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ORIGINAL ARTICLE

# Athlete, coach and practitioner knowledge and perceptions of post-exercise cold-water immersion for recovery: a qualitative and quantitative exploration

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## Abstract

This survey sought to establish current use, knowledge and perceptions of cold-water immersion (CWI) when used for recovery. 111 athletes, coaches and support practitioners completed the anonymous online survey, answering questions about their current CWI protocols, perceptions of benefits associated with CWI and knowledge of controlling mechanisms. Respondents were largely involved in elite sport at international, national and club level, with many having used CWI previously (86%) and finding its use beneficial for recovery (78%). Protocols differed, with the duration of immersion one aspect that failed to align with recommendations in the scientific literature. Whilst many respondents were aware of benefits associated with CWI, there remains some confusion. There also seems to be a gap in mechanistic knowledge, where respondents are aware of benefits associated with CWI, but failed to identify the underlying mechanisms. This identifies the need for an improved method of knowledge transfer between scientific and applied practice communities. Moreover, data herein emphasises the important role of the 'support practitioner' as respondents in this role tended to favour CWI protocols more aligned to recommendations within the literature. With a significant number of respondents claiming they were made aware of CWI for recovery through a colleague (43%), the importance of knowledge transfer and context being appropriately applied to data is as important as ever. With the firm belief that CWI is useful for recovery in sport, the focus should now be on investigating the psychophysiological interaction and correct use of this methodology.

**Keywords** Cryotherapy · Elite sport · Current use · Understanding · Sports science

## Introduction

It is well documented that exercise can lead to decrements in physiological function and performance. For the modern athlete, it is essential that recovery can be achieved quickly and optimally to ensure they are able to maintain the required workload and/or performance across subsequent training sessions or competitions. Without this, an imbalance between recovery and training stress is likely to lead to non-functional overreaching [1, 2] and consequently there now exists a plethora of research investigating optimal and appropriate recovery strategies following strenuous exercise [3, 4].

Cold-water immersion (CWI) has consistently been reported as a popular choice for recovery among professional athletes [3, 5–7]. The use of CWI for recovery from exercise stems from its use in athletic settings, where ice application in the immediate treatment of acute soft-tissue injuries was often combined with rest, compression and elevation [8, 9].

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Efficacy of CWI for post-exercise recovery has previously been considered equivocal [10] likely due to inconsistency in CWI protocols, with different temperatures [11–13], durations [14, 15], depths [16, 17] and even time applied after exercise [18] being utilised in research and applied practice [19]. Meta-analyses suggest a protocol of 10–15 °C for 10–15 min [20] can effectively promote recovery. Others have suggested a dose of 1.1 (i.e. 11 min at 10 °C) [21] is required to significantly reduce muscle tissue temperature, a key physiological mechanism by which CWI is purported to influence recovery in several ways. It should be noted that CWI is not effective simply by a reduction in muscle tissue temperature, but is a proposed combined result of a reduced perception of pain and soreness via decreased nerve conduction velocity, alongside temperature- and pressure-induced changes in blood flow, metabolism, inflammation and skeletal tissue temperature [1, 22]. There now exists a number of systematic reviews and meta-analyses outlining the beneficial influence of CWI on post-exercise recovery [23–26].

Whilst the acute recovery period is vital for restoration of energy stores and recovery from exercise induced muscle damage, it is also an important window for mediating adaptation to the training stimulus via cell signalling and remodelling [27]. As such, the focus of investigations has recently turned from the efficacy of post-exercise CWI for recovery, to how CWI might influence adaptive processes in skeletal muscle following exercise. Indeed, work from our laboratories and others has consistently shown post-exercise CWI to enhance molecular responses associated with endurance-based adaptations, namely mitochondrial biogenesis and angiogenesis in skeletal muscles [1, 6–35]. In contrast, it seems a paradox exists whereby a similar augmentation of the molecular pathways controlling adaptation to resistance exercise is not evident. Indeed, regular use of CWI following resistance type exercise has been shown to dampen the magnitude of anabolic signalling [36] and myofibrillar protein synthesis [37], said to be responsible for diminished gains in muscle strength and mass [36, 38, 39].

Alongside this research, it is vital to understand practitioners' knowledge and perception on the mechanisms underpinning CWI-mediated recovery, as this information enables a targeted approach towards achieving specific recovery objectives. Such recent work, reporting a trend for dampened gains in skeletal muscle strength and mass following regular use of post-exercise CWI, has drawn some negative attention against this recovery modality across social media, the press and within the literature itself [40]. It is important that the correct context is applied to mechanistic data so that applied practitioners understand the most appropriate, effective and efficient use of this (and other) recovery technique(s) [41–43]. Incorrect application of scientific data to applied practice will only augment the confusion and equivocal perception of CWI's efficacy, be it for recovery or adaptation. The importance of knowledge transfer has previously been discussed [44]. Indeed, it was recently reported that a low belief in the efficacy of CWI for recovery may be because of a discordance within the associated literature [45]. Therefore, the aim of this survey is to assess the current perception, knowledge, and use/prescription of CWI by athletes, coaches, and performance support practitioners. It is hoped that the findings from this survey will allow for discussion around where practice does and does not match prescription as suggested in the scientific literature (i.e. peer-reviewed articles), giving insight into these discrepancies.

## Methods

### Participants and study design

Perception, knowledge, and use/prescription of CWI were assessed using an anonymous online survey (Microsoft Forms). Respondents were recruited through direct email (authors' network) and globally through social media (Twitter, Instagram, Linkedin, Facebook). To be eligible to participate, individuals were required to self-identify as an athlete, coach, or other support practitioner (e.g. medical staff, S&C, sport science). All respondents provided informed consent via the first question on the survey, failure to give consent prevented any further completion of the survey. Ethical approval for the study was granted by the University Ethics Review Panel (reference: HEALTH 0109 UG Amendment 14Dec20) in line with the principles of the Declaration of Helsinki. A total of 111 participants (96 males, 15 females) gave informed consent and completed the survey.

Four subject matter experts reviewed the survey for face validity in its various iterations, providing feedback and suggesting alterations prior to ethical review and subsequent circulation. The survey was available for online completion for 6 weeks between the dates 22.12.2020 to 02.02.2021. All survey responses were anonymous. Respondents provided some demographic information followed by a series of multiple choice, Likert scale-based (strongly agree, agree, neutral, disagree, strongly disagree) and open-ended questions. Multiple choice questions served to assess knowledge, perception and prescription/use of CWI (when "other" was an option, respondents had the opportunity to elaborate), open-ended questions provided an opportunity to provide greater detail surrounding knowledge and prescription and were used to ask "why?" to follow up on responses to previous questions where applicable. This method of mixed closed and open questions is beneficial as it provides a range of data for analysis and dissemination [46] and may provide specific information on the support athletes require in relation to CWI. The survey comprised of a total of 36 questions, however the number of questions each respondent answered varied because specific questions directed participants towards different branches. The online survey was split into three main topics as outlined below.

*Demographics* Initially (Q.2–7), respondents were required to provide some demographic information, including: their role (athlete, coach or performance support); sex (a "prefer not to say" option was available); age group; the number of years they had been in their current or a similar role; the sport they are involved in and the level of competition they are involved in. *Current Use/prescription of CWI* The second section (Q.8–18) featured questions designed to gain an understanding of respondent's current use and/or prescription of CWI. Respondents who did not, nor ever have used/prescribed CWI, were redirected to Q.35–36 which focused on their reasons for not using CWI and what their preferred recovery modality is. *Perception and Knowledge of CWI* Q.19–34 focused on respondent perception and knowledge of CWI. This section included closed questions (some allowed multiple responses): scale-based and open-ended questions, allowing respondents to explain reasons for previous responses and gave opportunity to display more specific knowledge.

## Data analysis

The current study is of a cross-sectional and descriptive design; hence, the data are presented in a descriptive format. For "closed" questions, the frequency of categorical responses was determined and trends within the data were established. The responses to open-ended questions were read multiple times by a minimum of two researchers as this enables a comprehensive understanding of their content and the themes within it [47]. Where applicable, one-way chi-square ($X^2$) goodness of fit tests were conducted to test whether the pattern of responses differed from randomness. Cohort analyses using two-way Chi-square tests were also conducted to assess differences between groups. All data were analysed using SPSS version 27 (IBM, Armonk, New York) software with an alpha level of significance accepted at the of $p \leq 0.05$ level.

# Results

## Participant demographics

A total of 111 individuals participated in the study, which was male dominated [$n = 96$, 86%; $X^2_{(1,\ N=111)} = 59.11$, $p < 0.001$]. Respondent age differed significantly from randomness with the greatest response frequency in the 31–35 ($n = 28$, 25%) and 36–40 ($n = 24$, 22%) age groups [$X^2_{(7,\ N=111)} = 36.39$, $p < 0.001$]. Frequency of response from Performance Support personnel (Medical Staff, S&C, Sport Science) ($n = 72$, 65%) differed significantly from athlete/player ($n = 28$, 25%), coach ($n = 9$, 8%) and research ($n = 1$, < 1%), indicating that respondents were more likely to be performance support personnel [$X^2_{(4,\ N=110)} = 158.55$, $p < 0.001$]. Respondents most frequently reported having spent 0–3 years ($n = 25$, 23%) and > 15 years ($n = 22$, 20%) in their current/similar role [$X^2_{(5,\ N=110)} = 10.66$, $p = 0.059$].

The majority of respondents declared their role within a sport was in soccer (association football) ($n = 44$, 41%), with other notable frequencies for rugby/American football ($n = 9$, 8%), triathlon ($n = 9$, 8%), combat sports ($n = 6$, 5%), and seven respondents declaring involvement in multiple sports (6.5%) [$X^2_{(20,\ N=107)} = 339.10$, $p < 0.001$] (Fig. 1a). Most participants reported being involved in national ($n = 33$, 30%) and international ($n = 31$, 28%) competition, suggesting that 58% of participants were involved in elite level sport. The frequency of response for participant level of competition differed significantly from randomness, participants were more likely to be involved in international ($n = 31$), national ($n = 33$) and club ($n = 22$) than university ($n = 1$), county ($n = 4$), academy ($n = 3$) or non-competitive ($n = 15$) sport [$X^2_{(7,\ N=110)} = 92.62$, $p < 0.001$] (Fig. 1b).

## Current use/prescription of CWI (Q8–18)

Of the entire sample, significantly more participants ($n = 94$, 86%) had used or prescribed the use of CWI for post-exercise recovery at some point during their career [$X^2_{(1,\ N=109)} = 57.28$, $p < 0.001$]. Respondents were significantly more likely to use pool/spa (specialised CWI system) ($n = 32$, 34%), bath tubs ($n = 27$, 29%) and makeshift tubs (wheelie bin or similar) ($n = 23$, 24%) than inflatable systems ($n = 8$, 9%), "cryotherapy chambers", "chest freezer filled with water", "cold shower/ocean" or "none" (all $n = 1$, 1%) [$X^2_{(7,\ N=94)} = 106.00$, $p < 0.001$]. When asked if they attempt to control the temperature of the water used, only 15 (16%) replied 'No'. Most attempted to control the water temperature with the addition of ice/cold water (without monitoring for a particular temperature) ($n = 34$, 36%), whilst others added ice/cold water whilst monitoring for a particular target temperature ($n = 16$, 17%). 29 respondents (31%) utilised a temperature-controlled system/pump [$X^2_{(3,\ N=94)} = 11.45$, $p = 0.010$].

A target temperature for CWI of 9–11 °C was the most popular ($n = 30$, 32%), significantly more popular than other temperature ranges [$X^2_{(9,\ N=93)} = 106.89$, $p < 0.001$] (Fig. 2a). The next most common response was "no target temperature" ($n = 23$, 25%), followed by 12–15 °C ($n = 15$, 16%) and < 5 °C ($n = 13$, 14%). Immersion depth was varied within the sample: 33% ($n = 31$) reported using "whole body (i.e. head out)" immersion, while 43% ($n = 40$) immersed waist deep only; 24% ($n = 23$) did not control for immersion depth

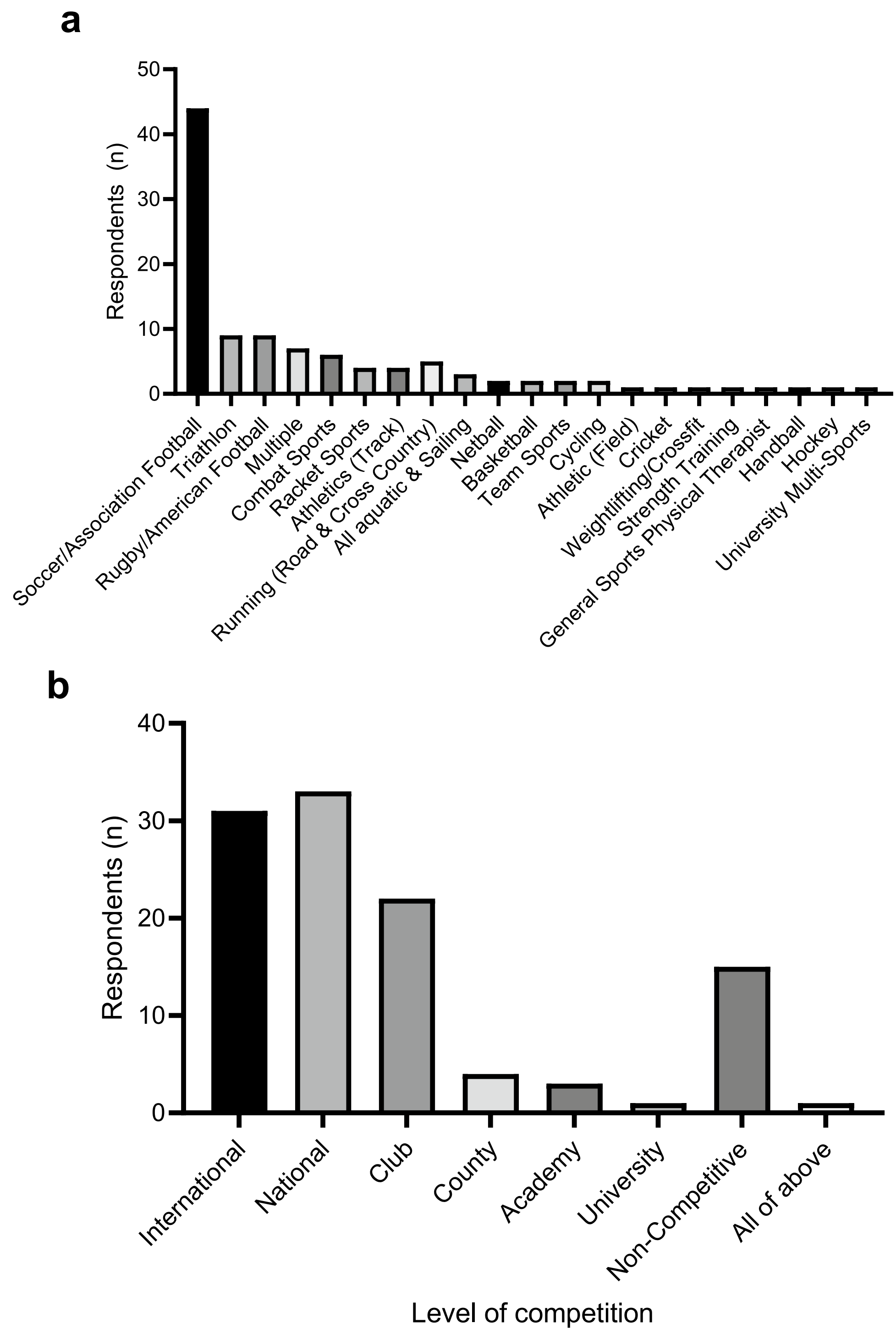


**Fig. 1** Respondents-associated sport (**a**) and current level of competition (**b**)

$[X^2_{(2, N=94)} = 4.62, p = 0.099]$ (Fig. 2c). A single-immersion protocol was favoured ($n = 69$, 75%) over a two immersion period separated by a short break ($n = 18$, 20%) or varied ($n = 5$, 5%) protocol $[X^2_{(2, N=92)} = 74.63, p < 0.001]$, with the highest number of responses indicating a cumulative immersion time per CWI session of 2.5–5 min ($n = 30$, 32%); followed by 7.5–10 min ($n = 22$, 24%) and 5–7.5 min ($n = 19$, 20%) and 10–12.5 min ($n = 10$, 11%) ($X^2_{(6, N=93)} = 50.84$, $p < 0.001$) (Fig. 2b). The time at which CWI was first completed following competition/training tended to be 15–30 min ($n = 42$, 46%) or 0–15 min ($n = 26$, 28%) ($X^2_{(8, N=92)} = 161.96$, $p < 0.001$) (Fig. 2d). Other responses included 45–60 min ($n = 9$, 10%), 30–45 min ($n = 8$, 9%), 24 h or "it depends" ($n = 2$, 2% each) with 3 h, 1 h and "0–30 min" reporting one count each.

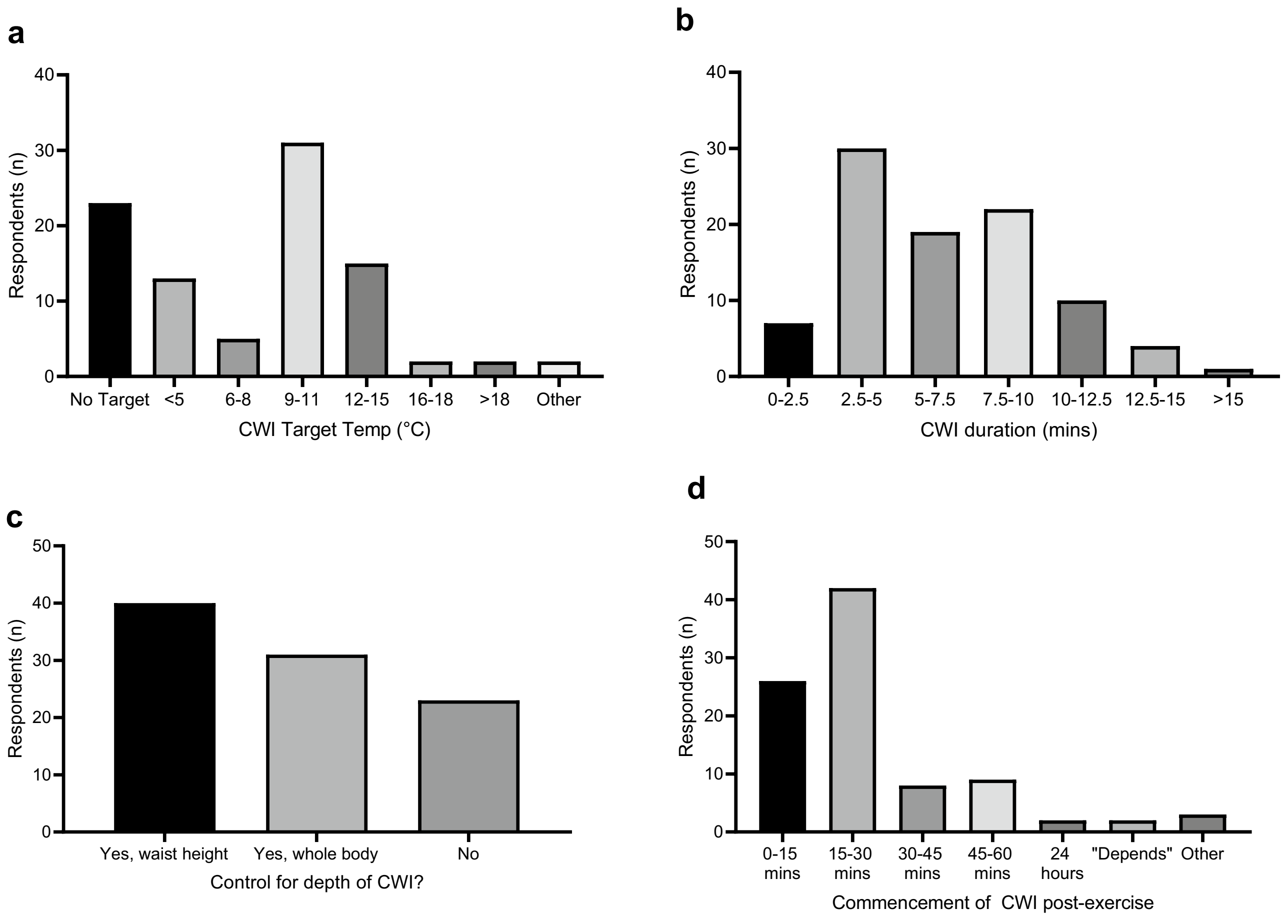


**Fig. 2** Current reported methodologies for CWI. **a** Reported target temperature when utilising CWI, "Other" includes "as cold as possible" and "Depends on the situation" reporting one count each. **b** Reported duration of immersion when using CWI. **c** Reported depth of immersion during CWI, "No" is inclusive of "other" answers that included an explanation like 'depends'. **d** Time at which CWI is completed following exercise, "other" is inclusive of 3 h, 1 h and 0–30 min reporting onecount each

## Perceptions of CWI (Q.19–26)

The majority of participants ($n=79$, 85%) reported having a positive perception of CWI, with only 2 (2%) expressing a negative perception; 12 (13%) responded with "don't know" regarding their perception of CWI [$X^2_{(2, N=93)}=113.10$, $p<0.001$] (Fig. 3a). Of the respondents who reported having a positive perception of CWI, 72 provided details as to why. Their responses varied in detail; however, some themes were apparent in the responses. The most common was that players/athletes felt "fresher/refreshed" following CWI. Another common theme was that of enhanced recovery with several respondents mentioning improved time to recovery, a heightened sense of recovery and reduced sensations of DOMS and inflammation. A less common theme within the responses was that of psychological effects of CWI, participants mentioned: "feel good factor"; "psychological benefit for majority of athletes"; "mind–body connection". A final theme, presumably from coaches and performance support practitioners, was that of receiving positive feedback from players/athletes on CWI, e.g. "best feedback", "players get immediately relieved from fatigue", "based on players' positive feedback and short recovery duration", "positive feedback from players", "most players ask for it". The two participants who reported a negative perception of CWI gave the following justifications: "Benefits muscles, particularly quads and hamstrings but found tightens Achilles"; and "Research, experience".

When asked "can CWI help in the prevention and treatment of injury?", response frequency differed significantly from randomness [$X^2_{(4, N=92)}=11.15$, $p=0.025$] (Fig. 3b). The most frequent response was "helps with the prevention and treatment of injury" ($n=25$, 27%). Other responses included "helps with the treatment but not prevention of injuries" ($n=22$, 24%) and "don't know" ($n=22$, 24%) and "helps with the prevention but not treatment of injuries" ($n=7$, 8%). Sixteen participants (17%) had the perception

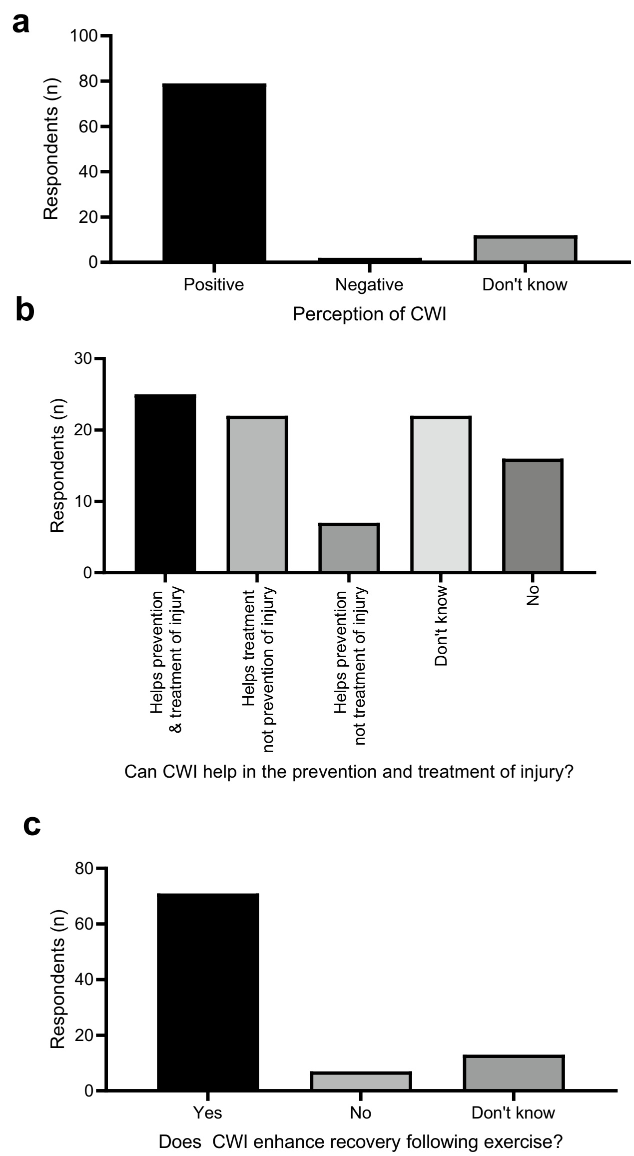


**Fig. 3** Overall perception of CWI (**a**) for the prevention and treatment of injuries (**b**) and for enhancement of recovery following exercise (**c**)

that CWI could not help with the prevention and/or treatment of injury.

The significant majority ($n = 71$, 78%) of participants thought that CWI enhanced recovery post-exercise, 14% ($n = 13$) said they "don't know" and 8% ($n = 7$) reported that they found no enhanced recovery following CWI [$X^2_{(2,\ N=91)} = 82.37$, $p < 0.001$] (Fig. 3c). With regard to CWI being able to enhance performance following recovery, participants who responded "yes" (CWI does enhance performance following recovery) had the highest response rate ($n = 33$, 36%), followed by "decrease in performance immediately post-CWI but improved performance several hours later or on subsequent days" ($n = 26$, 28%). Nineteen respondents (21%) stated that they did not know whether CWI enhanced subsequent performance, with the remaining respondents stating they believed it "depends" ($n = 1$, 1%), it could temporarily ($n = 5$, 5%) or did not enhance subsequent performance ($n = 8$, 9%) [$X^2_{(5,\ N=92)} = 52.52$, $p < 0.001$]. Respondents were significantly more likely to believe that most athletes/players/coaches/practitioners were aware of CWI and its associated benefits ($n = 49$, 53%) [$X^2_{(3,\ N=92)} = 36.44$, $p < 0.001$] with others either disagreeing ($n = 13$, 14%) or remaining neutral ($n = 30$, 33%). Respondents reported first becoming aware of the benefits of CWI through "scientific literature" ($n = 46$, 50%) and "fellow athlete/coach/practitioner" ($n = 40$, 43%).

**Table 1** Number and relative percentage of answers from respondents when asked about the benefits CWI provides

| Possible benefit of CWI | Selected by respondents (*n*) | Selected by respondents (%) |
|---|---|---|
| Reduced post-exercise inflammation | 70 | 76 |
| Reduced sensation of DOMS | 68 | 74 |
| Reduced sensation of pain | 68 | 74 |
| Psychologically beneficial | 63 | 68 |
| Improved recovery time/return to play | 60 | 65 |
| Enhanced subsequent training/competitive performance | 41 | 45 |
| Reduced post-exercise tissue damage | 40 | 43 |

Respondents could select multiple answers. $n = 92$ as some chose not to answer

## Knowledge of CWI associated benefits and mechanisms (Q.27–30)

When assessing respondents understanding of the benefits associated with CWI, Question 27 asked participants what the benefits of CWI included, providing the opportunity to select all answers that they felt applied. Several participants ($n = 19$) left this question blank. The remaining participants displayed varied perceptions on the benefits of CWI; the majority expressed the belief that CWI reduced inflammation (76%) reduced pain sensations (74%), and reduced sensations of DOMS (74%). Respondents also reported psychological benefits (68%) and enhanced recovery time/return to play (65%) (Table 1). Question 28 asked participants to identify the physiological mechanisms behind CWI and the benefits it provides. Multiple answers were permitted with frequencies of choices identified in Table 2. More than 50% of respondents selected constriction of blood vessels, alterations in blood flow, and reductions in core, skin and muscle temperature alongside alterations in inflammatory biomarkers, as a mechanisms of CWI action.

If CWI is applied following strength/speed/power training, 19 (21%) of respondents agree or strongly agree that

**Table 2** Number and relative percentage of answers from respondents when asked about the physiological mechanisms said to be responsible for the benefits associated with CWI

| Possible mechanisms of action | Selected by respondents (*n*) | Selected by respondents (%) |
|---|---|---|
| Constriction of blood vessels | 60 | 67 |
| Increased/decreased blood flow | 59 | 66 |
| Reduction in core body temp | 55 | 61 |
| Reduction in muscle temp | 53 | 59 |
| Reduction in skin temp | 49 | 54 |
| Alterations in inflammatory biomarkers | 48 | 53 |
| Decreased pain receptor activation | 44 | 49 |
| Increased hormone response | 28 | 31 |
| Increased central blood volume | 22 | 24 |
| Alterations in genetic pathways controlling muscle adaptation | 19 | 21 |
| Reduction in nerve speed | 15 | 17 |
| Osmotic gradients | 15 | 17 |

Respondents could select multiple answers. $n=90$ as some chose not to answer

CWI would enhance adaptations to the training stimulus, while 44 (47%) disagreed or strongly disagreed and 29 (32%) had a neutral opinion [$X^2_{(4, N=92)}=22.78$, $p<0.001$] (Fig. 4a). Conversely, when asked if CWI enhanced adaptation to the training stimulus following endurance/high intensity intermittent training, the results again differed significantly from randomness [$X^2_{(4, N=92)}=23.33$, $p<0.001$] (Fig. 4b), displaying the opposite trend: 50% ($n=46$) strongly agreed or agreed, 26% ($n=24$) disagreed or strongly disagreed, with 24% ($n=22$) of participants reported not knowing.

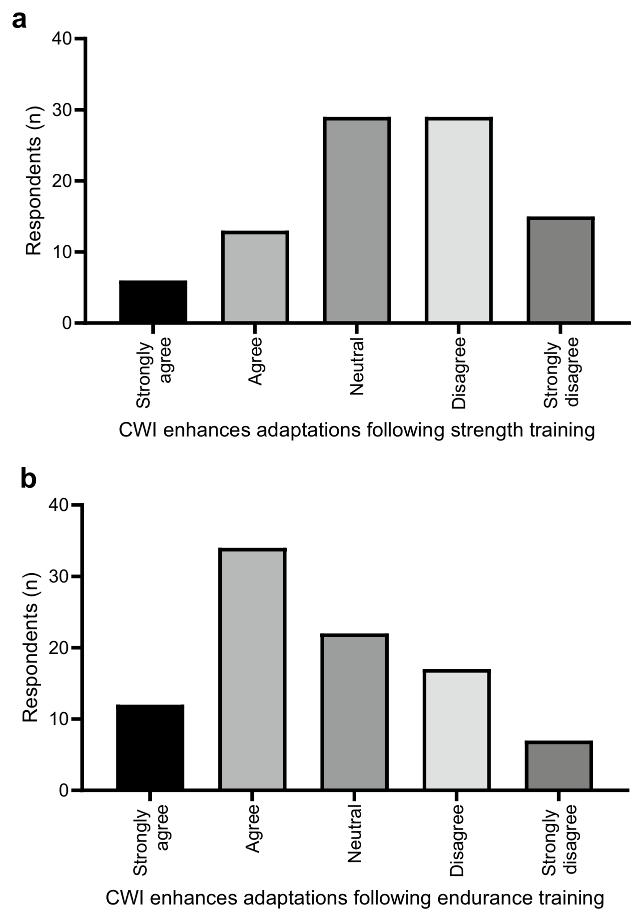


**Fig. 4** Participants opinion on CWI enhancing adaptations to strength (**a**) and endurance (**b**) training

## Recommendations Q.31–36

When respondents were asked when they would recommend the use of CWI for recovery more opted for "in-season" ($n=48$) over "pre-season" ($n=20$) and "immediately post-competition" ($n=52$) over "immediately post-training" ($n=31$). Respondents also highlighted that they would recommend CWI be used "after some competitions" ($n=35$) more than "after all competitions" ($n=15$), suggesting a periodised and tailored use. When asked when they thought CWI should be avoided the most popular answers were "immediately prior to competition" ($n=22$) and "pre-season" ($n=15$).

Questions 33 and 34 asked participants "For whom is CWI suitable?" and then asked for explanation of their previous answer. Several themes were identified in the explanation's respondents provided. Several stated that CWI was suitable for all athletes; some provided greater clarity with the addition of words to the effect of "dependent on training/competition schedule" or "under appropriate circumstances". Others identified a need to carefully plan when to utilise CWI with strength/speed/power athletes "so as not to negatively impact adaptation to training". Many participants felt that there were clear benefits of CWI on endurance performance, but more information was required on its appropriate use for strength/speed/power.

## Reasons for not using CWI

A total of 15 respondents reported not using CWI. When asked what their preferred method of recovery was, the most popular response was "massage" ($n=5$, 33%), followed by "hot-water therapy" ($n=3$, 20%). After being asked for their reasons for not using CWI, 47% ($n=7$) reported not having access to facilities as the main reason whilst 20% ($n=3$) reported not knowing CWI could be utilised for recovery.

### Cohort analysis

#### Inter-role analysis

The likelihood of respondents using or advocating the use of CWI currently or at any point previously did not differ between roles [$X^2_{(4, N=109)} = 1.58$, $p = 0.81$]. For questions seeking to determine current uses of CWI, when opting to control for a certain temperature of CWI significant differences existed between participants in different roles [$X^2_{(12, N=93)} = 29.36$, $p = 0.003$], with the majority of performance support practitioners ($n = 25$, 40%) utilising a temperature-controlled system/pump, with athletes ($n = 11$, 50%) and coaches ($n = 4$, 57%) more likely to use the addition of ice and cold water without monitoring for a certain temperature. Performance support practitioners were most likely to desire a water temperature of 9–11 °C ($n = 26$, 43%), athletes/players were most likely to report having no target temperature ($n = 11$, 50%), whilst coaches were most likely to report a target temperature of < 5 °C ($n = 3$, 43%) or have no target temperature ($n = 2$, 29%) [$X^2_{(36, N=92)} = 162.35$, $p = 0.004$]. Total immersion time per CWI session differed significantly based on respondent role [$X^2_{(24, N=92)} = 37.55$, $p = 0.039$]. Performance support practitioners most frequently reported an ideal total immersion time of 7.5–10 min ($N = 17$, 27%), with 2.5–5 min ($n = 15$, 24%) and 5–7.5 min ($n = 16$, 26%) also popular choices. The most frequent immersion duration among athletes/players ($n = 11$, 50%) and coaches ($n = 3$, 50%) was shorter, at 2.5–5 min. No differences were noted between the different roles for depth of immersion, number of immersions used and time until immersion after exercise ($p > 0.05$).

When asked if CWI enhanced subsequent performance following recovery, response frequency differed significantly between respondent roles [$X^2_{(20, N=91)} = 108.13$, $p < 0.001$]. Performance support practitioners were most likely to respond "yes" ($n = 22$, 36%) or "decrease performance immediately post-CWI but increased performance several hours later or on subsequent days" ($n = 21$, 34%). Athletes/players most frequently responded "don't know" ($n = 8$, 38%) or 'Yes' ($n = 7$, 33%), with coaches most frequently responding 'yes' ($n = 3$, 43%). No differences were noted between the different roles for perception of CWI for recovery, if it is useful for the prevention/treatment of injury, or if it enhances performance ($p > 0.05$).

#### Inter-sport and experience analysis

Participants from all sports were equally likely to use/advocate the use of CWI, with chi-square cross tabulation of sport and CWI advocation/use insignificant [$X^2_{(20, N=107)} = 24.04$, $p = 0.241$]. The most commonly used method of CWI [$X^2_{(140, N=92)} = 245.91$, $p < 0.001$], choice to control for temperature or not [$X^2(_{60, N=92}) = 91.57$, $p = 0.005$], and target temperature of CWI [$X^2_{(180, N=91)} = 246.27$, $p = 0.001$], differed significantly between sports.

#### Analysis by level of competition

A significant difference was identified between the level of competition a participant was involved in and their likelihood of using/advocating the use of CWI [$X^2_{(7, N=110)} = 15.26$, $p = 0.033$]. CWI use tended to be more frequent in elite level of competition (i.e. international 97%, national 88%, non-competitive 67%). The controlling of CWI temperature [$X^2_{(18, N=94)} = 32.66$, $p = 0.018$] and target immersion temperature [$X^2_{(54, N=93)} = 80.75$, $p = 0.011$] differed significantly between levels of competition. The most popular target temperature was 9–11 °C (international, national, academy level) or no target temperature (county, club, university and non-competitive), suggesting more elite level sports adopt greater control over their recovery practices. Responses to the question "do you find CWI enhances performance following recovery?" differed significantly between level of competition groups [$X^2_{(30, N=92)} = 53.30$, $p = 0.006$]. The most frequent response for those involved in international level competition was "decrease performance immediately post-CWI, but increased performance several hours later or on subsequent days" ($n = 12$, 40%); while those in the national group were more likely to respond "yes" ($n = 11$, 38%), the most common response from the non-competitive group was "don't know" ($n = 5$, 56%).

## Discussion

This survey assessed the current perception, knowledge, and use/prescription of CWI by athletes, coaches and performance support practitioners. A key finding is that support practitioners tend to be led by scientific data in their approach to recovery. Furthermore, whilst many are aware of potential benefits of CWI for recovery, few can recall the controlling mechanisms at play highlighting a gap in knowledge transfer between scientific and applied practice communities. This is the first recovery focussed survey of its kind to include cohort analysis that can be used to highlight differences in perception, knowledge and use of CWI between athletes, coaches, and support practitioners.

### Current use of CWI

Recent works have attempted to identify the most effective protocol and have suggested 10–15 min at 10–15 °C [20] or a dose of 1.1 (i.e. 11 min at 10 °C) [21] as most appropriate. Almost half (48%) of respondents reported that they attempt to monitor for a specific target temperature of water during immersion, with 48% opting for a target temperature between 9 and 15 °C. Importantly, this temperature range sits within the recommended temperatures and has further been shown to be effective for post-exercise recovery [48]. However, it remains that more than half of respondents failed to use a temperature within the recommended range. Moreover, only 14% of respondents selected an immersion duration within the suggested range of 10–15 min. The most popular immersion duration noted was 2.5–5 min (32%) and 7.5–10 min (24%). This suggests that whilst almost half of respondents are utilising an appropriate water temperature, the duration of immersion is often not long enough and is perhaps being overlooked. This raises the question of whether an appropriate dose of cold stimulus is being applied in practice. Ultimately short durations will be unable to illicit sufficient reductions to either core or muscle temperatures and have any subsequent impact on physiological mechanisms. One example here is fluid shifts as a result of changes in hydrostatic pressure, which have been shown to require an immersion of at least 10 min duration [49]. It should further be noted that the second most frequently reported target temperature was "no target temperature", suggesting many respondents may be unaware an optimal CWI temperature exists or actively choose not to control the temperature of the water, thus further influencing the dose and impact of the cold stimulus applied. Indeed, the dose of the cold stimulus has been suggested vital to the responses seen and the efficacy of cooling upon post-exercise recovery. For instance, the magnitude of the increase in sympathetic discharge to skeletal muscle, important in many physiological alterations following CWI, is influenced by not only the size of the tissue area exposed to cooling [50] but the magnitude (or dose) of the cooling stimulus [51]. As the mechanisms of action of CWI are thought to somewhat be derived from a reduction in tissue temperature it is sensible to suggest that water temperature should be adequate to reduce tissue temperature in a time frame no longer than the duration of immersion, highlighting a need to recognise that an appropriate immersion duration may be just as important as the temperature of the water itself.

Other determinants of the CWI protocol are immersion depth and the time at which immersion is completed following the cessation of exercise. Within the current survey, 43% of respondents reported they utilise an immersion depth of waist height, with a further 33% opting for whole body immersion. The importance of immersion depth towards the CWI protocol lies in the belief that the effectiveness of CWI is related to not only temperature, but pressure related changes in blood flow and muscle temperature [52, 53]. Therefore, a greater immersion depth might be successful by way of greater hydrostatic pressures. Indeed, recent work from Chauvineau et al. [16] suggests whole body immersion (including head immersion) might benefit recovery through improved sleep architecture, reducing arousal and limb movements through the first part of the night. However, no difference was noted between whole and partial body CWI for markers of fatigue and muscle damage. Similarly, Leeder et al. [17] suggests the depth of immersion has little influence on recovery, with no noted differences between seated vs. standing CWI. In contrast, the time at which CWI is applied following the cessation of exercise might play an important role in its effectiveness. Brophy-Williams et al. [18] noted that immediate CWI showed superior recovery of performance when compared with delayed CWI (3 h post-exercise). Seventy four percent of respondents within the current survey declared CWI was completed within 30 min post-exercise, showing good agreement between applied practice and scientific literature.

Ultimately, results from the present survey suggest current use of CWI in an applied setting shows good agreement with the scientific literature for CWI temperature, depth, and timing. However, more effort needs to be made in emphasising the importance of the duration of the CWI protocol. Whilst durations that are too long are not advisable due to the potential for augmenting the post-exercise inflammatory response [15], the duration should be aligned with the water temperature to elicit a sufficient reduction in temperature and subsequent physiological alterations beneficial for recovery. Moreover, people are often unaware of the post-immersion drop in muscle tissue temperature that arises if the legs remain wet [52]. Vromans et al. [27] suggestion of a dose of 1.1 (i.e. 11 min at 10 °C) seems a suitable recommendation.

## Current perceptions of CWI

Overall, the current perception of CWI from athletes, coaches and support practitioners is largely positive. Seventy-eight percent of respondents believe CWI improves recovery. However, whilst other recovery methods, such as massage, have been shown to have a positive psychophysiological mechanism influencing the perception of recovery [54], few investigations have looked at a similar response following CWI [55]. Broatch et al. [56] showed that a recovery placebo in the form of a pH neutral soap, suggested to participants to enhance recovery, stimulated a similar response to that of CWI, highlighting the importance of belief in the recovery method being undertaken. Results herein support this conclusion with respondents reporting additional benefits of CWI including "feeling good", "positive feedback from the end-user" and "a positive psychological benefit", emphasising the power of athlete wellness and subjective measurements. Indeed, this supports anecdotal reports from applied practice that "if they think it works, we use it" and poses the question as to why certain recovery strategies are preferred and how much the end user really knows about the associated physiological benefits.

Interestingly, roughly half (53%) of respondents believe most athletes, coaches and support practitioners are aware of the benefits associated with CWI, which, considering the volume of research surrounding this topic and the strong positive opinion from respondents herein, is somewhat surprising. Awareness of benefits seems to be led by scientific literature (50%). This point alone emphasises the importance of unbiased context being applied to mechanistic data in published writings. If the incorrect context or message is being portrayed in the literature this has a significant influence upon the application of certain methodologies, be it positive or negative. Moreover, a large proportion of respondents were made aware of CWI from colleagues (43%) and therefore if the wrong message is portrayed in the literature, it is likely that this may be passed on via colleagues. This could perhaps explain the confusion and discordance noted between applied practice and scientific literature. With this level of peer-to-peer education future work should look to regularly establish and recognise appropriate methodologies and protocols whilst outlining the mechanisms responsible for physiological changes resulting in effective recovery. Future work should also look to establish the best method of knowledge transfer between scientific and applied practice communities.

## Current knowledge of benefits and associated physiological mechanisms

The benefits and mechanisms of CWI have been described previously [1, 57]. In the current survey, athletes, coaches, and support practitioners reported the top benefits they associate with CWI are a reduction in post-exercise inflammation and a reduced sensation of pain and delayed onset muscle soreness (DOMS). CWI has long been reported effective for reducing perceived pain and muscle soreness, with particular efficacy alleviating symptoms of DOMS at 24, 48, 72 and 96 h post-exercise [25]. However, one area with decisively more disagreement is the impact of post-exercise CWI on the ensuing inflammatory response. The idea that post-exercise cooling, through tissue temperature reductions and muscle blood flow alterations, can reduce the rate of inflammation in the exercised/damaged tissues has been long-standing [58]. Belief stems from positive reductions in secondary cell injury and/or reducing inflammation following injury in animal models [59]. However, whilst some research shows post-exercise CWI might positively influence some markers of inflammation post-exercise [60, 61], there remains a substantial contrasting volume of research showing a neutral effect, whereby CWI has no influence in moderating the post-exercise inflammatory response [15, 62–66]. This is supported further by cellular and molecular investigations [58]. Considering this, it seems respondents herein are led by older, animal-model-informed suggestions that CWI is beneficial for inflammation, whilst more recent neutral data in humans are perhaps either unknown, ignored or poorly translated into practice. This again highlights a struggle in the transfer of knowledge to practice.

Interestingly a "psychological benefit" scored higher than "improved recovery time/return play". This suggests that many athletes, coaches, and support practitioners believe enhanced wellness could also contribute to a speedy return to play. Indeed, it is common procedure in many professional sports to assess daily subjective wellness, with CWI previously reported to improve athlete wellness scores [67]. With respondents in the current survey suggesting CWI is used for psychological benefits to a greater extent than return to play future work should look to address the discord in the volume of research between these associated benefits, with more work required to address the psychophysiological influence of post-exercise CWI.

A primary aim of this survey was to establish athlete, coach, and support practitioner knowledge of the physiological mechanisms responsible for producing the associated benefits of post-exercise CWI. Whilst the benefits are critically important for decision making, the mechanisms responsible might support such decisions by answering the 'how' and 'why'. Such an approach might be useful for improving coach and athlete acceptance of the technique. Table 2 highlights available options when asked about physiological mechanisms associated with perceived benefits of CWI. Importantly, all possible mechanistic answers have at some point been shown to be responsible for at least one benefit associated with CWI. This question allowed assessment of the direct translation of knowledge into practice. The most reported mechanisms associated with benefits of CWI were cardiovascular alterations in blood flow and constriction of blood vessels. To date, a significant amount of work has demonstrated reduced limb blood flow, or reduced blood volume, across the exercised muscle following CWI [47, 53–70]. However, more recent data [71] employing positron emission tomography (PET) with an oxygen-15-labelled water radiotracer ($[^{15}O]H_2O$) suggests that application of noxious water temperatures (< 8 °C) may actually result in less pronounced reductions in muscle perfusion compared with less noxious (15 °C) immersion (under resting conditions). While this may at first seem paradoxical, it can be attributed to increased muscle perfusion in deeper lying tissue in colder water, speculated due to the presence of shivering thermogenesis. In this context, the application of CWI to decrease muscle blood flow appears more in alignment with the responses from support practitioners, as opposed to coaches, who predominantly select colder temperatures (< 5 °C) over shorter durations (2.5–5 min).

Interestingly, decreased activation of pain receptors (49%) and a reduction in nerve speed (17%) showed a lower response than cardiovascular and temperature-based mechanisms. This is despite the analgesic effect of cooling representing a key mechanism by which CWI was reported to have positive effects on post-exercise recovery. Herrera and colleagues [72, 73] showed cooling reduces neural conductance velocity (or a reduction in nerve speed) in both sensory and motor neurons, with sensory neurons influenced by more modest changes in temperature, suggesting an analgesic benefit occurs before cooling can impair contraction kinetics. Additionally, analgesic effects of CWI may directly reduce the sensation of DOMS through TRPM8-mediated mechanisms [1], cold activated receptors that mediate analgesia through inhibitory inputs to nociceptors (pain receptors). Clearly the notion that CWI promotes analgesic benefits is well-established, stemming from a popularity in therapeutic rehabilitation settings for the treatment of acute soft-tissue injuries [9]. Even within the current survey a reduction of soreness (DOMS) and pain were two of the top three reported benefits of CWI. However, athletes, coaches and support practitioners seem to be less aware of the mechanisms controlling the analgesic response. Ultimately, this could suggest an emphasis should be placed on the mechanism responsible for associated benefits when translating research into practice. Improved methods of knowledge transfer should be investigated to best apply the scientific knowledge into real-world situations.

One recent discussion of interest in post-exercise CWI, and perhaps one of significant debate, is the influence the cold stimulus might have on subsequent muscular adaptations to the training stimulus. A paradox exists whereby CWI may augment molecular signals for enhanced endurance type adaptations, such as mitochondrial biogenesis and angiogenesis [41, 42], whilst contrastingly CWI has been shown to blunt resistance based adaptive signals leading to a dampened gain in mass and strength [36, 37]. We have spoken previously of the importance for context when applying such results in professional practice, particularly where the athlete, environment, situation, training, and competition cycle can vary considerably [41, 42]. Readers are directed to several reviews assessing this paradox [42, 74, 75]. Sixty-nine percent of respondents disagreed that CWI enhanced strength adaptation, showing good agreement with the scientific literature. In contrast, only 50% agreed that CWI can enhance endurance adaptations. It is unknown whether the difference in opinions is due to the reported negative associations of CWI with strength adaptation highlighted in the literature, press and social media, or if it is because of the lack of change seen in functional proteins in endurance phenotypic pathways [42]. Either way it seems a more efficient method of knowledge transfer is again required.

### Cohort analysis

The current survey also aimed to assess differences in answers between cohorts so any potential gaps in knowledge could be identified. The most common method of CWI (i.e. "choice to control for temperature" and "target water temperature") differed between sports, highlighting discordance previously reported [45]. Interestingly, the experience of the respondents showed no bearings over their choice of methods, opinion on CWI for recovery or knowledge of benefit and mechanisms. The level of competition did, however, have some bearing on choices and opinions. CWI was more frequently used in higher levels of competition, with these higher levels also tending to control for a target water temperature. The current survey did not assess reasons as to why these differences are apparent, however it could be speculated that higher levels of competition have greater access to funding and therefore better systems to implement CWI modalities and control the target temperature.

Alternatively, this data could offer evidence to emphasise the importance of support practitioners implementing research informed practice in an elite setting, as it is likely that higher levels of competition employ greater numbers of support personnel. This is supported by the fact that performance support practitioners were most likely to utilise methodologies that agree with recommendations in current literature, whereas coaches and athletes' choices were not so aligned. For example, most support practitioners opted for a temperature-controlled system, set to 9–11 °C, for a duration between 5 and 10 min. All choices that are within, or close to, suggested parameters in peer reviewed research. However, athletes and coaches were more likely to use simpler systems such as cold water and the addition of ice, without monitoring for a target temperature. Additionally, whilst athletes most likely opted for no target temperature of CWI, coaches tended to go for a much colder temperature (< 5 °C), and in terms of the duration of CWI athletes and coaches also opted for a much shorter duration (2.5–5 min). Therefore, it could be suggested that support practitioners are likely guided in their approach by scientific literature, whereas the same cannot be said for athletes and coaches.

## Conclusion

One thing that is apparent from the current survey is that there exists somewhat of an inefficiency in knowledge transfer between those completing scientific research and those using the methodology in practice. Whilst the importance of support practitioners is emphasised by the use of methodologies recommended within the scientific literature, the same cannot be said for athletes and coaches. This in no way devalues the role of the coach or the athlete, only serving to highlight the benefits a support practitioner can bring to a multi-dimensional team. It is suggested future work looks to assess this gap in knowledge, or funnel in knowledge transfer, and works to improve the transfer of scientific results, within context, to coaches and athletes. Whether the improvements required in knowledge transfer is the role of the support practitioner or scientific community remains to be seen; however, it is clear that a greater understanding of the benefits, mechanisms and associated adaptations might assist towards the correct methodological use of CWI. Indeed, this is vital if the discord and ambiguity surrounding CWI is to be removed and the correct and efficient use of CWI for recovery is to continue.

In addition, one point that perhaps does not receive enough attention from the scientific community is the psychophysiological relationship that exists for CWI as a method of recovery. Whilst anecdotal reports, and answers within this survey, highlight that CWI allows the sensation of "feeling fresher", a "heightened sense of recovery", the "feel good factor" and a "mind–body connection", future work should look to establish the psychological influence CWI can have upon an athletes' recovery. In a setting where small improvements may lead to significant results, perhaps the subjective opinion, or even placebo effect, might play an important role.

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**Availability of data** Available upon request.

## Declarations

**Conflict of interest** The authors declare no competing interests.

**Ethical approval** Ethical approval for the study was granted by the University Ethics Review Panel (reference: HEALTH 0109 UG Amendment 14Dec20) in line with the principles of the Declaration of Helsinki.

**Informed consent** A total of 111 participants (96 males, 15 females) gave informed consent and completed the survey.

**Consent to participate** All respondents provided consent for participation via the online anonymous survey.

**Consent for publication** Participants were informed before providing consent that data was intended to be used for publication.



## References

1. Ihsan M, Watson G, Abbiss CR (2016) What are the physiological mechanisms for post-exercise cold water immersion in the recovery from prolonged endurance and intermittent exercise? Sports Med 46(8):1095–1109. https://doi.org/10.1007/s40279-016-0483-3
2. Kellmann M, Bertollo M, Bosquet L et al (2018) Recovery and performance in sport: consensus statement. Int J Sports Physiol Perform 13(2):240–245. https://doi.org/10.1123/ijspp.2017-0759
3. Altarriba-Bartes A, Peña J, Vicens-Bordas J, Milà-Villaroel R, Calleja-González J (2020) Post-competition recovery strategies in elite male soccer players. Effects on performance: a systematic review and meta-analysis. PLoS One 15(10):e0240135. https://doi.org/10.1371/journal.pone.0240135 (**Published 2020 Oct 2**)
4. Dupuy O, Douzi W, Theurot D, Bosquet L, Dugué B (2018) An evidence-based approach for choosing post-exercise recovery techniques to reduce markers of muscle damage, soreness, fatigue, and inflammation: a systematic review with meta-analysis. Front Physiol 9:403. https://doi.org/10.3389/fphys.2018.00403 (**Published 2018 Apr 26**)
5. Crowther F, Sealey R, Crowe M, Edwards A, Halson S (2017) Team sport athletes' perceptions and use of recovery strategies: a mixed-methods survey study. BMC Sports Sci Med Rehabil 9:6. https://doi.org/10.1186/s13102-017-0071-3 (**Published 2017 Feb 24**)
6. Fleming JA, Naughton RJ, Harper LD (2018) Investigating the nutritional and recovery habits of tennis players. Nutrients 10(4):443. https://doi.org/10.3390/nu10040443 (**Published 2018 Apr 3**)
7. Allan R, Sharples AP, Cocks M et al (2019) Low pre-exercise muscle glycogen availability offsets the effect of post-exercise cold water immersion in augmenting PGC-1α gene expression. Physiol Rep 7(11):e14082. https://doi.org/10.14814/phy2.14082
8. Alexander J, Allan DR, Rhodes DD (2021) Cryotherapy in sport: a warm reception for the translation of evidence into applied practice [published online ahead of print, 2021 Mar 10]. Res Sports Med. https://doi.org/10.1080/15438627.2021.1899920
9. Meeusen R, Lievens P (1986) The use of cryotherapy in sports injuries. Sports Med 3(6):398–414. https://doi.org/10.2165/00007256-198603060-00002
10. Goodall S, Howatson G (2008) The effects of multiple cold water immersions on indices of muscle damage. J Sports Sci Med 7(2):235–241
11. Almeida AC, Machado AF, Albuquerque MC et al (2016) The effects of cold water immersion with different dosages (duration and temperature variations) on heart rate variability post-exercise recovery: a randomized controlled trial. J Sci Med Sport 19(8):676–681. https://doi.org/10.1016/j.jsams.2015.10.003
12. de Oliveira OV, de Castro MF, de Paula F et al (2014) The effect of different water immersion temperatures on post-exercise

parasympathetic reactivation. PLoS One. 9(12):e113730. https://doi.org/10.1371/journal.pone.0113730 (**Published 2014 Dec 1**)
13. Wilson LJ, Cockburn E, Paice K et al (2018) Recovery following a marathon: a comparison of cold water immersion, whole body cryotherapy and a placebo control. Eur J Appl Physiol 118(1):153–163. https://doi.org/10.1007/s00421-017-3757-z
14. Peiffer JJ, Abbiss CR, Watson G, Nosaka K, Laursen PB (2009) Effect of cold-water immersion duration on body temperature and muscle function. J Sports Sci 27(10):987–993. https://doi.org/10.1080/02640410903207424
15. White GE, Wells GD (2013) Cold-water immersion and other forms of cryotherapy: physiological changes potentially affecting recovery from high-intensity exercise. Extrem Physiol Med 2(1):26. https://doi.org/10.1186/2046-7648-2-26 (**Published 2013 Sep 1**)
16. Chauvineau M, Pasquier F, Guyot V, Aloulou A, Nedelec M (2021) Effect of the depth of cold water immersion on sleep architecture and recovery among well-trained male endurance runners. Front Sports Act Living 3:659990. https://doi.org/10.3389/fspor.2021.659990 (**Published 2021 Mar 31**)
17. Leeder JD, van Someren KA, Bell PG et al (2015) Effects of seated and standing cold water immersion on recovery from repeated sprinting. J Sports Sci 33(15):1544–1552. https://doi.org/10.1080/02640414.2014.996914
18. Brophy-Williams N, Landers G, Wallman K (2011) Effect of immediate and delayed cold water immersion after a high intensity exercise session on subsequent run performance. J Sports Sci Med 10(4):665–670 (**Published 2011 Dec 1**)
19. McGorm H, Roberts L, Coombes J, Peake J (2015) Cold water immersion; practices, trends and avenues of effect. Aspetar Sports Med J 4(1):106–111. https://doi.org/10.13140/RG.2.1.4272.2721
20. Machado AF, Ferreira PH, Micheletti JK et al (2016) Can water temperature and immersion time influence the effect of cold water immersion on muscle soreness? A systematic review and meta-analysis. Sports Med 46(4):503–514. https://doi.org/10.1007/s40279-015-0431-7
21. Versey NG, Halson SL, Dawson BT (2013) Water immersion recovery for athletes: effect on exercise performance and practical recommendations. Sports Med 43(11):1101–1130. https://doi.org/10.1007/s40279-013-0063-8
22. Allan R, Mawhinney C (2017) Is the ice bath finally melting? Cold water immersion is no greater than active recovery upon local and systemic inflammatory cellular stress in humans. J Physiol 595(6):1857–1858. https://doi.org/10.1113/JP273796
23. Bleakley CM, Davison GW (2010) What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. Br J Sports Med 44(3):179–187. https://doi.org/10.1136/bjsm.2009.065565
24. Higgins TR, Greene DA, Baker MK (2017) Effects of cold water immersion and contrast water therapy for recovery from team sport: a systematic review and meta-analysis. J Strength Cond Res 31(5):1443–1460. https://doi.org/10.1519/JSC.0000000000001559
25. Leeder J, Gissane C, van Someren K, Gregson W, Howatson G (2012) Cold water immersion and recovery from strenuous exercise: a meta-analysis. Br J Sports Med 46(4):233–240. https://doi.org/10.1136/bjsports-2011-090061
26. Poppendieck W, Faude O, Wegmann M, Meyer T (2013) Cooling and performance recovery of trained athletes: a meta-analytical review. Int J Sports Physiol Perform 8(3):227–242. https://doi.org/10.1123/ijspp.8.3.227
27. Vromans BA, Thorpe RT, Viroux PJ, Tiemessen IJ (2019) Cold water immersion settings for reducing muscle tissue temperature: a linear dose-response relationship. J Sports Med Phys Fit 59(11):1861–1869. https://doi.org/10.23736/S0022-4707.19.09398-8
28. Aguiar PF, Magalhães SM, Fonseca IA et al (2016) Post-exercise cold water immersion does not alter high intensity interval training-induced exercise performance and Hsp72 responses, but enhances mitochondrial markers. Cell Stress Chaperones 21(5):793–804. https://doi.org/10.1007/s12192-016-0704-6
29. Allan R, Sharples AP, Close GL et al (2017) Postexercise cold water immersion modulates skeletal muscle PGC-1α mRNA expression in immersed and nonimmersed limbs: evidence of systemic regulation. J Appl Physiol (1985) 123(2):451–459. https://doi.org/10.1152/japplphysiol.00096.2017
30. Allan R, Morton JP, Close GL, Drust B, Gregson W, Sharples AP (2020) PGC-1α alternative promoter (Exon 1b) controls augmentation of total PGC-1α gene expression in response to cold water immersion and low glycogen availability. Eur J Appl Physiol 120(11):2487–2493. https://doi.org/10.1007/s00421-020-04467-6
31. Broatch JR, Petersen A, Bishop DJ (2017) Cold-water immersion following sprint interval training does not alter endurance signaling pathways or training adaptations in human skeletal muscle. Am J Physiol Regul Integr Comp Physiol 313(4):R372–R384. https://doi.org/10.1152/ajpregu.00434.2016
32. D'Souza RF, Zeng N, Markworth JF et al (2018) Divergent effects of cold water immersion versus active recovery on skeletal muscle fiber type and angiogenesis in young men. Am J Physiol Regul Integr Comp Physiol 314(6):R824–R833. https://doi.org/10.1152/ajpregu.00421.2017
33. Ihsan M, Watson G, Choo HC et al (2014) Postexercise muscle cooling enhances gene expression of PGC-1α. Med Sci Sports Exerc 46(10):1900–1907. https://doi.org/10.1249/MSS.0000000000000308
34. Ihsan M, Markworth JF, Watson G et al (2015) Regular postexercise cooling enhances mitochondrial biogenesis through AMPK and p38 MAPK in human skeletal muscle. Am J Physiol Regul Integr Comp Physiol 309(3):R286–R294. https://doi.org/10.1152/ajpregu.00031.2015
35. Joo CH, Allan R, Drust B et al (2016) Passive and post-exercise cold-water immersion augments PGC-1α and VEGF expression in human skeletal muscle. Eur J Appl Physiol 116(11–12):2315–2326. https://doi.org/10.1007/s00421-016-3480-1
36. Roberts LA, Raastad T, Markworth JF et al (2015) Post-exercise cold water immersion attenuates acute anabolic signalling and long-term adaptations in muscle to strength training. J Physiol 593(18):4285–4301. https://doi.org/10.1113/JP270570
37. Fuchs CJ, Kouw IWK, Churchward-Venne TA et al (2020) Postexercise cooling impairs muscle protein synthesis rates in recreational athletes. J Physiol 598(4):755–772. https://doi.org/10.1113/JP278996
38. Fröhlich M, Faude O, Klein M, Pieter A, Emrich E, Meyer T (2014) Strength training adaptations after cold-water immersion. J Strength Cond Res 28(9):2628–2633. https://doi.org/10.1519/JSC.0000000000000434
39. Fyfe JJ, Broatch JR, Trewin AJ et al (2019) Cold water immersion attenuates anabolic signaling and skeletal muscle fiber hypertrophy, but not strength gain, following whole-body resistance training. J Appl Physiol (1985) 127(5):1403–1418. https://doi.org/10.1152/japplphysiol.00127.2019
40. Cheng AJ (2018) Cooling down the use of cryotherapy for post-exercise skeletal muscle recovery. Temperature (Austin) 5(2):103–105. https://doi.org/10.1080/23328940.2017.1413284 (**Published 2018 Feb 6**)
41. Ihsan M, Abbiss CR, Gregson W, Allan R. Warming to the ice bath: Don't go cool on cold water immersion just yet!: Comment on: 1) Arthur J. Cheng. Cooling down the use of cryotherapy for post-exercise skeletal muscle recovery. *Temperature*. 2018; 5(2): 103–105. doi: https://doi.org/10.1080/23328940.2017.14132

84. 2) Cheng et al. Post-exercise recovery of contractile function and endurance in humans and mice is accelerated by heating and slowed by cooling skeletal muscle. *Journal of Physiology.* 2017; 595(24): 7413–7426. doi: https://doi.org/10.1113/JP274870. *Temperature (Austin)*. 2020;7(3):223–225. Published 2020 Feb 20. doi:https://doi.org/10.1080/23328940.2020.1727085
42. Ihsan M, Abbiss CR, Allan R (2021) Adaptations to post-exercise cold water immersion: friend, foe or futile? Front Sports Act Living. https://doi.org/10.3389/fspor.2021.714148
43. Mawhinney C, Allan R (2018) Muscle cooling: too much of a good thing? J Physiol 596(5):765–767. https://doi.org/10.1113/JP275695
44. Bartlett JD, Drust B (2020) A framework for effective knowledge translation and performance delivery of Sport Scientists in professional sport [published online ahead of print, 2020 Nov 29]. Eur J Sport Sci. https://doi.org/10.1080/17461391.2020.1842511
45. Shell SJ, Slattery K, Clark B et al (2020) Perceptions and use of recovery strategies: do swimmers and coaches believe they are effective? J Sports Sci 38(18):2092–2099. https://doi.org/10.1080/02640414.2020.1770925
46. Harper LD, McCunn R (2017) "Hand in Glove": using qualitative methods to connect research and practice. Int J Sports Physiol Perform 12(7):990–993. https://doi.org/10.1123/ijspp.2017-0081
47. Thomas DR (2006) A general inductive approach for analysing qualitative evaluation data. Am J Eval 27(2):237–246
48. Venter RE (2014) Perceptions of team athletes on the importance of recovery modalities. Eur J Sport Sci 14(Suppl 1):S69–S76. https://doi.org/10.1080/17461391.2011.643924
49. Hinghofer-Szalkay H, Harrison MH, Greenleaf JE (1987) Early fluid and protein shifts in men during water immersion. Eur J Appl Physiol Occup Physiol 56(6):673–678. https://doi.org/10.1007/BF00424809
50. Seals DR (1990) Sympathetic activation during the cold pressor test: influence of stimulus area. Clin Physiol 10(2):123–129. https://doi.org/10.1111/j.1475-097x.1990.tb00246.x
51. Kregel KC, Seals DR, Callister R (1992) Sympathetic nervous system activity during skin cooling in humans: relationship to stimulus intensity and pain sensation. J Physiol 454:359–371. https://doi.org/10.1113/jphysiol.1992.sp019268
52. Gregson W, Black MA, Jones H et al (2011) Influence of cold water immersion on limb and cutaneous blood flow at rest. Am J Sports Med 39(6):1316–1323. https://doi.org/10.1177/0363546510395497
53. Gregson W, Allan R, Holden S et al (2013) Postexercise cold-water immersion does not attenuate muscle glycogen resynthesis. Med Sci Sports Exerc 45(6):1174–1181. https://doi.org/10.1249/MSS.0b013e3182814462
54. Mawhinney C, Jones H, Low DA, Green DJ, Howatson G, Gregson W (2017) Influence of cold-water immersion on limb blood flow after resistance exercise. Eur J Sport Sci 17(5):519–529. https://doi.org/10.1080/17461391.2017.1279222
55. Alexander J, Carling C, Rhodes D (2022) Utilisation of performance markers to establish the effectiveness of cold-water immersion as a recovery modality in elite football. Biol Sport 39(1):19–29. https://doi.org/10.5114/biolsport.2021.103570
56. Broatch JR, Petersen A, Bishop DJ (2014) Postexercise cold water immersion benefits are not greater than the placebo effect. Med Sci Sports Exerc 46(11):2139–2147. https://doi.org/10.1249/MSS.0000000000000348
57. White GE, Rhind SG, Wells GD (2014) The effect of various cold-water immersion protocols on exercise-induced inflammatory response and functional recovery from high-intensity sprint exercise. Eur J Appl Physiol 114(11):2353–2367. https://doi.org/10.1007/s00421-014-2954-2
58. Peake JM, Roberts LA, Figueiredo VC et al (2017) The effects of cold water immersion and active recovery on inflammation and cell stress responses in human skeletal muscle after resistance exercise. J Physiol 595(3):695–711. https://doi.org/10.1113/JP272881
59. Kwiecien SY, McHugh MP (2021) The cold truth: the role of cryotherapy in the treatment of injury and recovery from exercise [published online ahead of print, 2021 Apr 20]. Eur J Appl Physiol. https://doi.org/10.1007/s00421-021-04683-8
60. Earp JE, Hatfield DL, Sherman A, Lee EC, Kraemer WJ (2019) Cold-water immersion blunts and delays increases in circulating testosterone and cytokines post-resistance exercise. Eur J Appl Physiol 119(8):1901–1907. https://doi.org/10.1007/s00421-019-04178-7
61. Lindsay A, Carr S, Cross S, Petersen C, Lewis JG, Gieseg SP (2017) The physiological response to cold-water immersion following a mixed martial arts training session. Appl Physiol Nutr Metab 42(5):529–536. https://doi.org/10.1139/apnm-2016-0582
62. Ahokas EK, Kyröläinen H, Mero AA, Walker S, Hanstock HG, Ihalainen JK (2020) Water immersion methods do not alter muscle damage and inflammation biomarkers after high-intensity sprinting and jumping exercise. Eur J Appl Physiol 120(12):2625–2634. https://doi.org/10.1007/s00421-020-04481-8
63. Bartley JM, Stearns RL, Munoz C et al (2021) Effects of cold water immersion on circulating inflammatory markers at the Kona Ironman World Championship [published online ahead of print, 2021 Jan 28]. Appl Physiol Nutr Metab. https://doi.org/10.1139/apnm-2020-0602
64. de Freitas VH, Ramos SP, Bara-Filho MG et al (2019) Effect of cold water immersion performed on successive days on physical performance, muscle damage, and inflammatory, hormonal, and oxidative stress markers in volleyball players. J Strength Cond Res 33(2):502–513. https://doi.org/10.1519/JSC.0000000000001884
65. Siqueira AF, Vieira A, Bottaro M et al (2018) Multiple cold-water immersions attenuate muscle damage but not alter systemic inflammation and muscle function recovery: a parallel randomized controlled trial. Sci Rep 8(1):10961. https://doi.org/10.1038/s41598-018-28942-5 (**Published 2018 Jul 19**)
66. Wilcock IM, Cronin JB, Hing WA (2006) Physiological response to water immersion: a method for sport recovery? Sports Med 36(9):747–765. https://doi.org/10.2165/00007256-200636090-00003
67. Tabben M, Ihsan M, Ghoul N et al (2018) Cold water immersion enhanced athletes' wellness and 10-m short sprint performance 24-h after a simulated mixed martial arts combat. Front Physiol 9:1542. https://doi.org/10.3389/fphys.2018.01542 (**Published 2018 Nov 1**)
68. Ihsan M, Watson G, Lipski M, Abbiss CR (2013) Influence of postexercise cooling on muscle oxygenation and blood volume changes. Med Sci Sports Exerc 45(5):876–882. https://doi.org/10.1249/MSS.0b013e31827e13a2
69. Mawhinney C, Jones H, Joo CH, Low DA, Green DJ, Gregson W (2013) Influence of cold-water immersion on limb and cutaneous blood flow after exercise [published correction appears in Med Sci Sports Exerc. 2014 Feb;46(2):426]. Med Sci Sports Exerc 45(12):2277–2285. https://doi.org/10.1249/MSS.0b013e31829d8e2e
70. Mawhinney C, Low DA, Jones H, Green DJ, Costello JT, Gregson W (2017) Cold water mediates greater reductions in limb blood flow than whole body cryotherapy. Med Sci Sports Exerc 49(6):1252–1260. https://doi.org/10.1249/MSS.0000000000001223
71. Mawhinney C, Heinonen I, Low DA et al (2020) Changes in quadriceps femoris muscle perfusion following different degrees of cold-water immersion. J Appl Physiol (1985) 128(5):1392–1401. https://doi.org/10.1152/japplphysiol.00833.2019

72. Herrera E, Sandoval MC, Camargo DM, Salvini TF (2010) Motor and sensory nerve conduction are affected differently by ice pack, ice massage, and cold water immersion. Phys Ther 90(4):581–591. https://doi.org/10.2522/ptj.20090131
73. Herrera E, Sandoval MC, Camargo DM, Salvini TF (2011) Effect of walking and resting after three cryotherapy modalities on the recovery of sensory and motor nerve conduction velocity in healthy subjects. Rev Bras Fisioter 15(3):233–240. https://doi.org/10.1590/s1413-35552011000300010
74. Broatch JR, Petersen A, Bishop DJ (2018) The influence of post-exercise cold-water immersion on adaptive responses to exercise: a review of the literature. Sports Med 48(6):1369–1387. https://doi.org/10.1007/s40279-018-0910-8
75. Petersen AC, Fyfe JJ (2021) Post-exercise cold water immersion effects on physiological adaptations to resistance training and the underlying mechanisms in skeletal muscle: a narrative review. Front Sports Act Living 3:660291. https://doi.org/10.3389/fspor.2021.660291 (**Published 2021 Apr 8**)