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The Relationship between Body Composition and Thermal Responses to Hot and Cold Water Immersion

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Abstract

The current study aimed to examine the influence of body fat percentage on thermal responses to water immersion at the two temperature extremes used in athletic recovery, by comparing the thermal responses of low- and high-fat individuals to immersion in hot water (HWI) or cold water (CWI). Thirty-nine subjects completed a body composition assessment (to determine low-fat and high-fat groups), and 15 minutes of either CWI ($n = 20$) or HWI ($n = 19$), followed by 30 minutes of passive rest. Core temperature (Tc), skin temperature (Tsk), and thermal sensation (TSS) were recorded at various time points during immersion and throughout the rest period. There were no significant differences between the low- and high-fat groups during CWI; however, the low-fat group had a significantly lower Tc compared to the high-fat group at 10, 20, and 30 minutes post-CWI ($p < 0.05$). During HWI, the low-fat group had a significantly higher Tc at 5 minutes ($p < 0.05$). In the low-fat group, TSS was significantly lower at 15 minutes of CWI ($p = 0.03$) and significantly higher at 15 minutes of HWI ($p = 0.03$), relative to the high-fat group. There were no significant differences between groups for Tsk measurements. Percentage body fat affects physiological and perceptual responses to immersion in both hot and cold water. Current hydrotherapy practices may need to be individualized to ensure optimal recovery.

Keywords: hydrotherapy, recovery, body composition, core temperature, thermal sensation

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Introduction

Hydrotherapy modalities, particularly cold water immersion, have become increasingly popular for enhancing athletic recovery (Vaile, Halson, Gill, & Dawson, 2008a). There is a growing body of evidence examining the effects of hydrotherapy on performance (Versey, Halson, & Dawson, 2013), with a number of studies showing positive effects (Bailey et al., 2007; Coffey, Leveritt, & Gill, 2004; Eston & Peters, 1999; Vaile et al., 2008a; Vaile, Halson, Gill, & Dawson, 2008b; Vaile, Halson, Gill, & Dawson, 2008c; Vaile et al., 2011; Versey, Halson, & Dawson, 2011; Versey, Halson, & Dawson, 2012; Viitasalo et al., 1995), and some showing no effect or even negative effects on certain performance measures (Coffey et al., 2004; Dawson, Gow, Modra, Bishop, & Stewart, 2005; Hamlin, 2007; Paddon-Jones & Quigley, 1997; Sellwood, Brukner, Williams, Nicol, & Hinman, 2007; Yamane et al., 2006). These varied findings highlight the need to understand the possible mechanisms responsible for the change in performance (Vaile et al., 2008c).

Water immersion is believed to induce cardiac, blood flow, and temperature changes to the body through the effects of hydrostatic pressure and water temperature (Vaile, Halson, & Graham, 2010; Wilcock, Cronin, & Hing, 2006). Hydrostatic pressure is believed to initiate the displacement of body fluid to the central cavity (Wilcock et al., 2006). This displacement causes an increase in interstitial fluid transfer into the vascular space, consequently reducing exercise-induced swelling and increasing cardiac output (Wilcock et al., 2006). An increase in cardiac output leads to increased blood flow, which accelerates the removal of metabolites and waste products and facilitates delivery of oxygen and nutrients required to induce the repair of damaged tissue (Wilcock et al., 2006). Cold water temperatures are thought to cause peripheral vasoconstriction (Bleakley & Davison, 2010) which leads to a reduction in the amount of fluid that diffuses into the interstitial space. The resultant decrease in swelling would reduce pain and loss of force generation which are all consequences of acute inflammation caused by muscle damage (Wilcock et al., 2006). Hot water temperatures are

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associated with an increase in peripheral vasodilatation, which results in increased blood flow, but the effect of hot water immersion on performance remains poorly understood (Vaile et al., 2010).

An area that has received little attention is individual differences in body composition and its impact on physiological responses to water immersion. Individual responses to hydrotherapy modalities may depend on a number of factors, with total body fat considered one of the most important, as it influences both blood flow and heat conductivity (Zhang, Huizenga, Arens, & Yu, 2001). Other factors with the potential to impact thermal and physiological responses to hydrotherapy include muscle mass, individual blood flow responses, height, weight, and water immersion depth, duration, and temperature of the specific protocol (Xu, Castellani, Santee, & Kolka, 2007). Body fat has a low heat conductivity which provides insulation and greater thermal resistance compared to that of skin and muscle tissue (Xu et al., 2007). The heat conductivity of fat is approximately 50% less than that of muscle (Zhang et al., 2001) and 35% less than that of blood (LaForgia, Gunn, & Withers, 2008). Therefore, fat provides greater insulation and protection from exposure to hot or cold conditions. It is this insulating factor that is thought to affect the magnitude and rate of intramuscular temperature change in response to cold exposure as well as the rate of re-warming following exposure to the cold (Myrer, Myrer, Measom, Fellingham, & Evers, 2001).

While body composition has been shown to have a significant impact on thermal responses of men and women to temperature extremes (Stocks et al., 2004), its impact on thermal responses to the hydrotherapy protocols used for sports recovery and water immersion in general is relatively unknown. Sports involving extreme environments, for example open water swimming, can benefit from a greater understanding of the impact of body composition on thermal responses to water immersion. Another common extreme environment in which many different forms of exercise are performed is the heat. Research thus far has shown that cold water immersion can be effective in maintaining performance in hot conditions (Vaile et al., 2008a, 2011); however, further research is required to determine the best protocols for doing so. Therefore the purpose of the current study was to compare the thermal responses of low- and high-fat individuals to the hot and cold water immersion protocols that are currently being used for athletic recovery.

Materials and Methods

Subjects

Thirty-nine physically active males from the Australian Defence Force Cycling Club (mean ± SD: age, 35.5 ± 8.1 years; height, 180.4 ± 7.1 cm; weight, 83.3 ± 9.9 kg; body fat, 17.9 ± 6.5%) volunteered to participate in the study. All subjects completed an average of ~11 hr of cycling-specific training per week, in addition to an average of ~3 hr of additional physical training such as weight training, running, or swimming. None of the subjects were regular users of cold or hot water immersion. Subjects were fully informed of the requirements and risks associated with participation. Each subject provided written consent prior to commencement of the study. Subjects were required to attend the laboratory in a fully hydrated state and to have refrained from alcohol (48 hr), caffeine (24 hr), and strenuous exercise (12 hr) prior to data collection. All testing and recovery sessions were completed in a temperature-controlled laboratory (25.6 ± 0.6℃, 38.6 ± 0.8% relative humidity). This study was approved by the Australian Institute of Sport Research Ethics Committee.

Experimental Design and Procedures

A randomized, parallel groups design was used, whereby subjects were randomly assigned to the cold water immersion ($n = 20$) or hot water immersion ($n = 19$) group. Each subject completed one testing session which consisted of an initial body composition analysis, baseline core temperature, skin temperature, and thermal sensation measurement followed by 15 min of seated immersion to the level of the C7 vertebrae in either hot water (38℃) or cold water (15℃). During water immersion, core temperature and thermal sensation were measured at 5 min intervals. Immediately post-immersion, skin temperature was assessed. During immersion subjects wore only swimming trunks and were allowed a 2 min period to gently dry off and change into a dry T-shirt and shorts before being required to sit passively in a temperature-controlled room (25.6 ± 0.6℃, 38.6 ± 0.8% relative humidity) for 30 min. During this passive rest period, core temperature and thermal sensation were measured every 10 min. Skin temperature was measured for a final time at 30 min post-immersion.

Hydrotherapy Protocols

Subjects performed 15 min of full body standing immersion (excluding the head and neck) in either hot water (38℃) or cold water (15℃).

Core Temperature (Tc)

Tympanic core temperature was measured by a ThermoScan thermometer (Type 6201, Braun, Germany). The thermometer was inserted fully into the aural canal and held in position for 5 s while the measurement took place. A new ThermoScan probe cover (PC20, Braun, Germany) was placed over the measurement probe prior to each measurement being taken. This measure was recorded at baseline, every 5 min during immersion, and every 10 min post-immersion for 30 min (Table 1). Tympanic temperature measurement has been found to be a valid method when compared to rectal temperature measurement, which is generally considered to be the "gold standard" method of measuring core temperature (Sehgal et al., 2002). Indeed, Kocoglu, Goksu, Isik, Akturk, and Bayazit (2002) examined rectal versus tympanic temperature measurements and found a mean difference of 0.03℃ (expressed as a standard error of measurement).

Thermal Sensation Scale (TSS)

Subjects were asked to rate their perceived thermal comfort on a scale of zero (unbearably cold) to eight (unbearably hot) (Young, Sawka, Epstein, Decristofano, & Pandolf, 1987), at baseline, every 5 min during immersion and every 10 min post-immersion for 30 min (Table 1).

Cutaneous Temperature (Tsk)

Cutaneous (skin) temperature was measured using a thermal imaging camera (UCF 9000, Drager, Germany). Readings were taken at four sites: chest, anterior forearm, anterior mid-thigh, and posterior calf. Mean skin temperature (Tsk) was calculated using the following equation: $\mathrm{Tsk} = 0.3 \times (\mathrm{Tchest} + \mathrm{Tarm}) + 0.2 \times (\mathrm{Tthigh} + \mathrm{Tleg})$ (Ramanathan, 1964). Skin temperature was recorded at baseline, immediately post-immersion, and 30 min post-immersion.

Body Composition Analysis

Height was measured by an accredited Level 1 International Society for the Advancement of Kinanthropometry (ISAK) anthropometrist using a portable stadiometer (S+M Height Measure, Axis Pacific, Australia) according to ISAK guidelines. Bioelectrical impedance analysis (BIA) using bioelectrical impedance scales (BC-587, Tanita, USA) was performed next. Subjects were required to stand motionless with bare feet placed on the electrodes while an alternating current (~200 μA, 50 kHz) passed through the body. BIA uses proprietary software to calculate percentage body fat (%BF), fat mass (FM), fat-free mass (FFM), and bone mineral mass (BMM). Previous studies have found no significant difference between Tanita scales estimation of percentage body fat and skinfold thickness (Jebb, Cole, Doman, Murgatroyd, & Prentice, 2000). Additionally, LaForgia et al. (2008) found only a small bias in BIA compared to a four-compartment model, and concluded that Tanita scales do have some efficacy in providing general body composition descriptors of a cohort.

Percentage body fat data obtained from BIA were used to divide subjects into high- and low-fat groups. Table 2 describes the body fat thresholds that were used to determine the groups.

Statistics

The effect of body composition on thermal responses to either hot or cold water immersion was assessed using a paired *t*-test. Where data were not normally distributed, a Wilcoxon signed rank test was used to compare across time points for each group. When comparing time points between high- and low-fat groups a Kruskil-Wallis one-way ANOVA was used due to violations of normality and/or homogeneity. The strength of association between variables was assessed using Pearson's correlation coefficient with significance set at $p < 0.05$. Data are presented as mean ± SD.

Results

Temperature

During cold water immersion there was no significant difference between high- ($n = 7$) and low-fat ($n = 13$) groups; however, following cold water immersion core temperature was significantly lower in the low-fat group compared to the high-fat group at the 10, 20, and 30 min post-immersion time points ($p \leq 0.01$; Figure 1). There were no significant differences between any of the time points for the high-fat group. The low-fat group had significantly lower core temperature at 10, 20, and 30 min post-immersion compared to baseline ($p \leq 0.01$). There was also a significant decline in core temperature between 15 min of immersion and 10 min post-immersion in the low-fat group ($p = 0.01$).

During hot water immersion, core temperature was only significantly different between body fat groups at the 5 min

Table 1
Time-course of measures.

Measure	Baseline	During immersion			Immediately post-immersion	Post-immersion		
		5 min	10 min	15 min		10 min	20 min	30 min
Tc	*	*	*	*		*	*	*
TSS	*	*	*	*		*	*	*
Tsk	*				*			*
BC	*							

Note. Tc = core body temperature, Tsk = skin temperature, TSS = thermal sensation scale, BC = body composition.

Table 2
Body fat percentage ranges used to define high- and low-fat groups. Adapted from Baechle and Earle (2008).

	Age (years)			
Body fat group	18–25	26–35	36–45	46–55
Low-fat (n = 27)	≤ 13.9	≤ 18.8	≤ 21.9	≤ 23.9
High-fat (n = 12)	⩾ 14	⩾ 19	⩾ 22	⩾ 24

immersion time point ($p = 0.01$) (Figure 2). There were no significant differences between any time points for the high-fat group. There was a significant increase from baseline at the 10 and 15 min immersion time points for the low-fat group ($p = 0.02$, $p < 0.01$). There was also a significant increase in core temperature from 10 to 15 min of immersion ($p < 0.01$) and a significant drop in core temperature from 15 min of immersion to 10 min post-immersion ($p < 0.01$).

Thermal Sensation and Skin Temperature

There were no significant differences by body composition group or water temperature in thermal sensation at baseline, as well as at 5 and 10 min of immersion; however, for both water conditions, low-fat subjects had a significant difference in thermal sensation compared to high-fat ones ($p < 0.05$). Thermal sensation was also significantly different between body composition groups at 10 min post-immersion in the cold water group ($p = 0.05$) and approaching significance in the hot water group ($p = 0.09$). No significant differences were present at both the 20 and 30 min post-immersion time points for both body composition and water temperature groups (Table 3). There were no significant differences in skin temperature between body fat groups at any time point (Figure 3).

Discussion

The main findings of the present study were: (1) skin temperature is not affected by body composition differences, (2) low-fat individuals take longer to re-warm following cold water immersion, (3) core temperature takes longer to increase in high-fat individuals during hot water immersion, (4) low-fat individuals have greater thermal sensitivity at 15 min of immersion in both hot and cold water, and (5) low-fat individuals have greater thermal sensitivity at 10 min post-immersion in both hot and cold water.

It is believed that individual body size and composition will greatly impact upon the physiological responses to water immersion (Sawaka & Young, 2005). The current study supports this contention, with results showing significant differences in thermal sensation and core temperature between the high- and low-fat groups. Anthropometric characteristics such as height, weight, body fat (Xu et al., 2007), and unperfused muscle tissue (Veicsteinas, Ferretti, & Rennie, 1982) all contribute to the variation in individual responses. When subjects were split into low- and high-fat groups according to the percentage body fat ranges specified in Table 2 (Baechle & Earle, 2008), low-fat individuals were found to be more thermally sensitive than high-fat individuals. This sensitivity is evident from the significantly lower thermal sensation ratings at 15 min of cold water immersion and the significantly higher thermal sensation ratings at 15 min of hot water immersion (Table 3). Xu et al. (2007) found body fat to have a significant impact on physiological responses to heating and cooling as it has a low heat conductivity allowing it to provide insulation and greater thermal resistance compared to that of skin and muscle tissue. The heat conductivity of fat is approximately half that of muscle (Zhang et al., 2001); therefore, fat provides greater insulation and protection from

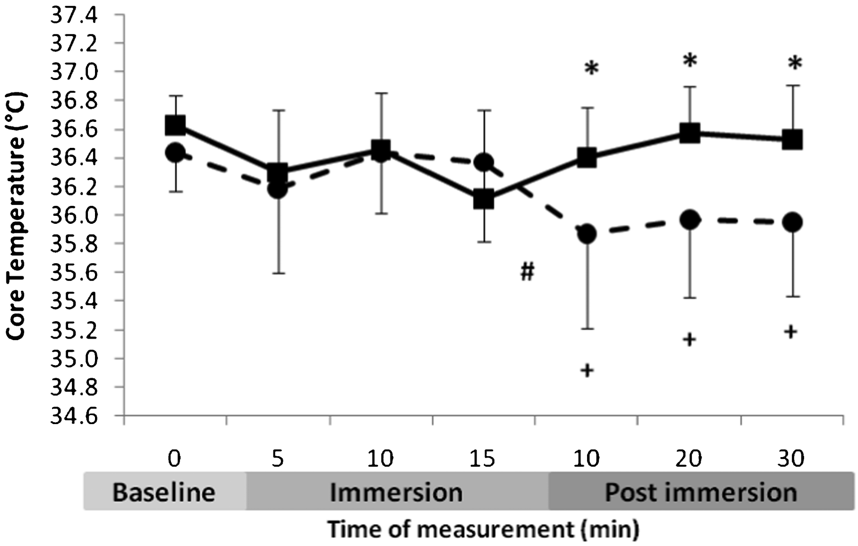

Figure 1. Core temperature of low-fat group (n = 13) ● versus high-fat group (n = 7) ■ during cold water immersion. *, Significant difference between groups ($p < 0.05$); +, significant difference from baseline ($p < 0.05$); #, significant difference between consecutive time points ($p < 0.05$).

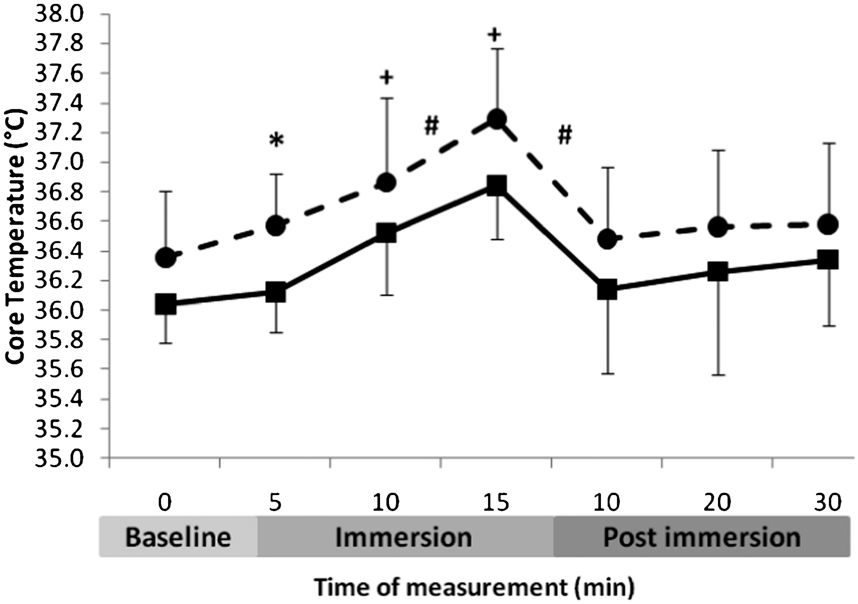

Figure 2. Core temperature of low-fat group ($n = 14$) ● versus high-fat group ($n = 5$) ■ during hot water immersion. *, Significant difference between groups ($p < 0.05$); +, significant difference from baseline ($p < 0.05$); #, significant difference between consecutive time points ($p < 0.05$).

exposure to hot or cold conditions. It is this insulating factor that is thought to affect the magnitude and rate of intramuscular temperature change as well as the rate of return to baseline following exposure to temperature extremes (Myrer et al., 2001). It has been shown that the depth of muscular tissue affects intramuscular temperature change, whereby the deeper the muscle tissue, the longer it will take to both cool and re-warm the muscle (Myrer et al., 2001). The present study was unable to measure intramuscular temperature to determine whether greater amounts of body fat impact on the temperature change of muscle tissue in response to hot and cold water immersions. This gap in knowledge should be addressed by future research.

A significant difference in core temperature at 5 min of hot water immersion (Figure 2) shows that low-fat individuals are quicker to heat up in response to hot water as they do not have as much body fat to provide thermal resistance to the heat. Additionally, during cold water immersion there was a significant difference between low- and high-fat individuals at 10, 20, and 30 min post-immersion (Figure 1) showing that it took longer for the low-fat individuals to re-warm. A possible explanation for this could be that the low-fat individuals have less protection against cooling and heating, and therefore deeper muscle tissue would be cooled or warmed during immersion compared to high-fat individuals who have more body fat to provide insulation and so did not achieve the same depth of muscle cooling or warming. This is in line with the findings of Cannon and Keatinge (1960) who observed that thin men had a higher stimulation of deep thermal receptors compared to fat men when immersed in hot and cold water. However, further research examining muscle temperature responses is needed to confirm this supposition.

Height and weight impact on individual body mass to surface area ratios: for example, short individuals with low

Table 3
Mean ± SD thermal sensation (TSS) ratings (arbitrary units) during hot water immersion (HWI) and cold water immersion (CWI) for the low-fat (LF) and high-fat (HF) groups.

	HWI			CWI		
Time point	LF ± SD ($n = 14$)	HF ± SD ($n = 5$)	p-value	LF ± SD ($n = 13$)	HF ± SD ($n = 7$)	p-value
Baseline	4.3 ± 0.3	4.1 ± 0.2	0.56	4.0 ± 0.7	4.1 ± 0.6	0.68
5 min	5.0 ± 0.4	4.6 ± 0.6	0.07	1.7 ± 0.6	1.9 ± 0.5	0.90
10 min	5.5 ± 0.5	5.1 ± 0.6	0.23	1.9 ± 0.4	2.3 ± 0.6	0.36
15 min	6.0 ± 0.5	5.6 ± 0.4	0.03	2.0 ± 0.5	2.4 ± 0.6	0.03
10 min post	4.5 ± 0.4	4.0 ± 0.4	0.09	3.0 ± 0.6	3.4 ± 0.4	0.05
20 min post	4.3 ± 0.5	4.3 ± 0.3	0.73	3.5 ± 0.6	3.6 ± 0.4	0.40
30 min post	4.1 ± 0.2	4.1 ± 0.2	0.83	3.7 ± 0.4	3.7 ± 0.3	0.61

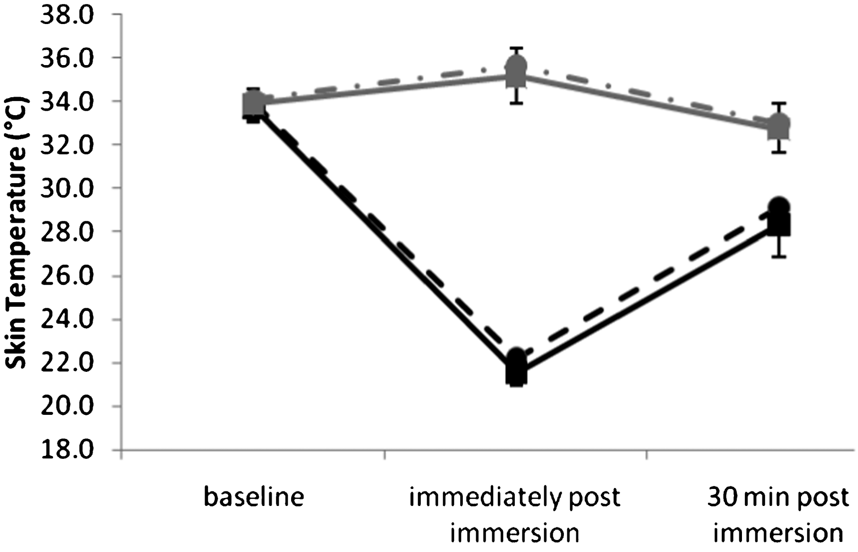

Figure 3. Skin temperature of low-fat group ($n = 5$) ● versus high-fat group ($n = 5$) ■ during cold water immersion; and low-fat group ($n = 7$) ● versus high-fat group ($n = 3$) ■ during hot water immersion.

weight will have a much greater surface area to mass ratio than tall individuals with a greater weight (Wilmore, Costill, & Kenney, 2008). A larger surface area to mass ratio facilitates heat loss, as having a greater surface area exposes more area to facilitate cooling and a lower body mass provides less insulation reducing heat retention (Glickman-Weiss, Cheatham, Caine, Blegen, & Marcinkiewicz, 2000). The subjects in both the cold water and hot water groups were found to have a mean body surface area of 2.0 ± 0.1 m^2. Therefore analysis of the influence of body surface area on thermal responses was not possible in this study due to the homogeneity of the subjects. However, it is something that should be investigated in the future (Anderson, 1999).

Changes in skin temperature are the first stimuli the body receives in order to maintain thermal homeostasis. Cutaneous thermoreceptors detect temperature change and the rate of temperature change (Cole & Becker, 2004). The cutaneous thermoreceptors then transmit nerve impulses to the hypothalamus (via the spinal cord) which is responsible for signaling physiological changes such as vasoconstriction, vasodilatation, shivering, and sweating (Brooks, Fahey, & Baldwin, 2004). Given that there was no significant difference in skin temperature between high- and low-fat individuals (Figure 3) at any time point, it might be suggested that body composition does not affect the initiation of thermoregulation or cutaneous vasoconstriction, but increases thermal resistance through peripheral tissues (Anderson, 1999). Peripheral tissues such as adipose tissue, muscle, and skin (Anderson, 1999) all impact upon body insulation, with vasoconstricted muscle considered to contribute the largest proportion of insulation (Park, Prendergast, & Rennie, 1984; Veicsteinas et al., 1982). Unperfused muscle tissue has been shown to provide a large proportion of the body's total insulation during rest in cold water (Stocks, Taylor, Tipton, & Greenleaf, 2004). Veicsteinas et al. (1982) found that unperfused muscle accounts for approximately 80% of total insulation. The core temperature responses observed in this study demonstrated that low-fat individuals took longer to re-warm after cold water immersion and appeared to get hotter in response to hot water immersion compared to the high-fat individuals, indicating that they had less thermal resistance from peripheral tissues to protect them from temperature change. This could solely be related to adipose tissue, or muscle mass may also be a contributing factor, but as muscle mass was not measured in this study that cannot be determined at present. Future research should examine muscle mass in addition to body fat to gain an understanding of which peripheral tissue provides more influence on thermal resistance.

Another factor that may impact upon thermal responses to hydrotherapy is whether exercise is performed immediately prior to immersion. Exercise leads to the increased perfusion of muscle tissues which has been shown to negate the insulation provided by muscle tissue (Veicsteinas et al., 1982). This exercise induces an increase in blood flow and tissue perfusion causes increased heat transfer as blood is a good thermal conductor (Stocks et al., 2004). Exercising in extreme environments prior to performing hydrotherapy for recovery may also have significant impacts on thermal responses due to changes in skin and core temperature caused by exercise and environment. For example, exercise in a hot environment will cause increased core, skin, and muscle tissue temperature which will increase the temperature gradient between warm body tissues and cold water immersion which increases the rate of heat transfer (Bender et al., 2005; Long, Cordova, Bruker, Demchak, & Stone, 2005; Rech, 2013). This could lead to low-fat individuals cooling at a faster rate and having deeper muscle tissues cooled as they do not have adipose tissue to provide a thermal barrier. The impact of exercise, particularly exercise in extreme environments, on thermal responses to post-exercise hydrotherapy and its interaction with body composition difference is currently unknown and warrants further scientific investigation, as hydrotherapy for recovery from exercise tends to be performed after exercise when body temperature and blood flow are still elevated.

The impact of body size and composition on thermal responses to hydrotherapy is complex and requires future research to examine factors such as body fat, muscle mass, surface area, surface area to mass ratio, and blood flow. A greater understanding of the impact of body composition as well as the time-course of physiological changes will allow hydrotherapy protocols to be individualized to athletes based on their body composition. This will reduce the risk of performance being hindered by over-cooling in low-fat subjects, and will also enable inflammation and swelling to be attenuated by ensuring adequate muscle temperature cooling occurring in high-fat subjects.

Conclusion

The results of this study indicate that core body temperature and thermal sensitivity differ between individuals with low and high body fat in response to hot and cold water immersion and highlight the fact that protocols may need to be adjusted depending on body composition differences to ensure both groups achieve the required amount of core temperature change. The impact of water immersion on muscle temperature change and the impact of muscle tissue on thermal resistance have been identified as two key areas that future scientific research should investigate. In addition to this, future research should also examine how other body composition characteristics such as body surface area and surface area to mass ratios affect responses to the hydrotherapy methods used for sports recovery. Finally future research should investigate whether body composition impacts thermal responses to hydrotherapy post-exercise in normal and extreme environments.

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