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POST-EXERCISE COLD WATER IMMERSION ON SPORTS PERFORMANCE RECOVERY: A REVIEW

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ABSTRACT

Post-exercise cold water immersion (CWI) has recently been developed and applied in professional sports. CWI has become widely accepted for use in sports and is endorsed by various organisations, such as the American College of Sports Medicine (ACSM), the International Amateur Athletic Federation (IAAF), and the National Athletic Trainers' Association (NATA). Specific considerations on the extensive use of CWI in the field of sports, the effects of performance recovery after CWI intervention are noteworthy to be examined. This article aimed to review and summarize reports studying effects of CWI on post-exercise recovery. A comprehensive examination of literature was conducted and the decided databases were reviewed. Positive effects of post-exercise CWI on athletes' endurance performance and perceived recovery were found. The possible reasons relate to the reduction of core temperature and blood redistribution. However, CWI effects on power related performance did not receive a consensus understanding in this review. Cryotherapy is normally used for limiting muscle damages, but post-exercise CWI on alternating blood markers for the muscle damages did not show a clear finding in this review. Particularly, Jadad score analysis in this review shows low on average (average Jadad score = 1.80±1.17) of the quality of the studies. It is necessary to reconsider the application on the previous examination. Further investigation is recommended, specifically on power related recovery and neural transmission alternations using randomized controlled trial with masking design.

Keywords: Cold water immersion, Recovery, Sports performance, Post-exercise, Ice-bath, Jaded Score.

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Contribution/ Originality

The paper contributes the first logical analysis on assessing the quality of the studies related to post exercise cold water immersion recovery by the Jadad score analysis, which is assessed by three criteria: A) description of randomization, B) blinding, and C) withdrawals with dropout rates. This study also tried to provide the unbiased and exact findings through systematic reviews.

1. INTRODUCTION

Rapid recovery is an important issue in modern competitive sports training due to two reasons. First, athletes are required to reach several peaks of performance for many competitions at specific times in a single competitive season (Bompa and Carrera, 2005), and so strategies must be developed to facilitate fast recovery and lower the variability of between-competition performance (Müehlbauer *et al.*, 2010). Second, coaches and athletes typically pursue high-intensity training (HIT) and high workload in a practice, because HIT performance, such as high intensity running performance [i.e., concurrent repeated, high-intensity activity (RHIA) and repeated-sprint activity (RSA)], is crucial to success in team sports (Austin *et al.*, 2011; Mooney *et al.*, 2011; Gabbett *et al.*, 2013). To maintain an effective HIT volume and to avoid hyperthermia, swift body cooling and recovery is thus necessary.

A recovery method that has recently been developed and applied in professional sports is the post-exercise cold application. Several possible beneficial mechanisms have been suggested. These include reduction in 1) heart rate and cardiac output, 2) peripheral vasoconstriction, 3) acute inflammation from muscle damage, and 4) the rate of transmission along neurons (Wilcock *et al.*, 2006). Rather than the general application of ice on an injured area or muscle, the more aggressive recovery approach - ice-bath - is now widely used in high-level sports competitions. Ice-bath is also known as cold-water immersion (CWI) or whole-body cryotherapy (WBC).

Cold-water immersion has become widely accepted in sports and is endorsed by various organisations. The American College of Sports Medicine (ACSM) advocates the use of ice water immersion or CWI as the most rapid cooling therapy for heat-related issues, with recommended cooling rates ranging from 0.15 to 0.24°C·min^{-1} (Armstrong *et al.*, 2007). The International Amateur Athletic Federation's (IAAF) Competition Medical Guide (Alonso *et al.*, 2013) suggests providing CWI equipment as standard official equipment in the warm-up areas of stadia during major championships, and at the finish line for road race and cross-country events. The National Athletic Trainers' Association (NATA) suggests that the powerful cooling potential of immersion outweighs any potential concerns over its use (Binkley *et al.*, 2002). The cooling effect of water immersion is the main concern for coaches and athletes to treat the post-exercise heat related fatigue.

CWI is also a recovery technique that has been used in numerous sports disciplines, such as Australian Rules football (Elias *et al.*, 2012; Elias *et al.*, 2013), swimming (Parouty *et al.*, 2010), cycling (Halson *et al.*, 2008; Vaile *et al.*, 2008; Peiffer *et al.*, 2009; Peiffer *et al.*, 2010; Vaile *et al.*, 2011), soccer (Rowsell *et al.*, 2009; Ascensao *et al.*, 2011; Rowsell *et al.*, 2011) and rugby (Higgins *et al*., 2011; Pointon *et al*., 2012). Paula Radcliffe, the British runner shared her dramatic experience on reduction of inflammation after using CWI (Mailonline, 2003). The United States National Ski Team also applied cold post-workout baths during their summer training (Hewitt, 2012). Attributable to the well-known recovery that has been asserted in both professional and amateur sports, CWI is now commonly applied in community. In light of the increasing popularity of using CWI in sports recovery and performance, effects of CWI intervention should be examined thoroughly. This article aimed to review and summarize studies reporting the effects of CWI on post-exercise recovery.

2. MATERIAL AND METHODS

A comprehensive literature search was carried out in May 2014 and the following databases were used: CINAHL full text, SCOPUS ®, and MEDLINE. Search terms included "water immersion", "cold", "exercise" and "recovery", but excluded "pre-cooling" and "pre cooling". The keywords were searched connectively in each of the databases. In addition, based on the reference lists of the collected papers, supplementary manual searches were conducted to identify more papers of potential interest. However, those papers without full text (e.g., conference proceedings) or were not published in English were excluded.

2.1. Methodological Quality of the Studies

The Jadad score was used to assess the quality of the studies, which was calculated by assessing three criteria: A) description of randomization, B) blinding, and C) withdrawals with dropout rates. Oxford five-point scoring scale was applied in order to achieve a high level of inter-examiner reliability (Jadad *et al*., 1996). The scale ranged from 0 (poorest) to 5 (highest) (Table 1). Points were awarded as follows: A) 1 point was given if randomization was mentioned; additional 1 point was given if appropriate randomization was used; but 1 point was deducted if the randomization method was inappropriate; B) 1 point was given if blinding was mentioned; additional 1 point was given if the method of blinding was appropriate; however 1 point was deducted for inappropriate blinding methods; C) 1 point was given for clear description of withdrawals and dropouts. Clinical trials score of 3 or above are considered to be of high quality. Taking into account that participants are virtually impossible to be blinded for CWI intervention, 1 point was given if the outcome assessor was blinded.

3. RESULTS

Twenty-eight articles were listed from the databases. After manual screening, a total of 19 original papers including 5 supplemented papers and 2 review articles were deemed relevant to the topic and met the inclusion criteria. The major outcomes examined were i) performances (i.e., sprinting and jumping performance) and physical changes (i.e., heart rate and body temperature) (Table 2), ii) neuromuscular functions (i.e., muscle power and strength) (Table 3), iii) biochemical changes (i.e., hormones and inflammatory markers) (Table 4), and iv) perception (i.e., fatigue and soreness) (Table 5). The methodological quality of the studies was low on average (average Jadad score = 1.80±1.17). Fourteen articles described as randomized. Details of dropout and withdrawals were described in 7 studies, but only one study adopted double blinding for the measurements.

4. DISCUSSION

The effectiveness of recovery methods (i.e. CWI) is determined by the restoration of optimum sports performance. CWI has been reported as a significant recovery intervention including 5km run (Bosak *et al.*, 2009), Yoyo intermittent recovery test (Level 1) (Brophy-Williams *et al.*, 2011), cycling 4km time trial with restored cadence and average cycling power output (Peiffer *et al.*, 2010), running distance covered during high intensity soccer match (Rowsell *et al.*, 2011), and total work recovery on 35 minutes exercise bouts (Vaile *et al.*, 2011).

4.1. Query of Using CWI on Power Performance Recovery

Muscle power is an important determinant of the effectiveness of acceleration and agility during sports. In this review, 16 articles are reviewed and related to performances and physical changes. All in all, no significant recovery was found after CWI intervention (Table 2) on muscle power related measures, including jump performance (Crowe *et al.*, 2007; Ascensao *et al.*, 2011; Corbett *et al.*, 2012; Elias *et al.*, 2012) and sprinting performance (Rowsell *et al.*, 2009; Ascensao *et al.*, 2011; Higgins *et al.*, 2011; Rowsell *et al.*, 2011; Pointon *et al.*, 2012). Particularly, (Rowsell *et al.*, 2011); Pointon *et al.* (2012) emphasised the insignificant recovery difference between CWI (8.9±0.9°C) and passive recovery (control) groups, even the invited male rugby players was statistically recovered in both recovery conditions on repeated sprint ability over 5 x 15m sprints at any time point. CWI seems not really effective enough for power related indicators comparing with passive recovery. In in-field study, CWI intervention (i.e. in term of ice-bath; i.e. 10-12°C) is also reported as a detriment on phosphate restoration after rugby game (Higgins *et al.*, 2011).

In terms of effect size, CWI intervention demonstrated moderate to large effects on repeated sprinting agility (Elias *et al.*, 2012; Elias *et al.*, 2013), small to very large effects on jump performance (Elias *et al.*, 2013), and even 100m freestyle swimming time was able to be prolonged after CWI intervention though with a small effect size (Parouty *et al.*, 2010). The effect of CWI on recovery is varied. Nevertheless, coaches and athletes have still widely accepted the use of CWI as a crucial recovery method and claim that it is effective. The CWI recovery findings on power related indicators are not really supportive, however, the subjective comments from coaches and athletes present in their practice. The anecdotal experience may be higher impact on coaches and athletes than the scientific research. On the other hand, the recovery effect maybe just sports-type dependent or relies on placebo effect. It is necessary to clarify the potential recovery effect by systematic study.

However, significant lower blood lactate production, peak power and total work in the second exercise bout after CWI intervention were reported in Crowe *et al.* (2007) (i.e. 30s "all-out" maximal cycling test), while those measures are not affected by the control condition. The reduced blood lactate concentration in the second exercise bout after CWI is still unclear, but this is tended to be a reason for the lowered peak power and work done. The ability of lactic acid production during exercise is also an important mean for the rate of glycolysis in anaerobic performance, the CWI's detrimental effect on anaerobic power would be unfavourable to power related athletes. CWI seems not to have immediate recovery benefits for single bout of short duration, all-out exercise.

The decrease in muscle blood flow and temperature caused by CWI (Vaile *et al.*, 2011) could be detrimental to anaerobic performance. Removal of blood lactate is important for anaerobic power recovery, however, many studies in CWI did not show its effect on removal of blood lactate (Halson *et al.*, 2008; Rowsell *et al.*, 2009; Parouty *et al.*, 2010; Brophy-Williams *et al.*, 2011; Pointon *et al.*, 2012), and was even significantly less effective than active recovery (Vaile *et al.*, 2008).

Leeder *et al.* (2013) completed a meta-analysis on CWI recovery after strenuous exercise. They reported that CWI enhanced muscle power performance recovery rate at all-time points (24, 48 and 72 hours post-exercise). However, in this review, the effect on sports recovery, especially for the essential performance indicator, anaerobic power and capacity is still equivocal. On the whole, sports with high intermittent intensity exercise pattern, such as soccer and rugby use CWI for recovery often, further studies investigating the effectiveness of CWI on anaerobic power with fatigue index is deemed to be necessary. It is also worthwhile to reconsider the use of CWI on post-exercise recovery, particularly in high intermittent intensity, repeat performance.

4.2. Endurance Performance Recovery

CWI recovery intervention is believed to have positive effect particularly on endurance performance recovery, which may be related to successful reduction on core temperature (Crowe *et al.*, 2007; Halson *et al.*, 2008; Vaile *et al.*, 2008; Peiffer *et al.*, 2009; Peiffer *et al.*, 2010; Vaile *et al.*, 2011; Lee *et al.*, 2012) with enhanced cooling rate during the immersion (Lee *et al.*, 2012; Pointon *et al.*, 2012). The significant faster cooling rate following CWI was observed in the first 6 minutes (Lee *et al.*, 2012) and last for mostly 40 minutes (Halson *et al.*, 2008). Gradual decreases in core temperature and significant difference between post-CWI 35 and 40 minutes were found comparing with passive recovery (Peiffer *et al.*, 2009). Furthermore, CWI also lowered heart rate significantly (Halson *et al.*, 2008; Vaile *et al.*, 2008; Vaile *et al.*, 2011; Pointon *et al.*, 2012) and this effect was able to last for a relatively long period after immersion (20 minutes (Halson *et al.*, 2008) and 40minutes (Vaile *et al.*, 2008; Vaile *et al.*, 2011). In Vaile *et al.* (2011)'s study , heart rate responded lower after CWI immediately, and even able to last in the first 5 minutes of the second exercise bout. Furthermore, effective reduction in limb blood flow was also observed to sub-pre-exercise level after full body CWI. The modifications on post-exercise heart rate and blood flow would be a possible physiological mechanisms induced by CWI to restore endurance performance.

4.3. Does CWI Alter the Neuromuscular Function?

To date, the effects of CWI on neuromuscular and functional recovery are not clear (Table 3). In this review, CWI was not effective in improving the recovery rate of post-exercise muscle strength (isometric knee extension/leg extension) in most studies (Sellwood *et al.*, 2007; Peiffer *et al.*, 2009; Corbett *et al.*, 2012), on the other hand, significant recovery effect on neuromuscular function of using post-CWI was reported (Ascensao *et al.*, 2011; Pointon *et al.*, 2012).

In terms of maximal voluntary isometric contractions (MVC), CWI provided successful acute recovery (i.e., after CWI and 2 hours post-recovery (Pointon *et al.*, 2012) with possible reason of enhanced voluntary muscle activation (VA) and voluntary surface electromyography (EMG; in term of root mean square, RMS amplitude). However, the restoration in MVC is not able to last for 24-h post-recovery and is even significantly lower than the passive recovery group. This imperfect recovery effect is questionable. Work to exhaustion is the normal exercise protocol requirement for the studies. However, type of exercise (i.e. cycling, repeated sprinting, and match) is varied. The recent findings could be (1) time and mode dependent on the acute effects of CWI on MVC in heat situations among team-sport players. The counter-productive effects at 24-hour post-recovery should be further examined; and (2) isometric static muscle contraction test may not be relevant to the dynamic movement in sports situation. Isotonic or isokinetic strength should be measured instead in further studies.

4.4. Does CWI Enhance Recovery in Terms of Limiting Muscle Inflammation?

Vigorous exercises such as intermittent sprinting exercise (Pointon *et al.*, 2012) tend to induce muscle damages. Cryotherapy is commonly used to limit muscle damage and the associated inflammatory responses as measured by inflammatory markers such as Creatine Kinase (CK), C-reactive protein (CRP), interleukin-6 (IL-6), and myoglobin. Limited studies showed that there was a significant reduction in inflammatory markers after CWI (Ascensao *et al.*, 2011; Brophy-Williams *et al.*, 2011), but most of the studies did not find any difference in inflammatory response when compared CWI to other recovery protocols (Crowe *et al.*, 2007; Halson *et al.*, 2008; Rowsell *et al.*, 2009; Corbett *et al.*, 2012; Lee *et al.*, 2012; Pointon *et al.*, 2012) (Table 4). The discrepancy in findings may be related to the different exercise intensities, timing of measurements, and so peak level of inflammatory makers among studies.

4.5. CWI Really Works in Athletes' Mind

Delayed onset muscle soreness (DOMS) is a familiar experience for both elite and novice athletes and it can adversely affect sports performance (Cheung *et al.*, 2003). In Cheung *et al.* (2003)'s DOMS review (Cheung *et al.*, 2003), localized cryotherapy is identified as having little or no effect on the magnitude of muscle soreness. However, in studies related to cold-water immersion, CWI appears to have a consistent positive effect on muscle soreness. Leeder *et al.* (2013) found that CWI had a moderate effect in alleviating DOMS post-exercise, and was highly effective in DOMS reduction following high intensity exercise (HIT) at 24 and 48 hours.

Regarding eccentric exercise, CWI had a moderate effect on DOMS reduction at 48 hours post-eccentric exercise, but not at 24 hours post-exercise. Seven out of ten studies demonstrated a significant reduction in perceived level of muscle soreness or general fatigue after CWI intervention (Halson *et al.*, 2008; Rowsell *et al.*, 2009; Ascensao *et al.*, 2011; Rowsell *et al.*, 2011; Elias *et al.*, 2012; Pointon *et al.*, 2012; Elias *et al.*, 2013) (Table 5). While localized cryotherapy may not have any beneficial effects on muscle soreness, cold-water immersion may hasten the recovery of muscle soreness. Athletes tend to perceive better (i.e. less muscle soreness and fatigue) though the actual sports performance or neuromuscular functions did not change after CWI intervention (Halson *et al.*, 2008; Rowsell *et al.*, 2009; Elias *et al.*, 2012; Pointon *et al.*, 2012; Elias *et al.*, 2013). It is possible that the subjective decreased in muscle soreness is due to the placebo effect only. However, neural transmission alternation by cold might also be a possible reason to influence the perception.

4.6. Methodological Limitation

Before considering the wider applications of this review, it is important to consider the effect of bias caused by the fact that it is virtually impossible to have blind test participants in CWI, especially the potential bias effect on the perceptional alternations. In this review, only one study by Sellwood *et al.* (2007) was able to clearly describe the appropriate blinding procedure on participants and investigator. It is worthwhile to apply randomized controlled trial design with blinding to study post-exercise CWI effects. CWI studies generally use exercise protocols in order to induce participants' fatigue and sore. In which the exercise protocols applied are varied from match or training base to exercise to exhaustion. The actual exercise intensity and the impact of inducing fatigue would be different, which might affect the results of CWI recovery. It is suggested to apply standardized exercise intensity for the future investigation.

5. CONCLUSION

Cold water immersion is widely used in sports training and competition, yet its efficiency in sports recovery and performance enhancement is not well understood. This article reviews and summarizes previous studies relating to cold water immersion and the recovery effects after exercise. Positive effects of post-exercise CWI on athletes' endurance performance are found and the possible reasons may be due to the reduction of core temperature and blood redistribution. Athletes tend to perceive faster recovery after applying CWI intervention. Conversely, for the essential performance indicators including jump performance (Crowe *et al.*, 2007; Ascensao *et al.*, 2011; Corbett *et al.*, 2012; Elias *et al.*, 2012) and sprinting performance (Rowsell *et al.*, 2009; Ascensao *et al.*, 2011; Higgins *et al.*, 2011; Pointon *et al.*, 2012), a consensus understanding could not be attained in using CWI on muscle power related performance recovery. Nevertheless, the Jadad score analysis in this review shows low on average (average Jadad score = 1.80 ± 1.17) of the quality of the studies. It is necessary to reconsider the use of the previous examination. Further investigation is recommended, especially for the use of post-exercise CWI on muscle power related recovery and alternations of neural transmission using randomized controlled trial with masking design.

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REFERENCES

Alonso, J., F. Yamasawa, G. Fischetto, S. Bermon, T. Kallio, H. Adams, P. Branco, B. Adams and P. Garnier, 2013. IAAF competition medical guidelines – January 1st (Edn). Available from http://www.iaaf.org/about-iaaf/documents/medical#medical-information-for-competitions.

Armstrong, L.E., D.J. Casa, M. Millard-Stafford, D.S. Moran, S.W. Pyne and W.O. Roberts, 2007. American college of sports medicine position stand: Exertional heat illness during training and competition. Med Sci Sports Exerc, 39(3): 556-572.

Ascensao, A., M. Leite, A. Rebelo, S. Magalhaes and J. Magalhaes, 2011. Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. J Sports Sci, 29(3): 217-225.

Austin, D., T. Gabbett and D. Jenkins, 2011. Repeated high-intensity exercise in professional rugby union. J Sports Sci, 29(10): 1105-1112.

Binkley, H.M., J. Beckett, D.J. Casa, D.M. Kleiner and P.E. Plummer, 2002. National athletic trainers association position statement: Exertional heat illnesses. J Athl Train, 37(3): 329–343.

Bompa, T.O. and M. Carrera, 2005. Periodization training for sports. Champaign, Ill: Human Kinetics.

Bosak, A., P. Bishop, J. Green and G. Hawver, 2009. Impact of cold water immersion on 5km racing performance. Sport Journal, 12(2): 1.

Brophy-Williams, N., G. Landers and K. Wallman, 2011. Effect of immediate and delayed cold water immersion after a high intensity exercise session on subsequent run performance. J Sports Sci Med, 10(4): 665-670.

Cheung, K., P.A. Hume and L. Maxwell, 2003. Delayed onset muscle soreness: Treatment strategies and performance factors. Sports Med, 33(2): 145-164.

Corbett, J., M. Barwood, H. Lunt, M. Tipton and A. Milner, 2012. Water immersion as a recovery aid from intermittent shuttle running exercise. Eur J Sport Sci, 12(6): 509-514.

Crowe, M.J., D.O. Connor and D. Rudd, 2007. Cold-water recovery reduces anaerobic performance. Int J Sports Med, 28(12): 994-998.

Elias, G.P., M.C. Varley, V.L. Wyckelsma, R.J. Aughey, M.J. McKenna and C.L. Minahan, 2012. Effects of water immersion on posttraining recovery in Australian footballers. Int J Sports Physiol Perform, 7(4): 357-366.

Elias, G.P., V.L. Wyckelsma, M.C. Varley, M.J. McKenna and R.J. Aughey, 2013. Effectiveness of water immersion on postmatch recovery in elite professional footballers. Int J Sports Physiol Perform, 8(3): 243-253.

Gabbett, T.J., H. Wiig and M. Spencer, 2013. Repeated high-intensity running and sprinting in elite women's soccer competition. Int J Sports Physiol Perform, 8(2): 130-138.

Halson, S., M. Quod, D. Martin, A. Gardner, T. Ebert and P. Laursen, 2008. Physiological responses to cold water immersion following cycling in the heat. Int J Sports Physiol Perform, 3(3): 331-346.

Hewitt, S., 2012. Take an ice bath -- it feels great. Cross Country Skier, 31(3): 66-67.

Higgins, T.R., I.T. Heazlewood and M. Climstein, 2011. A random control trial of contrast baths and ice baths for recovery during competition in u/20 rugby union. J Strength Cond Res, 25(4): 1046-1051.

Jadad, A.R., R.A. Moore, D. Carroll, C. Jenkinson, D.J.M. Reynolds, G.J. Gavaghan and H.J. McQuay, 1996. Assessing the quality of reports of randomized clinical trials: Is blinding necessary. Control Clinical Trials, 17(1): 1-12.

Lee, E.C., G. Watson, D. Casa, L.E. Armstrong, W. Kraemer, J.L. Vingren, B.A. Spiering and C.M. Maresh, 2012. Interleukin-6 responses to water immersion therapy after acute exercise heat stress: A pilot investigation. J Athl Train, 47(6): 655-663.

Leeder, J., C. Gissane, K.V. Someren, W. Gregson and G. Howatson, 2013. Cold-water immersion and recovery from strenuous exercise: A meta-analysis. Br J Sports Med, 46(4): 233-240.

Mailonline, 2003. Radcliffe relaxes in ice bath. Available from http://www.dailymail.co.uk/news/article-176551/Radcliffe-relaxes-ice-bath.html.

Mooney, M., B.O. Brien, S. Cormack, A. Coutts, J. Berry and W. Young, 2011. The relationship between physical capacity and match performance in elite Australian football: A mediation approach. J Sci Med Sport, 14(5): 447-452.

Müehlbauer, T., C. Schindler and S. Panzer, 2010. Pacing and sprint performance in speed skating during a competitive season. Int J Sports Physiol Perform, 5(2): 165-176.

Parouty, J., H. Al Haddad, P. Leprêtre, S. Ahmaidi, M. Buchheit and M. Quod, 2010. Effect of cold-water immersion on 100-m sprint performance in well-trained swimmers. Eur J Appl Physiol, 109(3): 483-490.

Peiffer, J., C. Abbiss, G. Watson, K. Nosaka and P. Laursen, 2009. Effect of cold-water immersion duration on body temperature and muscle function. J Sports Sci, 27(10): 987-993.

Peiffer, J., C. Abbiss, G. Watson, K. Nosaka and P. Laursen, 2010. Effect of a 5-min cold-water immersion recovery on exercise performance in the heat. Br J Sports Med, 44(6): 461-465.

Pointon, M., R. Duffield, J. Cannon and F.E. Marino, 2012. Cold-water immersion recovery following intermittent-sprint exercise in the heat. Eur J Appl Physiol, 112(7): 2483-2494.

Rowsell, G., A. Coutts, P. Reaburn and S. Hill-Haas, 2009. Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. J Sports Sci, 27(6): 565-573.

Rowsell, G., A. Coutts, P. Reaburn and S. Hill-Haas, 2011. Effect of post-match cold-water immersion on subsequent match running performance in junior soccer players during tournament play. J Sports Sci, 29(1): 1-6.

Sellwood, K., P. Brukner, D. Williams, A. Nicol and R. Hinman, 2007. Ice-water immersion and delayed-onset muscle soreness: A randomized controlled trial. Br J Sports Med, 41(6): 392-397.

Vaile, J., C.O. Hagan, B. Stefanovic, M. Walker, N. Gill and C. Askew, 2011. Effect of cold water immersion on repeated cycling performance and limb blood flow. Br J Sports Med, 45(10): 825-829.

Vaile, J., S. Halson, N. Gill and B. Dawson, 2008. Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. J Sports Sci, 26(5): 431-440.

Wilcock, I.M., J.B. Cronin and W.A. Hing, 2006. Physiological response to water immersion. A method for sport recovery. Sports Med, 36(9): 747-765.

Table-1. Jadad scale for reporting quality of studies

Criteria	Max points	Description	
Randomization	2	(+1) (+1) (−1)	if randomization is mentioned if the method of randomization is appropriate if the method of randomization is inappropriate (minimum 0)
Blinding	2	(+1) (+1) (−1)	if blinding is mentioned if the method of blinding is appropriate if the method of blinding is inappropriate (minimum 0)
Withdrawals with dropout rates	1	(+1)	The fate of all patients in the trial is known. If there are no data the reason is stated

Table-2. An overview of cold water immersion recovery on sports performance

Study	Design (Recovery)	JS	Sample	Exercise	Measures	Results
Ascensao *et al.* (2011)	RCT: CWI (10min, 10°C); TWI (10min, 35°C)	2	20 M junior soccer players	Soccer match	20m sprint, CMJ, SJ	NS
Bosak *et al.* (2009)	Counter-balanced crossover: CWI (12min, 15.5°C); PAS	1	12 (9M; 3F) well trained runners	12-18min GXT	5km performance trial	*↑ after CWI
Brophy-Williams *et al.* (2011)	Counter-balanced crossover: CWI (15min, 15±1°C); CWI3hr (15min, 15±1°C); PAS	0	8 M well trained athletes	HIIS	YRT	*↑ after CWI with large ES
Corbett *et al.* (2012)	RCT: CWI (12min, 12°C); TWI (12min, 35°C); CWI (2min, 12°C, seat); ACT (12min)	2	40 M volunteers	HIIS	Hop test	NS
Crowe *et al.* (2007)	Random crossover: CWI (15min, 13-14°C, seated); PAS	2	17 (13M, 4F) healthy, active volunteers	2x 30s max cycling tests	R-peak power, Peak power time, R-total work	R-Peak power & R-total work: *↓ after CWI; Peak power time:

						NS
(Elias *et al.*, 2013)	RCT: CWI (14min, 12°C); CWT (7x1min, 38°C; 1min, 12°C); PAS	2	24 M Australian Football League players	Australian Football Match	RSA, CMJ, SJ	RSA (24h & 48h): ↓, moderate to large ES; CMJ (24h): ↑, small ES; SJ (24h): ↑, very large ES
Elias *et al.* (2012)	Random crossover (counter-balanced): CWI (14min, 12°C); CWT (7x1min, 38°C; 1min, 12°C); PAS	2	14 M Australian Football League players	Australian Football Training	RSA, CMJ, SJ	RSA (24h): ↓, large ES; CMJ & SJ: NS
Higgins *et al.* (2011)	RCT: CWI (5min, 10-12°C); CWT (7x1min: 10-12°C; 1min, 38-40°C); PAS	3	26 M elite rugby players	Rugby match	Phosphate decrement test; 300m sprint test	NS
Parouty *et al.* (2010)	RCT: CWI (5min, 14-15°C, seated); PAS	2	10 (5M, 5F) elite swimmers	2x100m$_{max}$ freestyle sprints	100m freestyle swim test	Swim time: ↑, small ES
Peiffer *et al.* (2010)	Control (counter-balanced): CWI (5min, 14°C); PAS	0	10 M well-trained cyclists	HIT 25min constant-pace cycling	4km time trial, cadence, average power, VO_2, exercise economy	Cadence & average power: *↑ after CWI; 4km time trial: *↓ after CWI; VO_2 & exercise economy: NS
Pointon *et al.* (2012)	Random crossover: CWI [2x (9min, 8.9±0.9°C; 1min rest)]; PAS	2	10 M rugby athletes	2x prolonged ISE	ISE, RSA	NS
Rowsell *et al.* (2011)	Control: CWI (5x1min, 10°C); TWI (5x1min, 34°C)	1	20 M junior soccer players (Excluded: 7)	Soccer match	Total distance run & time (low: <80% MHR), (moderate: 80-90% MHR), (high: >90% MHR)	Total distance run & time (moderate: 80-90% MHR): *↑ after CWI; Time (low: <80% MHR): *↓ after CWI
Rowsell *et al.* (2009)	RCT: CWI (5x1min, 10±0.5°C); TWI (5x1min, 34±0.5°C)	3	20 M junior soccer players	Soccer match	RSA, CMJ	NS
Sellwood *et al.* (2007)	RCT: CWI (3x1min, 5±1°C); TWI (3x1min, 24°C)	5	40 (11M, 29F) healthy participants	Seated leg extension eccentric exercise	One-legged hop-for-distance test	NS
Vaile *et al.* (2011)	Random crossover: CWI (15min, 15°C); ACT (15min, active cycling)	2	10 M endurance-trained cyclists	2x[35min exercise + 60min recovery]	Total work recovery (b/w two 15min performance trials)	*↑ after CWI
Vaile *et al.* (2008)	Random crossover: CWI (5x1min, 10°C); CWI (5x1min, 15°C); CWI (5x1min, 20°C); CWI (15min, 20°C); ACT (15min, active cycling)	2	10 M well-trained cyclists	2x[30min exercise + 60min recovery]	Total work recovery (b/w two 15min performance trials)	*↑ after all CWIs vs ACT

Jadad score (JS): Range: 0-5 (0–2 Low; 3–5 High); *P< 0.05; NS: No significant difference
Exercise: GXT: Exhausted Graded exercise test; HIIS: High intensity interval session
Recovery: CWI: Cold Water Immersion; TWI: Thermo-neutral Water Immersion; CWT: Contrast Water Therapy; ACT: Active Recovery; PAS: Passive Recovery; CON: Control

Measures (Sports Performance markers): ISE: Intermittent-sprint exercise; RSA: Repeated Sprinting Agility test; YRT: Yo-Yo Intermittent Recovery test [Level 1]; CMJ: Countermovement jump; SJ: Static jump; MHR: Maximum Heart Rate

Table-3. An overview of cold water immersion recovery on neuromuscular function

Study	Design (Recovery)	JS	Sample	Exercise	Measures	Results
Ascensao *et al.* (2011)	RCT: CWI (10min, 10°C); TWI (10min, 35°C)	2	20 M junior soccer players	Soccer match	MVC (knee extension at 90°)	MVC (24h): *↑ after CWI
Corbett *et al.* (2012)	RCT: CWI (12min, 12°C); TWI (12min, 35°C); CWI (2min, 12°C, seat); ACT (12min, active walking)	2	40 M volunteers	HIIS	MVC (knee extension & flexion)	NS
Peiffer *et al.* (2009)	Control: CWI (14.3±0.4°C): 5min, 10min, 20min; CON	0	12 M cyclists	Time-to-exhaustion cycling test	60s MVC & 240°/s isokinetic torque (knee)	NS
Pointon *et al.* (2012)	Control (counter-balanced): CWI [2x (9min, 8.9±0.9°C; 1min rest)]; PAS	2	10 M rugby athletes	2x prolonged ISE	MVC (knee extension & flexion); VA	*↑ after CWI , but *↓ CWI (24h)
					Surface EMG (RMS)	*↑ after CWI, (*↓ CWI (24h)); RMS of biceps femoris: NS
					Potential evoked twitch contractile	(4)RR, (6)CD: *↓ after CWI , but RR: *↓ CWI (24h); (1)Pt, (2)RTD, (3)TPt, (5): 1/2RT: NS
					M-wave properties	(2) duration: *↑ after CWI; (1) peak to peak amplitude & (3) latency: NS
Sellwood *et al.* (2007)	RCT: CWI (3x1min, 5±1°C); TWI (3x1min, 24°C)	5	40 (11M, 29F) healthy participants	Eccentric exercise	MVC	NS

Jadad score (JS): Range: 0-5 (0–2 Low; 3–5 High); *P< 0.05; NS: No significant difference
Exercise: ISE: Intermittent-sprint exercise; HIIS: High intensity interval session
Recovery: CWI: Cold Water Immersion; TWI: Thermo-neutral Water Immersion; CWT: Contrast Water Therapy; ACT: Active Recovery; PAS: Passive Recovery; CON: Control
Measures (Neuromuscular function markers): MVC: Maximal voluntary isometric contraction; VA: muscle activation; Surface EMG: Surface electromyography; RMS: root mean square amplitude; Pt: peak potentiated twitch torque; RTD: the rate of torque development; TPt: time to peak torque; RR: the rate of relaxation; 1/2 RT: half-& relaxation time; CD: contraction duration

Table-4. An overview of cold water immersion recovery on biochemical changes

Study	Design (Recovery)	JS	Sample	Exercise	Measures	Results
Ascensao *et al.* (2011)	RCT: CWI (10min, 10°C); TWI (10min, 35°C)	2	20 M junior soccer players	Soccer match	CK, Mb, CRP	CK (24h, 48h); Mb (30min); CRP (30min, 24h): *↓ after CWI
Brophy-Williams *et al.* (2011)	Counter-balanced crossover: CWI (15min, 15±1°C); Delayed CWI_{3hr} (15min, 15±1°C); PAS	0	8 M well trained athletes	HIIS	CRP, La	CRP: *↓ after CWI; La: NS
Corbett *et al.* (2012)	RCT: CWI (12min, 12°C); TWI (12min, 35°C); CWI (2min, 12°C, seat); ACT (12min, active walking)	2	40 M volunteers	HIIS	CK, Mb	NS
Crowe *et al.* (2007)	Random crossover: CWI (15min, 13-14°C, seated); PAS	2	17 (13M, 4F) healthy, active volunteers	2x30s max cycling tests	Blood pH, La	Blood pH: NS; La: *↓ after CWI
Halson *et al.* (2008)	Random crossover (counter-balanced): CWI (3x1min, 11.5±0.3°C); PAS	2	11 M endurance-trained cyclist	40 min max cycling exercise in hot	CK, CRP, IGF-1, IL-6, Prolactin, GH, cortisol, testosterone, adrenaline, noradrenaline	NS
					La, glucose, pH, chloride, potassium, bicarbonate, sodium, PO_2, and PCO_2	Only PO_2: *↓ at 40 min post-exercise; Others: NS
Lee *et al.* (2012)	RCT: CWI (11.70±2.02°C); TWI (23.50±1.00°C) till core temp. had decreased to 38.0°C	3	8 M college students (Excluded: 1)	Fastest treadmill walking 90min / until volitional cessation	IL-6	NS, but stronger correlation was found b/w CWI and IL-6 increases
Parouty *et al.* (2010)	RCT: CWI (5min, 14-15°C, seated); PAS	2	10 (5M, 5F) National level	$2x100m_{max}$ freestyle sprints	La	Unclear
Pointon *et al.* (2012)	Random crossover: CWI [2x (9min, 8.9±0.9°C; 1min rest)]; PAS	2	10 M rugby athletes	2x prolonged ISE	Blood pH, La, bicarbonate, CK, CRP, AST	NS
Rowsell *et al.* (2009)	RCT: CWI (5x1min, 10±0.5°C); TWI (5x1min, 34±0.5°C)	3	20 M junior soccer players	Soccer match	IL-lb; IL-6; IL-10; Mb; fatty acid binding protein; La dehydrogenase; plasma CK	NS, but *↑ CK and La dehydrogenase in both CWI & TWI
Sellwood *et al.* (2007)	RCT: CWI (3x1min, 5±1°C); TWI (3x1min, 24°C)	5	40 (11M, 29F) healthy participants	Seated leg extension eccentric exercise	CK	NS
Vaile *et al.* (2011)	Random crossover: CWI (15min, 15°C);	2	10 M endurance-	2x[35min exercise +	La	*↑ after CWI

	ACT (15min, active cycling)		trained cyclists	60min recovery]		
Vaile *et al.* (2008)	Random crossover: CWI (5x1min, 10°C); CWI (5x1min, 15°C); CWI (5x1min, 20°C); CWI (15min, 20°C); ACT (15min, active cycling)	2	10 M well-trained cyclists	2x[30min exercise + 60min recovery]	La	*↓ ACT vs All CWIs after recovery intervention

Jadad score (JS): Range: 0-5 (0–2 Low; 3–5 High); *P< 0.05; NS: No significant difference
Exercise: ISE: Intermittent-sprint exercise; HIIS: High intensity interval session
Recovery: CWI: Cold Water Immersion; TWI: Thermo-neutral Water Immersion; CWT: Contrast Water Therapy; ACT: Active Recovery; PAS: Passive Recovery; CON: Control
Measures (Biochemical markers): AST: Aspartate aminotransferase; CK: Creatine Kinase; CRP: C-Reactive Protein; GH: Growth hormone; IGF-1: Insulin-like growth factor; Interleukin-lb: IL-lb; Interleukin-6: IL-6; IL-10: Interleukin-10; La: Lactate; Mb: Myoglobin

Table-5. An overview of cold water immersion recovery on perception

Study	Design	JS	Sample	Exercise	Measures	Results
Ascensao *et al.* (2011)	RCT: CWI (10min, 10°C); TWI (10min, 35°C)	2	20 M junior soccer players	Soccer match	DOMS	DOMS (24h at quadriceps & calf; 30min at adductor): *↓ after CWI
Bosak *et al.* (2009)	Counter-balanced crossover: CWI (12min, 15.5°C); PAS	1	12 (9M; 3F) well trained runners	12-18min GXT	Fatigue, MS, RPE	RPE: *↓ after CWI; MS & Fatigue: NS
Brophy-Williams *et al.* (2011)	Counter-balanced crossover: CWI (15min, 15±1°C); Delayed CWI3hr (15min, 15±1°C); PAS	0	8 M well trained athletes	HIIS	TQRP, MS	TQRP: *↑ after CWI & delayed CWI3hr; MS: NS
Corbett *et al.* (2012)	RCT: CWI (12min, 12°C); TWI (12min, 35°C); CWI (2min, 12°C, seat); ACT (12min, active walking)	2	40 M volunteers	HIIS	MS, Fatigue	NS
Crowe *et al.* (2007)	Random crossover: CWI (15min, 13-14°C, seated); PAS	2	17 (13M, 4F) healthy, active volunteers	2x 30s maximal cycling tests	RPE	NS
Elias *et al.* (2013)	RCT: CWI (14min, 12°C); CWT (7x 1min, 38°C; 1min, 12°C); PAS	2	24 M Australian Football League players	Australian Football Match	PRE; MS. Fatigue	Fatigue (1h, 24h, 48h): ↓ after CWI, very large ES; MS (1h, 24h, 48h): ↓ after CWI, very large ES
Elias *et al.* (2012)	Random crossover (counter-balanced): CWI (14min, 12°C); CWT (7x 1min, 38°C & 1min, 12°C); PAS	2	14 M Australian Football League players	Australian Football Training	MS, Fatigue	Fatigue (1h, 24h, 48h): ↓ after CWI, moderate to large ES; MS (1h, 24h, 48h): ↓ after CWI, large ES
Halson *et al.* (2008)	Random crossover (counter-balanced): CWI (3x1min, 11.5±0.3°C); PAS	2	11 M endurance-trained cyclist	40 min max cycling exercise in hot	TSS, physical & mental recovery, MS, fatigue	TSS, MS & fatigue: *↓ after CWI; Physical & Mental Recovery:

						*↑ after CWI
Parouty *et al.* (2010)	RCT: CWI (5min, 14-15°C, seated); PAS	2	10 (5M, 5F) elite swimmers	2x100m$_{max}$ freestyle sprints	RPR, RPE	RPR: likely greater (Moderate ES); RPE: Unclear
Peiffer *et al.* (2010)	Counter-balanced crossover: CWI (5min, 14°C); PAS	0	10 M well-trained cyclists	HIT: 25min constant-pace cycling	RPE	NS

Continue

Pointon *et al.* (2012)	Random crossover: CWI [2x (9min, 8.9±0.9°C; 1min rest)]; PAS	2	10 M rugby athletes	2x prolonged ISE	RPE, MS, thirst, & thermal strain	MS & thermal strain: *↓ after CWI; Thirst & RPE: NS
Rowsell *et al.* (2011)	Control: CWI (5x1min, 10°C); TWI (5x1min, 34°C)	1	20 M junior soccer players (Eexcluded: 7)	Soccer match	RPE; MS; Fatigue	Fatigue & MS (Leg): *↓ after CWI
Rowsell *et al.* (2009)	RCT: CWI (5x1min, 10±0.5°C); TWI (5x1min, 34±0.5°C)	3	20 M junior soccer players	Soccer match	RPE of 5min submaximal shuttle run; Physical & mental recovery; MS; fatigue	RPE: NS; MS & fatigue: *↓ after CWI; Perceived better physical & mental recovery
Sellwood *et al.* (2007)	RCT: CWI (3x1min, 5±1°C); TWI (3x1min, 24°C)	5	40 (11M, 29F) healthy participants	Seated leg extension eccentric exercise	DOMS, Pain (VAS), Tenderness, swelling	Pain (sit to stand): *↑ 24h post CWI; Others: NS
Vaile *et al.* (2008)	Random crossover: CWI (5x1min, 10°C); CWI (5x1min, 15°C); CWI (5x1min, 20°C); CWI (15min, 20°C); ACT (15min, active cycling)	2	10 M well-trained cyclists	2x[30min exercise + 60min recovery]	RPE, TSS	RPE: *↓ at CWI (5x1min, 10°C), CWI (5x1min, 15°C), & CWI (15min, 20°C) vs ACT & CWI (5x1min, 20°C); TSS: *↓ after all CWIs vs ACT

Jadad score (JS): Range: 0-5 (0–2 Low; 3–5 High); *P< 0.05; NS: No significant difference
Exercise: GXT: Exhausted Graded exercise test; ISE: Intermittent-sprint exercise; HIIS: High intensity interval session
Recovery: CWI: Cold Water Immersion; TWI: Thermo-neutral Water Immersion; CWT: Contrast Water Therapy; ACT: Active Recovery; PAS: Passive Recovery; CON: Control
Measures (Perception markers): MS: Muscle soreness; RPE: Rate of perceived exertion; RPR: Rating of perceived recovery; TSS: Thermal sensation scale; TQRP: Total Quality Recovery Perception