International Journal of Aquatic Research and Education

5-1-2015

Adaptation of the Cold Shock Response and Cooling Rates on Swimming Following Repeated Cold Water Immersions in a Group of Children Aged 10 – 12 years

Flora Bird
Queen's Hospital, florabird1@gmail.com

Jim House
University of Portsmouth

Michael J. Tipton
University of Portsmouth

Follow this and additional works at: https://scholarworks.bgsu.edu/ijare

Human Kinetics

ORIGINAL RESEARCH

Adaptation of the Cold Shock Response and Cooling Rates on Swimming Following Repeated Cold Water Immersions in a Group of Children Aged 10–12 Years

Flora Bird

Queen's Hospital

James R. House and Michael J. Tipton

University of Portsmouth

Habituation of the cold shock response and adaptation in deep body cooling with prolonged cold water immersion is well documented in adults. This study aimed to determine whether children exhibit similar adaptive responses. Eight children aged 10–11 years underwent a 5 min static immersion in 15 °C (59 °F) water, five then swam for up to 40 min, before and after a year of regular cold water swim training. Following acclimatization, no differences were found in heart rates or respiratory frequencies on initial immersion, despite a smaller relative $\dot{V}O_2$. Children reported feeling warmer ($p < .01$) and more comfortable ($p < .05$), implying acclimatization of subjective perception of cold. No difference was found in cooling rates while swimming. On comparison with data of adults swimming in 12 °C (53.6 °F) water, no difference was found in cooling rates, but the trend in both acclimatized groups to a slower rate of cooling was significant ($p \leq .026$) when the data were pooled. These data may support a theory of insulative adaptation.

Keywords: swimming, cold water, cold shock response, hypothermia

It is recognized that on initial immersion in cold water, adults demonstrate a cold shock response: a reflex cardiovascular, respiratory, and metabolic response, considered potentially detrimental to survival (Tipton, 1989) and therefore potentially responsible in some part for the high rate of morbidity and mortality associated with drowning worldwide especially in colder climates (World Health Organization, 2012). Laboratory-based research has provided evidence for the potential advantage that may be gained from the habituation of this response in adults (Golden & Tipton, 1988; Keatinge & Evans, 1961; Tipton, Mekjavic, & Eglin, 2000). Centrally-acting

Flora Bird is with the Accident and Emergency Department at Queen's Hospital, Romford, UK. James House and Michael Tipton are with the Department of Sport and Exercise Science at the University of Portsmouth, Portsmouth, UK. Address author correspondence to Flora Bird at florabird1@gmail.com.

neurogenic pathways have been implicated in producing this habituation (Griffin, 1963; Tipton, Eglin, & Golden, 1998; Tipton, Golden, Higenbottam, Mekjavic, & Eglin, 1998), and evidence of a sympathoadrenal adaption has been shown in regular cold water swimmers pre- and postimmersion (Huttunen, Rintamäki, & Hirvonen, 2001).

The process of adaptation in the cooling rates of adults following repeated prolonged immersions in cold water remains somewhat unresolved. Hammel (1964) proposed three means by which humans adapt to cold:

Hypothermic: a greater fall in core temperature with repeated exposures

Insulative: maintenance of core temperature due to increased insulation

Metabolic: maintenance of core temperature due to increased metabolic heat production

There are examples within the literature to support each of these processes (Tipton, Pandolf, Sawka, Werner, & Taylor, 2008) implying that different mechanisms of adaption may exist in different scenarios. The most frequently reported response in adult humans is hypothermic adaptation which sees a faster fall in core temperature due to a blunted metabolic response, resulting from a downward shift in shivering threshold (Bruck, Baum, & Schwennicke, 1976; Rees, Eglin, Taylor, Hetherington, Mekjavic, & Tipton, 2002) and an increase in thermal comfort (Bittel, 1987; Bruck et al., 1976; Golden & Tipton, 1988; Tipton et al., 2008). It is recognized to be specific to the deep body temperatures experienced during adaptation (Tipton, Wakabayashi, Barwood, Eglin, Mekjavic, & Taylor, 2013). This process results in a greater homeostatic economy, with preservation of energy, despite the cost of a lower core temperature (Tipton et al., 2008).

Comparing the response of adapted cold water swimmers to static *versus* dynamic immersions is complicated. Clark and Edholm (1985) attributed the ability of long-distance English Channel swimmers to maintain their core temperature to the metabolic heat produced by these athletes while swimming (i.e., metabolic adaptation) and to their subcutaneous fat thickness while resting (i.e., insulative adaptation). Early work done by Pugh and Edholm (1955) and Golden, Hampton, and Smith (1979) in acclimatized open cold water swimmers found that they exhibited features of insulative adaptation when swimming and hypothermic adaptation during resting. Furthermore, a laboratory based study has shown that different processes of adaptation occur within individuals depending upon whether immersions are static or dynamic during the acclimation period (Golden & Tipton, 1988).

A significant shortage of data regarding children's adaptation to cold remains to the current day. As a result, safety guidelines involving pediatric open-water swimmers are based on theory or extrapolated from adult studies rather than being strictly evidence-based. Research conducted in the heat has found that acclimatization to heat in children is similar to that of adults but occurs at a slower rate (Inbar, 1978; Wagner, Robinson, Tzankoff, & Marino, 1972). This study aimed to investigate whether children exhibit similar adaptation in their cold shock response and rates of deep body cooling following repeated immersions in cold water as that seen in adults. We hypothesized that a diminished cardiovascular, respiratory, and metabolic response would occur on initial immersion followed by an adaptation in thermal perception and a faster rate of fall in core temperature following prolonged swimming as compared with adults.

Method

Participants

Ethical approval for this study was granted by the University of Portsmouth Bio-Sciences Research Ethics Committee. Written informed assent and consent were obtained from each child and their parent/guardian respectively. During testing, each child was accompanied by a parent/guardian.

In 2009, 19 participants, 11 boys and 8 girls, aged 10–11 years, were recruited from applicants to the Bristol English Channel Swim Team (BEST)—an attempt by a group of children to break the world record and be the youngest relay team to swim the Channel. Participants were recruited to BEST through distribution of fliers and posters within a 30 mile radius of Bristol. All applicants received a presentation about this study by the Principal Investigator and were given written information. It was made clear that the BEST attempt and this study were two separate entities and that any involvement in this study had no impact on their selection or exclusion from BEST.

Participants completed a medical questionnaire, clinical examination, and 12-lead ECG. All had been assessed by a consultant pediatric cardiologist and were reviewed by an Independent Medical Officer (IMO) on each study day. Any considered unfit to begin the training program for BEST or to be involved in the research were excluded from this study. All participants were proficient swimmers.

Procedures

Each child visited the experimental facilities at the University of Portsmouth, for approximately 2 hrs during July 2009 and September 2010. Wearing swimming shorts/costume, participants had a restricted anthropometric profile taken and were asked to swallow an ingestible radio-pill thermometer measuring gastrointestinal core temperature (T_{GI}). They then entered the flume room (air temperature 20 °C/68 °F; humidity 50%) and were seated on an immersion chair with a seat belt fastened around their waist. Participants were instrumented with a 3-lead ECG, chest strap heart rate monitor, nose clip, and mouthpiece to collect expired air. Each participant was then lowered into the water (temperature 15 °C/59 °F at 8 cm.sec^{-1}) on the chair until immersed to the clavicle. They spent up to 45 min in the water.

Initial 5 min static immersion.   Participants remained seated while their cardio-vascular and respiratory responses were monitored and recorded throughout. During the first and fifth minute of immersion, metabolic rate was measured. They were then raised out of the water and ECG leads removed. Of the 19 participants, five were unable to swallow the thermometer pill and so did not partake in the swim part of this study; they were removed from the water and rewarmed.

40 min swim.   Participants were lowered on the immersion chair into the water (temperature 15 °C/59 °F at 8 cm.sec^{-1}) where they unseated themselves and swam for a maximum of 40 min. During this time, heart rate was recorded and T_{GI} monitored continuously. At approximately the eighth minute, and every 10 min thereafter, participants were brought to the side of the flume to don the nose clip and mouthpiece and then asked to recommence swimming using breaststroke with head above water. After 10 min, expired air samples were collected for 1

min. Participants were encouraged to swim at their own pace at a constant speed. Swimming hats were not worn, but goggles were worn by all. Subjective thermal sensation and comfort were recorded before immersion, after 5 min static immersion, and at the end of the swim. Each participant was then passively rewarmed in a bath of 39–40 °C (102.2–104 °F) water.

One year follow up.   Thirteen participants volunteered to return at 1 year; however, due to ill health, four were unable to participate although one attended a separate study day at a later date. Therefore, 10 participants, six boys and four girls, aged 12 years, repeated the above study; nine repeated it in September 2010 and one in January 2011. Eight of these had been subject to multiple exposures to swimming in cold water over the previous year and were therefore included in the data comparison for initial static immersion. Five of the original 10 participants who completed the swim phase of the study returned at 1 year. All participants' parents provided a swim history of the number of hours spent in cold open-water and heated swimming pools over the year and one year before the initial study. On their return, the speed of the flume was reproduced for the length of their initial swim, after which participants continued at their own pace.

Withdrawal Criteria

It was made clear that participants or their parent/guardian could end the immersion and be assisted from the water at any point. Throughout the immersion they were regularly asked if they were happy to continue. Participants were removed from the water if T_{GI} fell below 35 °C/95 °F, or at the request of participants, the IMO, investigators, or parent/guardian.

Measurements

Anthropometric profile.   Participants' height, body mass, percentage body fat, arm span, skinfold thickness at eight different sites (i.e., biceps, triceps, subscapular, suprailiac crest, supraspinale, abdominal, front-thigh, and medial-calf) and girth measurement at five different sites (i.e., medial calf, arm girth relaxed and flexed/tense, and waist and gluteal girth) were taken. These were taken, in duplicate, by an anthropometrist accredited by the International Society for the Advancement of Kinanthropometry.

Gastrointestinal temperature (T_{GI}).   Ingestible radio-pill thermometers (Vital-Sense, Mini Mitter Inc, Bend, OR, USA) recorded gastrointestinal temperature as a measure of deep body temperature every minute during the cold water exposure.

ECG and heart rate.   A 3-lead ECG (Lead II) displayed continuously during the static 5 min immersion (Miniman 7137 plus, Kondtron Instruments, Charter-Kontron Ltd, Milton-Keynes, UK). During the swim-phase, heart rate was recorded continuously using a heart-rate monitor chest strap (Team System, Polar Electro Oy, Kempele, Finland).

Respiratory and metabolic response.   During the static immersion, ventilation rate, tidal volume, and inspiratory frequency were measured continuously using a flow turbine (KL Engineering, Sylmar, California, USA) and recorded using data

acquisition software (PowerLab, AD Instruments, Oxford, UK). During the first and fifth minute of static immersion and every tenth minute while swimming, the participant's metabolic rate was measured using a 100 L Douglas bag connected by a length of breathing tubing to the exhalation port of a three way valve (Hans Rudolph Inc, Shawnee, KS, USA), connected to the mouthpiece of a swim snorkel. Subsequent fractional gas concentrations were analyzed using O_2 and CO_2 gas analyzers (Series 1400, Servomex Ltd, Cambridge, UK) and expired volume measured using a dry gas meter (Harvard, USA). Gas temperatures for $\dot{V}O_2$ were measured using an electronic thermometer (Model 810-080, Electronic Temperature Measurement Ltd, Worthing, UK). Expired air samples were collected for 1 min on each occasion.

Thermal perception.   Thermal sensation (TS) and thermal comfort (TC) were measured using validated (Davey, Reilly, Newton, et al., 2007) continuous visual analog scales (Figure 1). A sliding pointer was moved along the scale until the participant said "stop" at the point at which they valued their TS and TC. No numerical values were displayed, and the mark was removed once the measurement had been recorded, therefore no point of reference was visible.

Calculations

Oxygen uptake ($\dot{V}O_2$) was calculated, following conversion from ambient temperature pressure saturated (ATPS) to standard temperature pressure dry (STPD), using the Haldane transformation.
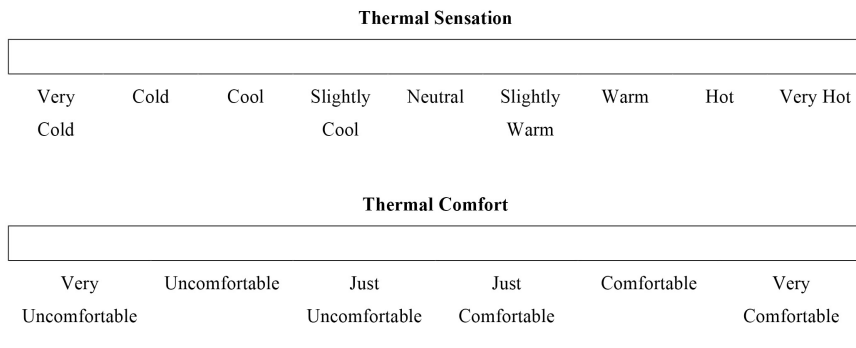
Percentage body fat (% BF) was calculated as follows with ΣSKF = sum of skinfolds calf + triceps (mm) (Slaughter, Lohman, Boileau, et al., 1988):

Boys: %BF = 0.735 (ΣSKF) + 1.0 $\qquad\qquad\qquad$ (1)

Girls: %BF = 0.610 (ΣSKF) + 5.1 $\qquad\qquad\qquad$ (2)

Body surface area was calculated using the formula proposed by Gehan and George (1970), and body surface area to mass ratio (SA: M) was calculated as follows:

SA: M = BSA (m^2)/mass(kg) $\qquad\qquad\qquad$ (3)

Thermal Sensation

Very Cold	Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot	Very Hot

Thermal Comfort

Very Uncomfortable	Uncomfortable	Just Uncomfortable	Just Comfortable	Comfortable	Very Comfortable

Figure 1 — Visual Analog Scales measuring thermal sensation and thermal comfort. Each scale measured 20 cm in total and was divided equally.

Statistical Analyses

Prism 5 (GraphPad Prism v6.01) was used for statistical analysis. D'Agostino and Pearson omnibus normality tests were calculated and where appropriate one tailed, two tailed and unpaired t tests and two way repeated measures analysis of variance tests were calculated. Where nonparametric tests were indicated due to nonnormality or ordinal data, the Mann Whitney test was applied. Statistical significance was taken to be at the 5% level ($\alpha \leq 0.05$). Cohen's d was calculated for selected comparisons where graphical data, mean values, and standard deviations suggested it might be worthwhile to assess effect size.

Results

Initial Static Immersion

Eight participants (five boys and three girls) underwent 5 min of static immersion in 15 °C/59 °F water on two occasions, separated by 1 year. These participants had no regular cold water exposure in the year before their initial visit; their exposure ranged from zero exposure in three children to 24 hr of UK seawater play in one child. In the subsequent year, all were exposed to 29.5 hr of cold open-water swimming (21 hr without wetsuit) as part of the BEST training. Several participants had undertaken regular cold baths and additional sea swims. Participants were therefore considered nonacclimatized on their initial visit and acclimatized at 1 year.

At 1 year, participants were heavier ($p < .01$) with a higher BMI ($p < .01$); however, no significant difference was found on comparison of their sum of skinfolds ($p = .07$) (see Table 1).

The initial responses to static immersion, before and after a year of cold water swim training are shown in Table 2. No significant differences were found in their heart rates or respiratory frequencies, but participants demonstrated a smaller relative $\dot{V}O_2$ during the first minute of immersion ($p = .01$). Effect size calculations between groups during minute one of immersion yielded a small variation in respiratory frequency (Cohen's $d = 0.16$) and a medium high variation in heart rate (Cohen's $d = 0.60$). Participants reported feeling more comfortable and less cold following 5 min static immersion in 15 °C/59 °F water after a year of acclimatization (Figures 2 and 3).

Table 1   Mean (SD) Anthropometric Characteristics in the Same Participants Before and After a Year of Cold Water Swim Training ($n = 8$)

Variable	Pretraining	Posttraining
Height (m)	1.52 (0.10)	1.60 (0.11)
Body mass (kg)	44.17 (9.54)	53.05 (11.35)
BMI (kg.m^2)	18.85 (2.07)	20.55 (2.29)
Sum of skinfolds (mm)	93.09 (28.64)	102.58 (21.09)

Table 2   Mean (SD) Heart Rates, Respiratory Frequencies, and Relative Oxygen Uptake ($\dot{V}O_2$ mL.kg-1.min-1) on Initial Immersion in 15 °C Water Before and After a Year of Cold Water Swim Training ($n = 8$)

Variable	Pretraining	Posttraining
fH Resting (beats.min^{-1})	79 (9)	69 (12)
fH, 1st minute (beats.min^{-1})	106 (13)	98 (15)
fH, fifth minute (beats.min^{-1})	94 (11)	91 (14)
fR Resting (breaths.min^{-1})	16 (3)	15 (2) ($n = 7$)
fR, 1st minute (breaths.min^{-1})	35 (4)	34 (8)
fR, 5th minute (breaths.min^{-1})	28 (4)	26 (6)
$\dot{V}O_2$ 1st minute (mL.kg^{-1}.min^{-1})	10.9 (1.061)	9.8 (1.374) ($p = 0.01$)
$\dot{V}O_2$ fifth minute (mL.kg^{-1}.min^{-1}) ($n = 7$)	11.6 (3.4)	9.5 (3.4) ($p = 0.06$)

Note: Resting fH and fR were taken before experimentation during participant's medical assessments where fH = heart rate and fR = respiratory frequency.
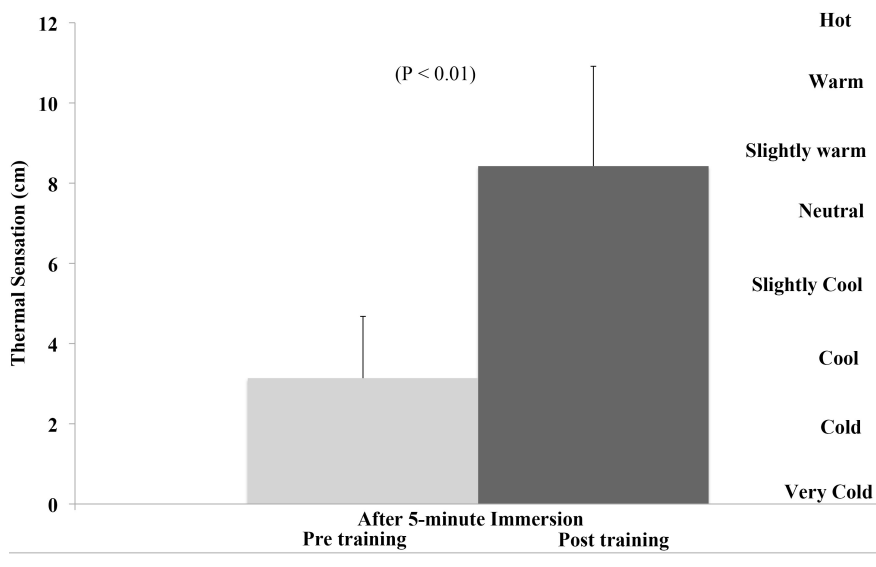
Figure 2 — Mean (± *SD*) thermal sensation in children after a 5 min static immersion in 15 °C/59 °F water, before and after a year of cold water swim training ($n = 8$).
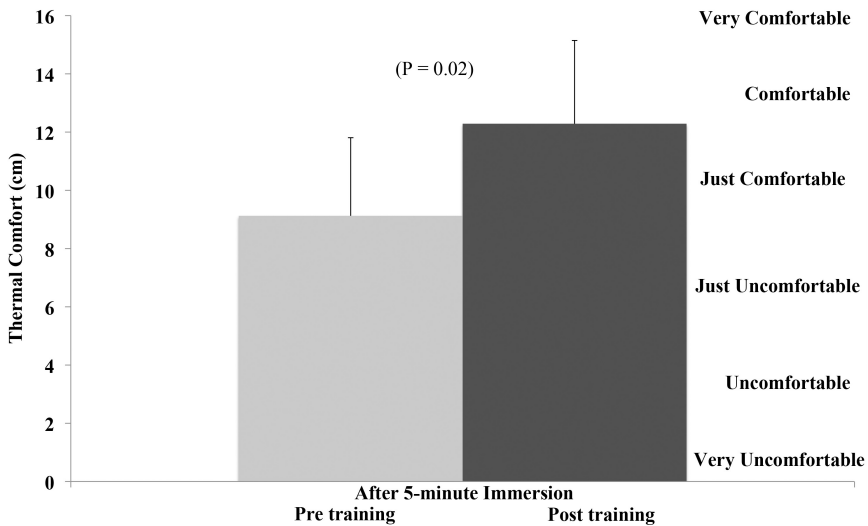
Figure 3 — Mean (± *SD*) thermal comfort in children after a 5 min static immersion in 15 °C/59 °F water, before and after a year of cold water swim training (*n* = 8).

Responses While Swimming

Matched data from five participants who completed the swim phase of the study, four boys and one girl, aged 12 years, were analyzed. Before their initial visit, all participants swam regularly in heated pools; they had experienced little, if any, cold open-water swimming (their cold open-water swimming experience ranged from zero to a 25 min lake swim and 48 hr of play in the UK seawater). At 1 year, all participants had a minimum of 32.5 hr of cold open-water swimming (24 hr without wetsuit), and several children had undertaken regular cold baths and additional sea swims. This cohort was considered nonacclimatized on their first visit and acclimatized at one year's follow up. Four participants completed the maximum 40 min swim time; one male voluntarily withdrew at 30 min. No differences were found in their anthropometric profiles at 1 year, including sum of skinfolds, triceps thickness, % body fat, and SA: M.

The mean (± *SD*) rate of deep body cooling while swimming was 2.43 °C.h^{-1} (± 2.51), initially, and 1.49 °C.h^{-1} (± 0.59) following a year of cold water swim training (Figure 4). This difference was not found to be significant (*p* = .31), due at least in part to the small sample size and lack of statistical power. Between visits, there were no differences in their V̇O$_2$ (mL.kg^{-1}.min^{-1}) while swimming, swim speeds, or thermal comfort and sensation over the course of their swim.

After a year, for all but one child, the flume speed was reproduced for the length of participants' initial swim, after which they continued at their own pace. The one participant for whom this was not possible had an erratic first swim and was therefore encouraged to swim at their own pace throughout. The group average flume speed was 7.7 units (± 1.0), equating to a water velocity of 0.57 m.sec^{-1}.
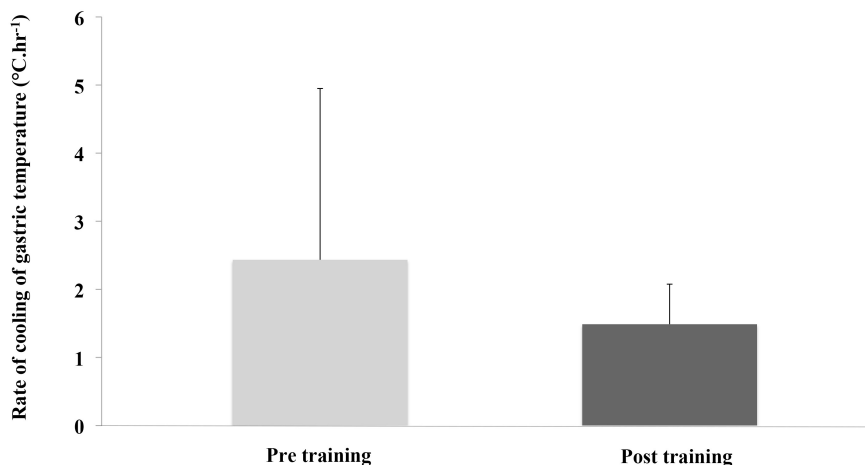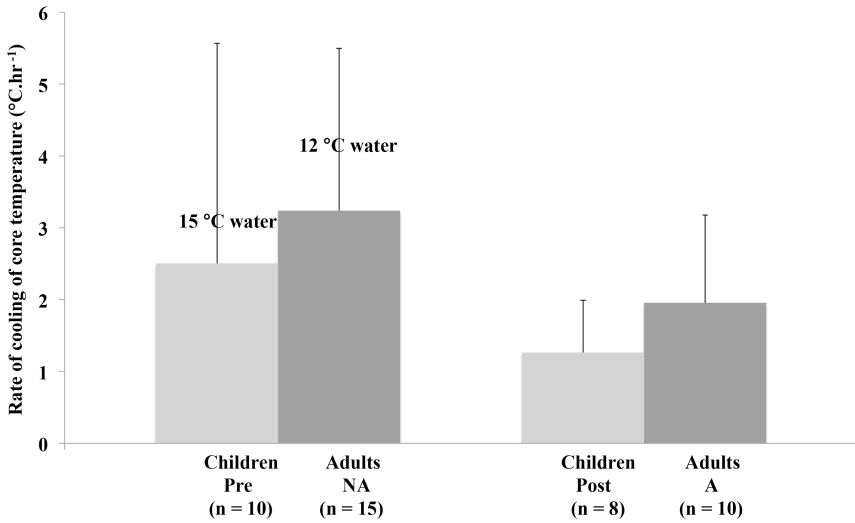
Figure 4 — Mean (± *SD*) rate of cooling in children swimming in 15 °C/59 °F water, before and after a year of cold water swim training (*n* = 5).

Cooling Rates in Children *Versus* Adults

We compared the data from this study with unpublished data collected in the same laboratory from similarly nonacclimatized and acclimatized adults swimming in cold water, temperature 12 °C/53.6 °F (S. Hingley et al., personal communication, July 6, 2009). Figure 5 demonstrates the rates of deep body temperature (T_{GI} in children, T_{RE} in adults) cooling in nonacclimatized and acclimatized children and adults swimming in cold water. No differences were found in cooling rates between children and adults either before or after acclimatization, and the trend of a slower cooling rate in both groups following acclimatization became significant ($p = .026$) once the child and adult data were pooled (Figure 6).

Discussion

This study failed to provide evidence for an adaptation in the cold shock response in this group of children; it did, however, show acclimatization of participants' subjective perception of cold on static immersion. A lack of habituation of the 'cold shock' response was surprising. With the moderate effect size observed on comparing mean heart rate during the first minute of immersion, a larger sample might have enabled us to observe a significant habituation response. If the finding of no habituation is accurate, it raises the possibility that children may differ physiologically from adults in their ability to habituate. Alternatively, a 'habituated' response may have been observed on their first visit when it was assumed they were nonacclimatized. The former explanation is supported by the understanding that reflex physiological responses may change with age, as demonstrated by the diving response reportedly being weaker in children compared with adults (Ramey, Ramey, & Hayward, 1987). If, however, these

Figure 5 — Mean (± *SD*) rate of cooling in children *versus* adults during steady states of swimming in cold water, nonacclimatized (children: pre; adults: nonacclimatized [NA]) *versus* acclimatized (children: post; adults: acclimatized [A]).
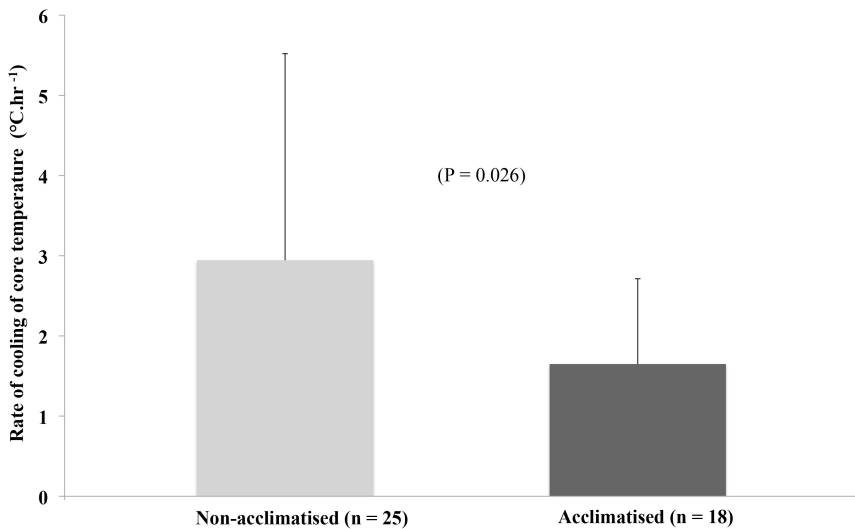
Figure 6 — Mean rate of cooling in adults and children swimming in cold water; nonacclimatized and acclimatized.

children were habituated before their first visit, either their previous exposure to cold water was underreported or less exposure than anticipated is required to render a child habituated. On the other hand, if the lack of habituation was accurate, it implies that middle-aged children may not gain the same advantage as seen in adults of attenuation in this response following repeated exposure to cold water.

On pooling the child and adult data, the finding of a reduction in the rate of deep body cooling while swimming in those considered acclimatized ($p = .026$) supports work done with Channel swimmers (Pugh & Edholm, 1955) and fresh-water lake swimmers (Golden, Hampton, & Smith, 1979; Hingley, Morrissey, House, et al., 2010). The implication of an insulative adaptation is that acclimatized individuals swimming in organized open-water events will be at reduced risk of a drop in deep body temperature with prolonged dynamic immersion, providing a greater window for the length of time acclimatized swimmers could be considered safe. If those same acclimatized individuals are accidentally immersed in open water and remain motionless rather than performing swimming motions to reduce the rate of onset of hypothermia (Keatinge, 1961), they may be at an increased risk of a faster fall in core temperature. Given that participants did not demonstrate significant changes in body morphology, we suggest that the inferred insulative habituation is the result of some kind of vascular adaptation, perhaps an intensification of vasoconstrictor response, not dissimilar to that seen in nonfreezing cold injuries or an increased degree of vascular insulation.

The opportunistic nature of this study limited the sample size, determined the water temperature, and provided an arguably specific cohort. Participants' initial exposure to cold water was arguably similar to that of a random population of British children. Unable to control for growth and puberty, this confounding effect is somewhat diminished by the nature of the within-subject, as opposed to between-subject, statistical comparisons which are inherently more powerful. We recognize the potential for recall bias in providing cold water exposure histories beyond the BEST training program and the limitations of comparing studies with differing methodologies, namely that of water and core temperature measurements. Rectal thermisters, as used in the adult studies, were deemed inappropriate in children, given that a reliable and suitable alternative was available.

This study does not provide evidence for an adaptation in the cold shock response of children; however, with a larger sample size we believe that the trend toward a habituated response could have been significant. It does provide evidence for acclimatization at least of children's subjective perceptions and interpretation of the cold with repeated exposure. It may provide some support for the theory of insulative adaption in cooling rates of children swimming in cold water. An unplanned benefit from the BEST project has enabled safer, successful quantitative data collection in a sparsely researched area. This data collection hopefully may enable further studies, and aid risk assessments of other projects involving pediatric immersion in cold water.

In September 2010, six children (all 12 years of age) successfully completed the 21 mile swim from Shakespeare beach, Dover, to Cap Gris Nez, France, to become the youngest relay team to swim the English Channel.

References

Bittel, J.H. (1987). Heat debt as an index for old adaptation in men. *Journal of Applied Physiology, 62,* 1627–1634. PubMed

Brück, K., Baum, E., & Schwennicke, H.P. (1976). Cold-adaptive modifications in man induced by repeated short-term cold-exposures and during a 10-day and night cold-exposure. *Pflügers Archives of European Journal of Physiology, 363*(2):125–133.

Clark, R., & Edholm, O. (1985). *Man and his thermal environment.* London: Edward Arnold.

Davey, S., Reilly, T., Newton, M., & Tipton, M. (2007, August 19-24). The reproducibility and validity of visual analogue scales (VAS) that assess thermal perceptions in stable and dynamic, asymmetric environments. *Proceedings of the 12th International Conference on Environmental Ergonomics,* Piran Slovenia.

Gehan, E.A., & George, S.L. (1970). Estimation of human body surface area from height and weight. *Cancer Chemotherapy Reports. Part 1, 54*(4): 225–235. PubMed

Golden, F.S., & Tipton, M.J. (1988). Human adaptation to repeated cold immersions. *The Journal of Physiology, 396*(1), 349–363. PubMed doi:10.1113/jphysiol.1988.sp016965

Golden, F., Hampton, I., & Smith, D. (1979). Lean long distance swimmers. *Physiology and the Royal Navy*, (Royal Society of Medicine (United Services Section)).

Griffin, J.P. (1963). The role of the frontal areas of the cortex on habituation in man. *Clinical Science, 24,* 127–134. PubMed

Hammel, J. (1964). Terrestrial animals in cold: Recent studies of primitive man. In D.B. Dill & E.B. Adolph (Eds.), *Handbook of Physiology Section 4. Adaptation to the Environment* (pp. 413–434). Washington, DC: American Physiological Society.

Hingley, S., Morrissey, D., House, J., ... (2010). *Physiology of cold water immersion: A comparison of cold water acclimatised and non-cold water acclimatised individuals during static and dynamic immersions*. (Master's thesis). Queen Mary University of London, London, UK.

Huttunen, P., Rintamäki, H., & Hirvonen, J. (2001). Effect of regular winter swimming on the activity of the sympathoadrenal system before and after a single cold water immersion. *International Journal of Circumpolar Health, 60,* 400–406. PubMed

Inbar, O. (1978). Acclimatization to dry and hot environment, Dissertation, *Columbia University.* As cited in Falk, B. (1998). Effects of thermal stress during rest and exercise in the paediatric population. *Sports Medicine, 25*(4):221-240.

Keatinge, W.R. (1961). The effect of work and clothing on the maintenance of the body temperature in water. *Experimental Physiology, 46,* 69–82. PubMed doi:10.1113/expphysiol.1961.sp001517

Keatinge, W.R., & Evans, M. (1961). The respiratory and cardiovascular response to immersion in cold and warm water. *Experimental Physiology, 46,* 83–94. PubMed

Pugh, L.G., & Edholm, O. (1955). The physiology of Channel swimmers. *The Lancet, 266,* 761–768. PubMed doi:10.1016/S0140-6736(55)92454-5

Ramey, C.A., Ramey, D.N., & Hayward, J.S. (1987). Dive response of children in relation to cold-water near-drowning. *Journal of Applied Physiology, 63*(2), 665–668. PubMed

Rees, A., Eglin, C., Taylor, N., Hetherington, M., Mekjavic, I., & Tipton, M. (2002, **\insert month, day here**). *The nature of human adaptation to cold.* Paper presented at the 10th International Conference on Environmental Ergonomics, Fukuoka, Japan.

Slaughter, M.H., Lohman, T.G., Boileau, R.A., ... (1988). Skinfold equations for estimation of body fatness in children and youth. *Human Biology, 60,* 709–723. PubMed

Tipton, M.J. (1989). The initial responses to cold-water immersion in man. *Clinical Science, 77*(6), 581–588. PubMed

Tipton, M.J., Eglin, C.M., & Golden, F. (1998). Habituation of the inital responses to cold water immersion in humans: a central or peripheral mechanism? *The Journal of Physiology, 512*(2), 621–628. PubMed doi:10.1111/j.1469-7793.1998.621be.x

Tipton, M.J., Mekjavic, I., & Eglin, C. (2000). Permanence of the habituation of the initial responses to cold water immersion in humans. *European Journal of Applied Physiology, 83,* 17–21. PubMed doi:10.1007/s004210000255

Tipton, M.J., Golden, F., Higenbottam, C., Mekjavic, I., & Eglin, C.M. (1998). Temperature dependence of habituation of the initial responses to cold-water immersion. *European Journal of Applied Physiology, 78,* 253–257. PubMed doi:10.1007/s004210050416

Tipton, M.J., Pandolf, K.B., Sawka, M.N., Werner, J., & Taylor, N. (2008). Physiological adaptation to hot and cold environments. In N.A.S. Taylor & H. Groeller (Eds.), *Physiological bases of human performance during work and exercise* (pp. 379–400). Edinburgh: Churchill Livingstone Elsevier.

Tipton, M.J., Wakabayashi, H., Barwood, M., Eglin, C., Mekjavic, I., & Taylor, N. (2013). Habituation of the metabolic and ventilatory responses to cold-water immersion in humans. *Journal of Thermal Biology, 38*(1), 24–31. PubMed doi:10.1016/j.jtherbio.2012.10.002

Wagner, J.A., Robinson, S., Tzankoff, S., & Marino, R. (1972). Heat tolerance and acclimatization to work in the heat in relation to age. *Journal of Applied Physiology, 33,* 616–622. PubMed

World Health Organization. (2012). Drowning Fact Sheet. Retrieved from http://www.who.int/mediacentre/factsheets/fs347/en/index.html