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Title: "Float First and kick for your life": psychophysiological basis for safety behavior on accidental short-term cold water immersion

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Abstract

Introduction. Accidental cold-water immersion (CWI) evokes the life threatening cold shock response (CSR) which increases the risk of drowning. Consequently, the safety behavior selected is critical in determining survival; the present advice is to 'float first' and remain stationary (i.e. rest). We examined whether leg only exercise (i.e., treading water; 'CWI-Kick') immediately on CWI could reduce the symptoms of the CSR, offset the reduction in cerebral blood flow that is known to occur and reduce he CSR's symptoms of breathlessness. We also examined whether perceptual responses instinctive to accidental CWI were exacerbated by this alternative behavior. We contrasted CWI-Kick to a 'CWI-Rest' condition and a thermoneutral control (35°C); 'TN-Rest'. **Method.** Seventeen participants were tested (9 males, 8 females). All immersions were standardised; water temperature in cold conditions (i.e., 12°C) was matched ± 0.5°C within participant. Middle cerebral artery blood flow velocity (MCAv) and cardiorespiratory responses were measured along with thermal perception (sensation and comfort) and dyspnea. Data were analysed using repeated measures ANOVA (alpha level of 0.05). **Results.** MCAv was significantly reduced in CWI-Rest (−6 (9)%; 1st minute of immersion) but was offset by leg only exercise immediately on cold water entry; CWI-Kick MCAv was never different to TN-Rest (−3 (16)% *cf* 5 (4)%). All CWI cardiorespiratory and perceptual responses were different to TN-Rest but were not exacerbated by leg only exercise. **Discussion.** Treading water may aid survival by offsetting the reduction in brain blood flow velocity, without changing the instinctive behavioral response (i.e. perceptions). "Float first – and kick for your life" would be a suitable amendment to the water safety advice.

Key words: Thermal perception, treading water, water safety.

1.0 Introduction

Each year approximately 372,000 people drown worldwide by accidentally entering water and failing to defend their airway against water ingress [1]. If the water is cold, the physiological responses evoked during the first few minutes of whole body cold water immersion (CWI) are life threatening [2] and are strongly implicated in this drowning statistic [3]. Consequently, the responses to CWI have been studied extensively in order to provide evidence based information that underpins the safety behavior to maximise the chances of survival should accidental CWI occur [4-11]. The cascade of responses that are seen have been described collectively as the 'cold shock' response (CSR; [3]), which is characterised by an initial inspiratory gasp, hyperventilation, tachycardia, peripheral vasoconstriction, and hypertension. The hyperventilatory component of the CSR makes coordinating breathing and swimming on immersion difficult and significantly decreases maximum breath-hold time in the majority of immersed individuals [4]. Such a hyperventilation is known to cause a reduction in brain blood flow which leads to symptoms of light-headedness[6]. Thus, during the early minutes of immersion the airway is vulnerable and there is an increased risk of involuntarily aspirating water and drowning [7].

The CSR peaks in the first 120 seconds of immersion [3] and subsides within 5-minutes to the extent that a survival strategy could be sought. As a consequence, the present advice is to "float first" and wait for the CSR to decline [12,13,14]. However, this approach does little to reduce the extent of the CSR and does not account for those who have difficulty floating without deploying limb movements to support themselves in the water. For example, because of an adult male's differing body composition to that of females, males tend to be less buoyant and are inclined to sink on immersion [12]. Contrary to the safety advice, it has recently been suggested that leg only exercise (i.e., treading water) immediately on water entry could be beneficial in this scenario by altering the ventilatory component of the CSR. Indeed, Croft et al [15] and Button et al [16] demonstrated that treading water increased metabolism and reduced the extent of the hyperventilation induced hypocapnia that is ordinarily seen at high respiratory rates in the absence of a raised metabolism. Consequently, the reduction in brain blood flow, specifically mid-cerebral artery velocity (MCAv), that is ordinarily seen on CWI [17] was lessened. In resting tests, which were not included in the studies of Croft et al [15] and Button et al [16], it has been documented that MCAv could fall by 21 [4]% and in extreme cases as much as 68%. This drop was linked to subjective sensations of dizziness and light-headedness and could increase the risk of fainting on immersion [17].

By contrast to the perceptual responses seen on resting (i.e., “floating”) CWI, the subjective sensations that are seen on CWI followed by immediate water treading may in fact be *less* pleasant and could potentially exaggerate the CSR. Indeed, sudden CWI induces a rapid drop in skin temperature thereby stimulating cutaneous cold thermoreceptors [3,6]. Following the detection of a change in skin temperature, the response characteristics of these receptors shows an initial peak in number of neural impulses sent to the CNS followed by a stabilisation period to a new, higher, frequency in accordance with the adapting temperature of the skin [18]. Following this adjustment, thermal input will be reset but the salience (i.e., unpleasant nature) of the sensory information from the skin will decline, thus enabling attentional resource to be focussed on other stimuli (developing a survival strategy). In relatively still cold water an insulating boundary layer of water could be established by remaining stationary (i.e., resting/floating). In this scenario the afferent thermal information will peak and then stabilise at the new adapting temperature [18]. However, immediate movement on CWI by commencing treading water will increase the flow of water over the skin and will disturb any boundary layer that could develop by remaining stationary. This may lead to repeated stimulation (i.e., switching ‘on’) of the cutaneous cold receptors and heighten and extend the duration of the CSR or its associated sensations. Likewise, exercise is also known to be a ventilatory driver [19]. Consequently, the extent of the sensations of dyspnea may actually increase and thermal perceptual disturbances may be exaggerated towards participants feeling colder and more thermally uncomfortable. In short, immediate exercise on cold water may have a negative effect on some of the physiological and perceptual responses that are evoked.

Before leg only exercise (i.e., treading water) can be advocated as a having a physiologically beneficial influence on the CSR and can be fully advocated as a survival strategy on CWI irrespective of whether persons can float unaided, the consequent perceptual responses that are evoked must be considered. Indeed, it is known that thermal discomfort is a primary driver of behavioral thermoregulation [20] and treading water may actually exaggerate the disturbances that are seen. Likewise, any benefits to cerebral blood flow that are seen with treading water must be contrasted to a suitable resting control in cold water (i.e., remaining stationary/floating) and considered against a true thermoneutral control; previous studies have used temperate, 27°C [15,16] water which will induce a temperature driven vasoconstriction in contrast to thermoneutral skin temperatures [21]. Consequently, we tested the hypothesis that leg only exercise could offset the reduction in MCAv that we expected to ensue in a resting CWI and be absent in thermoneutral water immersion (H_1). However, we also hypothesised that the thermal perceptual (i.e., comfort and sensation) and ventilatory (i.e., extent of dyspnea) responses that would be seen on leg only exercise would be exaggerated by immediate leg movement on water entry because of repeated stimulation of cutaneous cold receptors that would be lower in a resting CWI and absent on thermoneutral water immersion (H_2). As a consequence of this repeated thermoreceptor stimulation caused by the continued water movement during leg kicking, we hypothesised that CSR magnitude and duration would be increased in contrast that seen in a resting CWI (H_3).

2.0 Materials and Methods

The Research Ethics Committee of Northumbria University granted ethical approval for the study which was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki. The participants gave their written informed consent to participate.

2.1 Participants

Seventeen healthy, non-smoking participants (9 male, 8 female) volunteered for the experiment (mean [SD]; Age 21 [3] yrs; height 1.71 [0.1] m; mass 70.9 [10.1] kg). The participants were non-smokers and were not cold water habituated. They abstained from alcohol and caffeine consumption for 24 hours before each test and undertaking any exercise on the day of the test.

2.2 Experimental Design

The study utilized a within participant repeated measures design. After having provided their consent, participants visited the laboratory on three occasions to complete three experimental conditions (immersions). The participants were blinded to the experimental manipulation (i.e., water temperature and physical activity to be undertaken) until their arrival for the experiment. Each participant completed, in a randomized order, three 5-minute immersions i) at rest in thermoneutral water (35°C; TN-Rest), ii) at rest in cold water (12°C;CWI-Rest) and iii) cold water with the immediate commencement of leg only exercise (12°C; CWI-Kick).

2.2.1 Procedure

All three immersions took place at the same time of day to minimise circadian variation in the responses. Following arrival at the Laboratory of Extreme Environments, each participant’s height (m) and mass (kg) were recorded using a stadiometer (Holtain limited, Crymych, Dyfed) and calibrated weighing scales (Seca Model 705 232 1009, Vogel & Halke, Hamburg, Germany). Each participant changed into their swimming costume; the same type of close fitting swimming costume was worn by the participant on each occasion. They then entered the laboratory wearing a bathrobe and sat adjacent to the immersion pool. They received a verbal briefing on the experimental procedure which was repeated on each occasion. They also had the perceptual scales (see measurements section for description) introduced to them. These were explained using a standardised format and designed to measure thermal sensation (TS), thermal comfort (TC) and the sensation of breathlessness (i.e., dyspnea) in response to each immersion. Once the procedures were verified as clear to them, they were instrumented with a heart rate monitor (Polar FT1, Polar Electro Oy, Kempele, Finland) to measure cardiac frequency (f_c) and a stable cerebral blood flow velocity signal was established from the middle cerebral artery (MCAv) using a 2-MHz transcranical doppler ultrasound system (Digi-Lite^{TM}, Rimed Inc, New York, USA). The MCA was chosen for insonation as it supplies a large proportion of the total cerebral blood flow [22]. The Doppler probe depth and anatomical location were recorded prior to the first immersion to enable a reproducible measurement site for the remaining immersions. During the immersions, the probe was fixed in place using a commercially available headframe (Marc 600, Spencer Technologies, USA). The participants were also instrumented with an oronasal mask with respiratory turbine and gas sampling hose attached to an online gas analyser (Oxycon Pro, Erich Jaeger GmbH, Hoechberg, Germany) to enable the measurement of oxygen consumption (VO_2), carbon dioxide production (VCO_2), respiratory frequency (f_R) and end tidal carbon dioxide pressure ($P_{ET}CO_2$). The spirometer was calibrated against a syringe of known volume (3 L syringe, Harvard Instruments, Harvard, USA) and the gas analyser was calibrated using a 2-point procedure against gases of certified concentration (BOC Gases, Guildford, Surrey, U.K).

Once instrumented the participants sat at rest for 5-minutes and provided a perceptual measurement for thermal perception and dyspnea before entering the water. All immersions took place in to the same immersion pool (iCoolSport, iSprint, Queensland, Australia), were to the same depth (i.e., to the sternal notch), were in the same posture (i.e. supine) and the cold water conditions were matched within 0.5°C. All water temperatures were verified by a thermistor (Grant Instruments (Cambridge) Ltd, Shepreth, United Kingdom) secured to the wall of the immersion pool attached to a data logger (1000 series, Squirrel Data Logger, Grant Instruments (Cambridge) LtD, Shepreth, U.K). The ambient temperature was displayed and recorded using a portable laboratory monitoring station (Digital weather station, Model BAA913HG, Oregon Scientific, Tualatin, Oregon, USA). Following a 10-seond verbal countdown the participant entered the water and completed full water entry within 3-seconds. In the TN-Rest and CWI-Rest conditions the participants remained stationary throughout the immersion. In the CWI-Kick condition the participant commenced leg only exercise at an intensity of 80 bpm^{-1}. In order to ensure the exercise intensity was standardised the participants were required to produce their lower limb movements in time with an audible metronome (Mobile Metronome Pro 1.2.4H for Android, Google Apps, Google, CA, USA). The kicking action corresponded most closely to the sculling pattern described by Schnitlzer et al [23] which has been classified as moderately complex and moderately efficient [23]. MCAv was recorded continuously throughout the immersion and the respiratory parameters were recorded breath by breath. Heart rate was manually recorded every 30-seconds with perceptual responses requested in the first, third and fifth minute of immersion.

Once the 5-minute immersion was complete, the participant exited the immersion pool and towel dried before taking a hot shower (cold immersions only). Before leaving the immersion facility the participant was asked for any subjective comments about the immersion experience.

2.2.2 Perceptual Measurements

Thermal Sensation: Participants reported their sensation of temperature on a 13-point Likert scale ranging from 1 – *unbearably cold* to 7 – *Neutral* to 13 - *unbearably hot* [24].

Thermal Comfort: Participants reported their sensation of temperature on a 7-point Likert scale ranging from 1 – *very comfortable* to 7 – *unbearably uncomfortable* [24].

2.2.3 Sensations of Dyspnea: Participants rated the extent to which they felt breathless (dyspnea) on a 10 cm visual analogue scale ranging from 0 cm - *not at all breathless* to 10cm *extremely breathless*; [24].

2.3 Data Analyses

The magnitude of the cold shock response was examined by automatically identifying the peak values recorded in f_R and the nadir in $P_{ET}CO_2$ that occurred immediately on immersion. The duration of the cold shock was examined by generating 1-minute averages for the pre-immersion phase and for each 1-minute period of the 5-minute immersion; comparisons were made within-participant across time for $P_{ET}CO_2$, VO_2, VCO_2, MCAv, f_c, f_R, dyspnea, TS and TC (across 4 time points in the perceptual variables only). Univariate analyses were checked for sphericity using Mauchley's test and, where non-spherical data sets were evident, a Huynh-Feldt adjustment was applied. The direction of statistically significant effects were determined using a *post-hoc* pair-wise comparisons procedure. For all statistical tests α level was set at 0.05. Data are presented as mean [SD]. All statistical tests were conducted using SPSS version 21 (IBM SPSS Statistics, Chicago, IL, USA).

3.0 Results

The water temperatures recorded in the TN-Rest, CWI-Rest and CWI-Kick conditions were 34.7 (2.6)°C, 12.2 (0.5)°C and 12.1 (0.5)°C respectively; the cold immersion water temperatures were not different (p = .470). The ambient temperatures were 22.5 (1.4)°C, 22.2 (2.0)°C and 22.6 (1.2)°C, respectively.

3.1.1 Magnitude of the CSR

Immersion, irrespective of water temperature, caused an increase in respiratory frequency (main effect for condition: $F_{(2, 31)} = 6.01$; p = .006). On average, the f_R was greater in both the CWI-Rest (43 (16) breaths.min^{-1}) and CWI-Kick (40 (11) breaths.min^{-1}) conditions than the TN-Rest condition (31 (7) breaths.min^{-1}; p = .012 & .008, respectively). The cold immersion conditions were not different (p = .474). The nadir $P_{ET}CO_2$ data showed a similar pattern being lowest in the CWI-Kick (2.7 (1.1) kpa) and CWI-Rest (2.8 (1.3) kpa) conditions than the TN-Rest condition (4.4 (0.5) kpa; p = .001 & .001, respectively). The cold immersion conditions were not different (p = .702).

3.1.2 Brain Blood Flow Velocity (MCAv)

During immersion consistent MCAv responses could not be established in two of the participants, consequently the MCAv data are for 15 participants. Immersion induced significant changes in MCAv but these responses were highly variable in each condition (interaction effect $F_{(4,56)} = 2.66$; p = .042; figure 1A). Immersion in the TN-Rest condition induced, on average, an increase in the MCAv throughout the 5-minute immersion period. Both the CWI-Rest and CWI-Kick conditions induced reductions in MCAv in the first two minutes of immersion following which an increase in MCAv was seen. This initial reduction was greatest in the CWI-Rest condition in contrast to the CWI-Kick condition which was never statistically different to the TN-Rest immersion.

**** INSERT FIGURE 1 NEAR HERE ****

3.1.3 Cardiorespiratory Responses to Immersion

Oxygen uptake (VO_2) was changed, on average, by the experimental manipulations (interaction effect: $F_{(5,83)} = 8.90$; p = .001) and was different in all conditions being greatest in the CWI-Kick condition (grand mean: 575 (67) mL) than both the CWI-Rest (486 (104) mL) and TN-Rest (434 (115) mL) conditions (p = .001 & .001, respectively) which were also different (p = .018). As the immersion ensued VO_2 was sustained at a higher level in the CWI-Kick condition than both the CWI-Rest and TN-Rest condition. After the second minute of immersion, all of the test conditions were different (figure 1B).

Similarly, carbon dioxide production (VCO_2) was highest, on average (interaction effect: $F_{(10,,160)} = 7.349$; p = .001), in the CWI-Kick condition (583 (179) mL) than both the CWI-Rest (493 (198) mL) and TN-Rest conditions (377 (82) mL; p = .008 & .001, respectively) which were also different being higher in the CWI-Rest condition (p = .004). As the immersion ensued the differences in VCO_2 were sustained as higher in the CWI-Kick condition; see figure 1C for time specific differences. The consequent effect of the higher CO_2 production was a significantly higher average RER ((interaction effect: $F_{(10,,160)} = 14.825$; p = .001)) in the CWI-Kick condition (0.98 (0.19) than the TN-Rest condition (0.88 (0.03; p = .012) but did not differ to the CWI-Rest condition (0.97 (0.18); p = .831). The TN-Rest condition neared being different to the CWI-Rest condition (p = .058). As the immersion ensued, the differences in RER were exclusively seen between the cold water conditions and the TN-Rest condition and were evident only for the first two minutes of immersion (table 1).

Consistent with the RER data, the $P_{ET}CO_2$ changed in response to immersion (interaction effect: $F_{(4, 75)} = 7.71$; p = .001) and was highest in the TN-Rest condition than both the CWI-Rest and CWI-Kick conditions (p = .010 & .002, respectively) which were not different (p = .153). Consistent with the average changes, as the immersion ensued higher $P_{ET}CO_2$ was seen between the TN-Rest condition (4.78 (0.11) kpa) and the CWI-Rest (4.31 (0.15) kpa) and CWI-Kick (4.17 (0.11) kpa) conditions until the third minute of immersion following which differences between the cold conditions started to occur (figure 1D). The f_R data followed a similar pattern being higher (interaction effect: $F_{(5,85)} = 3.25$; p = .009), on average, in the CWI-Kick condition than the CWI-Rest condition only (p = .013) and neared being different to the TN-Rest condition (p = .092). As the immersion ensued f_R remained higher in the CWI-Kick condition than the CWI-Rest and TN-rest conditions (table 1).

**** INSERT TABLE 1 NEAR HERE ****

The experimental manipulations also had a significant effect on the f_c response that was seen (interaction effect: ($F_{(10,160)} = 6.26$; p =.001)). On average only the CWI-Kick condition produced a higher f_c than the TN-Rest immersion (p = .014) which was not different to the CWI-Rest condition (p = .757). Both cold conditions were different with f_c being higher in the CWI-Kick condition (p = .001). Time point specific data indicated an anticipatory effect of impending immersion on f_c prior to cold-water immersion being higher on both occasions (p = .002 & .008) when compared to TN-Rest. As the immersion ensued the f_c persisted in being higher in the CWI-Kick condition (table 1).

**** INSERT FIGURE 2 NEAR HERE ****

3.1.4 Thermal Perceptions

Ratings of thermal sensation indicated the participants reported becoming ‘very cold’ (interaction effect: $F_{(6,90)} = 136.36$; p =.001) in both the CWI-Rest and CWI-Kick condition in contrast to TN-Rest condition where they remained ‘warm’ throughout (p = .001 & .001, respectively). These differences persisted across time but did not show any differences between the two cold conditions (p = .504) aside from at the first minute of immersion which neared being higher in the CWI-Kick condition (p = .06; figure 2A).

Thermal comfort ratings indicated the participants reported becoming ‘very uncomfortable’ (interaction effect: $F_{(6,90)} = 28.95$; p =.001) in both the CWI-Rest and CWI-Kick condition in contrast to TN-Rest condition where they remained ‘comfortable’ throughout (p = .001 & .001 respectively). These differences persisted across time but did not show any differences between the two cold conditions (p = .715; figure 2B).

3.1.5 Dyspnea Ratings

The participants reported becoming breathless on immersion (interaction effect: $F_{(6,90)} = 13.43$; p =.001; figure 2C) in the CWI-Rest and CWI-Kick conditions in contrast to the TN-Rest condition which was unchanged (p = .001 & .001, respectively). Ratings five times greater than at rest were reported in the cold conditions although neither cold condition differed from the other (p = .893).

4.0 Discussion

We tested the hypothesis that leg only exercise could offset the reduction in MCAv that we expected to ensue in a resting CWI and be absent in thermoneutral water immersion (H_1); we find partial support for this suggestion. We also hypothesised that the thermal perceptual (i.e., comfort and sensation) and ventilatory (i.e., extent of dyspnea) responses would be exaggerated by immediate leg movement on water entry because of repeated stimulation of cutaneous cold receptors which would not occur on resting cold and thermoneutral water immersion (H_2); we find no evidence to support this idea. As a consequence of this repeated thermoreceptor stimulation we hypothesised that the CSR magnitude and duration may be extended in contrast that seen in a resting CWI (H_3). Yet the components of the CSR remained unchanged; H_3 can therefore be rejected. The present data provide further evidence that leg only exercise (i.e., treading water) would be beneficial from the perspective of offsetting the reduction in brain blood flow that normally occurs during resting CWI. The safety behavior and advice that is underpinned by these data should be considered accordingly to reflect this new evidence.

Our MCAv data agree with those of Croft et al [15] and Button et al [16] after habituation and in skilled and unskilled swimmers respectively. They demonstrated that the reduction in MCAv seen on CWI could be minimised if treading water was commenced immediately on water entry; this was when contrasted to treading water in a temperate condition. We make the important addition of a suitable resting cold-water control (i.e., CWI-Rest) and a true thermoneutral resting control (i.e., TN-Rest) in unhabituated persons reflecting the majority of the population. The magnitude of the reduction in MCAv in our resting trial was also similar (i.e., ~6% *cf* 7%) to that of Mantoni et al [17] who studied resting ice water immersion. However, the present study observed a variation that was larger (SD = 9% *cf* 4%)

and more so during leg only exercise (16%). The inter-individual range in the first two minutes of immersion was also large with a peak reduction of ~23% seen in the CWI-Rest condition and ~35% in the CWI-Kick condition. It may be that those participants who show the greatest reduction in MCAv are most vulnerable to the symptoms of the CSR [17]. These individuals should be targeted for additional protection against the cold if they are at daily risk of accidental water entry.

It is feasible that some individuals will have the choice to either “float first” unaided after immersion has taken place or to commence treading water. For example, in a previous study [12] we found that with the addition of just 7 N of buoyancy, in the form of a pair of running trainers, 88 (30)% of our female cohort (n = 12) could keep their airway clear of the water (i.e., maintain freeboard) unaided when less than 25% of them could do so without the additional buoyancy provided by the footwear. This small amount of additional buoyancy tended to position the participants in a supine position as was used in the present study. By comparison, males were much less buoyant, probably because of their differing natural body composition in the form of lower body fat mass and a different fat distribution than females [26]. Hence, females could “float first” on their backs, unaided. In the same study, when a full winter clothing assembly was worn the floatation characteristics of the cohort improved further still; we contend that the majority of real life accidental CWIs would take place with at least some clothing being worn. Children also showed a high capability to float (94 (21)% of occasions) but male adolescents more so than their adult counterparts (92 (27)% of occasions; cohort of n = 16). Collectively, it seems that in the circumstance “floating first” might be achieved unaided, especially if clothing is worn but, in those who are not able to keep their airway clear of the water and in those who have a magnified CSR, treading water may aid survival because of the benefits to brain blood flow. It is difficult to convey these complexities in a simple safety maxim. Therefore “float first – and kick for your life” might be an accurate and encompassing amendment to the water safety behavior to deploy on accidental CWI.

The perceptual responses evoked by CWI in the CWI-Rest and CWI-Kick conditions were also of prime importance in the present study. Indeed, in order for immediate treading water to be advocated as an appropriate safety plan this behavior would need to avoid exacerbating the negative perceptions linked to the CSR. We found no evidence of this from the perceptual responses we recorded. Similarly the magnitude and duration of the CSR was not significantly influenced. Theoretically, remaining relatively still on cold water entry would minimise the thermal drive evoked by thermal stimulation of cutaneous cold receptors [18]. Immediate and extended movement on water entry, such as treading water, might maximise this thermal input by repeatedly stimulating the receptor thereby extending the duration of the CSR. This might be particularly applicable in a situation where a more substantial insulating boundary layer of water could build up, for example if clothing were worn; this represents an important future study. However, the time course of the CSR was far too short for this to be a factor in participants wearing only a bathing costume. One of the female participants commented that the CWI-Kick condition felt overwhelmingly colder and more unpleasant (we were careful to match water temperature within 0.5 °C of the CWI-Rest condition) but this assertion was not reflected in a significantly different perceptual response across our cohort of participants. It is possible that differing thermal perceptions by gender could be a factor in this scenario as has been shown in thermal perceptual studies in air [26]. Overall, the magnitude of thermal stimulation that was present in initial cold-water entry was sufficient to overwhelm any additional sensation driven from convective flow over the skin.

The present study is not without limitation. Clearly the laboratory conditions of the present tests are far removed from the real life scenario; alternatively Button et al [16] and Croft et al [15] did an excellent job of reducing this discrepancy. Yet, we were able to achieve an immersion speed (full immersion <3 seconds) close that of Button et al [16] and Croft et al [15] whilst standardising posture and leg kicking rate whilst others have not done so. We feel this helps the precision of our findings. It may also have been illuminating to include a clothed condition as this represents the majority of accidental immersion scenarios. In this scenario convection currents caused by limb movement may have produced more of a contrast between the experimental conditions [28]. Lastly, the exercise intensity we used in the present study was relatively modest and higher exercise intensities may have revealed a greater distinction between conditions. Likewise the addition of blood pressure measurement may have illuminated a mechanism underpinning our differences. With regard to exercise intensity, it is known that heat loss is accelerated during long-term CWI when even modest exercise is undertaken (e.g., 150 $W.m^2$ [29]). Using the average participant characteristics and work intensity in the CWI-Kick condition, participants in the present studied worked at approximately 103 $W.m^2$. Hence it is with the view to maximising survival prospects in the short-term whilst minimising the chances of developing hypothermia in the long-term that we selected this exercise intensity.

It is concluded that leg-kicking (i.e. treading water) may aid survival by offsetting the reduction in brain blood flow velocity that ordinarily occurs with resting CWI and may help keep the airway clear of the water. However, this behavior must be balanced against the possibility of an increased risk of aspirating water to the lung in the presence of higher exercise induced ventilation. Leg kicking did not result in any exaggerated physiological or psychological response by increasing water turbulence and therefore increasing cold-water convection. It is difficult to convey these complexities in a simple safety maxim. Therefore, “float first – and kick for your life” might be an accurate and encompassing amendment to the water safety behavior to deploy on accidental CWI.

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Figure Legends

Figure 1A-D. Mean (SD) MCAv, VO_2, VCO_2 and $P_{ET}CO_2$ responses prior to and on immersion in the TN-Rest, CWI-Rest and CWI-Kick conditions (n = 15 for MCAv; n = 17 for all other variables); a = $p<0.05$ TN-Rest *cf* CWI-Rest, b = $p<0.05$ TN-Rest *cf* CWI-Kick, c = $p<0.05$ CWI-Rest *cf* CWI-Kick, * = $p<0.05$ between all conditions.

Figure 2A-C. Mean (SD) TS, TC and dyspnea perceptual responses prior to and on immersion in the TN-Rest, CWI-Rest and CWI-Kick conditions (n = 17); a = $p<0.05$ TN-Rest *cf* CWI-Rest, b = $p<0.05$ TN-Rest *cf* CWI-Kick, c = $p<0.05$ CWI-Rest *cf* CWI-Kick, * = $p<0.05$ between all conditions.

Tables

Table 1. Mean (SD) f_c, f_R and RER responses on immersion in the TN-Rest, CWI-Rest and CWI-Kick conditions (*n* = 17); *a* = p<0.05 TN-Rest *cf* CWI-Rest, *b* = p<0.05 TN-Rest *cf* CWI-Kick, *c* = p<0.05 CWI-Rest *cf* CWI-Kick, * = p<0.05 between all conditions.

	1 MIN	2 MIN	3 MIN	4 MIN	5 MIN
TN-Rest f_c (b.min^{-1})	90 (14)^{a,b}	78 (14)^{b,c}	80 (15)^{c}	77 (15)^{c}	79 (15)^{c}
CWI-Rest f_c (b.min^{-1})	96 (16)	74 (14)	75 (14)	71 (14)	75 (15)
CWI-Kick f_c (b.min^{-1})	91 (15)	101 (14)	90 (14)	85 (14)	82 (14)
TN-Rest f_R (br.min^{-1})	23 (5)^{b}	20 (4)^{b,c}	20 (4)^{c}	18 (4)^{b,c}	20 (4)^{a,c}
CWI-Rest f_R (br.min^{-1})	26 (7)	19 (6)	18 (5)	17 (4)	19 (3)
CWI-Kick f_R (br.min^{-1})	27 (8)	23 (8)	22 (7)	22 (6)	21 (5)
TN-Rest RER	0.87 (0.10) ^{a,b}	0.82 (0.10) ^{a,b}	0.88 (0.10) ^{a,b}	0.89 (0.10) ^{a,b}	0.90 (0.10) ^{a,b}
CWI-Rest RER	1.22 (0.22)	1.07 (0.27)	0.91 (0.27)	0.83 (0.19)	0.79 (0.14)
CWI-Kick RER	1.21 (0.28)	1.14 (0.27)	0.92 (0.17)	0.84 (0.15)	0.79 (0.08)