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Article Title: Cold Water Immersion for Athletic Recovery: One Size Does Not Fit All

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Cold water immersion for athletic recovery: one size does not fit all.

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The use of cold water immersion (CWI) for post-exercise recovery has become increasingly prevalent in recent years, however there is a dearth of strong scientific evidence to support the optimisation of protocols for performance benefits. While the increase in practice and popularity of CWI has led to multiple studies and reviews in the area of water immersion, this research has predominantly focused on performance outcomes associated with post-exercise CWI. Studies to date have generally shown positive results with enhanced recovery of performance. However, there are a small number of studies which have shown CWI to have either no effect or a detrimental effect on the recovery of performance. The rationale for such contradictory responses has received little attention but may be related to nuances associated with the individual which may need to be accounted for in optimising prescription of protocols. In order to recommend optimal protocols to enhance athletic recovery, research must provide a greater understanding of the physiology underpinning performance change and the factors which may contribute to the varied responses currently observed. This review focuses specifically on why some of the current literature may show variability and disparity in the effectiveness of CWI for recovery of athletic performance by examining the body temperature and cardiovascular responses underpinning CWI and how these are related to performance benefits. This review also examines how individual characteristics (such as physique traits), differences in water immersion protocol (depth, duration, temperature) and exercise type (endurance vs maximal) interact with these mechanisms.

Keywords: Hydrotherapy, Body Composition, Performance, Physiology

Introduction

Recovery interventions have become an integral part of most athletes' training programs. Adequate recovery enables physiological and psychological functioning to be restored, minimising the effects of fatigue and allowing athletes to train and compete optimally.[1] Many strategies are utilised to enhance the recovery process, including, but not limited to, active recovery, stretching, massage, sleep, compression, and hydrotherapy.[1] Hydrotherapy is the broad term encompassing cold water immersion (CWI), hot water immersion, contrast water therapy and thermoneutral water immersion. CWI is a popular recovery strategy[2] and there is a growing body of evidence supporting its use.[3] Research has indicated that CWI is useful for maintaining repeat performance in hot environments by reducing thermal strain,[3-5] reducing muscle soreness, and aiding recovery from secondary muscle damage[6-8] which may occur following repetitive high intensity exercise and team sports.[5,9,10] CWI has also been shown to be beneficial to perceptions of recovery.[11] Conversely, some studies have shown CWI to have no benefit[12-15] or detrimental effects on performance recovery.[16,17] This highlights the need to better understand the physiological mechanisms responsible for performance changes, an area that has received limited attention to date.[18]

It is hypothesised that CWI instigates physiological changes via hydrostatic pressure, redistribution of blood flow and reductions in core- and tissue temperatures.[19] There is evidence that CWI reduces thermal strain, swelling, inflammation, limb blood flow, muscle spasm and pain.[20] However, the exact thermal and cardiovascular responses to post-exercise CWI remain to be fully elucidated. The effect of CWI and the ability to understand the underlying physiological mechanism/s is determined in part by the immersion protocol utilised. Optimal protocol parameters will likely differ depending upon the outcome of interest and the specific recovery needs, which are determined by the specific perturbations caused by prior exercise and also the time-frame available before subsequent performance is required. Current CWI protocols vary and there is a lack of understanding surrounding optimal duration, temperature, immersion depth and the number/frequency of immersions. CWI interventions with favourable outcomes tend to be performed in water between 10 ˚C and 20 ˚C, for 5-15 min for a single immersion protocol or 1-5 min per immersion for multiple immersions.[11] CWI performed to the level of the hips or shoulders has shown more beneficial performance outcomes than limb only immersion.[14,21]

Physiological responses to CWI will also depend on individual characteristics of the athlete/participant, for example their physique traits, yet there has been little regard for individual characteristics in the literature. Understanding the impact of hydrotherapy on all types of performance and the reasons some individuals have positive outcomes whilst others do not relies on an improved understanding of physiological changes associated with successful performance recovery.[3] A greater understanding of the physiology behind CWI, the recovery needs of different performance types (e.g. endurance vs sprint) and the factors impacting them will assist in developing individualised CWI protocols likely to maximise performance benefits.[3] This review will examine thermal and cardiovascular responses underpinning performance recovery benefits of CWI, and will explore how differences in individual characteristics and variance in protocols may influence the physiological and performance responses.

Performance Effects

The ultimate goal of using CWI is to enhance subsequent performance, however as already highlighted, research to date has shown significant variability. One factor likely contributing to this variance is the different exercise protocols utilised. Performance measures utilised in the current literature vary and can be broadly categorised as whole body endurance performance or explosive maximal performance (which includes local muscle function and sprint tests). The differing physiological demands of these exercise modalities result in different effects on recovery, due to the associated mechanisms of fatigue, and therefore studies of each exercise type should be considered independently. While the precise mechanisms of fatigue associated with endurance performance remain widely debated,[22] one may postulate that CWI assists recovery through the effects of cold temperature reducing thermoregulatory fatigue. Studies by Vaile, et al.[3] (CWI duration:15 min; CWI Temp:15 ˚C), Vaile, et al.[23] (5 x 1 min; 10 ˚C, 15 ˚C & 20 ˚C and 15 min; 20 ˚C), Vaile, et al.[5] (14 min; 15 °C) and Peiffer, et al.[4] (5 min; 14 ˚C) found CWI enabled the maintenance of cycling time trial (TT) performance in the heat in a subsequent bout performed between 40 and 155 min post-CWI and across subsequent days.[3,5,23] In contrast, Peiffer, et al.[24] and Buchheit, et al.[25] found CWI (5 min; 14 ˚C and 10 ˚C respectively) had no significant effect on 1 km cycling TT performance in the heat. The variability in results across these studies highlights the fact that CWI may be more effective for longer duration, endurance type exercise. The studies which found performance benefits employed a cycling TT between 5 and 15 min[3-5,23] whereas the 1 km TT utilised by the studies showing negligible results[24,25] only took 1-2 min to complete, akin to a sprint effort. It has been suggested CWI is ineffective for high intensity exercise of short durations due to 1) the lack of thermal strain from the initial bout and 2) the enhanced parasympathetic re-activation which may impact muscular contractions through the effects on oxygen consumption and glucose metabolism.[18]

Muscle function has been shown to be reduced in response to an acute exercise bout involving eccentric, high intensity or prolonged duration exercise.[26] This has led to the investigation of the impact of CWI on the recovery of muscle function using tests such as maximal voluntary isometric contractions (MVIC), jumps, and sprints. While the mechanisms of fatigue associated with such tests differ to endurance performance, there is still a similar spread of mixed results across studies that have tested CWI. MVIC force was found to be significantly greater at 24 h post-exercise with CWI (10 min; 10 ˚C) compared to TWI.[9] Similarly, the decrement in MVIC was reduced following post-exercise CWI (2 x 5 min; 10 ˚C) and a faster return to baseline was observed compared to control.[27] Conversely, CWI did not assist recovery of MVIC of the knee extensors compared to a placebo TWI.[28] Recovery of jump performance following CWI has shown more positive results indicating that CWI may be more effective for recovery of stretch-shortening cycle (SSC) movements rather than isolated concentric movements (e.g. MVIC).[26] This is supported by White, et al.[26] who found CWI (10 min; 10 ˚C) reduced the decrement in drop jump height and enabled a faster return to baseline compared to control following a running high intensity interval training session. In the same study, recovery of squat jump height following CWI was not significantly different than control at any time point.

Sprint performance has shown a greater tendency towards being negatively influenced by CWI. Although it has been found that CWI (5 x 1 min; 11 ˚C) enabled 20 m sprint performance to be better maintained,[10] negligible effects have also been shown as CWI (10 min; 10 ˚C and 2 x 5 min; 10-12 ˚C) was found to have no significant effect on recovery of 10-20 m sprint running performance.[6,29] Sprint cycling performance has also shown mostly negative results with reductions in power following CWI observed across multiple studies.[16,17,30] Sprint cycling performance was re-assessed between 5 and 35 minutes post-CWI in the aforementioned studies, therefore it may be possible that the short time-frame led to participants being required to perform before muscle tissue had re-warmed. With muscle temperature being an important determinant of muscular power and sprint performance[31,32] it is likely that the negative results observed are due to the muscle being cold from the CWI when the performance task was undertaken, therefore careful consideration of the timeframe between immersion and sprint performance is required.

Summary of Performance Effects

Current literature shows significant variability in the effectiveness of CWI on performance recovery. The type of exercise performed is a critical factor contributing to the variation and it is hypothesised that endurance and SSC exercise will be more responsive to CWI than isolated concentric exercises. However, there is still considerable variance in the recovery of endurance and SSC performance across current literature. Part of this variability may be related to the time-frame utilised by current research, particularly when maximal explosive performance is required shortly after CWI. Nevertheless, there remains a need to understand the physiological responses to CWI and how these responses are influenced by the characteristics of the exercise stress.

Thermal and cardiovascular responses to cold water immersion

CWI stimulates a number of thermal and cardiovascular responses that may contribute to the enhancement of performance recovery. Studies to date have focused mainly on body temperature, cardiac and haemodynamic responses to CWI at rest and following exercise. While understanding the impact of CWI on basal physiological responses provides some insight into the mechanisms by which CWI may be effective, it is perhaps most important to understand how these physiological responses might differ following exercise. This section examines the effect of CWI performed both at rest and post-exercise on body temperature, cardiovascular dynamics and blood flow.

Skin Temperature (T_{sk})

Skin is the first site to respond to cold exposure and is responsible for initiating thermoregulatory responses resulting in core temperature (T_c) and muscle temperature (T_m) change. T_{sk} is significantly reduced during and following CWI without prior exercise and post-exercise CWI. Immediately following CWI without prior exercise, reductions of between 7 ˚C and 14 ˚C have been observed.[33,34] Similar reductions in T_{sk} of between 6 ˚C and

18 °C have been observed following post-exercise CWI. The extended post-CWI change in T_{sk} has only been examined for 30-40 min post-CWI,[35,36] and while significant reductions were found at this time point the full time-course of this "after-drop" and its impact on performance recovery remains unknown. However, it is likely that a lower T_{sk} at the commencement of subsequent performance will enable athletes to perform at higher work outputs for longer as increases in T_{sk} signal the thermoregulatory responses that limit work outputs to prevent the body reaching a critical T_c.[22]

Muscle Temperature (T_m)

CWI has been shown to reduce T_m, however the magnitude of this reduction varies significantly.[24,34,37,38] There is currently limited evidence with different T_m measurement and CWI methodologies making it difficult to determine the true impact of CWI on T_m. The variability in responses is highlighted when examining studies which have utilised the same post-exercise CWI protocol (5min; 14 °C), but have shown vastly different results with a decrease of 2.5 °C and a decrease of 0.4 °C in T_m.[24,37] While both studies utilised the same T_m measurement protocol (3cm into the rectus femoris) and the same CWI protocol, differences existed in the time frame between the end of exercise and the start of CWI (25 min[37] vs 7.5 min[24]) which likely contributed to the differences in T_m at the commencement of CWI (37.8 °C[37] vs 37.0 °C[24]). This difference in temperature would have potentially had an impact on the temperature gradient between the water and the muscle which may contribute in part to the variability between studies. Variability of responses is also evident following longer duration CWI protocols (10 min; 8 °C and 22 °C), with decrements of between 0.2 °C and 4.0 °C observed.[34,38] However the variability between these studies is likely due to differences in the pre-immersion state of the participants as Mawhinney, et al.[38] utilised a post-exercise study design whereas Gregson, et al.[34] performed CWI without prior exercise, which again would likely have impacted the thermal graident.

The time-course of post-CWI changes is also variable, with decrements of between 1.0 and 7.9 °C observed 15-30 min post-CWI.[34,38,39] Given the relationship between T_m and muscle contractile performance,[32] it is important to further examine the time-course and impact of post-exercise CWI on T_m to avoid detrimental effects and optimize beneficial performance effects.

Core Temperature (T_c)

T_c is significantly reduced immediately post-CWI performed without prior exercise and post-exercise.[40] The extent and time-course of this reduction is varied, and with inconsistencies in study methodologies it is difficult to determine exactly how CWI impacts T_c and subsequent performance. When comparing studies matched for protocol, variability in the immediate post-CWI (5 min; 14 °C) responses become obvious with changes of -0.4 °C,[4] +0.4 °C,[24] and -0.3 °C[37] observed. The small changes in T_c observed during short duration CWI (5 min) may be related to the initial re-distribution of warm blood from the periphery to the core which enables the preservation of T_c. Furthermore, it is likely that such a short exposure to the CWI stimulus does not sufficiently impact tissue temperature and blood flow thus the potential beneficial effects of a 5 min CWI may be minimal.

However, the varied T_c response has also been shown to persist for up to 90 min[40] post-CWI with decrements ranging from 0.1 °C to 2.3 °C at 30 min post-immersion regardless of the duration of CWI (5-20 min). T_c has not been examined beyond 90 min post-CWI and therefore the full time-course of the change and recovery remains unknown. As with T_{sk}, T_c at the commencement of subsequent performance can potentially have a "pre-cooling" effect and enhance the athlete's heat storage capacity, therefore enabling more work to be performed before reaching a critical T_c.[41] Future studies should focus on determining the exact degree of change in T_c that leads to an optimal "pre-cooling" effect for subsequent performance and how to induce this change across individual athletes/participants.

Cardiovascular Dynamics

Increases in hydrostatic pressure with water immersion cause venous and lymphatic compression.[19] Venous return is sensitive to external pressure and when hydrostatic pressure exceeds venous pressure, blood flow is redirected from peripheral to central areas. This redistribution of blood flow leads to an increased central blood volume (CBV) of 1.9 ± 0.5 L, which has been shown to increase right atrial pressure and pulmonary arterial pressure.[42] This stimulates an increase in cardiac contractility and results in an increased stroke volume (SV) of up to 110 ± 2.4 ml.[43] Similar increases in cardiac output (Q) of up to 30 % are observed during thermoneutral immersion.[42]

There have been limited studies of the effect of CWI on cardiac dynamics, and our understanding is somewhat guided by investigations of cold exposure. Cold temperatures can activate shivering thermogenesis, which increases venous return via the activation of muscle pump activity, although this does not always occur.[44] Cold exposure also increases sympathetic activity, and the resultant peripheral vasoconstriction facilitates redistribution of blood increasing CBV. These vascular changes contribute to increases in SV, Q, total peripheral resistance and blood pressure.[42,43,45] Indeed, a significant increase in Q and SV following CWI (15 min; 15 °C) performed at rest has been reported.[45] While these specific cardiac responses have not been assessed in response to post-exercise CWI, it is likely any such improvements in cardiac output would enhance oxygen delivery and the recovery of aerobic performance.

Limb, Skin and Muscle Blood Flow

Consistent with the notion that cold exposure induces peripheral vasoconstriction, most studies have observed reductions in limb blood flow during and following CWI. Femoral artery vascular conductance is reduced by 75 % following post-exercise CWI, and 30 % following CWI without prior exercise.[34] One might conclude that the reduction in vascular conductance, which is reflective of vessel diameter, indicates the occurance of vasoconstriction following CWI performed post-exercise and at rest.[34,38] Leg blood flow responses following CWI without prior exercise have found CWI (20 min; 13 °C) to have no acute effect on leg blood flow.[46] Whereas Vaile, et al.[3] found significant reductions in blood flow to the arm and leg from 5-40 min following post-exercise CWI (15 min; 15 °C). Large increases in the leg-to-arm blood flow ratio were also reported, which were taken to reflect a greater reduction in skin flow than muscle flow, and these changes were correlated with the magnitude of the fall in T_c with CWI.

To understand the significance of these blood flow changes it is important to assess blood flow to the skin and muscle. The effect of CWI (10 min; 8 and 22 °C) on skin blood flow has only been examined by two previous studies. It was found that regardless of the pre-immersion state (rested or post-exercise), a significant reduction in cutaneous vascular conductance of the thigh occurs. This significant reduction was shown to persist from 1 min post-CWI until 30 min post-CWI.[34,38]

There have been no direct assessments of muscle blood flow in response to CWI. Muscle tissue oxygenation, measured by near infrared spectroscopy, is dependent on metabolic activity and blood perfusion, and was found to be attenuated following post-exercise CWI (15 min; 10 °C).[47] This lends some support to the notion that CWI reduces intramuscular metabolism, although the direct effect on muscle perfusion cannot be determined. Reductions in muscle temperature might be expected to reduce blood flow (perfusion), muscle metabolism, inflammation and oedema.[39,47] Conversely vasoconstriction of the skin, as evidence by a reduction in skin blood flow with CWI, might enhance the distribution of blood towards working muscles during subsequent performance. Further studies including direct investigations of limb, skin and muscle blood flow in response to

CWI are required to better understand the influence of blood flow changes on performance recovery.

Summary of Thermal and Cardiovascular Effects

Both resting and post-exercise CWI cause significant thermal and cardiovascular changes to occur. The magnitude and time-course of these thermal and cardiovascular changes are varied making it difficult to determine the true physiological effect of CWI. Much of this variability is likely related to the disparity in immersion protocols, pre-immersion state of the athlete/participant and individual differences. These variable physiological responses to CWI are likely the cause of the variation in performance recovery.

Water Immersion Protocols

Physiological and performance variation is dependent (in part) on the "dose" of cooling provided by CWI.[39] No "gold standard" currently exists for CWI and protocols tend to be based on those used practically without strong efficacy or physiological evidence.[39,48]

Temperature

Water is an effective conductor causing heat exchange to occur 25 times faster than air,[44] placing significant thermal stress on the body. Water temperature has an impact on the duration and level of immersion utilised as colder temperatures induce a greater initial "cold shock", increasing discomfort and, possibly limiting exposure to CWI. The impact of water temperature was examined by comparing CWI in 8 and 22 °C,[34,38] and unsurprisingly 8 °C resulted in a larger decrement in T_c. Water temperatures of between 10 °C and 15 °C appear to be optimal for performance recovery,[31,49] however if these temperatures are not achievable in a practical setting similar thermal responses may be induced by altering immersion duration or depth.

Duration

Duration of immersion is likely to impact the cooling induced by CWI, with a longer exposure to the cold stimulus resulting in a greater thermal effect. CWI durations of 10-20 min have been suggested as optimal for performance recovery, as anything shorter may not cause sufficient tissue temperature change.[39] However, duration should be explored in conjunction with water temperature, as colder temperatures will have a greater thermal stress and therefore cause tissue temperature to decrease at a faster rate. The impact of immersion duration is evident after examining responses when participants completed CWI to the mid-sternum at 14 °C for 5, 10 and 20 min.[37] Pre-immersion T_m was 38.8 °C for all trials and immediate post-immersion decrements of 2.5 °C (5 min), 4.0 °C (10 min) and 6.0 °C (20 min) were observed. T_c showed similar effects for immersion duration, with a pre-immersion T_c of 38.8 °C for all trials and immediate post-immersion decrements of 0.3 °C (5 min), 0.6 °C (10 min) and 1.0 °C (20 min) were observed. This response continued into the post-recovery period with T_c at 30 min post-immersion showing reductions of 1.3 °C (5 min), 1.5 °C (10 min) and 2.3 °C (20 min).

Depth of Immersion

The level of immersion affect thermal and physiological responses in two ways; firstly if more of the body is exposed there will be greater surface area for heat exchange to occur; secondly, the deeper the immersion, the greater the impact of hydrostatic pressure.[19] The influence of immersion depth becomes evident when comparing studies that utilised similar CWI protocols (15 min; 15 °C), differing only in immersion depth[3,30]. Immediately post-CWI Vaile, et al.[3] (whole body immersion) observed a decrement in T_c of 1.3 °C whereas Crampton, et al.[30] (leg immersion) only observed a decrement of 0.4 °C. Less surface area exposed to the cold stimulus may result in smaller T_c changes. A comparison of two studies with different CWI protocols (5 min, 14 °C, whole body immersion[24] and; 5 min, 10

°C, legs only[50]), that found the same immediate post-immersion T_c change (0.4 °C) show that different protocol combinations can have the same impact. So while one study had a greater surface area exposed to the cold stimulus, the other utilised a lower water temperature leading both studies to result in the same degree of T_c change.

Summary of Water Immersion Protocols

Water temperature, plus the duration and depth of immersion all significantly impact the magnitude and rate of cooling in response to CWI. The interaction between each of these factors is complex and while it has been shown that different combinations of these three factors can result in the same degree of T_c change,[24,50] it is unknown whether duration, temperature or depth will have the greatest impact upon thermal and cardiovascular responses. It is also unknown what the optimal combination of these factors is and further research is required to fully understand the impact of temperature, duration and depth and how they may interact with individual differences physique.

Individual Characteristics and Responses to Cold Water Immersion

Whilst some of the variability in physiological and performance responses to CWI can be explained by methodological differences or variation in water immersion protocols, there remains some variability within the literature, which indicates that individual characteristics may influence CWI responses.[51] Given the known impact of physique traits on thermoregulatory responses to cold exposure,[44] it is important to consider these traits when trying to understand the variance in the effectiveness of CWI.

Physique traits

Body Mass, Body Surface Area and Surface Area to Mass Ratio

Body surface area (BSA), body mass (BM) and body surface area to mass ratio (BSA:M) are considered to be important factors impacting one's ability to maintain thermal homeostasis.[52] BSA influences individual responses to thermal exposure as heat exchange via evaporation, convection and conduction all depend on the available surface area.[53] While BM affects the rate of heat production and heat storage, a larger BSA should theoretically cause heat exchange to be increased. However, while overweight individuals have a greater BSA than lean individuals, their rates of heat loss are comparatively lower due to greater BM.[53] The BSA:M ratio has been proposed to reflect this interaction between body trait characteristics, where a larger BSA:M facilitates heat loss and a smaller BSA:M facilitates body insulation (heat storage).[54] From thermoregulatory studies we know that the increase in metabolic rate and decrease in T_c during exposure to cold air is significantly greater in those with a higher BSA:M than in those with a lower BSA:M.[53] However, no studies to date have examined the impact of BSA:M on responses to CWI.

Body Fat

Body fat is considered one of the most important body composition factors impacting the effectiveness of CWI as it influences both heat conductivity and blood flow.[52] Body fat has a low heat conductivity providing greater insulation and thermal resistance compared to skin and muscle.[55] This insulating effect is thought to affect the magnitude and rate of T_m change as well as the rate of re-warming following cold exposure.[51] Gastrocnemius T_m was found to decrease at a slower rate during cooling in participants with high-, compared with low, subcutaneous fat, and returned towards baseline at a slower rate.[51] Additionally, significant differences in the decrease in maximum T_m were observed between groups where the decrement was greatest in those with less body fat.[51] It is interesting to note, however, that the standard deviations of the drop in 1 cm T_m ranged between 4.4 and 4.6 °C. This variance indicates the wide range of individual responses and highlights the fact that there may have been some individuals who responded more favourably than others in each of the body composition groups. Blood flow is impacted by body fat as individuals with high body fat have been shown to have a lower than average blood volume per unit weight.[52] This reduced blood volume impacts conductive heat transfer through the tissues improving the insulative capacity of individuals with greater body fat.[53] Body fat not only vary from sport to sport but even within sports we see significant differences in body fat.[56] This highlights the fact that even in the same team, athlete's body compositions may vary substantially therefore individualising CWI protocols may be warranted.

Muscle Mass

Muscle tissue has a significant impact on individual thermoregulatory responses. Indeed, vasoconstricted muscle was found to provide approximately 80 % of total body insulation during resting water immersion.[57] The depth of measurement affects T_m change, whereby deeper muscle tissue (e.g. 3cm depth) takes longer to cool and re-warm than superficial muscle sites.[51] This was supported by the finding that T_m at 1 cm decreased by 6 ˚C, whereas T_m at 3 cm only decreased by 1.5 ˚C immediately following post-exercise CWI.[38] Muscularity has been shown to impact T_c responses to exercise, particularly in hot environments, with mesomorphic participants having higher T_c and greater risk of hyperthermia.[58] Mesomorphic athletes are likely to present with higher T_c post-exercise and one might conclude that a greater dose of CWI would be necessary to account for the higher temperatures in these individuals. In contrast, it may also be concluded that the higher T_c may create a greater temperature gradient between the body and the water therefore increasing the cooling rate, which is in line with Newtons law of cooling.[59] While it is well established that muscle mass impacts upon thermal responses to both exercise and CWI, it has not yet been determined whether a greater dose of CWI is required the enhance recovery for mesomorphic athletes/participants.

Other Factors

Other individual differences such as age, gender and ethnicity also have the potential to impact the responses to CWI, and this is largely due to their relationship with body composition. Age impacts thermoregulation, this is shown by examining the young and elderly, as these groups have lower subcutaneous fat and larger BSA:M compared to adults.[44] The elderly also experience reduced responsiveness of cutaneous blood flow to cold exposure and erratic temperature regulation.[44] Subcutaneous fat and body surface area is also one of the reasons for thermoregulatory differences between genders.[44] Compared to males, females tend to have greater total body fat, thicker layers of subcutaneous fat, and BSA:M.[60] A comparison of males and females with the same body fat percentage found females cool to a greater extent, confirming the assumption that lower surface area to mass ratios of males is favourable for heat retention.[60] Female thermoregulatory responses and thermosensitivity are also influenced by the menstrual cycle, where during the luteal phase T_c and T_{sk} are higher than during the follicular phase.[44,61] Ethnicity also influences factors such as subcutaneous adipose tissue thickness, height, body surface area and mass. These genetic differences are believed to explain differences in heat conductance between African Americans and Caucasians.[62] Given the potential impact of these individual factors on responses to CWI, practitioners should give consideration to age, gender and ethnicity. CWI protocols utilised for male and female teams, for example, may need to differ in order to provide optimal benefits for each group of athletes.

Conclusion

This review demonstrates that a number of factors have the potential to impact an individual's response to CWI, and failing to recognise these in the individual prescription of CWI therapy may impact on the effectiveness of this as a recovery strategy. This review has focused on temperature and cardiovascular responses to CWI as these are likely to underpin performance changes, and are likely to also influence other outcomes including markers of inflammation and muscle damage. Future research must further investigate the physiological responses to CWI to gain an understanding of the optimal degree of change so that appropriate protocols may be determined. It is also important to further examine all factors which contribute to the variance (e.g. immersion protocol and individual characteristics). Physique traits such as body fat, muscle mass, and their regional distribution, plus body surface area to mass ratios may influence thermal and physiological responses to water immersion. These individual characteristics have been shown to impact thermal responses to temperature extremes,[63] however the impact on responses specifically to CWI remains unknown.[3,63] Before utilising CWI for both research and practical applications careful consideration should be given to: i) the time frame between CWI and performance; ii) performance variables and familiarity; iii) the water immersion protocol (i.e. temperature, duration and depth); iv) environmental conditions and degree of thermal strain the athlete/participant is under; and v) the characteristics of the individual (i.e. physique traits, gender, age and ethnicity). It is vital that these factors are considered as their potential impact on results observed may give an inappropriate indication of the true efficacy of CWI.

Practical Recommendations

Based on the evidence reviewed there is no one size-fits-all protocol for CWI and the following suggestions can be made for the determination of appropriate CWI protocols.

- The objective of recovery should be established first and where possible the cooling protocol should be specific to the desired outcome. For example, CWI being used to reduce thermal strain will likely be shorter duration than for the reduction of secondary exercise induced muscle damage.
- Consideration should be given to the subsequent exercise and the time-frame available. If whole body endurance performance is required CWI may have positive impacts due to pre-cooling effects, however if maximal efforts are required CWI may not be appropriate due to the impact of cold muscle temperature on muscle contractions.

- Body temperature at the beginning of immersion should be considered as athletes commencing the immersion with high temperatures will possess a greater thermal gradient and therefore larger thermal changes are to be expected.

- Physique traits should be considered and protocols may need to be individualised based on body fat and muscle mass to ensure optimal cooling.

- Regional and whole body composition should be assessed by an accepted technique prior to prescribing individual protocols.

- Protocols may need to be altered when dealing with both young (adolescent) and masters athletes compared to adults, as these groups may not tolerate long durations of cold water exposure.

- Male and female athletes will likely require different protocols.

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