Habituation of the cold shock response may include a significant perceptual component

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Word Count Abstract: 249
Word Count Text: 3065
Number of tables: 1
Number of references: 12
Number of figures: 2

Re-submitted: July 2013

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Abstract

Introduction: Accidental immersion in cold water is a risk factor for many occupations. Habituation to cold-water immersion (CWI) is one practical means of reducing the cold shock response (CSR) on immersion. We investigated whether repeated thermoneutral water immersion (TWI) induced a perceptual habituation (*i.e.* could lessen perceived threat and anxiety) and consequently reduce the CSR on subsequent CWI. **Methods:** Twelve subjects completed seven, 7-minute head-out immersions. Immersions one and seven were CWIs (15.0 [0.1]°C), immersions two to six were TWI (34.9 [0.10]°C). Anxiety (20cm visual analogue scale) and the cardiorespiratory responses (heart rate [f_c]), respiratory frequency [f_R], tidal volume [V_T] and minute ventilation [$\dot{V}_E$)]) to immersion were measured throughout. Data were compared within subject between condition using ANOVA to an alpha level of 0.05. **Results:** Acute anxiety significantly reduced after repeated exposure to the immersion scenario (*i.e*. TWI); CWI-1: 6.3 [4.4]cm, CWI-2: 4.5 [4.0]cm (condition mean [SD]). These differences did not influence the peak in the CSR. The f_c, f_R and V_E responses were similar between CWI-1 and CWI-2. V_T response was significantly lower in CWI-2; mean [SD] across the immersion: CWI-1 1.27 [0.17] *vs*. CWI-2 1.11 [0.2]L. **Discussion:** Repeated TWI lessened the associated anxiety with CWI (perceptual habituation). This had a negligible effect on the primary components of the CSR but did lower V_T which may reduce the volume of any aspirated water in an emergency situation. Reducing the threat appraisal of an environmental stressor may be a useful bi-product of survival training thereby minimising psychophysiological strain.

Key words: Helicopter underwater escape, cold shock response, habituation, anxiety.

Introduction

Accidental cold-water immersion (CWI) is a risk factor for aviators and aircrew, for persons who work on or around cold water and the general public. The responses evoked by whole body CWI are life threatening and are described collectively as the “cold shock response.” The CSR is triggered by a rapid change in skin temperature and is characterised by an initial inspiratory gasp followed by uncontrollable hyperventilation and tachycardia which in combination impose a significant cardiorespiratory strain. In otherwise healthy individuals the loss of respiratory control that is of primary concern in the early minutes of immersion increasing the risk of aspirating water and drowning [10]. Using maximal breath-hold time as an index of respiratory control, only 34% of subjects completing offshore survival training could produce a breath-hold in cool water that was sufficient to enable them to egress a ditched and inverted helicopter in ideal conditions [5]. It is the short-fall between the maximum breath-hold time of individuals in cold water, and the time required to make an underwater escape from a helicopter (28-92 s; [5]), which provides the rationale for the use of survival aids that reduce the CSR or protect the airway until CSR subsides (*i.e.* immersion dry suits and Emergency Underwater Breathing Systems; [12]). However, survival aids are not always available if immersion is sudden and in these circumstances it is prudent to identify other means of reducing the CSR.

The CSR can be influenced by positive and negative psychological components [1,2]. Indeed, subjects who received a psychological skills training (PST) intervention improved (positive/beneficial effect) their maximal breath-hold time on immersion by 80% [2]. In contrast, in a separate recent study, components of the CSR (*i.e.* minute ventilation and heart rate) were increased (negative effect), which may increase the risk of drowning, when subjects were immersed in a hyper-anxious state [1]. The psychological component of the

CSR has also been studied after repeated CWIs which induce an habituation [3]. When PST was combined with habituation, subjects increased their maximal breath hold time by 26.86 (24.70) s. This beneficial effect equated to a 120% improvement on their maximal breath hold time in a control immersion. Importantly, the extent of the improvement *did not exceed* that of an "habituation alone" group who simply underwent repeated CWI and did not receive any psychological support [3]. This raises the possibility that repeated experience of the immersion scenario *per se*, as was the case with the "habituation alone" group, in itself confers a psychological benefit similar to that of PST. Theoretically subjects could evaluate the immersion scenario as being increasingly threatening or non-threatening depending on their appraisal of the psychological demands of the situation. It follows that those studies that have examined the effect of anxiety on the CSR, before and after habituation, indicate a change in appraisal [1,8] of the threat posed by imminent immersion. In these studies subjects were deceived about the expected water temperature as being 5°C colder than experienced previously; in reality it was unchanged [1]. The consequence of this re-appraisal was the negative emotional state of anxiety and a magnified CSR or a reversal of the previously habituated component of the CSR; both of which could be negative in the real life scenario. However, it has yet to be established whether habituation of this threat-perception carries a physiological benefit for the CSR.

Accordingly, we hypothesised that the CSR would be reduced after repeated exposure to the immersion scenario in the absence of a cold-water thermal stimulus which is known to, in part, produce an habituation. In short, we sought to separate the thermal and perceptual implications of habituation; anxiety rating was used as a surrogate of reduced threat perception and a change in appraisal of threat.

Method

Subjects

The study protocol was approved by the Biosciences Research Ethics Committee and the subjects gave their written informed consent. Twelve healthy, non-smoking subjects (8 male, 4 female) volunteered for the experiment (mean [SD]; Age 20 [1] yrs; height 1.72 [0.10] m; mass 70.48 [14.95] kg). The subjects were non-smokers, were not cold water habituated and were naïve to the aims of the experiment. They were asked to abstain pre-test from alcohol and caffeine consumption for 24 hours.

Experimental Design

The study utilized a within-subject repeated measures design. The subjects visited the laboratory on seven separate occasions to complete seven whole body water immersions; two CWI (immersions 1 & 7; water temperature [T_{water} 15°C]) and five habituation immersions into thermoneutral (35°C) water. Immersion (IMM) 1 and 7 took place at the same time of day to minimise circadian variation. IMM 2 to 6 were thermoneutral water immersions (TWI) and were performed in order to habituate the perceptual threat component associated with the immersion scenario; these were completed on separate days between 9 a.m and 5 p.m.

Procedure

Following arrival at the Extreme Environments Laboratory, each subject's height (m) and mass (kg) was recorded using a stadiometer (Bodycare Stadiometer, Leicester, U.K) and calibrated weighing scales (OHAUS digital weighing scales, New Jersey, USA). Each subject changed into a swimming costume; the same swimming costume was worn by the subject on each occasion. Subjects were then instrumented with a 3-lead ECG (HME Lifepulse, England) and entered an ambient temperature (T_a) controlled laboratory. They sat on an immersion chair attached to an electronic winch (CPM, F1-8; 2-8; 5-4, Yale, Shropshire, U.K) with a seat belt fastened around their waist to counteract buoyancy. The subject inserted a two-way mouthpiece (Harvard, USA) and attached a noseclip. The mouthpiece was connected to a spirometer (spirometric transducer module, KL Eng. Co, Northridge, USA) by respiratory tubing in order to measure the respiratory responses to immersion. The subject was winched above the immersion tank to rest for 1-minute. Thirty seconds in to the 1-minute rest period they provided their acute anxiety rating on a visual analogue scale; they were familiarised with the scale in advance of the study. Towards the end of the one-minute period a 10-second verbal countdown preceded the subject being lowered at a reproducible rate (8 $m \cdot min^{-1}$) until immersed to the clavicle; immersion depth was standardised within subject on each occasion. After 1,3,5 and 7-minutes of immersion they again reported their anxiety rating, following which they were winched from the immersion tank.

Measurements

T_w, T_a were measured and recorded using a calibrated thermistor (Grant Instruments (Cambridge) LtD, Shepreth, U.K) secured to the wall of the immersion tank and a Wet Bulb Globe Thermometer station respectively, both attached to a data logger (1000 series, Squirrel Data Logger, Grant Instruments (Cambridge) Ltd, Shepreth, U.K). Average T_w was closely matched within subject (± 0.1°C) between CWIs; T_w CWI-1 15.0 [0.1]°C, CWI-2 15.0 [0.2]°C. The average T_a during the CWIs was: CWI-1 22.6 [2.1] °C and CWI-2 21.0 [2.10]. T_w and T_a during TWI averaged 34.9 [0.1]°C and 24.7 [0.2]°C respectively across the 5 immersions.

The ECG and spirometer were interfaced with a digital data acquisition system (16SP PowerLab, Castle Hill, Australia) which captured data continuously throughout the rest and immersion periods. Chart analysis software (Chart version 6, AD Instruments, Axminster, Devon) was used to automatically identify R-waves from the ECG and calculate cardiac frequency (f_c); movement artefacts were visually identified and excluded from analysis. The spirometer was calibrated using a syringe of known volume (3 L syringe, Harvard Instruments, Harvard, USA). Respiratory frequency (f_R) was recorded by Chart analysis software using auto-recognition of the peak after inspiration. The peak value after the onset of inspiration was recorded as tidal volume (V_T) and multiplied by the calculated f_R to generate minute ventilation ($\dot{V}_E$). The state anxiety response to immersion was quantified using a 20 cm visual analogue scale (VAS) with descriptive phrases ranging from 0cm (*not at all anxious)* to 20cm (*extremely anxious)*.

Data Analyses

The normality of data were checked. With the exception of the state-anxiety data, the analyses were focussed on the CWI responses. The magnitude of the CSR was examined by visually identifying the absolute peak value (*i.e.* the highest 'true' value generated between two consecutive breaths) in f_c and f_R that occurred immediately prior to immersion and 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 7-minute immersion. Univariate analyses were checked for sphericity using Mauchley's test and, where non-spherical data sets were evident, a Greenhouse-Geisser 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 18 (Chicago, IL, USA).

The T_w and Ta during the CWI were compared using an independent samples t-test. The anxiety scores pre immersion and from minutes 1, 3, 5 and 7 were compared across all immersions using factorial ANOVA (condition [7] x time[5]). The peak in CSR (f_c & f_R) in each CWI were examined using a repeated measures ANOVA (condition [2] x time [2]). The duration of CSR was examined using the 1-minute average data for f_c, f_R, V_T, and $\dot{V}_E$ pre and on immersion using a separate repeated measures factorial ANOVA (condition [2] x time [8]).

Results

There was no significant difference in the T_w (t = 1.958, p = .537) or T_a (t = .963, p = .903) between CWI-1 and CWI-2.

Subject's state anxiety peaked prior to immersion and gradually declined from minute 1 to minute 7 of the immersion irrespective of water temperature (significant main effects for time; F(4,44) = 11.695, p = .001). The anxiety experienced prior to and during CWI was significantly greater than that evident during TWI (significant main effects for condition; F(6,66) = 16.247, p = .001). Anxiety associated with TWI gradually declined from TWI 1 to TWI 3 following which there were no differences in the anxiety reported indicating a plateau in the response and a perceptual habituation. There were significant differences in the anxiety experienced during CWI-2 being lower overall than CWI-1 (p = .013). Time point specific differences were also evident at minutes 1 (p = .025), 3 (p = .042), 5 (p = .001) and neared being different after 7-minutes of immersion (p = .052); pre immersion the anxiety ratings were similar (p = .296). Interaction effects were also evident (F(24,264) = 4.574, p = .008). State anxiety responses are summarised in figure 1.

INSERT FIGURE 1 NEAR HERE

The peak in the CSR during CWI occurred on immersion in both f_c (F(1,11) = 62.117, p = .001) and f_R (F(1,11) = 48.505, p = .001). The significant differences in anxiety did not influence the peak in the CSR (no main effect for condition: f_c; F(1,11) = .001, p = .986) f_R; F(1,11) = .471, p = .507) in anticipation of immersion (peak f_c CWI-1: 105 [17] *vs*.CWI-2 105 [19] $b.min^{-1}$ and f_R 32 [8] *vs*.31 [9] $breaths.min^{-1}$) or on immersion (peak f_c was CWI-1: 126 [19] *vs*.CWI-2 127 [19] $b.min^{-1}$ and f_R 84 [28] *vs*.80 [31] $breaths.min^{-1}$. There were no interaction effects (f_c; F(1,11) = .034, p = .857) f_R; F(1,11) = .186, p = .657).

Consistent with the state anxiety responses and peak CSR data, the 1-minute averaged CSR data increased from pre to on immersion and gradually declined as the immersion ensued (significant main effects for f_c, f_R, $\dot{V}_E$ and V_T; p<0.05). Each minute across the immersion the f_c, f_R, and $\dot{V}_E$ responses were similar between CWI-1 and CWI-2 (no significant main condition effect for these variables; p>0.05); see table I. Similarly, f_c, f_R, and $\dot{V}_E$ also showed no interaction effect (p>0.05) but the V_T response decreased at a significantly faster rate in CWI-2 (main interaction effect F(7,77) = 2.970, p = .041). Time point specific differences were evident after 2 (p = .025) and 6 (p = .046) minutes of immersion, neared being different at 4 minutes (p = .069) of immersion and had a tendency to be lower throughout (see figure 2); mean [SD] across the immersion: CWI-1 1.27 [0.17] vs. CWI-2 1.11 [0.2] L.

INSERT TABLE I NEAR HERE

INSERT FIGURE 2 NEAR HERE

Discussion

This study examined the possibility that the CSR could be reduced by habituation of the perceptual component of the CSR alone in the absence of any repeated cold-water stimulation. The significant difference in anxiety data during CWI-2 (figure 1), as a consequence of repeated TWI, are consistent with the idea that subjects began to evaluate the immersion scenario *per se* as less threatening. This perceptual change did not induce any significant alteration in the CSR peak or in the majority of CSR variables. However, the ventilatory component of the CSR (V_T) was significantly lower in CWI-2 than CWI-1 which suggests the lower anxiety ratings in CWI-2, at least in part, culminated in an altered physiological response. This difference was not of a sufficiently consistent magnitude, when coupled with f_R data, to equate to an increase in $\dot{V}_E$. Collectively, these data enable our hypothesis only to be partly accepted.

Previous literature suggests an increase in acute anxiety has the potential to magnify the f_c and sustain the ventilatory components of the CSR, on average, even after habituation has taken place [1]. However, it seems that an increase in state anxiety has a greater influence on components of the CSR, irrespective of habituation, than the modest reduction seen with the habituation of the perceptual component of the response as demonstrated in the present study. The findings of the present study also contextualise the data of Barwood et al [3], who suggested that CSR habituation may include a perceptual component. The lack of difference in maximal breath-hold time (a surrogate of respiratory control) between an 'habituation alone' and an habituation plus PST group observed in their study appeared to suggest the presence an inherent perceptual and evaluative component to an habituation regimen.

Previous studies examining habituation of the cold pressor response during hand immersion have suggested that perceptual afferent information, in the form of an increase in anxiety, arriving for processing at the same time as thermal afferent information has the potential to disrupt the central nervous system processing of the temperature related sensory information [7]. We supported this idea in whole body immersion, and suggested a role for the amygdala in appraising the emotional valence of the environmental stimuli prior to and on immersion [1] and the present and the previous studies now seem to highlight a need to confirm this idea. In support, it is known that the amygdala is involved in the central nervous system response to psychological stress and anxiety. It is also known that the amygdala projects to dorsomedial hypothalamus which provides at least one viable route by which the efferent response during CWI may be influenced [6]. From a psychological perspective, current stress theory would suggest that repeated exposure to the immersion scenario would culminate in a change in the primary (i.e. importance, novelty) or secondary (i.e. coping resources) appraisal of the immersion scenario as threatening [8]. The present study suggests that this, in part, has some physiological consequence.

This study is not without limitation. Indeed, the study lacks a distinct control group to directly test the hypothesis that the anxiety rating, and therefore the threat perception, is not naturally lower on secondary CWI in contrast to an initial CWI. However, this idea can be roundly rejected based on evidence from other studies that have examined the anxiety response over consecutive immersions [1] or examined the extent of the CSR across two CWIs [11]. Indeed, it seems that an *increased* or *unchanged* anxiety rating is more likely in consecutive immersions accompanied by an increased or matched CSR [2]. Other prominent researchers in this area concur that, possibly due to re-calibration of expectation after initial immersion (subjects often report greater perceived CSR than expected in the first CWI), the

CSR on secondary immersion is more likely to be greater than lesser (personal communication Prof. M. J Tipton). The reverse of which was evident in the present study. One such solution for this oversight would be to match subjects based on their initial CWI response and examine for any differences in the response with and without five TWI between two CWIs. However, it is difficult to determine exactly which CSR matching criteria should be used and, coupled with other literature evidence, this seems unnecessary. The findings are also limited to the specific cohort we tested; variations associated with selection bias, swimming capability, gender, ethnic group and occupational background cannot be uncovered by the data produced by the present study.

The practical implications of our findings are important. Indeed, given that the aspiration of as little as 22 mL.kg of seawater can be fatal (1.65 L an average 75 kg individual; [9]), even the relatively small reduction in V_T seen in the present study as a consequence of the perceptual habituation could be meaningful in reducing the potential volume of water aspirated on accidental CWI. It is also possible that perceptual habituation may be achieved through repeated exposure to other emergency test scenarios such as survival training. Indeed, helicopter underwater escape training (HUET), may represent a means of inducing threat reappraisal of a ditch scenario and consequently the associated anxiety in the real life situation. Consistent with this idea, Tipton et al [11] reported lower heart rate responses to repeated HUET tests (a possible perceptual habituation) in the absence of any repeated CWI. Similarly, Brooks et al [4] treated a subject who was excessively anxious and underperforming in HUET tests by repeatedly exposing him to parts of the test scenario and reducing the associated anxiety. With this treatment, the subject eventually passed the HUET test course. Based on evidence from the work of Tipton [11] and Brooks [4] and that reported in the present study, it may be that survival training carries a perceptual habituation and consequent reduction in the physiological response to a given test scenario that carries over to the emergency situation. However, we are not suggesting that thermoneutral immersion is entirely sufficient to enable habituation; it probably comprises only a small part of the response. Therefore, replicating the likely environmental conditions as closely as possible during survival training is most likely to confer a benefit in the emergency scenario.

In summary, our data show that repeated exposure to the immersion scenario, in the absence of repeated cold-water stimulation, reduces the ventilatory component of the CSR. Given that surviving an accidental immersion is decided by fine margins, this difference could be meaningful in the real life scenario.

Acknowledgements

The authors wish to thank Miss Sarah Barnes, Miss Stephanie Bone, Mr Daniel Fitzgerald, Miss Alice Fryer, Mr Frazer Laird, Mr David Moon, Mr Alex Payne, Mr Arron Pounds, Mr Joe Renton, and Miss Charlotte Scaiffe for their support with data collection. We also wish to thank the subjects for their reliability and forbearance and the technical support staff who worked on this project.

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Table I. Mean [SD] 1 minute averaged f_c, f_R, and $\dot{V}_E$ responses in CWI-1 and CWI-2 (n = 12).

	PRE	MIN 1	MIN 2	MIN 3	MIN 4	MIN 5	MIN 6	MIN 7
CWI-1	91	95	90	87	83	81	80	78
f_c (b.min^{-1})	[17]	[19]	[19]	[18]	[16]	[15]	[13]	[15]
CWI-2	93	91	89	85	84	82	80	81
f_c (b.min^{-1})	[21]	[21]	[19]	[17]	[16]	[15]	[15]	[15]
CWI-1	19	29	21	20	19	20	21	21
f_R (br.min^{-1})	[4]	[7]	[5]	[5]	[5]	[5]	[7]	[6]
CWI-2	19	27	21	20	19	19	19	19
f_R (br.min^{-1})	[4]	[8]	[8]	[4]	[4]	[4]	[5]	[4]
CWI-1	16.8	41.1	28.5	24.0	23.6	23.50	24.0	23.2
$\dot{V}_E$ (L.min^{-1})	[4.3]	[13.9]	[12.2]	[10.3]	[12.4]	[14.1]	[14]	[15.4]
CWI-2	17.2	40.6	24.8	21.1	19.0	18.1	17.1	17.8
$\dot{V}_E$ (L.min^{-1})	[3.2]	[15.4]	[9.5]	[7.0]	[7.2]	[6.0]	[6.1]	[5.6]

Figure Captions

Figure 1. Mean (SD) acute anxiety response to CWI-1 and 2 and TWI 1 to 5; * indicates significant difference between condition; ♯indicates significant difference between CWI-1 and CWI2 (n = 12).

Figure 2. Mean (SD) V_T response to CWI-1 and 2; * indicates significant interaction effect; ♯ indicates significant difference between CWI-1 and CWI2 (n = 12).