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EDITORIAL

Effects of cold water exposure on stress, cardiovascular, and psychological variables

Cold water exposure has been employed across various cultures and traditions for centuries, often linked to health and well-being benefits. In recent decades, scientific interest in the effects of cold water exposure on the human body has surged, leading to a plethora of research spanning areas such as physiology, psychology, and biochemistry.[1,2] While athletes and physically active individuals have frequently adopted cold water immersion as part of their recovery routines,[1] the potential implications for nonathletic individuals are not clear, and the existing literature presents conflicting outcomes and, in some instances, inconclusive findings.[2]

For this editorial, we followed the PRISMA[3] approach to review the effects of cold water exposure in healthy nonathletes. We included studies published until July 17, 2023, and registered on OSF its protocol on the same day (accessible at https://osf.io/mu4xd).

The revised Cochrane risk-of-bias tool for randomized trials[4] was used to assess methodological quality of the studies (Table 1).

A total of 840 articles were retrieved from PubMed and a total of 98 articles were retrieved from Scopus, amounting to a grand total of 939 unique citations. After duplication removal, 931 articles remained. 742 articles were removed after title screening and an additional147 articles were removed after screening the abstract. Of the 42 remaining articles, 24 articles could be used for data extraction. As shown in Table 1, the included articles were published from 1953 to 2022, on a total of 445 subjects (F: 88; M: 357).

Mood was investigated by Seo et al.[5] who used the Profile of Mood States (POMS) tool and did not find any differences between subjects in their crossover clinical trial.

Three studies investigated cognitive function.[4,6,7] Cheung et al.[7] and Seo et al.[4] did not find any differences. Cheung et al.[7] analysed vigilance and spatial attention, in a controlled clinical trial on 20 subjects, but described no statistically significant differences after 75 min at 21.5°C (mean); Seo et al.[4] found no influence on selective attention with the Stroop Color-Word Test after 50 min of exposure. Finally, Duncko et al.[6] did find a significant difference in virtual navigation Morris water task (VNMWT) after a single minute of exposure at 1°C ($t^{26} = 2.3$, $P < 0.05$).

Eimonte et al.,[8-10] in three studies, found muscular temperature to be significantly lower with respect to controls/before-treatment spanning from 1 to 2 h after treatment, but Beelen et al.[11] did not substantiate this effect.

Lactate blood concentration was progressively reduced when participants were exposed to 10°C water, either for 90 min or in single dabs, over a week,[12,13] but Beelen et al.[11] did not find any influence of cold exposure on blood lactate.

Fatigue perception and exhaustion perception brought mixed results, as three studies[11,14,15] did not find any significative changes against controls. Meanwhile, two studies[16,17] did find significative results with experimental subjects having lower perceived fatigue.

Neither systolic nor diastolic blood pressures were altered in the long-term by cold water exposure.[17,18] Heart rate did not change in five studies,[6,9,17,19,20] whereas two studies[10,18] found significant changes. There are mixed results on heart rate after exercise, as Jones et al.[12] found a lowering heart rate after the first day of cold exposure (10°C for 90 min) during exercise, whereas Tikuisis et al.[21] described an augmented post-fatigue heart rate in cold-exposed subjects after maximal exercise.

Total Cholesterol, LDL-c, and BMI were never found to have variations between the controls and the exposed groups, as perused by three studies.[8,21,22] Conversely, Eimonte et al.[8] did find a significant variation in triglycerides and HDL-c between the controls and the exposed groups, as they described an increase of 7% in HDL-c and 14% in triglycerides in cold-exposed subjects at 14°C for 170 min. HDL-c was increased up until 6 h after exposure and triglycerides after 12 h.

Blood cortisol was described to be unchanged between the controls and the exposed groups by two studies,[21,23] but three studies[8-10] by the same author show a statistically significant prolongation of the diurnal peak of cortisol until 1–2 h after cold exposure, and an higher concentration of cortisol was also observed at 12 h after 10 min of exposure.

TABLE 1 Included studies.

Title	Publication Year	No of subjects (Males and Females)	Overall Risk of Bias Assessment
Pulse rate, blood pressure and vision after a cold hip bath	1953	10 (M: 10; F: 0)	High
Circulatory response to cold showers: Effect of varied time lapses before exercise	1969	10 (M: 10; F: 0)	High
Effect of length of cold showers on skin temperatures and exercise heart rate	1970	10 (M: 10; F: 0)	Some concerns
Plasma norepinephrine responses of man in cold water	1977	6 (M: 6; F: 0)	High
Effect of lowered muscle temperature on the physiological response to exercise in men	1991	6 (M: 6; F: 0)	Some Concerns
Acute and chronic effects of winter swimming on LH, FSH, prolactin, growth hormone, TSH, cortisol, serum glucose and insulin	1995	11 (M: 6; F: 5)	High
Physiological responses of exercised-fatigued individuals exposed to wet-cold conditions	1999	13 (M: 13; F: 0)	High
Thermal regulatory responses to submaximal cycling following lower-body cooling in humans	2002	8 (M:8; F: 0)	High
Acute exposure to stress improves performance in trace eyeblink conditioning and spatial learning tasks in healthy men	2007	28 (M: 28; F: 0)	Low
Mild body cooling impairs attention via distraction from skin cooling	2007	20 (M: 14; F: 6)	High
Cognitive function during lower body water immersion and post-immersion afterdrop	2013	9 (M: 9; F:0)	Low
Cold water immersion in the management of delayed-onset muscle soreness: is dose important? A randomized controlled trial	2014	50 (M:32; F:18)	Low
The effect of various cold-water immersion protocols on exercise-induced inflammatory response and functional recovery from high-intensity sprint exercise	2014	8 (M:8; F: 0)	Some Concerns
Does Regular Post-exercise Cold Application Attenuate Trained Muscle Adaptation?	2015	14 (M: 14; F: 0)	High
Effects of Cold Water Immersion on Muscle Oxygenation During Repeated Bouts of Fatiguing Exercise: A Randomized Controlled Study	2016	20 (M: 10; F: 10)	Low
Variations in leptin and insulin levels within one swimming season in non-obese female cold water swimmers	2016	14 (M: 0; F: 14)	High
Dosages of cold-water immersion post exercise on functional and clinical responses: a randomized controlled trial	2017	60 (M:60; F: 0)	Low
Impairment of exercise performance following cold water immersion is not attenuated after 7 days of cold acclimation	2018	12 (M: 8; F: 4)	High
Evaluation of cognitive performance and neurophysiological function during repeated immersion in cold water	2019	12 (M: 8; F: 4)	High
Regular cold water swimming during winter time affects resting hematological parameters and serum erythropoietin	2019	34 (M: 18; F: 16)	High
Altered brown fat thermoregulation and enhanced cold-induced thermogenesis in young, healthy, winter-swimming men	2021	15 (M: 15; F: 0)	Some Concerns
Recovering body temperature from acute cold stress is associated with delayed proinflammatory cytokine production in vivo	2021	26 (M: 26; F:0)	High
Residual effects of short-term whole-body cold-water immersion on the cytokine profile, white blood cell count, and blood markers of stress	2021	12 (M: 12; F: 0)	High
Kinetics of lipid indicators in response to short- and long-duration whole-body, cold-water immersion	2022	17 (M: 17; F: 0)	High

Adrenaline was perused by four studies.[8,9,10,21] Eimonte et al.[9] described a peak in adrenaline at 24 h after exposure and a peak in noradrenaline by 48 h after exposure to 14°C water for 10 min. Eimonte et al.[8] described peaks of adrenaline at both 24 and 48 h after 10 and 170 min of exposures, respectively. They did not describe the same peaks for noradrenaline, and substantiated earlier findings.[10] Contrarily two authors[21,24] did not find any differences in adrenaline nor in nor adrenaline measuring right after exposure at 10°C for 30 min.

Eimonte et al.[9] described a peak release of Interleukin 6 (IL-6) at 6 and 12 h after cold water exposure (14°C for 10 min), as well as a TNF-α decrease from 15 min to 24 h after exposure; at the same time, Interleukin 1-Beta (IL-1β) concentration was unaffected. These results, were not replicated by the same author in 2021[10] as IL-6, IL-1β, and TNF-α were unaffected at 12 h after 170 min of intermitted exposure at 14°C. Finally, two other studies assessed IL-6,[14,25] but none of them found significant changes after exposure to cold water (20°C for 10 min).

The present research adheres to the good publishing practice endorsed by Acta Physiologica.[26]

The 24 publications reveal multifaceted impact of cold water exposure on physiological, psychological, and biochemical parameters, but there is inconclusive evidence on the psychological effects, limited effects on cognitive functions, and varied effects on muscular temperature, lactate concentration, and fatigue perception. Blood pressure remained stable, while heart rate showed contradictory results depending on exposure conditions. Lipid profile and body composition remained largely unchanged, with intriguing variations in HDL-c and triglycerides. Stress-related hormone responses were mixed, and inflammatory markers showed inconsistent impacts. There is a need for standardized protocols, larger sample sizes, and longer follow-up times to advance our understanding of cold water exposure's effects and potential therapeutic applications. Notably, long-term effects (beyond 1 year of exposure) remain unexplored.

AUTHOR CONTRIBUTIONS

Davide Tarditi: Writing – review and editing; formal analysis; methodology. **Giovanni Leonardo Briganti:** Writing – original draft; formal analysis. **Giulia Chesini:** Writing – original draft; formal analysis. **Davide Serli:** Formal analysis. **Angelo Capodici:** Conceptualization; supervision; project administration; methodology; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

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