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"Float first and kick for your life": Psychophysiological basis for safety behaviour on accidental short-term cold water immersion

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HIGHLIGHTS

- Accidental cold water immersion evokes the cold shock response.
- Brain blood flow is typically reduced by cold-water immersion.
- Leg-only exercise offsets the reduction in brain blood flow that occurs at rest.
- This may reduce symptoms of hyperventilation and dizziness.
- "Float first and kick for your life" may be a suitable survival behaviour.

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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 behaviour 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 the CSR's symptoms of breathlessness. We also examined whether perceptual responses instinctive to accidental CWI were exacerbated by this alternative behaviour. 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 dyspnoea. 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 behavioural response (i.e. perceptions). "Float first — and kick for your life" would be a suitable amendment to the water safety advice.

1. 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 behaviour 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

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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 s of immersion [3] and subsides within 5 min 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 dyspnoea 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 behavioural 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 dyspnoea) 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. 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 h 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, 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., dyspnoea) 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)