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# Effects of post-exercise cold-water immersion on resistance training-induced gains in muscular strength: a systematic review and meta-analysis

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**Short title:** Cold-water immersion and strength gains

## Abstract

The aim of this review was to perform a meta-analysis examining the effects of CWI coupled with resistance training on gains in muscular strength. Four databases were searched to find relevant studies. Their methodological quality and risk of bias were evaluated using the PEDro checklist. The effects of CWI vs. control on muscular strength were examined in a random-effects meta-analysis. Ten studies ($n$ = 170; 92% males), with 11 comparisons across 22 groups, were included in the analysis. Studies were classified as of good or fair methodological quality. The main meta-analysis found that CWI attenuated muscular strength gains (effect size [ES]: –0.23; 95% confidence interval [CI]: –0.45, –0.01; $p$ = 0.041). In the analysis of data from studies applying CWI only to the trained limbs, CWI attenuated muscular strength gains (ES: –0.31; 95% CI: –0.61, –0.01; $p$ = 0.041). In the analysis of data from studies using whole-body CWI, there was no significant difference in muscular strength gains between CWI and control (ES: –0.08; 95% CI: –0.53, 0.38; $p$ = 0.743). In summary, this meta-analysis found that the use of CWI following resistance exercise sessions attenuates muscular strength gains in males. However, when CWI was applied to the whole body, there was no significant difference between CWI and control for muscular strength. Due to the attenuated gains in muscular strength found with single limb CWI, the use and/or timing of CWI in resistance training should be carefully considered and individualized.

**Keywords:** exercise; 1RM; isometric strength; isokinetic strength

## Highlights

1. The main finding of this meta-analysis is that post-exercise cold-water immersion attenuates resistance training-induced gains in muscular strength.
2. Attenuated gains in strength were found when cold-water immersion was applied to the trained limbs. However, there was no significant difference between control and cold-water immersion protocols that were applied to the whole-body.
3. Due to the attenuated gains in muscular strength found with post-exercise single limb cold-water immersion, its use and/or timing in resistance training should be considered carefully.

## 1. Introduction

Cold-water immersion (CWI) is commonly used after exercise to enhance and expedite recovery between training sessions (Broatch et al., 2018; Versey et al., 2013; Wilcock et al., 2006). As the name suggests, this method involves immersing a body part or the whole body in cold water. In CWI protocols, the water temperature is generally between 10 and 15 °C, and the duration of the immersion is around 5 to 15 min (Broatch et al., 2018; Versey et al., 2013; Wilcock et al., 2006). Research has established that CWI positively affects markers of exercise-induced muscle damage, inflammation, muscle soreness, and perceptions of fatigue (Broatch et al., 2018; Roberts et al., 2014; Versey et al., 2013; Wilcock et al., 2006). Besides these outcomes, studies have also explored the acute and long-term effects of CWI when applied following resistance exercise.

Studies with an acute design have reported that the use of CWI following resistance exercise may contribute to improved recovery. In a crossover design, one study compared the effects of 10 min of CWI at 10 °C vs. 10 min of low-intensity cycling on recovery after a resistance exercise session (Roberts et al., 2014). Six hours after using these two recovery strategies, the participants performed six sets of squats at 80% of one-repetition maximum (1RM). Compared to low-intensity cycling, the use of CWI increased the total workload during the last three sets by 38%. These results suggested that using CWI after a resistance exercise session may decrease the time needed for recovery, allowing individuals to complete more work (i.e., volume) during subsequent exercise sessions. The positive effects of CWI on increasing total volume in resistance exercise may be of substantial practical importance. Specifically, previous research established a linear relationship between resistance training volume and muscular strength gains (Ralston et al., 2017). As CWI may increase volume, the use of this recovery method in-between resistance training sessions may, over the long term, also enhance muscular strength.

Even though a positive effect of CWI is observed when applied acutely, research has also observed that CWI attenuated strength gains when used over the long term (Roberts et al., 2015). For example, Roberts et al. (2015) included 21 physically active men who performed resistance training for 12 weeks, with 10 min of CWI (applied only to the legs) or active recovery (low-intensity cycling) after each training session. In contrast to the data presented from the acute studies, the use of CWI in this study actually attenuated isotonic, isometric, and isokinetic strength gains. However, more recent studies also utilized CWI following each resistance training session and reported that its use did not negatively affect gains in muscular strength (Fyfe et al., 2019; Wilson et al., 2021). In the study by Fyfe et al. (2019), whole-body CWI applied over the course of 7 weeks of resistance training attenuated gains in muscular hypertrophy but not strength. Possible discrepancies between the studies might be due to different CWI protocols (i.e., immersion of the limbs to cold water vs. whole-body immersion). Owing to the conflicting reports, there is still no consensus on this topic.

Several narrative reviews, editorials, and opinion pieces have been published that discussed the suitability of CWI as a post-exercise recovery tool (Allan and Mawhinney, 2017; Broatch et al., 2018; Cheng, 2018; Ihsan et al., 2021; Petersen and Fyfe, 2021). For example, Broatch et al. (2018) reviewed the influence of post-exercise CWI on adaptive responses to different forms of exercise. However, the effects of CWI after resistance exercise on muscular strength have only been briefly touched upon, with the findings among the analyzed studies interpreted as unclear. In another recent review, the authors summarized the evidence on the topic and concluded that CWI, in some cases, attenuates muscular strength gains (Petersen and Fyfe, 2021). Some of the discrepancies among the conclusions from previous narrative reviews might be because these authors did not perform a meta-analysis that would allow pooling of outputs from primary studies. A meta-analysis would be important to perform given that some of the primary studies might have been underpowered to find significant differences as most included sample sizes of 11–16 participants (Fröhlich et al., 2014; Fyfe et al., 2019; Ohnishi et al., 2004; Poppendieck et al., 2021; Wilson et al., 2021; Yamane et al., 2006; Yamane et al., 2015). While meta-analytic data provide a summary effect, they also add insights into the pattern of effect sizes and the influence of possible moderators (e.g., CWI protocol). Due to the popularity of CWI in practice and the equivocal evidence on the topic, the aim of this review was to perform a meta-analysis examining the effects of CWI on resistance training-induced increases in muscular strength.

## 2. Material and methods

### 2.1. Search strategy

This review was performed while following the PRISMA guidelines (Moher et al., 2009). In total, the search was carried out through four databases: PubMed/MEDLINE, Scopus, SPORTDiscus, and Web of Science. The search in all of these databases was performed using the following search syntax: ("cold-water immersion" OR "cold water immersion" OR cryotherapy OR "cold exposure" OR "cold application") AND ("muscle strength" OR "muscular strength" OR "muscular performance" OR "muscle performance" OR 1RM OR "one repetition maximum" OR MVC OR "maximal voluntary contraction") AND ("resistance exercise" OR "resistance training" OR "strength exercise" OR "strength training"). Secondary searches were performed in two phases; first, reference lists from all included studies were screened, followed by forward citation tracking using Google Scholar (i.e., examining the papers that cited the included studies). The search was performed on September 22$^{nd}$ 2021.

### 2.2. Inclusion criteria

Studies that met the following criteria were included:

1. Published in English
2. Explored the effects of CWI applied after resistance exercise sessions on muscular strength gains
3. Incorporated a control group that included passive or active recovery after exercise

This review considered all forms of strength tests, including isotonic, isometric, or isokinetic assessments.

### 2.3. Data extraction

From each included study, the following data were extracted:

1. Lead author name and year of study publication
2. Participants characteristics
3. Resistance training frequency and total duration
4. CWI and control protocols
5. Strength test
6. Main study findings

When the data were not available, the corresponding author of the study (Poppendieck et al., 2021) was contacted to provide the data needed for the analysis (i.e., pre- and post-intervention mean ± standard deviation from the CWI and control groups). For studies that presented data in figures, the mean ± standard deviation values were extracted using the WebPlotDigitizer software.

### 2.4. Methodological quality

The methodological quality and risk of bias appraisal of the included studies was evaluated using the PEDro checklist (Maher et al., 2003). This checklist has 11 items, which refer to different aspects of the study design, including: eligibility criteria, randomization, concealed allocation, the similarity of groups, blinding, attrition, intention to treat, and the reporting of results. The maximum number of points on this checklist is 10, given that the first item is not included in the total score. Based on the summary scores, studies were classified as excellent, good, fair, and poor quality if they scored 9–10, 6–8, 4–5, or ≤3 points, respectively (Grgic and Pickering, 2019).

### 2.5. Statistical analysis

The meta-analysis was performed using standardized mean differences (Cohen's *d*). Cohen's *d* effect sizes were calculated as the posttest-pretest mean change in each group, divided by the pooled standard deviation. When studies presented multiple related outcomes (i.e., multiple strength tests), Cohen's *d* effect sizes and variance for each outcome were calculated and the average values were used for the main analysis. Sensitivity analysis was performed by excluding two studies (Ohnishi et al., 2004; Yamane et al., 2006) that used the handgrip test to evaluate gains in strength. Subgroup analyses were performed to explore the effects of whole-body CWI vs. CWI applied only to the exercised limbs. Cohen's *d* effect sizes were interpreted as: "trivial" (≤0.20); "small" (0.21–0.50); "medium" (0.51–0.80); and "large" (>0.80) (Cohen, 1992). $I^2$ statistic was used to explore heterogeneity and interpreted as ≤50% (low heterogeneity), 50–75% (moderate heterogeneity), and >75% (high heterogeneity). All meta-analyses were performed using the Comprehensive Meta-analysis software, version 2 (Biostat Inc., Englewood, NJ, USA). Group differences were considered statistically significant at $p < 0.05$.

## 3. Results

### 3.1. Search results

There was a total of 113 results in the primary search. Sixteen full-text papers were read and eight studies were included. In the secondary search, there were 845 results, and two new studies (Jones, 2017; Montano et al., 2018) were included. Therefore, ten studies were included in this review (Fröhlich et al., 2014; Fyfe et al., 2019; Jones, 2017; Montano et al., 2018; Ohnishi et al., 2004; Poppendieck et al., 2021; Roberts et al., 2015; Wilson et al., 2021; Yamane et al., 2006; Yamane et al., 2015) (Figure 1). Of note, one paper contained two studies published within the same manuscript (Yamane et al., 2006). Therefore, there was a total of 11 comparisons across 22 groups included in the analysis (i.e., 11 groups that used CWI and 11 control groups).

### 3.2. Study characteristics

The pooled number of participants was 170 (14 females). The sample sizes in individual studies ranged from 11 to 21 participants (Table 1). The duration of the resistance training protocols ranged from 4 to 12 weeks, with a training frequency of 2 to 3 days per week. CWI protocols ranged from 10 to 20 min, and the water temperature was from 10 to 15 °C. Six studies applied the CWI protocols to the limbs that underwent resistance training. Four studies utilized whole-body CWI, where the participants were immersed in the water up to their sternum area. Eight studies compared the effects of CWI with the condition that included passive rest, while two studies compared the effects with active recovery protocols involving low-intensity cycling or running. Changes in muscular strength were evaluated using different assessments, including the 1RM test and different forms of isokinetic and isometric tests.

### 3.3. Methodological quality

Seven studies scored 6 points on the PEDro checklist and were classified as being of good methodological quality. Three studies scored 4 or 5 points and were classified as being of fair methodological quality (Table 2).

### 3.4. Meta-analysis results

The main meta-analysis found that CWI attenuated muscular strength gains (Cohen's *d*: –0.23; 95% CI: –0.45, –0.01; $p = 0.041$; $I^2 = 0\%$; Figure 2). These findings remained consistent in the sensitivity analysis that analyzed gains in muscular strength after excluding studies that used the handgrip strength test (Cohen's *d*: –0.26; 95% CI: –0.52, –0.001; $p = 0.046$; $I^2 = 0\%$). In the analysis of data from studies applying CWI only to the trained limbs, CWI attenuated muscular strength gains (Cohen's *d*: –0.31; 95% CI: –0.61, –0.01; $p = 0.041$; $I^2 = 0\%$). In the analysis of data from studies using whole-body CWI, there was no significant difference in muscular strength gains between CWI and control (Cohen's *d*: –0.08; 95% CI: –0.53, 0.38; $p = 0.743$; $I^2 = 0\%$).

## 4. Discussion

The main finding of this meta-analysis is that CWI following resistance exercise sessions attenuates gains in muscular strength. CWI also attenuated the increase in muscular strength when applied to the trained limbs. However, when CWI was applied to the whole body, there was no significant difference between CWI and control for muscular strength. This should be considered as using whole-body CWI is a more common training practice. Due to the attenuated gains in muscular strength found with single limb CWI, its use in resistance training should be carefully considered and individualized.

The mechanisms underpinning the attenuation of muscular strength may be related to the inhibition of translational efficiency in skeletal muscle after exercise or the decreased delivery and/or uptake of amino acids in muscle due to CWI's effects on reducing muscle blood flow (Figueiredo and von Walden, 2020; Hyldahl and Peake, 2020; Mawhinney et al., 2013). For example, one recent study applied CWI post-resistance exercise and reported that it reduces myofibrillar protein synthesis rates (Fuchs et al., 2019). These findings need to be placed in the context of previous observations that increased muscle protein synthesis contributes to gains in muscular strength (Snijders et al., 2015). Therefore, the reduction in blood flow and muscle protein synthesis that occurs with the use of CWI post-exercise may explain its attenuation of muscular strength gains. Due to these physiological effects, studies have also reported that CWI negatively affects hypertrophy, which may also be associated with attenuated gains in muscular strength (Folland and Williams, 2007; Fyfe et al., 2019; Roberts et al., 2015). In a detailed review of mechanisms, CWI has been reported to blunt anabolic and ribosomal biogenesis signaling, inhibit the satellite cell response and alter cellular stress response (Petersen and Fyfe, 2021). All these factors, in some part, may contribute to the attenuation of muscular strength gains with CWI.

Besides the main analysis, we also opted to analyze the data after excluding the studies that used the handgrip strength because it has been hypothesized that there is only a limited ability to increase handgrip strength as an adult (Buckner et al., 2019). Indeed, one study used a 24-week resistance training program and recorded significant increases in 1RM strength, which were not accompanied by any changes in handgrip strength (Tieland et al., 2015). Therefore, using only the handgrip strength test might not be entirely appropriate to evaluate resistance training's effectiveness to increase strength. Subsequently, the effects of CWI on strength gains might not be fully pronounced in the handgrip strength test vs. other tests such as the 1RM. When the studies that used the handgrip test were excluded, the pooled effect of CWI on strength gains slightly increased (Cohen's $d$: –0.23 vs. –0.26). It might be that the effects of CWI are more evident in complex strength tests (e.g., 1RM leg press). Nevertheless, future studies on this topic may consider using both the handgrip and 1RM tests to explore if the effects of CWI on strength gains are test-specific.

In subgroup analyses, attenuated muscular strength gains were also observed when considering the data from studies that applied CWI only to the trained limb. However, there was no significant difference in strength gains between control and CWI protocols where the participants were immersed in cold water up to their sternum. The design used by these studies is much more practically relevant, as using CWI only to the limbs is an uncommon training practice. Therefore, it might be that the effect of CWI on muscular strength gains is observed only when applied to the limbs but not the whole body. The contrasting findings might be explained by the divergent physiological effects with different CWI protocols. For example, whole-body vs. CWI applied to the limbs may have different effects on hydrostatic pressure (Leeder et al., 2015). This is relevant to mention, given that varying hydrostatic pressure in CWI protocols has been reported to influence markers of delayed onset muscle soreness (Leeder et al., 2015). Furthermore, CWI protocols applied to the limb influence signaling markers both in the immersed and in the non-immersed limb, likely resulting from systemic increases in noradrenaline (Allan et al., 2017). However, such an effect would not be expected in whole-body CWI, given that all regions of the body (usually up to the sternum area) are equally exposed to cold water. Future studies are needed to explore this topic further, especially since the mechanisms underpinning these differential effects are unclear.

Out of all included studies, the largest effect of CWI was observed in the study by Roberts et al. (2015). Besides reporting the largest effect, this study also had the longest duration. The resistance training intervention in this study lasted for 12 weeks, whereas most other included studies were shorter (i.e., 4 to 8 weeks). In one study that lasted only 6 weeks and had a total of 12 exercise sessions, there was no significant difference between control and CWI on muscular strength (Montano et al., 2018). Based on the comparisons of findings between studies, it might be that the effects of CWI increase along with the duration of its use. Hypothetically, there might not be a disadvantage to using CWI when a fast recovery is needed (e.g., between games in close succession or during a tapering period), and the attenuation effect on muscular strength might only occur with the long-term use of CWI (Peake, 2020). Future studies interested in exploring the time course of the effects of CWI on muscular strength gains may consider using a longer duration training intervention (e.g., 16 weeks) and evaluate strength periodically (e.g., every 4 weeks). Indeed, the amount of exposure to CWI is likely to be of substantial practical importance (Ihsan et al., 2021). For example, one study used a 3-week high-volume training program (12 total exercise sessions) where rugby players were randomized to post-exercise CWI or passive rest (Tavares et al., 2019). This study observed a positive effect of CWI on muscle soreness and countermovement jump performance. Therefore, while the present meta-analysis observed attenuated muscular strength gains with CWI, this recovery strategy may benefit when it is periodized into the training program or when the timing is carefully considered.

Thus far, only one meta-analysis has explored the effects of CWI on gains in muscular strength (Malta et al., 2021). In this analysis that included five studies, it was found that CWI attenuated strength gains (Cohen's *d*: –0.60). However, there are several limitations associated with this meta-analysis that should be considered. Specifically, Malta et al. (2021) did not account for correlated (i.e., non-independent) effects within the same study. Non-independent outcomes from the same study were analyzed separately (i.e., as if these effects were from different studies), which might have resulted in estimates that are not fully valid (Tanner-Smith et al., 2016). Furthermore, the authors also used the fixed-effect model for the meta-analysis, when the random-effects model would be more appropriate given the differences in methodology among the included studies (Borenstein et al., 2010). These issues were accounted for in the present meta-analysis by using average effect size and variance values in the random-effects model. Finally, some studies (Ohnishi et al., 2004) were not included by Malta et al. (2021), and new research on the topic was recently published (Poppendieck et al., 2021; Wilson et al., 2021), therefore, justifying a need for an updated meta-analysis. Compared to the previous meta-analysis, the pooled effect presented herein was much smaller (Cohen's *d*: –0.60 vs. –0.23).

### 4.1. Methodological quality and limitations

Studies were classified as being of fair or good methodological quality. Therefore, the results presented herein are not confounded by studies with poor methodological quality. Still, several aspects of methodological quality should be mentioned. First, in three studies, it was unclear if the participants were randomized to the CWI and control groups (Jones, 2017; Wilson et al., 2021; Yamane et al., 2006). Second, while some studies blinded the assessors that evaluated muscle hypertrophy outcomes, none of the included studies blinded assessors who evaluated muscular strength (Fyfe et al., 2019; Roberts et al., 2015; Yamane et al., 2015). In exercise intervention studies, it is generally difficult to blind the participants to the interventions. However, researchers may consider blinding the participants to the study aims. For example, one study used an interesting approach where the participants in the control group were informed that their protein supplements contained an additional dose of leucine (Wilson et al., 2021). Broatch et al. (2014) compared the effect of CWI vs. thermo-neutral water immersion (TWI), where the participants in the TWI group were falsely led to believe in using a newly developed “recovery oil”, purported to be comparably effective as CWI for recovery. Interestingly, both of these studies did not find a significant effect of CWI on their analyzed outcomes. Therefore, future studies may consider blinding the participants to the study aims, which would contribute to increased methodological quality.

Out of the 170 pooled participants in the meta-analysis, only 8% were females. Therefore, the main limitation of this review is that the findings of this review are specific to male participants and cannot be generalized to females. One recent study demonstrated that males experienced greater improvements in performance (44% vs. 26%) than females following a CWI protocol (Baláš et al., 2020). These findings indicated that there might be a sex-specific response to CWI. Because of these differences, future studies may also consider exploring the effects of CWI on muscular strength gains between males and females.

## 5. Conclusion

This meta-analysis found that the use of CWI following resistance exercise sessions attenuates gains in muscular strength. CWI also attenuated the increase in muscular strength when applied to the trained limbs. However, when CWI was applied to the whole body, there was no significant difference between CWI and control for muscular strength. This should be considered as using whole-body CWI is a more common training practice. Due to the attenuated gains in muscular strength found with single limb CWI, its use in resistance training should be carefully considered and individualized.

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**Figure 1.** Depiction of the search process

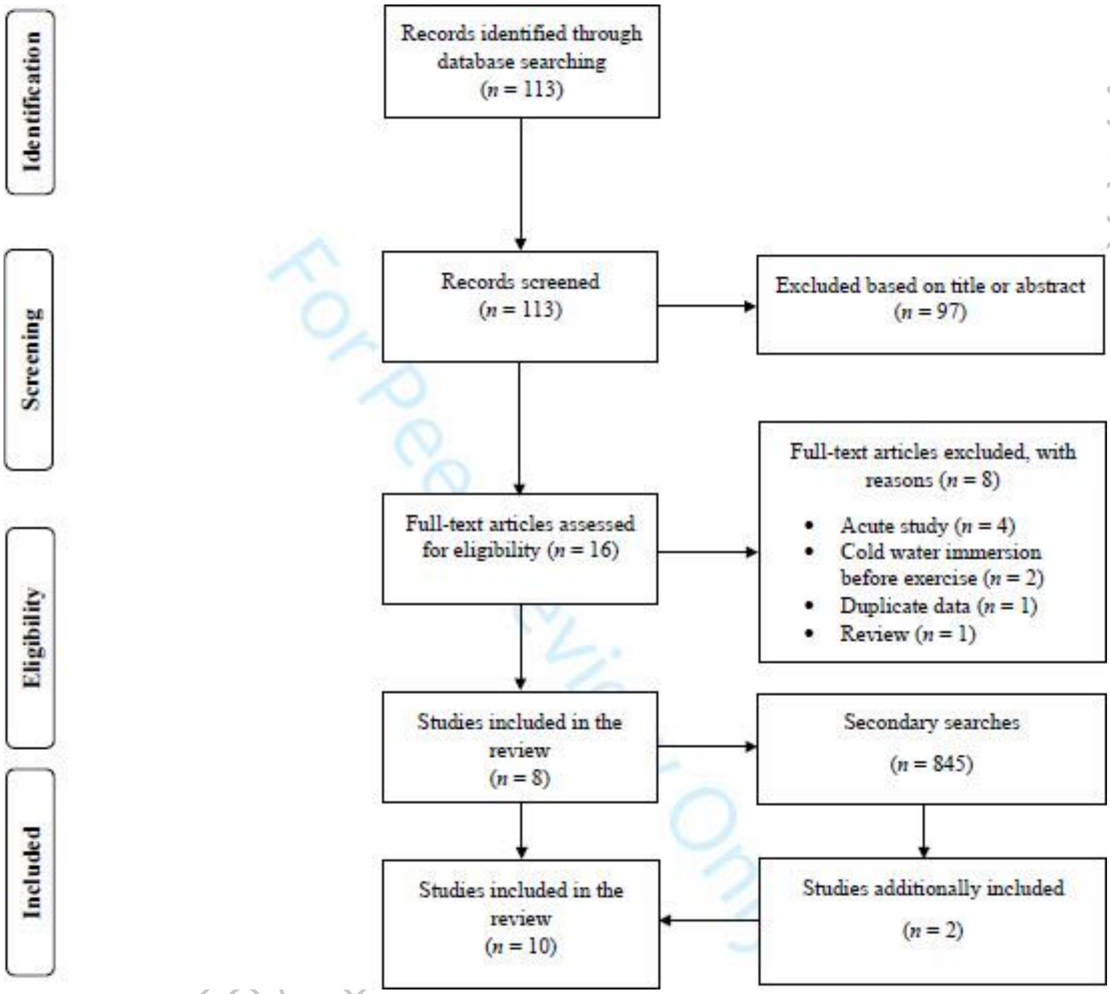


**Figure 2.** Forest plot displaying the results from the meta-analysis on the effects of cold-water immersion (CWI) after resistance exercise on muscular strength gains compared to control groups. The plotted squares denote effect sizes (ES), and the whiskers represent 95% confidence intervals (CIs). One study had multiple groups, and for that study, the effects are presented independently and marked as (a) and (b). The results of the meta-analysis found that there was a significant negative effect of CWI on muscular strength gains.

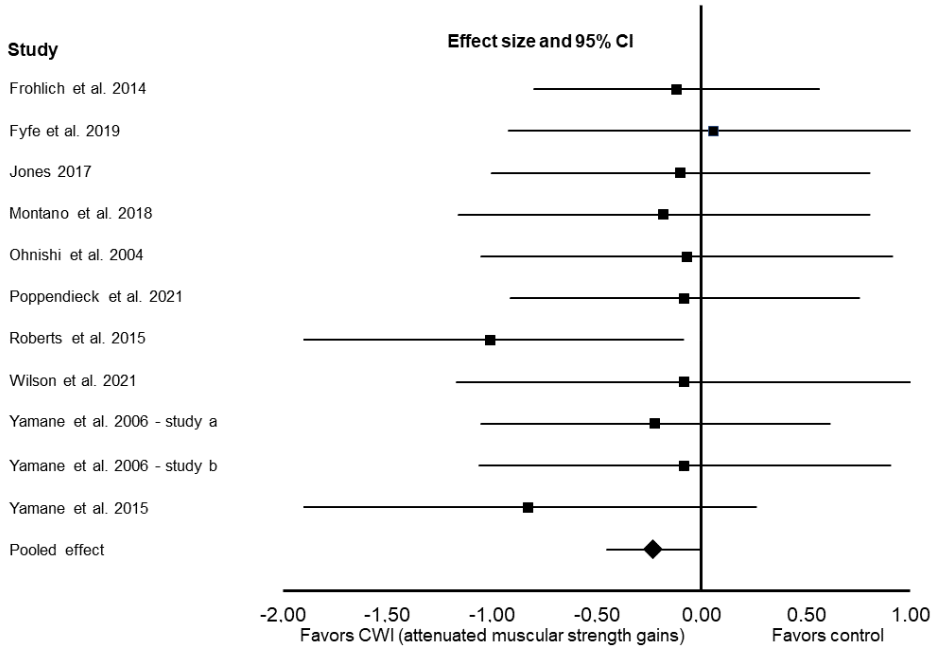


**Table 1.** Summary of studies included in the meta-analysis

| Study | Participants | Resistance training protocol | Training frequency and duration | CWI protocol | Control protocol | Main findings |
|---|---|---|---|---|---|---|
| Fröhlich et al. (2014) | Resistance-trained men (*n* = 17) | 3 × 8-12 repetitions of knee flexion | 2 days per week; 5 weeks | Legs were immersed for 3 × 4-min, with 30-seconds of rest. The water temperature was 12.0 ± 1.5 °C. | Passive rest | 1RM knee flexion: ↔ |
| Fyfe et al. (2019) | Untrained men (*n* = 16) | 3-5 × 12-20 repetitions of multiple resistance exercises | 3 days per week; 7 weeks | Participants were immersed up to their sternum for 15 min. The water temperature was 10 °C. | Passive rest | 1RM leg press: ↔ 1RM bench press: ↔ |
| Jones (2017) | Recreationally trained men (*n* = 19) | 1-2 × 4-10 repetitions of multiple | 2 days per week; 10 weeks | Participants were immersed up to their chest for | 15 min of low intensity running | Isometric leg press: ↔ Isometric knee |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | resistance exercises | | 10 min. The water temperature was 12 ± 1 °C. | | flexion: ↑ in the control group Isometric knee extension: ↑ in the control group 1RM leg press: ↔ |
| Montano et al. (2018) | Untrained men and women (*n* = 16) | 1-2 × 10-12 repetitions of multiple resistance exercises | 2 days per week; 6 weeks | Participants were immersed up to their clavicles for 10 min. The water temperature was 15 °C. | Passive rest | 1RM chest press: ↔ |
| Ohnishi et al. (2004) | Untrained men (*n* = 16) | 3 × 8 repetitions of eight handgrip exercises | 3 days per week; 6 weeks | Forearm was immersed 20 min. The water temperature was 10 ± 1 °C. | Passive rest | Handgrip strength: ↔ |
| Poppendieck et al. (2021) | Resistance-trained men and women (*n* = 11) | 3 × 10 repetitions of multiple lower-body resistance exercises | 3 days per week; 8 weeks | Participants were immersed up to their sternum for 10 min. The water temperature was from 14 to 15 °C. | Passive rest | 1RM leg press: ↔ |
| Roberts et al. (2015) | Physically active men (*n* = 21) | 3-5 × 8-18 repetitions of multiple lower-body resistance exercises | 2 days per week; 12 weeks | Legs were immersed for 10 min. The water temperature was 10 ± 0.5 °C. | 10 minutes of low intensity cycling | 1RM knee extension: ↑ in the control group Isometric knee extension |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | : ↑ in the control group Isokinetic knee extension: ↑ in the control group 1RM leg press: ↑ in the control group |
| Wilson et al. (2021) | Resistance-trained men (*n* = 13) | 3-4 × 2-6 repetitions of multiple lower-body resistance exercises | 2 days per week; 8 weeks | Legs were immersed for 10 min. The water temperature was 10.1 ± 0.3 °C. | Passive rest | Isometric squat: ↔ 4RM squat: ↔ |
| Yamane et al. (2006) | Untrained men and women (*n* = 11) or untrained men (*n* = 16) | 3 × 8 repetitions of repeated handgrip exercises | 3 days per week; 4 weeks | Forearm was immersed for 20 min. The water temperature was 10 ± 1 °C. | Passive rest | Handgrip strength: ↑ in the control group |
| Yamane et al. (2015) | Untrained men (*n* = 14) | 3 × 8 repetitions of wrist-flexion exercises | 3 days per week; 6 weeks | Forearm was immersed for 20 min. The water temperature was 10 ± 1 °C. | Passive rest | Isometric strength of wrist flexors: ↑ in the control group |

CWI: cold-water immersion; RM: repetition maximum; ↔ no significant difference; ↑ significantly greater increase;

**Table 2.** Results from the methodological quality assessment using the PEDro checklist

| **Study** | **Item 1** | **Item 2** | **Item 3** | **Item 4** | **Item 5** | **Item 6** | **Item 7** | **Item 8** | **Item 9** | **Item 10** | **Item 11** | **Total score** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fröhlich et al. (2014) | Yes | Yes | Unclear | Yes | No | No | No | Yes | Yes | Yes | Yes | 6 |
| Fyfe et al. (2019) | Yes | Yes | Unclear | Yes | No | No | No | Yes | Yes | Yes | Yes | 6 |
| Jones (2017) | Yes | Unclear | Unclear | Yes | No | No | No | No | Yes | Yes | Yes | 4 |
| Montano et al. (2018) | Yes | Yes | Unclear | Yes | No | No | No | Yes | Yes | Yes | Yes | 6 |
| Ohnishi et al. (2004) | No | Yes | Unclear | Yes | No | No | No | Yes | Yes | Yes | Yes | 6 |
| Poppendieck et al. (2021) | Yes | Yes | Unclear | Yes | No | No | No | No | Yes | Yes | Yes | 5 |
| Roberts et al. (2015) | Yes | Yes | Unclear | Yes | No | No | No | Yes | Yes | Yes | Yes | 6 |
| Wilson et al. (2021) | Yes | Unclear | Unclear | Yes | Yes | No | No | Yes | Yes | Yes | Yes | 6 |
| Yamane et al. (2006) | Yes | Unclear | Unclear | Yes | No | No | No | Yes | Yes | Yes | Yes | 5 |
| Yamane et al. (2015) | No | Yes | Unclear | Yes | No | No | No | Yes | Yes | Yes | Yes | 6 |

Yes: criterion is satisfied; No: criterion is not satisfied; Unclear: unable to rate