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Conclusions

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Introduction

The therapeutic practice of cold-water immersion (CWI), such as ice baths or cold showers, has gained considerable traction in recent years as a potential modality for promoting overall health and wellbeing [1]. CWI, which involves immersing the body partially or fully in cold water, in temperatures typically ranging from 10–15°C (50–59°F) [2,3], has been utilized across various cultures for centuries, but it is only in the modern era that it has been promoted as a remedial and performance-enhancing therapy in sport settings and, more recently, as a regular addition to self-care routines among the general population. CWI is believed to elicit a range of physiological responses, including the activation of the autonomic nervous system, modulation of the immune system, and the release of various biochemical mediators [2–5]. These physiological effects have prompted investigations into the potential applications of CWI in managing a diverse array of health conditions and promoting overall wellness.

CWI has been extensively researched in sporting contexts, with a notable emphasis on its ability to accelerate recovery after exercise. Meta-analysis has demonstrated that CWI after strenuous exercise can speed up the recovery of physical function, reduce muscle soreness, enhance perceived feelings of recovery, and reduce post-exercise inflammation [6]. However, cardiovascular health and cognitive benefits [11]. Similarly, while some evidence suggests that CWI can acutely improve mood [12], this finding is based on a small, non-randomized controlled trial where participants completed CWI in a group setting at the beach, raising questions about the role of social interaction and the natural environment in these effects. Proposals for using CWI to treat mood disorders such as depression [13], are further hampered by significant methodological limitations in existing studies. Research examining CWIs effects on physiological and mental health often combines it with physical activity (i.e., cold water swimming) or compares regular cold-water users (i.e., winter swim term searches for terms related to "cold-water immersion" (see S1 File for the full search strategy). A broad search strategy was used to capture as many studies as possible reporting outcomes related to CWI.

Database search results were exported to EndNote (version 20.2.1), where duplicates were removed and then uploaded to Covidence (Veritas Health Innovation, Melbourne, Australia). Two independent reviewers screened all titles and abstracts, and full-text articles for eligibility; any discrepancies were resolved by a third independent reviewer.

Inclusion criteria were as follows: i) healthy adults aged ≥ 18 years, ii) acute or long-term exposure to CWI, iii) CWI exposure was conducted via cold shower, ice bath, or cold plunge, iv) CWI water temperature was ≤ 15°C, v) a minimum CWI exposure time of 30 seconds, vi) immersion was at or above chest level (defined as the xiphoid process), vii) reported outcomes related to sleep, stress, fatigue, energy, skin health, immunity, inflammation, mental wellbeing, depression, anxiety, mood, concentration, alertness, or focus, viii) randomized controlled trial, and ix) published in a peer-reviewed journal. Studies were excluded if they included i) athletes, tier 3 and above [18], which includes highly trained and elite athletes competing at a national level or higher, ii) populations with chronic illness or musculoskeletal injury, iii) CWI exposure was through cryotherapy chamber or accidental exposure, iv) participants wore protective garments. CWI interventions that were conducted pre- or post-exercise were included if they reported appropriate outcomes.

Quality assessment

Studies were critically appraised for methodological quality by two independent authors using the PEDro scale [19]. Any discrepancies were resolved by an independent author. The PEDro scale assesses eligibility criteria, random allocation, concealed allocation, baseline comparability, blinding of participants, therapists and assessors, adequate follow-up, intention-to-treat, between-group comparison, and point measures and variability. Each appraisal item was given a score of 'yes,' 'no,' or 'not reported.' A score ≥ 7 was considered 'high quality,' a score of 5 or 6 was considered 'moderate quality,' and ≤ 4 was considered 'poor quality.'

Data extraction

Data were extracted independently by two authors using a pre-determined data extraction template and performed in Covidence (Veritas Health Innovation, Melbourne, Australia). Data extracted included publication details (author information, publication date, country of origin, funding), study methodology (sample size, study type, timepoints, intervention condi

[33], comprised of 3018 participants. All other studies were comprised of 100% male participants. Study design was varied; six studies [5,25–27,29,30] were conducted in a randomized crossover design, and 5 studies [28,31–34

Table 1. Characteristics of the included studies.

Author, year	Country	Study design	Participants (N)	Age	Female (%)	Interven-tion type	CWI[a] tem-perature (°C)	CWI duration	Depth of immersion	Comparator/Control
Ahokas, 2020	Finland	Crossover	9	26 ± 3.7	0	Bath	10	10 min	Xiphoid process	Seated in an empty bath for 10 min[b]
Buijze, 2016	Netherlands	Parallel	798 (30 s) 727 (60 s) 775 (90 s) 718 (CON[c])	39.7 ± 11.3 (30 s) 38.9 ± 10.6 (60 s) 39.6 ± 10.6 (90 s) 39.2 ± 10.6 (CON)	59 (30 s) 58 (60 s) 60 (90 s) 56 (CON)	Cold shower	10–12	30 consecutive days 30, 60, 90 s	Whole body	Shower as regular (not cold)
Earp, 2019	United States	Crossover	12	21.1 ± 2.1	0	Bath	15	15 min	Xiphoid process	Seated for 1 hour in similar body position

Risk of bias

Assessment of the methodological quality of the studies using the PEDro scale produced a mean of 6.4. Seven studies [25–27,29–32] were considered as 'moderate quality' and another four studies [5,28,33,34] as 'high quality' (see S2 File for full results of the PEDro assessment).

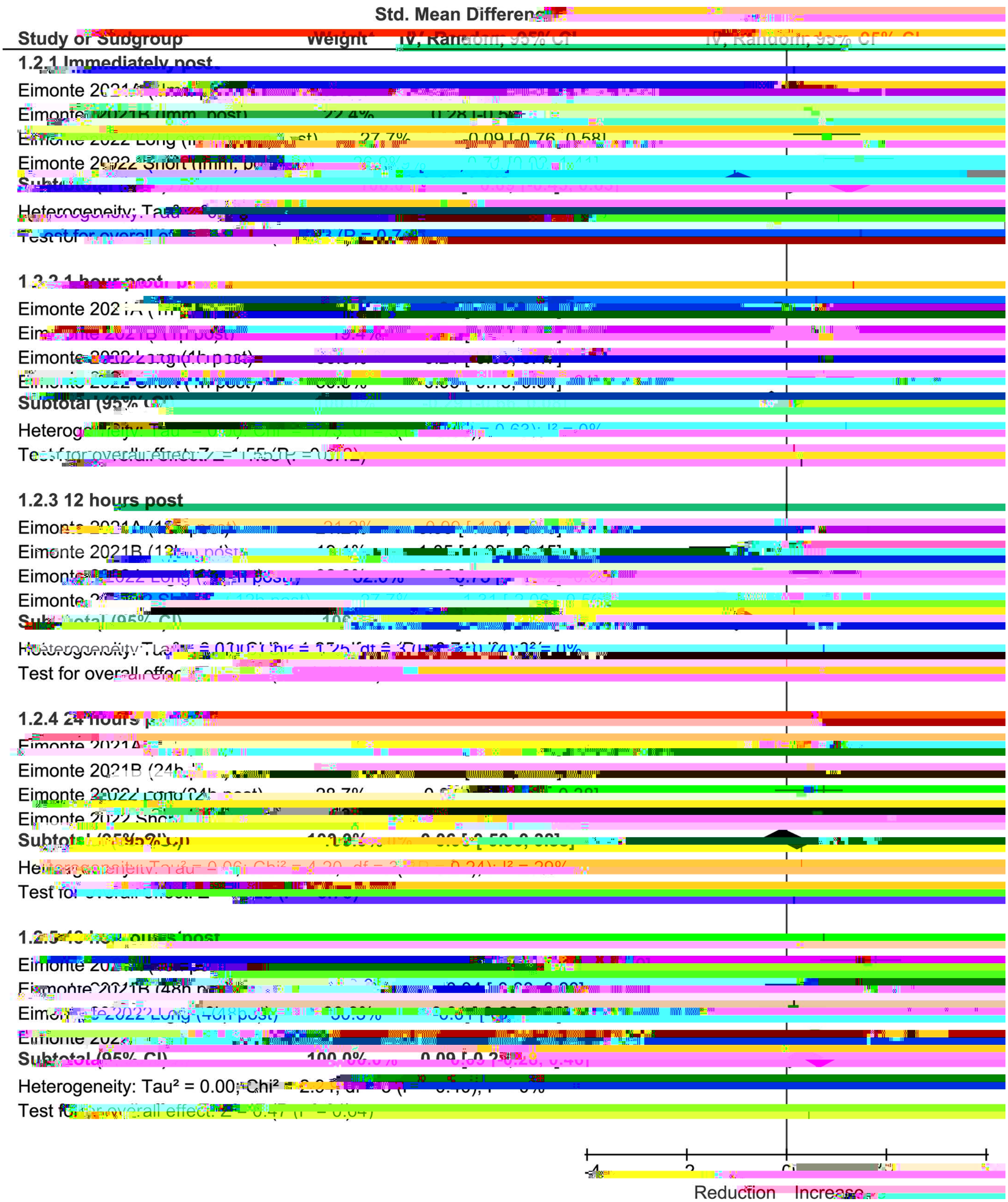

Fig 3. Meta-analysis results of the effects of cold-water immersion on stress immediately post, 1 hour post, 12 hours post, 24 hours post, and 48 hours post-exposure. *IV* instrumental variables, *CI* confidence interval, *Imm.* immediately.

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Fig 4. Meta-analysis results of the effects of cold-water immersion on immunity immediately post- and 1 hour post-exposure. *IV* instrumental variables, *CI* confidence interval, *Imm.* Immediately.

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Inflammation and immunity

Versteeg et al. (2023) evaluated the effects of a 3-week repeated CWI in a sample of 12 males randomly assigned to either CWI (12 minutes at 7°C, 4 times/week) or a control condition. While total leukocyte counts significantly decreased in both the CWI group (median difference: −1.10 × 10^3/μL) and the control group (median difference: −0.8 × 10^3/μL), the minimal reduction observed in both groups suggests that repeated CWI did not result in clinically relevant changes in inflammation. Ahokas (2020) compared the efficacy of CWI recovery (10°C for 10 minutes) to an active recovery control in random order among 9 physically active males, following an intensive loading protocol. A significant increase in leukocyte and lymphocyte concentrations ($p < 0.01$) occurred 5 minutes post protocol. At 1 hour post-recovery, leukocytes returned to baseline, and a significant drop below baseline was seen in lymphocytes ($p < 0.001$). Lymphocytes returned to baseline post 24 hours. Despite these results, no differences were seen for leukocyte and lymphocyte response between CWI and control groups. Both studies are limited by small sample sizes, homogeneous participant groups, and a lack of control for confounding variables such as baseline fitness. These factors restrict the generalizability of findings and may contribute to variability in reported outcomes. The lack of long-term follow-up further limits the ability to assess sustained effects of CWI on inflammation and immunity.

Sickness and illness

In a pragmatic randomized controlled trial (n = 3018) by Buijze et al. (2016), participants aged 18–65 years were randomly assigned to CWI for either 30, 60, or 90 seconds, or to a control group, for 30 days. Findings showed a 29% reduction in sickness absence for those in any of the CWI groups compared to the control group (incident rate ratio: 0.71, P = 0.003). However, for the number of illness days reported, there was no significant difference between groups. The large sample size and pragmatic design improve the external validity of this study. However, the reliance on self-reported sickness absence introduces potential reporting and social desirability bias. The reduction in sickness absence without changes in illness days raises questions about the mechanisms driving these findings.

which includes cold exposure, specific breathing exercises, and meditation, has similarly demonstrated quality of life benefits [41]. However, the combined effects of its various components make it difficult to isolate the specific contribution of CWI. Studies with athlete populations have examined the impact of CWI on sleep. One such study [42] found that CWI after high-intensity exercise did not acutely affect overall night sleep quantity and quality, suggesting that CWI does not impact sleep when used post-exercise. Another study [43] indicated that whole and partial CWI post-exercise decreased sleep arousals and limb movements, particularly benefiting athletes during intense training and competition periods. Overall, CWI shows promise for improving sleep and quality of life, although its specific contributions are hard to isolate.

A key strength of our review is its novelty; to our knowledge, it is the first systematic review of general and wide-ranging health impacts of CWI in general populations. It considerably extends previous systematic reviews, which have considered the impacts of CWI in the context of exercise performance [2,6,44–46], muscle soreness [46–48], and athlete populations [49,50]. We adhered to the highest quality systematic review methodology, including a comprehensive search strategy across multiple databases, ensuring a broad capture of relevant studies. The use of rigorous inclusion criteria and the restriction to RCTs enhance the quality and validity of our findings. Furthermore, we used a meta-analysis synthesis approach for all outcomes with sufficient data to enable it. Several limitations also exist. The studies varied

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