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Core temperature responses to cold-water immersion recovery: a pooled-data analysis

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ABSTRACT

Purpose: To examine the effect of post-exercise cold water immersion (CWI) protocols compared with control (CON), on the magnitude and time-course of core temperature (T_c) responses. ***Methods:*** Pooled data analyses were used to examine the Tc responses of 157 subjects from previous post-exercise CWI trials in our laboratories. CWI protocols varied with different combinations of temperature, duration, immersion depth and mode (continuous vs intermittent). Tc was examined as a double difference ($\Delta\Delta T_c$), calculated as the change in Tc in CWI condition minus the corresponding change in CON. The effect of CWI on $\Delta\Delta T_c$ was assessed using separate linear mixed models across two time components (Component 1: immersion, and Component 2: post-intervention). ***Results:*** Intermittent CWI resulted in a mean decrease in $\Delta\Delta T_c$ that was 0.254±0.10°C (estimate ± SE) greater than continuous CWI during the immersion component (P=0.022). There was a significant effect of CWI temperature during the immersion component (P=0.050), where reductions in water temperature of 1°C resulted in decreases in $\Delta\Delta T_c$ of 0.03±0.01°C. Similarly, the effect of CWI duration was significant during the immersion component (P=0.01), where every 1 min of immersion resulted in a decrease in $\Delta\Delta T_c$ of 0.02±0.01°C. The peak difference in T_c between the CWI and CON interventions during the post-immersion component occurred at 60 min post-intervention. ***Conclusion:*** Variations in CWI mode, duration and temperature, may have a significant effect on the extent of change in T_c. Careful consideration should be given to determine the optimal amount of core cooling before deciding which combination of protocol factors to prescribe.

Key Words: Hydrotherapy, performance, exercise, ice-bath, protocol-variance.

INTRODUCTION

Cold water immersion (CWI) is a widely practiced recovery modality aiming to reduce fatigue and facilitate post-exercise recovery.[1] It is thought that the combination of cold temperature and hydrostatic pressure promotes reductions in tissue temperatures and blood flow, facilitating subsequent reductions in thermal and cardiovascular strain, oedema, inflammation and pain.[1,2] The dominant mechanism by which CWI is believed to be effective for acute recovery is its ability to ameliorate hyperthermia and the subsequent central nervous system mediated fatigue.[1] Indeed, previous research has attributed the enhanced recovery of maximal voluntary contraction force to faster return of central activation which is the resulting from of larger CWI induced reductions in core temperature (T_c).[3] With hyperthermia mediated fatigue being a key fatiguing factor for many forms of exercise,1 a greater understanding of the impact of CWI on Tc (as an indicator of hyperthermia) will enhance the effectiveness of CWI.

There is increasing evidence to support the notion that CWI enhances both short- and long-term recovery of performance, particularly for endurance and team sports, there are also several studies that have shown CWI to have either a negligible or detrimental effect on performance.[1,4,5] With consideration of this variance in findings, it may be that CWI is not suitable for all post-exercise contexts, and the exercise mode performed prior to immersion, in addition to the time frame available and the environment in which exercise is performed (e.g. hot vs. cool vs. thermoneutral) are key factors influencing the effectiveness of CWI.[4,6] Endurance based performance has been shown to be most responsive to CWI; however, there is still considerable variability across studies assessing endurance performance.[1,4] For example, while a number of studies have found CWI to be effective for maintaining cycling time-trial performance in a subsequent exercise bout performed 40 min to 3 days post-CWI,[7-10] others observed a decrease in time-trial performance over the same time frame.[11,12] The factors responsible for this large variation in findings across the current literature are unclear, and as such, there is substantial debate as to the true efficacy of CWI as a recovery strategy.[1,4]

Variation in the physiological and performance recovery responses to CWI is likely to depend the degree of cooling that can be achieved which is a result of the initial interaction between the protocol utilised and the characteristics of the individual (e.g. body composition, age, sex, ethnicity, etc).[4] Understanding the optimal degree of cooling is important as too little cooling may cause CWI to be less effective due to limited reductions in muscle temperature (T_m) and T_c.[13] Conversely, too much cooling may lead to a reduction in muscle contractile force.[14] Current CWI protocols administered in practice vary in terms of the water temperature, duration, depth and mode of immersion, and the optimal combination of these factors remains unknown.[4,14,15] The interaction between each of these protocol factors is complex and previous research has shown the same degree of T_c change (0.4°C) in response to different CWI protocols (e.g. 5 min, 14°C, whole body immersion16 vs. 5 min, 10°C, leg only immersion[17]). However, it remains unknown whether the thermal stress applied by the temperature stimulus, the duration of exposure to the cold stimulus, the depth of immersion and body surface area exposed to the cold stimulus, or the change in temperature gradient by moving in and out of the water during intermittent immersion has the greatest impact on T_c responses.

Recently it has been suggested that continuous immersion in water temperatures between 11-15°C for 11-15 min are optimal for reducing muscle soreness.[15] However, the most effective approach for reducing T_c and exercise-induced hyperthermia remains unknown, and further research is required to understand how each factor contributes to T_c change.[4] With previous research showing that the change in T_c is related to a change in performance,[3,9,18] it is important to gain a greater understanding of T_c responses as it will enable CWI protocols to be optimised and ultimately improve the restoration of performance for individual athletes. Therefore, the aims of the present study were twofold: 1) to conduct a pooled analysis across a large data set to examine the impact of variability in different CWI protocol factors on T_c change relative to a control condition; and 2) to characterise the time-course of T_c responses to post-exercise CWI both during immersion and post-immersion.

METHODS

Study Design

This study adopted a pooled analysis approach using data from 157 male subjects from 13 previous investigations of post-exercise CWI in our laboratories. Data were assessed using two respective linear mixed models based on different time components. The first component examined the change in Tc between the end of exercise and the end of the CWI/Control (CON) recovery intervention (Component 1: immersion). The second component examined the post-recovery change only and is defined as the difference in Tc between the end of the CWI/CON recovery intervention and each of the available post-intervention time-points (Component 2: post-intervention).

Data Sources

Individual de-identified raw data were collated from 13 previous studies by our groups for inclusion in this pooled analysis (Table 1). Criteria for inclusion were: 1) use of a cross-over controlled design, 2) included seated passive CON condition, 3) CWI performed post-exercise, 4) measured Tc via rectal thermister or telemetric pill, and 5) exercise resulted in a significant increase from baseline in mean Tc (≥38.0°C). Studies with missing data (where raw data could not be accessed) or without Tc measures immediately post-exercise and/or post-recovery were excluded (Figure 1). There were no specific criteria for type of exercise utilised; however, 11 studies examined cycling[8,10,11,19-26] and two examined sprint running[3,27]. Of the 13 studies included, ten are published in academic journals[3,8,10,11,18,19,21,23,26,27] and three in PhD theses.[20,24,25]

Subjects

De-identified raw data were extracted from 13 studies, providing data on 157 trained male subjects (Table 2). Subjects across all studies were classified as well-trained with 94 indentifying as predominantly participating in cycling or triathlon, 29 in team sports, leaving 36 with an unspecified sporting background.

Cold water immersion protocol combinations

CWI protocols varied across studies, with seven different temperatures, eight immersion durations, three depths and two modes of immersion utilised (Table 1), making a total of 336 possible combinations of which 16 were utilised. Of the 13 studies included, nine studies used just one CWI protocol,[3,8,10,18,19,21,23,24,27] two studies used two protocols,[25,26] one study included three protocols,[11] and another study used four[20] different protocols giving a total of 20 within-study-protocol combinations. Of these protocols, four were used in two studies so that there were only 16 of the 336 possible CWI protocols represented across the 13 studies. Further, there were only 15 (out of a possible 56) combinations of duration and temperature used, with just one combination used at more than one immersion depth. Additionally, all 15 of these combinations were associated with just one of the two modes, continuous or intermittent, resulting in partial confounding between the four components of the CWI protocols so that it is not possible to completely separate the effects of the various (protocol) factors. For analysis and to allow comparisons between studies, immersion depth was converted into a predicted body-surface-water-contact area of 1.3 m^2 for waist-depth, 1.6 m^2 for chest-depth, and 1.8 m^2 for neck-depth based on normative measurements of an average, and therefore comparable, male.[28] The offset time between the end of exercise and the commencement of CWI also varied, and there were seven different offset times used across the 13 studies (Table 1).

Calculation of the change in Core Temperature (Tc)

T_c was either measured by rectal thermister[8,10,11,18,19,21,23,24] or by sensor telemetry.[3,20,25-27] T_c was measured at different time-points across the 13 studies (Table 1), including immediately post-exercise, immediately post-recovery (0 min) and at 13 post-recovery time-points (5, 10, 15, 20, 30, 40, 60, 90, 120, 150, 180, 210, 240 min post-intervention). Two of the studies[3,21] recorded just two T_c values for each participant; one at the end of exercise and the other at the end of CWI, and therefore were only included in the immersion component analysis. The other 11 studies recorded T_c values at additional times following the completion of CWI and were therefore included in the post-intervention component analysis. One study controlled post-exercise T_c to ensure it was equal across subjects and trials,[23] while the remaining 12 studies did not attempt to control post-exercise T_c. Regardless, there was no significant difference between trials (CWI vs CON) for each participant, as determined by initial t-test analysis. The T_c response was calculated in each of the models as a double difference ($\Delta\Delta T_c$), whereby the change in T_c in the CWI condition minus the corresponding difference under the control condition relative to post-exercise in Component 1 and immediately post-recovery in Component 2, (e.g. $\Delta\Delta T_c$ =(CWI post-exercise T_c–CWI post-recovery T_c)-(CON post-exercise T_c–CON post-recovery T_c). A negative $\Delta\Delta T_c$ indicates that the change in T_c is greater in the CWI condition compared to the control.

Statistical analysis

The statistical analysis consisted of two, distinct components. The first component (immersion) considered the $\Delta\Delta T_c$ changes from the end of exercise to the end of the recovery treatment, while the second component (post-intervention) considered the $\Delta\Delta T_c$ changes following the recovery intervention. For each component, a linear mixed model was used with CWI protocols (combination of duration, temperature, depth and mode) and the offset from the end of exercise to the start of the CWI treatment treated as a fixed effects and either study-protocol (i.e. the different protocols within a study were essentially treated as being different studies) or subject as random effects for components 1 and 2, respectively. Five of the 11 studies with data following the CWI treatment period included more than one post-CWI observation and the models fitted to these data made allowance for possible autocorrelation within subjects. To fit these models, it was necessary to treat the subjects that used more than one protocol (within a study) as though they were different subjects. In addition to the effect of CWI treatment, it was also of interest to evaluate how the $\Delta\Delta T_c$ varied with time, post-recovery. When this time was fitted as a (fixed effect) factor (only 13 time points were used in the studies), the relationship was deemed appropriate to then subsequently model using regression splines. All models were fitted using the lme or gamm components of the mgcv package29 available in R.30 The significance level was P≤0.05 and data are reported as mean±standard deviation or estimate±standard error.

RESULTS

Component 1 – Immersion

Across all subjects average post-exercise T_c was 38.56±0.60°C and immediately post-intervention was 37.72±0.53°C. The effects of CWI time, temperature and mode are illustrated in Figure 2 which gives the estimated overall responses for each of the 20 study-protocol combinations used in the 13 studies. Intermittent CWI results in a significantly (P=0.02) greater decrease in $\Delta\Delta T_c$ 0.254±0.10°C (estimate ± SE) than that obtained with continuous CWI. The effect of CWI temperature can be described by a significant (P=0.05) linear regression with a coefficient of 0.03±0.01°C. That is, for each reduction in CWI temperature of 1°C, $\Delta\Delta T_c$ is estimated to decrease on average by 0.03°C. The effect of CWI duration was significant (P=0.01), with a decrease of 0.02±0.01°C $\Delta\Delta T_c$ for each additional minute of CWI immersion. Neither depth (P=0.19) nor offset time (P=0.90) had a significant effect on $\Delta\Delta T_c$.

The inclusion of the study-protocol in the model had a minimal effect on the parameter estimates, though it did result in slight increases in the standard errors and hence slight increases in the p-values. The residual standard deviation, which includes the between-subject variation not accounted for by the fitted model, and indicates the variation that was observed between the changes in individual subjects, was estimated to be 0.444 °C.

Component 2 – Post-intervention

The effect of offset time was significant (P=0.00), with an increase of 0.01°C $\Delta\Delta T_c$ for each minute increase in offset time. Further, the effect of post-recovery time was also significant (P<0.001) and was adequately described by a cubic regression spline. Specifically, peak difference between CWI and CON occurred at ~60 min post-intervention; following this $\Delta\Delta T_c$ slowly increased until there was no impact of the intervention (Figure 3). Also displayed in Figure 3 are estimates of the effect of post-recovery time when it was treated as a factor (with 13 levels, the number of different times used in the studies). Other effects such as CWI type (intermittent or continuous), duration, temperature and depth were also evaluated, but none of them made a (statistically) significant contribution.

The inclusion of within subject autocorrelation in the model had an appreciable effect on the parameter estimates with the autocorrelation being highly significant (P<0.001). The residual standard deviation, which includes within-subject variation not accounted for by the fitted model, was estimated to be 0.36°C.

DISCUSSION

The present study aimed to understand the implications of varying the temperature, duration, depth and mode of CWI protocols on T_c, and to identify the ensuing time-course of T_c responses based on these post-exercise CWI protocol variations. The main findings were: 1) that intermittent protocols resulted in a significantly greater decrement in Tc compared to continuous protocols for the T_c change during immersion; 2) decreasing water temperature and increasing duration of CWI resulted in a significant decrease in $\Delta\Delta T_c$ during immersion; 3) the longer the offset time (end of exercise to immersion commencement), the smaller the change in T_c post-recovery; and 4) the peak difference in Tc between CON and CWI protocols occurred at ~60 min post-recovery, irrespective of protocol mode.

Reported post-exercise CWI protocols vary substantially,[4,15] and while CWI is widely utilised by athletes, a lack of consensus as to the best protocols for different sport/athlete scenarios remains.[14]

Accordingly, the present study combined the data from a range of studies representing the variety of protocols currently utilised to determine the impact of different combinations and interaction of these factors on the change in T_c. One of the major findings of the present study was that intermittent CWI protocols appear to be more effective in lowering T_c compared to continuous CWI. It may be postulated that the lower T_c observed, on average, in response to intermittent CWI might be related to the frequent change in thermal gradient occurring each time the participant moves between the cold water and the warmer air. This frequent change may have led to repeated reactive hyperaemia responses where both skin and muscle blood flow increases when the participant moves out of the pool after a period of cold-induced vasoconstriction and ischemia which occurs during immersion.[31] This theory is supported by the findings of Romet [32] and Seo, et al. [33] who found that following removal from CWI, vasodilation occurred in the extremities and greater conductive heat transfer occurred due to the return of cooler blood to the central circulation. Nevertheless, as only three studies utilised intermittent protocols, the conclusions which can be drawn from these data need to be confirmed by future research.

Often in practical settings, the duration and depth of CWI are determined by the water temperature based on athlete tolerance; thus, these variables were also examined in the present study given their ecological interactions in many protocols. Although it has been suggested that the physiological changes in response to post-exercise CWI are temperature dependent,[14] the way these factors interact with each other and which factor has the greatest impact on T_c responses remains unknown.[4] Both temperature and duration were found to have a highly significant impact on $\Delta\Delta T_c$. The current study found that CWI temperature led to a decrease in $\Delta\Delta T_c$ of 0.025°C for every 1°C reduction in water temperature, and that CWI duration led to a reduction in $\Delta\Delta T_c$ of 0.018°C for every additional minute of immersion time. Collectively, colder water temperatures and greater immersion durations lead to a greater reduction in T_c compared to an equivalent duration CON. However, such an effect was only observed for continuous immersion protocols, as no evidence of a duration effect was apparent for intermittent protocols given the small range of intermittent protocols included in the analyses. The depth of immersion was not significant and highly confounded with the other protocol factors. Increasing immersion depth is believed to enhance responses to CWI by increasing hydrostatic pressure as well as exposing a greater body surface area for thermal exchange via convection to occur.[4] The impact of hydrostatic pressure was recently examined by comparing seated versus standing CWI, with no significant difference reported between the two conditions, suggesting water temperature may be of greater importance.[34] Given the absence of studies examining the effect of different immersion depths on T_c responses to post-exercise CWI, further research is required to fully determine the impact of varying CWI depth.

Post-exercise CWI has been shown to significantly reduce T_c; however, the extent of this reduction is highly variable, and the time-course of change remains to be fully elucidated.[4] The present study examined the change in T_c during and post-immersion as two separate components as it was recognised that the rate of T_c change would be vastly different depending on the thermal environment the body is placed in. The present study found that the sooner CWI is commenced post-exercise the greater the reduction in post-immersion T_c will be. This may be due to T_c and blood flow being elevated at the end of exercise, therefore, increasing the thermal gradient between the body and the water and thermal exchange between blood and body tissues. It was also found that when examining T_c change post-recovery, the greatest difference between CWI and CON occurred 60 min post-recovery (Figure 2). This novel finding highlights the importance of this time period post-immersion, and it highlights the potentially negative effect of a hot shower post-immersion. A hot shower immediately post-immersion is a common practice of some athletes which may prevent the after-drop in T_c therefore, potentially limiting the effectiveness of CWI on core cooling. However, with only three studies examining T_c change for ≥60 min post-immersion, the estimates of $\Delta\Delta T_c$ become weaker as time increases, potentially limiting the strength of conclusions which can be drawn.

This prolonged decrease in T_c after CWI may have practical implications for repeat-performance and should be considered when prescribing protocols. It is hypothesised that the optimal protocol parameters will vary depending on recovery needs of the athlete, which will be determined by the specific type of fatigue (e.g. central nervous system fatigue, cardiovascular fatigue, etc.), time-frame available and type of performance (e.g. endurance vs sprint) required.[1,4] It is also important to consider the environmental conditions.[1,35] For example, performing CWI during a short time-frame between endurance tasks may provide pre-cooling benefits for subsequent exercise, particularly when environmental conditions are warm or hot. However, when performance requires maximal contractions and the time-frame between repeat performances is short, CWI induced changes in body temperature will likely reduce muscular performance.[4,15]

Future studies should focus on determining the exact degree of change in T_c that leads to an optimal cooling effect for subsequent performance and how different CWI protocol factors work towards inducing this T_c change. Future research should also look to establish the optimal cooling effect for other physiological variables such as muscle temperature and blood flow as these also have the potential to impact performance recovery. The residual standard deviations were estimated to be 0.44°C and 0.36°C for components 1 and 2, respectively. Compared to the estimated effects of CWI, these values are relatively large which means that, while various effects have been found, on average, to be statistically significant, there is a lot of additional variation between subjects (for component 1) and within subjects (for component 2) so that it is not yet possible to deduce how individual athletes will respond to CWI.

The present pooled-data analysis study builds on a previous meta-analysis[36] by examining individual responses to a range of CWI protocols and highlights the fact that responses to post-exercise CWI are highly variable and are impacted by a myriad of factors. It is not solely the dose of cooling provided by the combination of CWI temperature, duration, depth and mode that impact these responses. Other factors such as laboratory/environmental conditions, differences in exercise induced thermoregulatory stress, offset differences (i.e. time between end of exercise and start of CWI) and individual participant differences (e.g. body composition, age, sex and ethnicity) also impact responses and may explain much of the variation in the current literature. The relatively homogenous cohort examined in this pooled analysis acts to delimit several of these potentially confounding factors (e.g. sex, age, body composition), yet this may also limit the applicability of findings to other populations. The large number of factors impacting the cooling response makes attempting to predict the optimal “dose” of CWI quite difficult, especially when many combinations of factors have not been tested. Nevertheless, this study has drawn on a large data set to provide some clarity around the influence of CWI protocol mode, temperature, duration and offset differences on Tc response. An understanding of how variations in these factors impact temperature change will enable future researchers to better prescribe CWI protocols, and ultimately facilitate the optimisation of performance recovery.

PRACTICAL APPLICATIONS

- Before prescribing a CWI protocol it is important to determine how much core cooling needs to be induced. For situations where more intense cooling is required, longer duration and colder water temperatures may be more effective.
- When greater reductions in T_c are required, CWI should be performed as soon as possible after exercise.
- Intermittent CWI protocols are effective in reducing T_c and can be used when there are a large number of athletes needing to complete CWI with limited resources (e.g. one ice bath) or when an athlete is uncomfortable with long duration CWI.
- Consideration should be given to what activities the athletes have in the 60 min post-immersion as T_c continues to decrease during this period.

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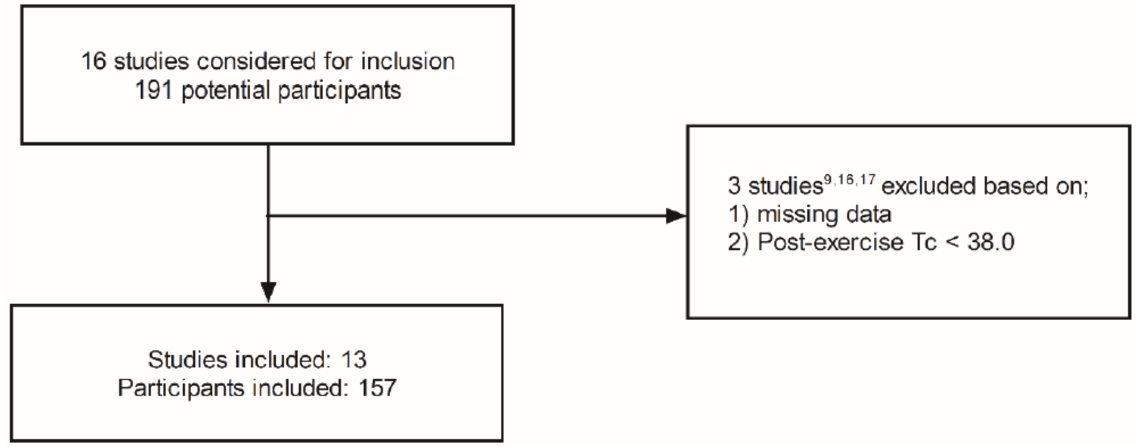

Figure 1: Flow chart on all relevant cold water immersion studies performed in our laboratories and the reason for exclusion

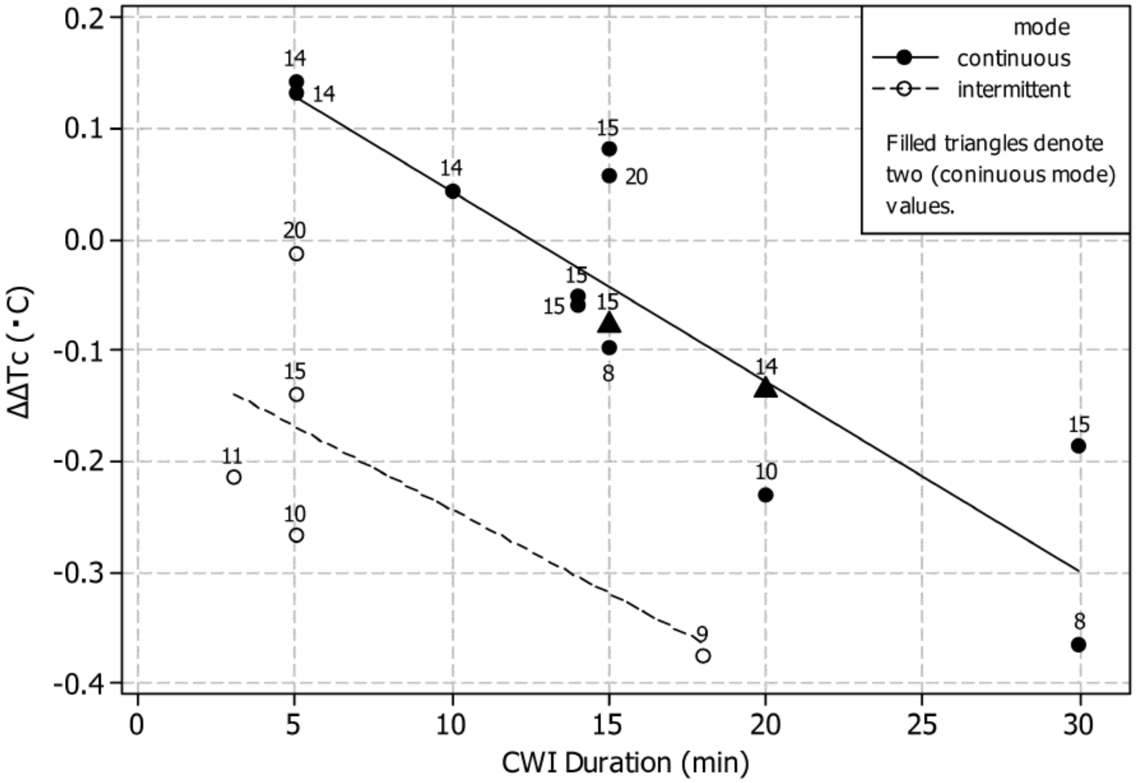

Figure 2: Estimated responses for each of the 20 study-protocol combinations used in the 13 studies. Numbers next to data points = water temperature. ΔΔTc = Change in Tc in CWI condition minus change in Tc in CON condition

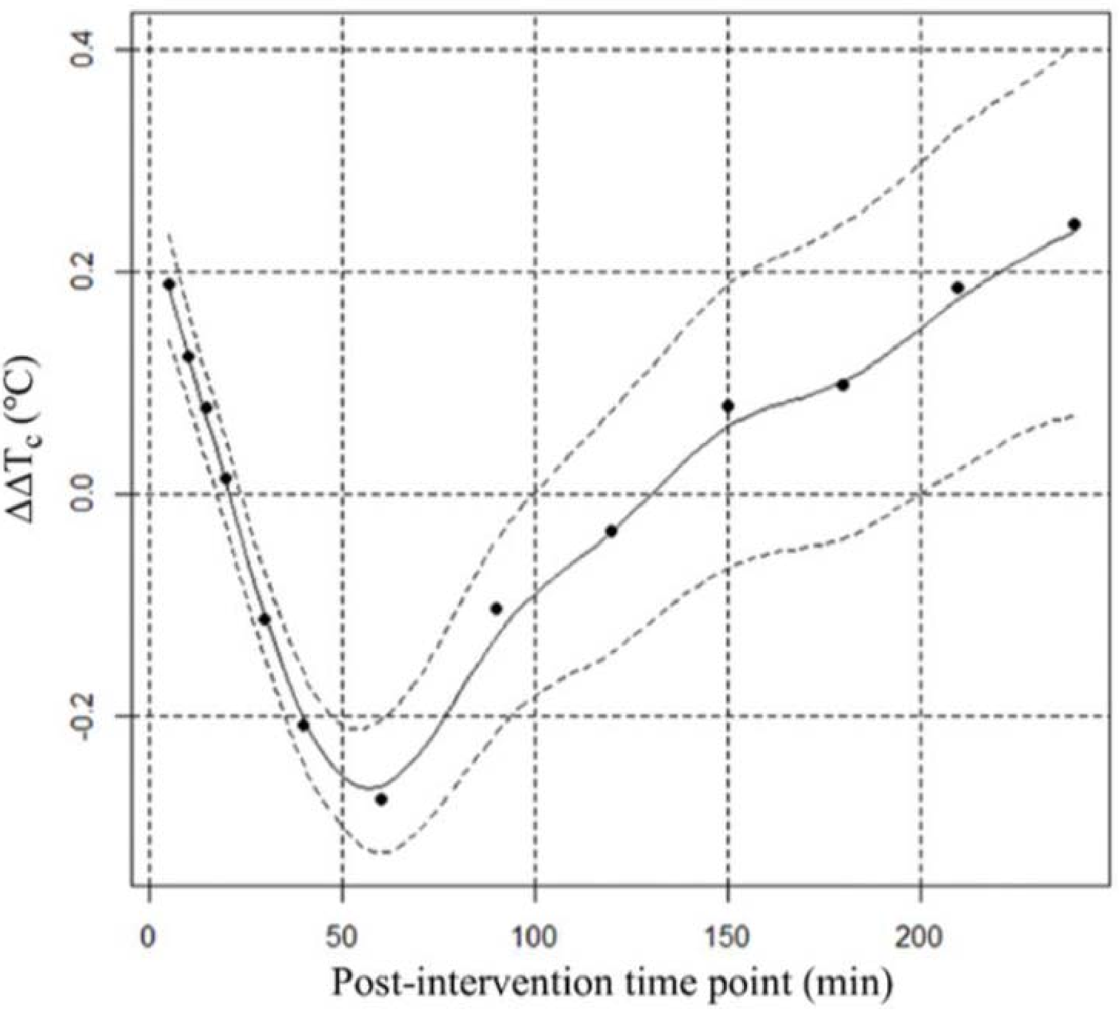

Figure 3: Parameter estimates and fitted spline with 95% confidence limits for the change in Tc from end of intervention to each of the post-intervention time points. ΔΔTc = Change in Tc in CWI condition minus change in Tc in CON condition

Table 1: Data sources

Study number	Reference	Number of participants	CWI condition(s)				CON condition	Tc method	T_c measurement time-points	Offset (EndEx to Rec0)	Ambient temperature (°C)	EndEx Tc (°C)
			CWI duration	CWI temperature	CWI depth	CWI mode						
1	Peiffer et al., (2009)	12		*Condition 1:*			20 min, seated, room temperature 24°C	R	EndEx EndRec PostRec: 5, 10, 20, 30, 40min	25 min	40°C	38.9°C
			5 min	14 ˚C	Chest	C						
				Condition 2:								
			10 min	14 ˚C	Chest	C						
				Condition 3:								
			20 min	14 ˚C	Chest	C						
2	Peiffer et al., (2009)	8	20 min	14 ˚C	Chest	C	20 min, seated, room temperature 24°C	R	EndEx EndRec PostRec: 5, 10, 20, 30, 40min	7.5 min	32°C	38.9°C
3	Peiffer et al., (2010a)	10	5 min	14 ˚C	Chest	C	15 min, seated room temperature 35°C	R	EndEx EndRec PostRec: 5 min	5 min	35°C	38.6°C
4	Stephens et al., (2017)	20	15 min	15 ˚C	Neck	C	15 min, seated, room temperature 25°C	R	EndEx EndRec PostRec: 10, 20, 30, 40min	15 min	22°C	38.1°C

Study number	Reference	Number of participants	CWI condition(s)				CON condition	Tc method	T_c measurement time-points	Offset (EndEx to Rec0)	Ambient temperature (°C)	EndEx Tc (°C)
			CWI duration	**CWI temperature**	**CWI depth**	**CWI mode**						
5	Minett et al., (2014)	9	20 min	10 ˚C	Chest	C	20 min, seated, room temperature 32°C	G	EndEx EndRec	10 min	32°C	38.9°C
6	Vaile et al., (2008)	12		*Condition 1:*			14 min, seated, room temperature unknown	R	EndEx EndRec PostRec: 40 min	0 min	n/a	38.5°C
			5 min (5x 1 min in;2 min out)	10 ˚C	Neck	I						
				Condition 2:								
			5 min (5x 1 min in;2 min out)	15 ˚C	Neck	I						
				Condition 3:								
			5 min (5x 1 min in;2 min out)	20 ˚C	Neck	I						
				Condition 4:								
			15 min	20 ˚C	Neck	C						
7		8		9 ˚C	Waist	I			EndEx	10 min	32°C	39.0°C

Study number	**Reference**	**Number of participants**	**CWI condition(s)**				**CON condition**	**Tc method**	**T_c measurement time-points**	**Offset (EndEx to Rec0)**	**Ambient temperature (°C)**	**EndEx Tc (°C)**
			CWI duration	**CWI temperature**	**CWI depth**	**CWI mode**						
	Pointon et al., (2012)		18 min (2x 9 min in; 1min out)				20 min, seated, room temperature 32°C		EndRec 120 min Post			
8	Vaile et al., (2008b)	12	14 min	15 ˚C	Neck	C	14 min, seated, room temperature not reported	R	EndEx EndRec 15 min Post	0 min	n/a	38.5°C
9	Dunne et al., (2013)	9	 15 min 15 min	*Condition 1:* 15 ˚C *Condition 2:* 8 ˚C	 Waist Waist	 C C	15 min, seated, room temperature 18°C	G	EndEx EndRec PostRec: 5 min	5 min	22°C	38.6°C
10	Stephens et al., (2017b)	27	15 min	15 ˚C	Neck	C	15 min, seated, room temperature 25°C	R	EndEx EndRec PostRec: 5, 30, 60, 90, 120, 150, 180, 210, 240 min	15 min	23°C	38.5°C

Study number	Reference	Number of participants	CWI condition(s)				CON condition	Tc method	T_c measurement time-points	Offset (EndEx to Rec0)	Ambient temperature (°C)	EndEx Tc (°C)
			CWI duration	CWI temperature	CWI depth	CWI mode						
11	Versey (2012)	9	14 min	15 ˚C	Neck	C	14 min, seated, room temperature 21°C	R	EndEx EndRec PostRec: 5, 30, 60, 90 min	15 min	22°C	38.8°C
12	Crampton (2012)	10	*Condition 1:* 30 min *Condition 2:* 30 min	15 ˚C 8 ˚C	Waist Waist	C C	30 min, seated, room temperature 20°C	G	EndEx EndRec PostRec: 5 min	5 min	20°C	38.0°C
13	Halson et al., (2008)	11	3 min (3x 1 min in ;2min out)	11 ˚C	Neck	I	9 min, seated, room temperature 24°C	R	EndEx EndRec	20 min	24°C	39.6°C

CWI = cold water immersion, CON = control, C = continuous, I = intermittent Tc = core temperature, EndEx = immediately post-exercise, Rec0 = start of recovery intervention EndRec = immediately post-recovery, PostRec = post-recovery intervention, R = Rectal temperature, G = Gastrointestinal temperature.

Table 2: Participant characteristic in each study; mean ± standard deviation.

Study #	**Reference**	**Height (cm)**	**Body Mass (kg)**	**Age (yrs)**	**$VO_{2\,max}$ (ml.kg^{-1}.min^{-1})**
1	Peiffer et al.,(2009)	181.0±6.0	77.9±6.6	27.0±7.0	61.7±5.0
2	Peiffer et al., (2009)	178.8±5.4	77.1±6.5	29.3±3.0	64.0±5.7
3	Peiffer et al., (2010a)	182.6±7.0	80.3±9.7	n/a	n/a
4	Stephens et al., (2017)	181.9±7.9	78.7±9.6	32.1±7.5	59.7±6.2
5	Minett et al., (2014)	183.0±7.0	78.7±8.1	21.0±2.0	n/a
6	Vaile et al., (2008)	181.3±4.6	76.4±7.1	32.8±3.8	69.9±4.8
7	Pointon et al.,(2012)	179.6±3.8	78.9±6.3	19.9±1.1	n/a
8	Vaile et al., (2008b)	176.6±4.5	68.8±7.2	32.2±4.3	68.8±3.6
9	Dunne et al., (2013)	177.0±5.0	68.0±5.0	29.0±7.0	62.1±5.0
10	Stephens et al., (2017b)	181.7±7.5	83.2±11.9	32.7±7.9	55.8±7.9
11	Versey (2012)	177.2±5.3	74.3±8.4	29.9±5.6	62.0±5.2
12	Crampton (2012)	184.0±5.0	86.0±86.0	26.0±5.0	54.6±7.4
13	Halson et al., (2008)	182.2±4.2	72.1±4.0	23.8±1.6	71.3±1.2

n/a = information not available, $VO_{2\,max}$ = volume of oxygen consumption at maximum exertion