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

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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 frío/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
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 metaanalytical 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.
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 by 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>
<thead>
<tr>
<th>Authors</th>
<th>Participants (level of training, gender, number)</th>
<th>Load that they were subjected to</th>
<th>Temperature of water (°C)</th>
<th>Time of immersion (min)</th>
<th>Number of immersions and frequency</th>
<th>Total time of immersion (min)</th>
<th>Type of immersion, 1: CWI 2: CWT</th>
<th>Global ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elias, et al., (2013).</td>
<td>Professionals players of Australian football, male, n:24</td>
<td>60 min training of Australian football</td>
<td>12°C</td>
<td>14 min</td>
<td>1</td>
<td>14</td>
<td>1</td>
<td>1.72 (DOMS)*</td>
</tr>
<tr>
<td>Elias, et al., (2013).</td>
<td>Professionals players of Australian football, male, n:24</td>
<td>60 min training of Australian football</td>
<td>Cold (12°C)</td>
<td>7 x 1 min</td>
<td>1</td>
<td>14</td>
<td>2</td>
<td>0.82 (DOMS)</td>
</tr>
<tr>
<td>Eston, et al., (1999)</td>
<td>Students, female, n:15</td>
<td>8 x 5 arms extension and flexion</td>
<td>15°C</td>
<td>15 min</td>
<td>7 (12 h)</td>
<td>105</td>
<td>1</td>
<td>0.25 (CK)</td>
</tr>
<tr>
<td>French, et al., (2008).</td>
<td>Physically active, male, n: 26</td>
<td>6 x 10 leg extension and flexion +5 sec eccentric</td>
<td>cold (8-10°C)</td>
<td>4 x 1 min</td>
<td>1</td>
<td>13</td>
<td>2</td>
<td>0.62 (CK)</td>
</tr>
<tr>
<td>Ingram et al., (2009).</td>
<td>Experienced in team sports, male, n: 11</td>
<td>Simulate game teams sports</td>
<td>10°C</td>
<td>(2 x5 min), 2.5 min out of water</td>
<td>2 (24 h)</td>
<td>20</td>
<td>1</td>
<td>0.13 (CK), 1.09 (DOMS)*</td>
</tr>
<tr>
<td>Ingram et al., (2009).</td>
<td>Experienced in team sports, male, n: 11</td>
<td>Simulate game teams sports</td>
<td>Cold (10°C)</td>
<td>3 x 2 min</td>
<td>2 (24 h)</td>
<td>24</td>
<td>2</td>
<td>0.13 (CK), 0.95 (DOMS)*</td>
</tr>
<tr>
<td>Kuligowsky, et al., (1998).</td>
<td>Healthy, 28 male y 28 female, n: 56</td>
<td>50 eccentric arms extensions</td>
<td>12.8°C</td>
<td>24 min</td>
<td>4 (24 h)</td>
<td>96</td>
<td>1</td>
<td>0.54 (DOMS)*</td>
</tr>
<tr>
<td>Kuligowsky, et al., (1998).</td>
<td>Healthy, 28 male y 28 female, n: 56</td>
<td>50 eccentric arms extensions</td>
<td>Cold (12.8°C)</td>
<td>6 x 1 min</td>
<td>4 (24 h)</td>
<td>96</td>
<td>2</td>
<td>0.20 (DOMS)</td>
</tr>
</tbody>
</table>
### Table 1 (Continuation)

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

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.

<table>
<thead>
<tr>
<th></th>
<th>ES</th>
<th>n trials</th>
<th>n ES</th>
<th>IC [95%]</th>
<th>Z</th>
<th>Q</th>
<th>I²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global effect size</td>
<td>0.38</td>
<td>8</td>
<td>20</td>
<td>[0.18, 0.58]</td>
<td>-3.7*</td>
<td>61.77</td>
<td>88.67</td>
</tr>
<tr>
<td>Dependent variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CK</td>
<td>0.29</td>
<td>4</td>
<td>12</td>
<td>[0.03, 0.55]</td>
<td>-2.2*</td>
<td>13.08</td>
<td>69.43</td>
</tr>
<tr>
<td>DOMS</td>
<td>0.53</td>
<td>4</td>
<td>8</td>
<td>[0.20, 0.85]</td>
<td>-3.18*</td>
<td>46.94</td>
<td>93.61</td>
</tr>
</tbody>
</table>


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.](image)

*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.


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


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*Note: *paper included in the meta-analysis.