TITLE

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) recovery protocols compared with control (CON), on the magnitude and time-course of core temperature (T_c) responses.

Methods

Pooled analyses were undertaken using raw data from 13 previous studies reporting T_c changes in response to post-exercise CWI compared to a passive CON condition. CWI protocols varied across the 13 studies; ten studies utilised a continuous protocol and three utilised intermittent protocols. Besides these differing modes, studies incorporated seven different temperatures, eight durations, and three immersion-depths. To accommodate these difference, T_c was calculated in the current model as a double difference ($\Delta\Delta T_c$), calculated as the change in T_c in the CWI condition minus the corresponding difference under the control condition. The effect of CWI treatment on $\Delta\Delta T_c$ was assessed using separate linear mixed models across two time components. The first component examined the change in T_c between the end of exercise and the end of the CWI/CON recovery intervention (Component 1: immersion). The second component examined the post-CWI change only and is defined as the difference in T_c between the end of the CWI/CON recovery intervention and each of the available post-recovery time-points (Component 2: post-recovery).

Results

Intermittent CWI protocols resulted in a decrease in $\Delta\Delta T_c$ that was 0.248±0.097°C (estimate ± SE) greater than continuous protocols during the immersion component (P=0.022), and also tended to be greater (0.141±0.097°C, P=0.150, NS) during the post-recovery component. There was a significant effect of CWI temperature during the immersion component (P=0.050), where a decrease in water temperature of 1°C resulted in a decrease in $\Delta\Delta T_c$ of 0.025±0.012°C. Similarly, the effect of CWI duration was significant during the immersion component (P=0.009), where every 1 min of immersion resulted in a decrease in $\Delta\Delta T_c$ of 0.018±0.006°C. Immersion temperature and time did not have a significant effect on $\Delta\Delta T_c$ during the post-recovery component; however, the offset between the end of exercise and start of immersion did have a significant effect where every 1 min of time between exercise and immersion resulted in an increase in $\Delta\Delta T_c$ of 0.011±0.004°C (P=0.002). The peak difference in T_c between the CWI and CON interventions during the post-immersion component occurred at 60 min post-recovery.

Conclusion

Variations in CWI protocols, particularly immersion exposure mode, duration and temperature, have a significant effect on the extent of change in T_c. Therefore, careful consideration should be given to determine the optimal amount of cooling before deciding which combination of protocol factors to prescribe when using cold water immersion for post-exercise recovery.

INTRODUCTION

Cold water immersion (CWI) is a widely practiced recovery modality which aims to reduce fatigue and facilitate post-exercise recovery (9). 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, 9). These physiological changes are believed to be the catalyst for the enhanced recovery of physical performance. While there is increasing evidence to support the notion that CWI enhances both short and long term performance recovery, there are also several studies that have shown CWI to have either a negligible or detrimental effect on performance (9, 13, 25). With consideration, it may be that CWI is not suitable for all post-exercise contexts, and the exercise mode performed prior to immersion is proposed to be a key factor influencing the effectiveness of CWI for recovery (25). Endurance based performance has been shown to be most responsive to CWI; however, there is still considerable variability across studies assessing endurance performance (9, 25). 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 (18, 28-30), others observed a decrease in time-trial performance over the same time frame (2, 16). The factors responsible for this large variation in findings across the current literature are unclear, and as such there is significant debate as to the true efficacy of CWI as a recovery strategy (9, 25).

Variation in the physiological and performance recovery responses to CWI are likely to depend on the protocol utilised and the degree of cooling that is able to be achieved (25). 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 (6). Conversely, too much cooling may lead to a reduction in muscle contractile force (12). Currently the CWI protocols utilised in practise vary in terms of the water temperature, duration, depth and mode of immersion, and the optimal combination of these factors remains unknown (11, 12, 25). The interaction between each of these protocol factors is complex and previous research has shown the same degree of core temperature (T_c) change (0.4°C) in response to different CWI protocols (5 min, 14°C, whole body immersion (17) vs. 5 min, 10°C, leg only immersion (23)). 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/the 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 immersions in water temperatures between 11-15°C for 11-15 min are optimal for reducing muscle soreness (12); however, …

the most effective approach for inducing reductions in T_c remains unknown and further research is required to understand how each factor contributes to T_c change (25).

With previous research showing that the change in T_c is related to a change in performance (24, 30), it is important to gain a greater understanding of T_c responses as it will enable protocols to be optimized 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-recovery.

METHODS

Study Design

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

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 a seated passive control condition, 3) CWI was performed post-exercise, 4) measured T_c via rectal thermometer or telemetric pill sensor, and 5) exercise resulted in a significant increase in the mean T_c (≥38.0°C). Studies with missing data or without T_c measures immediately post-exercise and/or post-recovery were excluded (Figure 1). There were no specific criteria for type of exercise utilised, however all included studies examined cycling. Of the 13 studies included in the analysis, eight are published (5, 8, 14-16, 18, 20, 29), and therefore some aspects of the pooled data have been previously reported.

**** Table 1 about here****

**** Figure 1 about here****

Participants

De-identified data from 157 trained males who participated in one of the 13 studies were extracted from our original raw data. Participants across all studies were classified as well-trained with 94 being described as predominantly participating in cycling or triathlon, 29 as team sports, leaving 36 with an unspecified sporting background.

****Table 2 about here****

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 the 13 studies included, nine studies used just one CWI protocol (8, 14, 15, 18, 20, 24, 29, 31), two studies used two protocols (3, 5), one study included three protocols (16), and another study used four different protocols (Vaile unpublished) 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 (4). The offset 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 (T_c)

T_c was either measured by rectal thermometer (8, 15, 16, 18, 24, 29, 31) or by sensor telemetry (3, 5, 14, 20). 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 (8, 14) 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 assessment of post-recovery temperature responses. 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-recovery) considered the $\Delta\Delta T_c$ changes following the recovery treatment. For each component, a respective linear mixed model was used with included CWI protocols (combination of duration, temperature, depth and mode). The offset from the end of exercise to the start of the CWI treatment was deemed as a fixed effect 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 as time post-recovery increased. 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 package (33) available in R (27).

RESULTS

Component 1 – Immersion

Intermittent CWI results in a significantly (P=0.022) greater decrease in $\Delta\Delta T_c$ 0.248±0.097°C (estimate ± SE) than that obtained with continuous CWI. The effect of CWI temperature can be described by a significant (P=0.050) linear regression with a coefficient of 0.025±0.012°C. That is, for each decrease in CWI temperature of 1°C, $\Delta\Delta T_c$ is estimated to decrease on average by 0.025°C. The effect of CWI time was highly significant (P=0.006), with a decrease of 0.018±0.006°C $\Delta\Delta T_c$ for each minute increase in CWI exposure. Neither depth (P=0.185) nor offset time (P=0.900) had a significant effect on $\Delta\Delta T_c$. The effects of CWI time, temperature and mode are illustrated in Figure 2 which gives the estimated responses for each of the 20 study-protocol combinations used in the 13 studies.

Inclusion of 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 provides an indication of the variation that was observed between the changes for individual subjects, was estimated to be 0.444°C.

****Figure 2 about here****

Component 2 – Post-recovery

The effect of offset time was highly significant (P=0.002), with an increase of 0.011°C $\Delta\Delta T_c$ for each minute increase in offset time. Further, the effect of post-recovery time was also highly significant (P<0.001) and was adequately described by a cubic regression spline. Specifcally, peak difference between CWI and CON occurred at ~60 min post immersion, following this $\Delta\Delta$Tc slowly increased until there was no impact of the intervention (Figure 2). No other variable related to water temperature, duration, mode or depth were significantly different (….),

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 0.358°C.

****Figure 3 about here****

DISCUSSION

The present study aimed to understand the effect of varying the temperature, duration, depth and mode of CWI protocols on Tc, and to identify the ensuing time-course T_c response based on these post-exercise CWI protocol variations. The main findings were: 1) that intermittent protocols resulted in a significantly greater decrement in T_c compared to continuous protocols for the T_c change during immersion; 2) decreasing water temperature and increasing duration of CWI had a significant effect to decrease $\Delta\Delta T_c$ 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 T_c between CON and CWI protocols occurred at ~60 min post-recovery, irrespective of protocol mode/type/thing…!.

Protocols utilised by athletes for post-exercise CWI vary (11, 25), and whilst CWI is widely utilised by athletes there remains a lack of consensus as to the best protocols for different sport/athlete scenarios (12). Accordingly, the present study combined the data from a range of studies representing a range protocols currently utilised to determine the optimal combination and interaction of factors on the change in Tc. 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 in response to intermittent CWI is 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 blood flow increases when the participant moves out of the pool after a period of cold-induced vasoconstriction and ischemia which occurs during immersion (32). Furthermore, it is likely that the frequent change in temperature led to a greater shivering response, increasing muscle blood flow (26). This theory is supported by the findings of Romet (21) and Seo, Kim, Ryan, Gunstad, Glickman and Muller (22) 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 central circulation. However, as only three studies utilised intermittent protocols the conclusions which can be drawn from these data need to be confirmed by future research.

Often the duration and depth of CWI and determined by the water temperature based on athlete tolerance; thus 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 (12), the way these factors interact with each other and which factor has the greatest impact on T_c responses remains unknown (25). Both temperature and duration were found to have a highly significant impact on $\Delta\Delta T_c$. The current study found that CWI led to a decrease in $\Delta\Delta T_c$ of 0.025°C for every 1°C decrease in water temperature, and that CWI time led to a reduction in $\Delta\Delta T_c$ of 0.018°C for every 1 min increase in exposure. 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. Depth of immersion was not significant and highly confounded by the other protocol factors. Increasing depth of immersion is believed to enhance responses to CWI by increasing hydrostatic pressure as well as providing a greater body surface area for thermal exchange via convection to occur (25). 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 (10). 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 (25). 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 at 60 min post-recovery (Figure 1), this novel finding highlights the importance of advising athletes to avoid a hot shower post-immersion when decreasing T_c is the goal of recovery. 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 in response to post-exercise CWI may have practical implications for repeat performance and should be considered when prescribing CWI protocols. It is hypothesised that the optimal protocol parameters will vary depending on the recovery needs of the athlete, which will be determined by the specific type of exercise induced fatigue (e.g. central nervous system fatigue, cardiovascular fatigue, etc.), the time-frame available and the type of performance (e.g. endurance vs sprint) required (9, 25). It is important to consider the type of exercise to be performed, the time-frame available and the environmental conditions (7, 9). For example, performing CWI during a short time-frame between endurance tasks may provide precooling 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 (11, 25).

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. The residual standard deviations were estimated to be 0.444°C and 0.358°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 study 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, gender and ethnicity) also impact responses and may explain much of the variation that is observed across the current literature. The large number of factors which impact the response makes trying to predict the optimal "dose" of CWI quite difficult, especially when many combinations of these 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 the T_c response.

PRACTICAL RECCOMENDATIONS

- Before prescribing a CWI protocol it is important to determine how much 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.

ACKNOWLEDGEMENTS

The authors would like to thank all of the researchers who contributed to each of the studies utilised in this study. The authors would like to acknowledge Dr. Andrew Govus for his assistance in the early stages of planning this study. This investigation was supported by funding from the University of the Sunshine Coast Faculty HDR research grant. The authors declare that there are no conflicts of interest in undertaking this study.

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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)	Published (Yes/No)
			CWI duration	**CWI temperature**	**CWI depth**	**CWI mode**					
1	Peiffer, et al. (16)	12		*Condition 1:*			20 min, seated, room temperature 24°C	Rectal	EndEx EndRec PostRec: 5, 10, 20, 30, 40min	25 min	Yes
			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. (15)	8	20 min	14 ˚C	Chest	C	20 min, seated, room temperature 24°C	Rectal	EndEx EndRec PostRec: 5, 10, 20, 30, 40min	7.5 min	Yes
3	Peiffer, et al. (18)	10	5 min	14 ˚C	Chest	C	15 min, seated room temperature 35°C	Rectal	EndEx EndRec PostRec: 5 min	5 min	Yes
4	Stephens (24) (Chapter 6)	20	15 min	15 ˚C	Neck	C	15 min, seated, room temperature 25°C	Rectal	EndEx EndRec PostRec: 10, 20, 30, 40min	15 min	No
5	Minett, et al.	9	20 min	10 ˚C	Chest	C	20 min,	Sensor	EndEx	10 min	Yes

	(14)						seated, room temperature 32°C		EndRec		
6	Vaile (unpublished)	12		*Condition 1:*			14 min, seated, room temperature unknown	Rectal	EndEx	0 min	No
			5 min (5x 1 min in;2 min out)	10 ˚C	Neck	I			EndRec PostRec: 40 min		
				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	Pointon, et al. (19)	8	18 min (2x 9 min in; 1min out)	18 ˚C	Waist	I	20 min, seated, room temperature 32°C	Sensor	EndEx EndRec 120 min Post	10 min	Yes
8	Vaile, et al. (29)	12	14 min	15 ˚C	Neck	C	14 min, seated, room temperature not reported	Rectal	EndEx EndRec 15 min Post	0 min	Yes
9	Dunne, et al.	9		*Condition 1:*			15 min,	Sensor	EndEx	5 min	Yes

	(5)		15 min 15 min	15 ˚C *Condition 2:* 8 ˚C	Waist Waist	C C	seated, room temperature 18°C		EndRec PostRec: 5 min		
10	Stephens (24) (Chapter 5)	27	15 min	15 ˚C	Neck	C	15 min, seated, room temperature 25°C	Rectal	EndEx EndRec PostRec: 5, 30, 60, 90, 120, 150, 180, 210, 240 min	15 min	No
11	Versey (31)	9	14 min	15 ˚C	Neck	C	14 min, seated, room temperature 21°C	Rectal	EndEx EndRec PostRec: 5, 30, 60, 90 min	15 min	No
12	Crampton (3)	10	 30 min 30 min	*Condition 1:* 15 ˚C *Condition 2:* 8 ˚C	 Waist Waist	 C C	30 min, seated, room temperature 20°C	Sensor	EndEx EndRec PostRec: 5 min	5 min	No
13	Halson, et al. (8)	11	3 min (3x 1 min in ;2min out)	11 ˚C	Neck	I	9 min, seated, room temperature 24°C	Rectal	EndEx EndRec	20 min	Yes

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

Table 2: Mean participant characteristic in each study

Study number	Reference	Height (cm)	Weight (cm)	Age (yrs)	$VO_{2\,max}$ (ml.kg.min^{-1})
1	Peiffer (16)	181.0±6.0	77.9±6.6	27.0±7.0	61.7±5.0
2	Peiffer (15)	178.8±5.4	77.1±6.5	29.3±3.0	64.0±5.7
3	Peiffer (18)	182.6±7.0	80.3±9.7	n/a	n/a
4	Stephens (24)	181.9±7.9	78.7±9.6	32.1±7.5	59.7±6.2
5	Minett (14)	183.0±7.0	78.7±8.1	21.0±2.0	n/a
6	Vaile (unpublished)	181.3±4.6	76.4±7.1	32.8±3.8	69.9±4.8
7	Pointon (19)	179.6±3.8	78.9±6.3	19.9±1.1	n/a
8	Vaile (29)	176.6±4.5	68.8±7.2	32.2±4.3	68.8±3.6
9	Dunne (5)	177.0±5.0	68.0±5.0	29.0±7.0	62.1±5.0
10	Stephens (24)	181.7±7.5	83.2±11.9	32.7±7.9	55.8±7.9
11	Versey (31)	177.2±5.3	74.3±8.4	29.9±5.6	62.0±5.2
12	Crampton (3)	184.0±5.0	86.0±86.0	26.0±5.0	54.6±7.4
13	Halson (8)	182.2±4.2	72.1±4.0	23.8±1.6	71.3±1.2

n/a = information not available

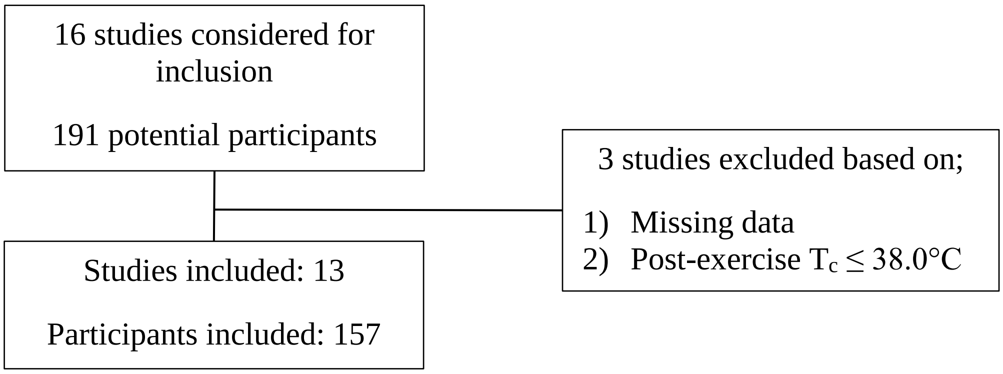

Figure 1: Flow chart on all relevant cold water immersion studies performed in our laboratories and the reason for exclusion

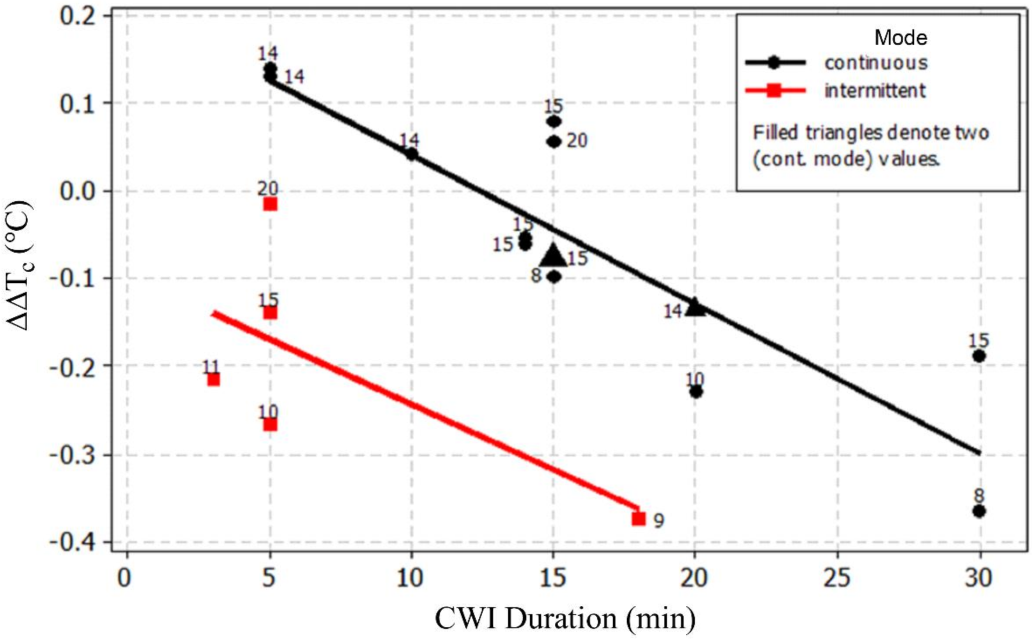

Figure 2: Estimated responses for each of the 20 study-protocol combinations used in the 13 studies. Numbers next to data points = water temperature. $\Delta\Delta T_c$ = Change in T_c in CWI condition minus change in T_c in CON condition

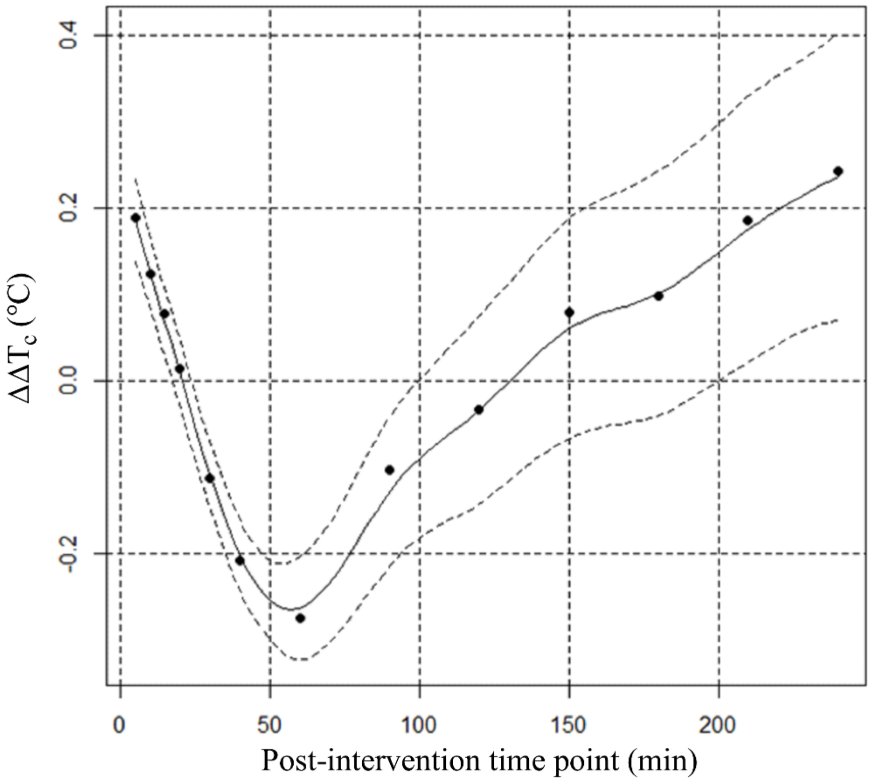

Figure 3: Parameter estimates and fitted spline with 95% confidence limits for the change in T_c from end of intervention to each of the post-intervention time points. $\Delta\Delta T_c$ = Change in T_c in CWI condition minus change in T_c in CON condition