European Journal of Human Movement, 2015: **34**, 1-14

EFFECT OF WATER IMMERSION ON RECOVERY FROM FATIGUE: A META-ANALYSIS

Braulio Sánchez-Ureña [1,2]; Kristy Barrantes-Brais [1]; Pedro Ureña-Bonilla [1]; Julio Calleja-González [3]; Sergej Ostojic [4]

1. School of Human Movement Science and Quality of Life. National University of Costa Rica.
2. Laboratory of Exercise Physiology. Exercise and Health Science Program.
3. Department of Physical and Sport Education.. University of the Basque Country, Spain.
4. Center for Health, Exercise and Sport Sciences, Stari DIF, Belgrade, Serbia.

ABSTRACT

The aim of this meta-analysis was to study the effect of cold water immersions and the contrast immersions of cold/hot water. METHODOLOGY: We analyzed studies including search terms in the: title, keywords and abstract. From the analysis overall and corrected (Hedges's g) effect sizes, 95% confidence intervals, meta-analysis Z, Cochran's Q and I2 for heterogeneity were obtained. RESULTS: We analyzed 11 studies published from 1998 to 2013, for a total of 48 effect sizes. The global effect size for the cold water immersion was significant (0.38, IC [0.18, 0.58]), Q = 61.77 and I2 = 88.67. For the contrast immersion cold/hot water the global effect size was not significant (0.17, IC [0.00, 0.33]) CONCLUSION: The evidence in this meta-analysis confirms the existence of a positive moderate effect of cold water immersion on the recovery process, but not with contrast immersion, which did not present effect on this process.
Key Words: immersion, cold water, contrast therapy, recovery, muscle damage

RESUMEN

El objetivo de este metaanálisis fue estudiar los efectos de las inmersiones en agua fría y las inmersiones de contraste frio/calor. METODOLOGÍA: Se analizaron estudios que incluyeran los términos de búsqueda en el título, las palabras clave y en el resumen. Se obtuvieron tamaños del efecto global y fueron corregidos (g de Hedges), también se calcularon los intervalos de confianza al 95%, la Z metaanalítica, la Q de Cochran's y prueba I2. RESULTADOS: se analizaron un total de 11 estudios publicados entre 1998 a 2013, para un total de 48 tamaños del efecto. El tamaño del efecto para las inmersiones en agua fría fue significativo (0.38, IC [0.18, 0.58]), Q = 61.77 y I2 = 88.67). Para las inmersiones de contraste frío/calor en tamaño del efecto no fue significativo (0.17, IC [0.00, 0.33]). CONCLUSIÓN: la evidencia aportada por este metaanálisis confirma el efecto positivo y moderado de las inmersiones en agua fría sobre el proceso de recuperación, no así en el caso de las inmersiones de contraste las cuales no presentaron efectos sobre dicho proceso.
Palabras clave: inmersiones, agua fría, terapia de contraste, recuperación, daño muscular

---

Correspondence:
Braulio Sánchez-Ureña
School of Human Movement Science and Quality of Life.
National University of Costa Rica.
Avenue 1 Calle 1,
Heredia 86-3000, Costa Rica.
brau09@hotmail.com
Submitted: 12/12/2014
Accepted: 03/06/2015

INTRODUCTION

Every day, specialists in high performance sports are more interested in different types of recovery models (Leal et al. 2011). In this case, the immersion in water has become one of the most used recovery methods, over the last years although there is not enough scientific evidence yet (Bleakley & Davison, 2010; Brukner, Williams, Nicol, & Hinman, 2007). There are four types of water immersion clearly defined by the scientific community: cold water immersions (CWI) (<15°C), thermo neutral immersion in water (15°C to 36°C), hot water immersions (> 36°C) and alternating immersion contrasting hot and cold (CWT) (Bieuzen, 2013).

These methods rely in the hypothesis that these forms of immersion contribute to a better recovery and a reduced time required for it. These approaches are based on three aspects: the hydrostatic pressure (Vaile, Halson, Gill & Dawson, 2008a,b), the analgesic and anti-inflammatory effect produced by vasoconstriction in the case of the CWI and the vasoconstriction/vasodilatation cycle in the CWT (Cochrane, 2004).

Based on the previous classification, there have been several studies about the effect of CWI several studies can be found analyzing the effect of CWI in training subjects, in individual sport for example cycling and in teams sports for example soccer, basketball (Rowsell, Coutts, Reaburn & Hill-Haas, 2009; Vaile, Halson, Gill, & Dawson, 2008c; Goodall & Howatson, 2008; Peiffer, Abbiss, Watson, Nosaka, & Laursen, 2009; Al Haddad, et al., 2010; Leal, et al., 2011; Stanley, Peake, & Buchheit, 2012; Delextrat, Calleja-González, Hippocrate, & Clarke, 2012). and, to a lesser extent, studying the effect of CWT either separately or jointly with the CWI in training subjects, in individual sport for example recreational and professional rowers, and in teams sports for example soccer, rugby and volleyball (Kuligowski, Lephart, Giannantonio, & Blanc, 1998; Morton, 2007; Vaile, Gill, & Blazevich, 2007; French, et al., 2008; Robey, Dawson, Goodman, & Beilby, 2009; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; Pournot, et al., 2011, Elias, Wyckelsma, Varley, McKenna, M & Aughe, 2013). The results reported in these studies suggest that both types of immersion accelerate recovery of the athlete.

With the aim of clarifying the evidence about it, systematic reviews on the use of CWI have been published over the last decade (Cochrane, 2004; Bleakley & Davison 2010; Vaile, et al. 2008c; Burgess & Lambert, 2010; White & Wells, 2013). All these previous authors cited that there is no clearly defined optimal method for the use of the CWI. Furthermore, A systematic review (Hing, White, Bouaaphone, & Lee, 2008) on the CWT shows that the effectiveness of this is unclear and more research is required.

Due to the existing discrepancy in these previous studies (experimental and reviews), it has not been possible to clearly establish the effects of each method; therefore, it is projected to analyze this evidence by meta-analytic technique. In this way, two meta-analyses have been recently published: one focusing in CWI (Leeder, Gissane, Van Someren, Gregson, & Howatson, 2012), in which a moderate positive effect is reported. The other accomplished by (Bieuzen, Bleakley, & Costello, 2013), whose purpose of analysis was contrasting hot/cold immersions (CWT), reported that CWT compared to passive recovery has positive effects. However, when compared with other forms of immersion no significant differences were recorded. Therefore, for our knowledge, there is not metaanalitical evidence comparing both methods.

Given that the effects of these methodologies have been analyzed separately and that there is not enough clarity regarding the effectiveness of these methods, the main aim of this meta-analysis was to analyze studies on both lines in order to find out the effects of both methods, and in this way try to contribute to the knowledge on the issue of the athlete's recovery, which is taking stronger relevance worldwide.

METHOD

Search of literature

In this meta-analysis we proceeded to search through the following databases: Sport Discus, Academic Search Complete, Springer Link, Science Direct and PudMed. The search terms used were: cold water immersion, contrast water therapy, cryotherapy, hydrotherapy, recovery, exercise, fatigue, sport, muscle damage, creatine, lactate the previous words with the purpose of being included in the title, abstract and key words. Under these terms, the scientific journal Medicine & Science in Sport & Exercise was consulted for further specific search; besides it, the manual search of references in other meta-analysis and the direct request from authors via email, were used. The results of this process are shown in Figure 1.

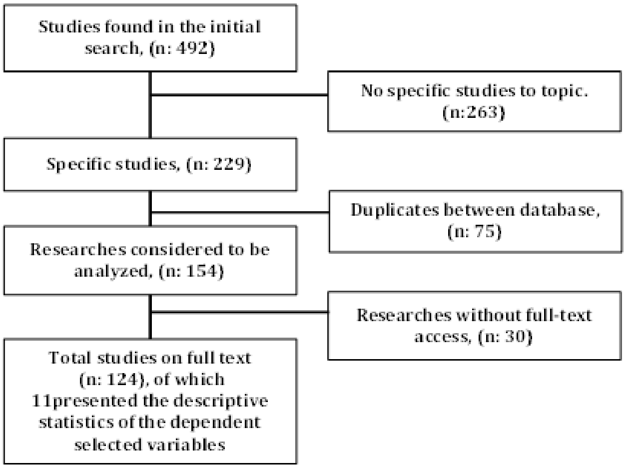

FIGURE 1: Search process studies.

Inclusion criteria

All those studies that included search terms in the title, abstract and keywords were considered at first. Subsequently, only those which report the data required being meta-analyzable (average and standard deviations) were analyzed. Finally, only the studies which reported as part of its dependent variables: the creatine kinase (CK) and Delayed-Onset Muscle Soreness (DOMS) as an indicator of average muscle damage between zero and 72 hours post treatment were considered. For purposes of analysis the variables where there were more than two effect sizes were selected. Regarding the quality of the studies, it was considered as a moderating variable; therefore, none of the studies were excluded by this criterion and the size of the sample of the studies.

Coding of moderator variables

Treatment characteristics were coded at the same time than the ones related with the design. In the case of the CWI, the moderating variables related to the treatment were water temperature and immersion time. For CWT, among the moderating variables related to the treatment was the amount of immersion cycles. In both cases (CWI, CWT), the moderating variable related to design was the time of measurement (zero, 24, 48 and 72).The quality of the study was evaluated, but not included in the analysis of moderating variables given that it behaved as a constant.

Statistical Analysis

The overall effect size (ES) were estimated by Cohen formula and corrected by Hedges (Thomas & French, 1986) and adjusted by the total variance, according to the formula given by (Cooper, Hedges, & Valentine, 2009). Confidence intervals at 95% and meta-analytic Z were calculated by formula (Thomas & French, 1986). The Cochran Q test and I^2 were estimated b formula (Borenstein, Hedges, Higgins, & Rothstein, 2009).

The analysis of continuous moderating variables was performed using Pearson's r; categorical moderating variables were analyzed using a t-student test for independent samples. The Statistical Package for the Social Sciences (SPSS), IBM version 21 was used.

RESULTS

As shown in the next table, a total of 11 trials were included. The effect of the CWI and CWT was analyzed separately and together in some cases, providing a total of 8 analyses per line. In total 341 subjects participated in these trials, calculating a final sample total of 48 effect sizes.

TABLE 1
Summary of the characteristics of the studies included in the meta-analysis, with their global effect sizes and significance of the variables analyzed.

Authors	Participants (level of training, gender, number)	Load that they were subjected to	Temperature of water (C°)	Time of immersion (min)	Number of immersions and frequency	Total time of immersion (min)	Type of immersion, 1: CWI 2: CWT	Global ES
Elias, et al., (2013).	Professionals players of Australian football, male , n:24	60 min training of Australian football	12C°	14min	1	14	1	1.72 (DOMS)*
Elias, et al., (2013).	Professionals players of Australian football, male, n:24	60 min training of Australian football	Cold (12 C°) Hot (38 C°)	7 x 1 min 7 x 1 min	1	14	2	0.82 (DOMS)
Eston, et al., (1999)	Students, female, n: 15	8 x 5 arms extension and flexion	15 C°	15 min	7 (12 h)	105	1	0.25(CK)
French, et al., (2008).	Physically active, male, n: 26	6 x 10 leg extension and flexion +5 sec eccentric	cold (8–10 C°) Hot (37–40 C°)	4 x 1 min 3 x 3 min	1	13	2	0.62(CK)
Ingram, et al., (2009).	Experienced in team sports, male , n: 11	Simulate game teams sports	10 C°	(2×5 min), 2.5 min out of water	2 (24 h)	20	1	0.13 (CK) 1.09 (DOMS)*
Ingram et al. (2009).	Experienced in team sports, male , n: 11	Simulate game teams sports	Cold (10 C°) Hot (40 C°)	3 x 2 min 3x 2 min	2 (24 h)	24	2	0.13 (CK), 0.95 (DOMS)*
Kuligowsky, et al., (1998).	Healthy, 28 male y 28 female, n: 56	50 eccentric arms extensions	12,8 C°	24 min	4 (24 h)	96	1	0.54 (DOMS)*
Kuligowsky, et al., (1998).	Healthy, 28 male y 28 female, n: 56	50 eccentric arms extensions	Cold (12.8 C°) Hot (38. C°)	6 x 1 min 6 x 3 min	4 (24 h)	96	2	0.20 (DOMS)

TABLE 1 (Continuation)

Authors	Participants (level of training, gender, number)	Load that they were subjected to	Temperature of water (C°)	Time of immersion (min)	Number of immersions and frequency	Total time of immersion (min)	Type of immersion, 1: CWI 2: CWT	Global ES
Montgomery, et al., (2008).	Well-trained basketball players, male, n: 19	Basketball tournament	11 C°	(5 x 1 min), 2 out of water room temperature	3 (24 h)	15	1	0.53 (DOMS)
Poiton, et al., (2012)a.	Rugby players of the union/league, male, n : 10	2 x (2 x 30 min) continuous running with intermittent sprint	8.9 C°	(2 x 9 min), 1 min out of water	1	18	1	0.42 (CK)
Poiton, et al., (2012)b.	Rugby players, male, n : 10	3 x (2 x 30 min) continuous running with intermittent sprint	9.2 C°	(2 x 9 min), 1 min out of water	1	18	1	0.11 (CK)
Robey, et al., (2009)	Recreational rowers , 8 male, 6 female, n:14	Running up steps	Cold (12 C°) hot (40 C°)	5 x 1 min 5 x 2 min	1	15	2	0.38 (DOMS)
Robey, et al., (2009)	Élite rowers, 4 male, 2 female, N:6	Running up steps	Cold (12 C°) Hot (40 C°)	5 x 1 min 5 x 2 min	1	15	2	0.70 (DOMS)*
Vaile, et al., (2007)	recreational athletes, 4 male, 9 female, n: 13	5 x 10 legs press eccentric	Cold (8-10 C°) Hot (40-42 C°)	5 x 1 min 5 x 2 min	1	15	2	0.18 (CK)
Vaile, et al., (2008)	Resistance training), male, n:38	5 x 10 legs press eccentric RM 120%, followed by 2 x 10 to 100% of the RM	15 C°	14 min	1	14	1	0.58(CK)*
Vaile, et al., (2008)	Resistance training), male, n:38	5 x 10 legs press eccentric RM 120%, followed by 2 x 0 to 100% of the RM	Cold (15 C°) Hot (38 C°)	7 x 1 min 7 x 1 min	4(24 h)	56	2	0.18 (CK), 0.52 (DOMS)*

Note:=significant effect, CI not including zero; CK= creatine kinase; CWI=cold water immersion; CWT=contrast immersion; DOMS=Delayed-onset muscles soreness.*

In general, it was found that the CWI presents a moderate and significant ES. In the case of CWT global effect size was not significant, as displayed in Figure 2.

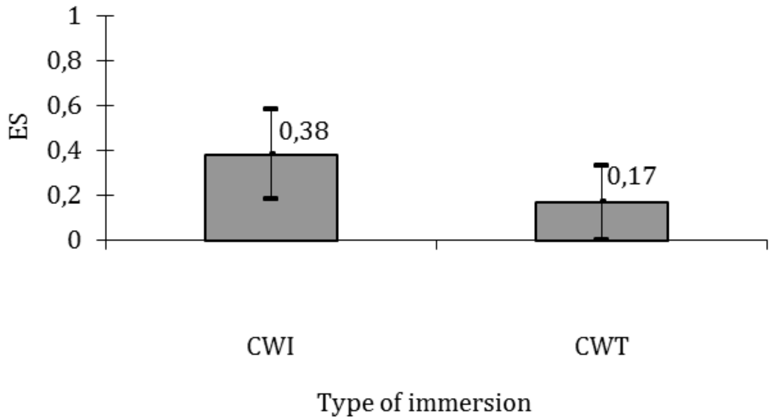

FIGURE 2: Global effect size of the CWI and CWT.
Note*: ES: Effect size, CWI: cold water immersion, CWT: contrast water immersion

TABLE 2
Summary of the characteristics of the studies included in the meta-analysis, with their global effect sizes and significance of the variables analyzed.

	ES	*n trials*	*n ES*	*IC [95%]*	*Z*	*Q*	*I^2*
Global effect size	0.38	8	20	[0.18,0.58]	*-3.7**	61.77	88.67
Dependent variable							
CK	0.29	4	12	[0.03, 0.55]	*-2.2**	13.08	69.43
DOMS	0.53	4	8	[0.20, 0.85]	*-3.18**	46.94	93.61

Abbreviations: ES: Effect size, CWI: cold water immersion, CWT: contrast water immersion, CK: creatine kinase, DOMS: delayed onset muscle soreness.
Note.: p<0.05; I2 >75%: considerable heterogeneity.*

The previous table shows that CWI generate moderating ES for both, global and for each of the variables analyzed; note that both the confidence interval (CI) as well as the meta-analytic Z indicate that information. Regarding the heterogeneity, it is present on both dependent variables (I2> 75 %); then, moderating variables analysis is necessary.

Analysis of moderating variables did not show significant differences (p> 0.05) in the moderating variables such as: water temperature, duration and type of immersion. This information does not help to establish a suitable scheme of treatment based on these variables.

On the other hand, the moderating variable number of immersions in the case of DOMS showed statistically significant differences (p <0.05), allowing the interpretation that the effect size of CWI on perception of muscle pain is greater in the first immersions, as shown in Figure 3.

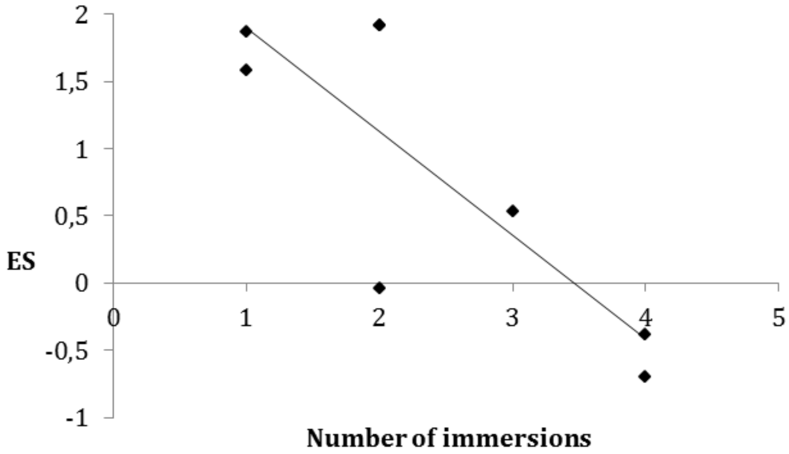

FIGURE 3: Correlation between the ES and the number of immersions in cold water
Abbreviations: ES: Effect size.

Analysis of the ES in the modality of contrast immersion does not show significant effects (p>0.05) not only globally, but also per variable CK and DOMS, table 3.

TABLE 3
Global effect size and dependent variable for the CWT.

	ES	*n trials*	*n ES*	*IC [95%]*	*Z*
Global effect size	0.17	6	25	[0.00, 0.33]	-2.01
Dependent variable					
CK	0.11	4	10	[-0.13, 0.36]	-0.89
DOMS	0.20	6	15	[-0.01, 0.42]	-1.89

Abbreviations: ES: Effect size, CWI: cold water immersion, CWT: contrast water immersion, CK: creatine kinase, DOMS: delayed onset muscle.

The few studies that examined the variables lactate dehydrogenase (LDH) and C-reactive protein (CPR), as indicators of muscle damage and inflammation, showed significant ES of the CWI in the case of LDH: 0.28 [0.21, 0.36] (3 ES), a non-significant ES in the case of CPR: 0.16 EN [- 0.08, 0.42] (3 ES). For CWT, effects were significantly adverse since the confidence interval is always in the negative range, LDH -0.19 [- 0.27, - 0.11] (3 ES), CPR -0.70 [-1.06, - 0.33] (2 ES).

DISCUSSION

To our best knowledge, this is the third meta-analysis of water immersion methods as recovery strategy, and it complements the findings reported by (Leeder, et al., 2012) in the case of the CWI and (Bieuzen, et al., 2013) in the case of CWT, but is the first article that compares both methods (CIW, CWT), supporting new findings in this way. The mean conclusion with regard to the results found in this study, indicate that the overall effect of the CWI was moderately significant (0.38 [0.18, 0.58]). In particular, its effect on the reduction of CK as a muscle damage indicator, it was also moderately significant (0.29 [0.03, 0.55]) and very similar to the previous (Leeder, et al., 2012) (0.22[0.03, 0.41]).

In regards to delayed on set muscle soreness (DOMS), the effect size was also significant (0.53[0.20, 0.85]) but at higher degree, and in the same way it is consistent with the reported by (Leeder, et al., 2012) which was (0.52 [0.38, 0.66]). These findings based on two meta-analyses allow ratifying the presence of a favorable effect of CWI on both biochemical and subjective muscle damage indicators. However, it is important to mention that in the current meta-analysis, as in previous research (Leeder, et al., 2012), moderate amount of studies have been used. Therefore, these findings cannot be considered as definitive.

Nevertheless, the positive effects found can be explained based on the fact that the CWI generate a vasoconstrictor effect given primarily by hydrostatic pressure, causing an increment in venous return, stimulating the elimination of metabolites (Cochrane, 2004; Wilcock, Cronin, & Hing, 2006). In this same line, it has been registered a significant reduction in blood flow and the temperature of the muscle tissue after immersion from 10 min around 8°C (Gregson, et al., 2011). Meanwhile, (Tipton, Stubbs, & Elliott, 1990; Tipton, Mekjavic, & Eglin, 2000; Tipton, Golden, Higenbottam, Mekjavic, & Eglin, 1998), it is reported that the reduction in skin temperature is between 30°C to 42°C per second during immersions at 10°C and 33°C per second in immersions at 15°C.

All these changes induced by cold, generate a reduction in the cell, lymphatic and blood vessels' permeability (Eston & Peters, 1999; Wilcock, et al., 2006), decreasing the interstitial space and hence reducing inflammation and edema (Wilcock, et al., 2006; Dolan, Thornton, Fish, & Mendel, 1997); this reduction in the level of inflammation is associated with a lessening of the sensation of pain (Friden & Lieber, 2001).

The scientific evidence analyzed in this study does not establish an optimal protocol. However, it is important to mention a summary of the characteristics about the trials included in this meta-analysis: water temperature between 8°C - 15°C, length of immersion between 10 to 14 min, which can be continuous or intermittent (fractionated); in the latter case, from one-minute to two and a half minutes break among dives. Therefore, more research is needed in this sense to identify the optimal dose of treatment with CWI.

In the case of CWT, the results were not significant either in the global or in the specific case of the CK and DOMS. Regarding biochemical indicator (CK) (Bieuzen, et al., 2013), it reported no significant differences between CWT and CWI; however, a slight tendency in favor of the CWI was mentioned, which is statistically evidenced and confirmed in this current meta-analysis.

Other authors (Gill, Beaven, & Cook, 2006; Vaile, et al., 2007; Vaile, et al., 2008b), have reported that when comparing CWT with control groups of passive recovery, it shows significant differences; however, it is also reported that when comparing with other forms of recovery, it does not show significant differences. Indeed, this fact was confirmed by (Bieuzen, et al., 2013) in his meta-analysis, who reports the previous information as one of his main conclusions. However, it is also important to mention that in the meta-analysis (Bieuzen, et al., 2013), as in the current study, the amount of studies analyzed was few; consequently for the moment it can only be confirmed that the CWT is more effective than performing a passive recovery; but they are not more effective than other modalities, and in this study the CWT do not show significant effects on recovery.

The evidence discussed in this paper, has as its main features: cold water temperature between 8°C - 15°C, hot water temperature between 38°C- 42°C, with a time of one minute immersion in cold water and two or three minutes in hot water, it means, ratio (1:2, 1:3).This idea should be analyzed in future studies, or even consider other ratios of immersion time between hot/cold. Another element to be studied is the number of immersion cycles; this with the purpose of identifying in the first place if the CWT have positive effects on recovery and being the case, find an optimal treatment protocol.

Finally, the assumptions of limitations in this study are in consonance with the number of studies (11), number of different sports (individual and team) and the natures of effort (continuous or intermittent) as well as the level of the participant (recreational, training subjects, elite athletes) in the studies included.

CONCLUSIONS

The evidence reviewed in this meta-analysis confirms the existence of a positive and moderate effect of CWI on recovery process, but not in the case of CWT, which have no effects on this process.

Moreover, future studies should be conducted in high-performance athletes. Also, to analyze both effects CWI and CWT based on the nature of the stimulus to which the athlete is exposed. Similarly, to compared the effects of continuous and intermittent CWI, as well as including the analysis of other indicators of damage and inflammation as lactate dehydrogenase, urea, protein C-reactive isoform-3; the afore-mentioned with the aim of providing greater specificity to the usage of immersion as recovery method. The scientific community in this field should include reports with all the data in their research, allowing it to be used in meta-analysis, in order to provide greater reliability to the usage of these recovery methods.

REFERENCES

Al Haddad, H., Laursen, P., Chollet, D., Lemaitre, F., Ahnire, S., & Buchheit, M. (2010). Effect of cold or thermo neutral water immersion on post-exercise heart rate recovery and heart rate variability indices. *Autonomic Neuroscience: Basic and Clinical, 156*, 111–116. doi:10.1016/ j.autneu.2010.03.017.

Bieuzen, F. (2013). Water Immersion Teherapy. In Hausswirts, C., & Mujika I. (Ed). *Recovery for performance in sport* (191 - 197).Human Kinetics, Champaing, IL.

Bieuzen. F., Bleakley, C.M., & Costello, J.T. (2013). Contrast water therapy and exercise induced muscle damage: A systematic review and meta-analysis. *PLoS ONE 8(4), 1-15.* doi: 10.1371/journal.pone.0062356.

Bleakley, Ch., & Davison, G. (2010). What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *British Journal Sports Medicine,44,* 179–187. doi:10.1136/bjsm. 2009.065565.

Borenstein, M., Hedges, L.V., Higgins, J.P.T., & Rothstein, H.R. (2009). *Introduction to Meta-Analysis*. Wiltshire: Wiley.

Brukner, P., Williams, D., Nicol, A., & Hinman, R. (2007). Ice-water immersion and delayed-onset muscle soreness: a randomised controlled trial. *British Journal Sports Medicine, 41,* 392–397. doi: 10.1136/bjsm.2006.033985.

Burgess. T., & Lambert, M. (2010). The efficacy of cryotherapy on recovery following exercise-induced muscle damage. *International Sport Medicine Journal 11(*2), 258-277.

Cochrane, D.J. (2004). Alternating hot and cold water immersion for athlete recovery: a review. *Phys Therapy Sport,5,* 26–32. doi:10.1016/ j.ptsp.2003.10.002

Cooper, H., Hedges, L., & Valentine, J. (2009). *The handbook of research synthesis and meta-analysis.* New York. Russell Sage Foundation.

Delextrat, A., Calleja-González, J., Hippocrate, A., & Clarke, N.D. (2012). Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players. *Journal of Sports Sciences, 31*(1), 11-19. doi: 10.1080/02640414.2012.719241.

Dolan, M.G., Thornton, R.M., Fish, D.R., & Mendel, F.C. *(1997).* Effects of cold water immersion on edema formation after blunt injury to the hind limbs of rats. *Journal Athletic Training, 32,* 233–7.

*Elias, G.P., Wyckelsma, V.L., Varley, M., McKenna, M., & Aughey, R. (2013). Effectiveness of water immersion on postmatch recovery in elite professional footballers. *International Journal of Sports Physiology and Performance,* 8, 243-253.

*Eston, R., & Peters, D. (1999). Effects of cold water immersion on the symptoms of exercise induced muscle damage. *Journal Sports Science,17(3),* 231-238. Doi: 10.1080/026404199366136.

*French., D., Thomson., K., Garland., S., Barnes., C., Portas., M, Hood., P., & Wilkes, G. (2008). The effects of contrast bathing and compression therapy on muscular performance. *Medicine and Science in Sports Exercise 40(7),*1297–1306. doi: 10.1249/MSS.0b013e31816b10d5.

Fridén, J., & Lieber., R.L. (2001). Eccentric exercise-induced injuries to contractile and cytoskeletal muscle fibre components. *Acta Physiol Scand, 171,* 321–6. doi:10.1046/j.1365-201x.2001.00834.x.

Gill, N.D., Beaven., C.M, & Cook., C. (2006). Effectiveness of postmatch recovery strategies in rugby players. *British Journal of Sports Medicine 40(3),* 260–263. doi: 10.1136/bjsm.2005.022483

Goodall, S & Howatson, G. (2008).The effects of multiple cold water immersions on indices of muscle damage. *Journal of Sports Science and Medicine 7,* 235-241.

Gregson, W., Black, M.A., Jones, H., Milson, J., Morton, J., Dawson, B., …Green, D.J. (2011). Influence of cold water immersion on limb and cutaneous blood flow at rest. *American Journal Sports Medicine, 39,*1316–23. doi: 10.1177/0363546510395497.

Hing, W., White, S., Bouaaphone, A., & Lee, P. (2008). Contrast therapy -A systematic review. *Physical Therapy in Sport, 9,* 148–161. doi:10.1016/j.ptsp.2008.06.001.

*Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby., J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science and Medicine in Sport, 12,* 417–421. doi: 10.1016/j.jsams.2007.12.011.

*Kuligowski, L., Lephart., S, Giannantonio, K., & Blanc., R. (1998). Effect of whirlpool therapy on the signs and symptoms of delayed-onset muscle soreness. *Journal of Athletic Training, 33(3),* 222-228.

Leal, E., De Godoi, V., Mancalossi., J.L., Rossi, R., De Marchi, T., Parente, M.,…Brandão, R.A. (2011). Comparison between cold water immersion therapy (CWIT) and light emitting diode therapy (LEDT) in short-term skeletal muscle recovery after high-intensity exercise in athletes -

preliminary results. *Lasers Medecine Science, 26*, 493–501. doi: 10.1007/s10103-010-0866-x.

Leeder, J., Gissane, C., Van Someren, K., Gregson, W., & Howatson, G. (2012). Cold water immersion and recovery from strenuous exercise: A meta-analysis. *British J Sports Medicine, 46,* 233–240. doi:10.1136/bjsports-2011-090061.

*Montgomery, P., Pine, D., Hopkins, W., Dorman, J., Cook, K., & Minaham, C. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Science,s 26*(11), 1135–1145. doi: 10.1080/02640410802104912.

Morton, R.H. (2007). Contrast water immersion hastens plasma lactate decrease after intense anaerobic exercise. *Journal of Science and Medicine in Sport,*10, 467-470. doi: http://dx.doi.org/10.1016/j.jsams.2006.09.004

Peiffer, J., Abbiss, C., Watson, G., Nosaka, K., & Laursen, P. (2009). Effect of cold-water immersion duration on body temperature and muscle function. *Journal of Sports Sciences, 27*(10), 987–993. doi: 10.1080/02640410903207424.

*Pointon, M., & Duffield, R. (2012b). Cold Water immersion recovery after simulated collision sport exercise. *Medicine Science Sports Exercise, 44*(2), 206–216. doi: 10.1249/MSS.0b013e31822b0977.

*Pointon, M., Duffield, R., Cannon, J., & Marino., F. (2012a). Cold water immersion recovery following intermittent-sprint exercise in the heat. *European Journal Applied Physiology, 112,* 2483–2494. doi: 10.1007/s00421-011-2218-3.

Pournot, H., Bieuzen, F., DuYeld, R., Lepretre, P., Cozzolino., C, & Hausswirth, C. (2011). Short term effects of various water immersions on recovery from exhaustive intermittent exercise. *European Journal Applied Physiology, 111*, 1287–1295. doi: 10.1007/s00421-010-1754-6.

*Robey, E., Dawson, B., Goodman, C., & Beilby, J. (2009). Effect of post exercise recovery procedures following strenuous stair-climb running. *Research in Sports Medicine,* 17, 245–259. doi: 10.1080/15438620902901276.

Rowsell, G., Coutts, A., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal Sports Science, 27*, 565–573. doi: 10.1080/02640414.2010.526132.

Stanley, J., Peake, J., & Buchhet, M., (2012). Consecutive days of cold water immersion: effects on cycling performance and heart rate variability. *European Journal Applied Physiology,113*(2), 371-84. doi: 10.1007/s00421-012-2445-2.

Thomas, J., & French., K. (1986). The use of meta-analysis in exercise and sport: A tutorial. *Research Quarterly for Exercise and Sport, 57*(3), 196-204.

Tipton, M.J., Golden, F.S., Higenbottam, C., Mekjavic, I.B., & Eglin, C.M. (1998).Temperature dependence of habituation of the initial responses to cold-water immersion. *European Journal Appl Physiol Occup Physiol, 78,* 253–7.

Tipton, M.J., Mekjavic, I.B., & Eglin, C.M. (2000). Permanence of the habituation of the initial responses to cold-water immersion in humans. *European Journal Appl Physiol, 83,* 17–21.

Tipton, M.J., Stubbs, D.A., & Elliott, D.H. (1990). The effect of clothing on the initial responses to cold water immersion in man. *J R Nav Med Serv, 76,* 89–95.

Vaile, J., Gill, N., & Blazevich, A. (2007). The effect of contrast water therapy on symptoms of delayed onset muscle soreness. Journal Strength Cond Research, 21,* 697–702.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008a). Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. *Journal of Sports Sciences, March 26*(5), 431 – 440. doi: 10.1080/02640410701567425.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008b). Effect of hydrotherapy on recovery from fatigue. *International Journal Sports Medicine, 29,* 539–544. doi: 10.1007/s00421-007-0605-6.

*Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008c). Effect of hydrotherapy on the signs and symptoms of delayed onset muscle soreness. *European Journal Applied Physiology, 102,* 447–455.

White G, Wells GD. (2013). Cold-water immersion and other forms of cryotherapy: physiological changes potentially affecting recovery from high-intensity exercise. *Extreme Physiology & Medicine, 2*(26), 371-384.

Wilcock, I., Cronin, J., & Hing, W. (2006). Physiological response to water immersion. A method for sport recovery? *Sports Medicine, 36*(9), 747-765.

Note: *paper included in the meta-analysis.