27 (2.90-6.41)
	TWI	2.74 (1.63-7.10)	5.04 (0.0-11.70)	2.31 (1.65-5.50)
	CWT	1.78 (1.36-2.15)	1.20 (0.86-1.46)	1.81 (1.51-2.05)
Monocytes ($10^9.L^{-1}$)	PAS	0.40 (0.33-0.51)	0.52 (0.34-0.87)*	0.42 (0.25-0.63)
	CWI	0.35 (0.14-0.61)	0.30 (0.16-0.62)	0.36 (0.14-0.82)
	TWI	0.23 (0.00-0.99)	0.30 (0.00 -1.21)*	0.44 (0.33-0.95)
	CWT	0.35 (0.16-0.56)	0.49 (0.24-1.04)*	0.39 (0.35-0.50)
Eosinophiles ($10^9.L^{-1}$)	PAS	0.23 (0.06-0.60)	0.16 (0.03-0.29)	0.16 (0.04-0.34)
	CWI	0.20 (0.07-0.45)	0.23 (0.10-0.43)	0.22 (0.10-0.38)
	TWI	0.07 (0.08-0.32)	0.05 (0.0-0.32)	0.16 (0.0-0.30)
	CWT	0.19 (0.06-0.30)	0.13 (0.03-0.2)	0.16 (0.05-0.30)
Erythrocytes ($10^{12}.L^{-1}$)	PAS	4.9 (4.3-5.6)	4.8 (4.4-5.1)	4.8 (4.5-5.3)
	CWI	4.8 (4.5-5.4)	4.9 (4.7-5.5)	4.7 (4.3-5.2)
	TWI	5.0 (4.35-5.81)	5.0 (3.24-5.47)	5.0 (3.85-5.35)
	CWT	4.7 (3.9-5.1)	4.6 (3.8-4.9)	4.7 (4.0-4.9)
Hémoglobine ($g.L^{-1}$)	PAS	147 (129-165)	144 (135-153)	145 (135-161)
	CWI	139 (117-157)	142 (127-158)	136 (119-153)
	TWI	138 (49-157)	138 (107-152)	141 (126-159)
	CWT	152 (125-211)	139 (117-155)	142 (121-149)
Hématocrite (vol. fraction)	PAS	43 (38-47)	44 (41-47)	42 (40-47)
	CWI	41(38.2-46.2)	42 (37.3-47.6)	40 (36.1-43.7)
	TWI	40 (39.6 – 44.8)	42 (29.4-44.3)	42 (37.6-46.7)
	CWT	42 (36.6-44.8)	40 (34.8-42.7)	41 (36.4-44.2)

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2 **Figures legend**

3 **Figure 1:** Experimental design. MVC, maximal isometric voluntary contraction; CMJ, Vertical counter-movement
4 jump; P_{30sec} , 30" all-out rowing exercise; ●, blood samples; R, Rest.

5 **Figure 2:** Mean \pm S.D Maximal isometric voluntary contraction (MVC), counter-movement jump (CMJ) and
6 mean power during 30 s all-out rowing exercise (P_{30sec}), for temperate water immersion (TWI), cold water
7 immersion (CWI), contrast water temperature (CWT) and passive (PAS) conditions. Group effect: no significant
8 difference between the groups for all values. Time effect: *, represents significant a difference to pre-exercise
9 ($P<0.05$).

10 **Figure 3:** Mean \pm S.D creatine kinase (CK) and lactate dehydrogenase (LDH) before and following the exercise
11 protocol for temperate water immersion (TWI), cold water immersion (CWI), contrast water temperature
12 (CWT) and passive (PAS) conditions. Time effect: *, represents significant difference between Pre-exercise and
13 Post 24h measures ($P<0.05$). #, represents significant difference between Pre-exercise and Post 1h measures
14 ($P<0.05$).

15 **Figure 4:** Mean \pm S.D Delayed onset muscle soreness (DOMS) for temperate water immersion (TWI), cold
16 water immersion (CWI), contrast water temperature (CWT) and passive (PAS) groups before and 24h after the
17 damaging bout of exercise. Time effect: *, represents significant difference between Pre-exercise and Post 24h
18 measures ($P<0.05$).

19 **Tables legend**

20 **Table 1:** Mean \pm SD haematological results before and following the exercise protocol for temperate water
21 immersion (TWI), cold water immersion (CWI), contrast water temperature (CWT) and passive (PAS) conditions.
22 Group effect: no significant difference between the groups for all values.
23 Time effect: *, represents significant difference with pre-exercise ($P<0.05$).

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