Eur J Appl Physiol (2000) 83: 17–21

ORIGINAL ARTICLE

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Permanence of the habituation of the initial responses to cold-water immersion in humans

Accepted: 25 May 2000

Abstract Sudden immersion in cold water initiates an inspiratory gasp response followed by uncontrollable hyperventilation and tachycardia. It is known that this response, termed the "cold shock" response, can be attenuated following repeated immersion. In the present investigation we examined how long this habituation lasts. Twelve healthy male volunteers participated in the experiment, they were divided into a control (C) group ($n = 4$), and a habituation (H) group ($n = 8$). In October, each subject undertook two 3-min head-out seated immersions into stirred water at 10 °C wearing swimming trunks. These immersions took place at the same time of day, with 4 days separating the two immersions. In the intervening period, the C group were not exposed to cold water, while the H group undertook six, 3-min head-out immersions in water at 15 °C. Two months (December), 4 months (February), 7 months (May) and 14 months (January) after their first immersion, all subjects undertook another 3-min head-out immersion in water at 10 °C. The H group showed a reduction in respiratory frequency (47 to 24 breaths $\cdot$ min^{-1}), inspiratory minute volume (72.2 to 31.3 l $\cdot$ min^{-1}) and heart rate (128 to 109 beats $\cdot$ min^{-1}) during the first 30 s of immersion on day 5 compared to day 1. Seven months later these responses were still significantly reduced compared to day 1. After 14 months, heart rate remained attenuated but respiratory frequency and inspiratory minute volume had returned towards pre-habituation levels. The responses of the C group during the first 30 s of immersion were not altered. Both groups showed an attenuation in the responses during the remaining 150 s of immersion following repeated immersions. It is concluded that repeated immersions in cold water result in a long-lasting (7–14 months) reduction in the magnitude of the cold shock response. Less frequent immersions produced a decrease in the duration, but not the magnitude of the response.

Key words Cold · Immersion · Cold shock · Habituation

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Introduction

It has been estimated that approximately 7 million people in the United Kingdom currently participate in water-based leisure activities (Tipton and Golden 1994). In some cases these activities require deliberate immersion in cold water, for example swimming, triathlons and diving, whilst for others such as sailing, canoeing, rowing and fishing, accidental immersion is an ever-present risk. Many occupational groups, including search and rescue personnel, naval personnel and off-shore workers, are also regularly exposed to the risk of immersion in cold water.

In the United Kingdom alone, approximately 450 deaths occur each year in open water (Hutchinson 1998), most of these deaths occur within 3 m of a safe haven and involve "good" swimmers (Home Office 1977). In these cases it is unlikely that hypothermia is the precursor to drowning, more probably it is the cardio-respiratory responses that occur in the first few minutes of immersion, termed the "cold shock" response, that are responsible. These responses are initiated by stimulation of the cutaneous cold receptors, and comprise a reflex inspiratory gasp, followed by a short period of uncontrollable hyperventilation and tachycardia (Tipton 1989). The reduction in both breath-hold time and voluntary control over breathing during this time increases the chances of aspirating water and drowning. For individuals with underlying heart or circulatory pathology, the increased cardiac workload associated with the tachycardia and cold-induced vasoconstriction may result in a cardiovascular accident.

It has been shown that the cold shock response is reduced following repeated immersions in cold water (Keatinge and Evans 1961; Golden and Tipton 1988). The mechanism underlying this attenuation is unclear, but appears to take the form of a habituation. Recent studies have indicated that the majority of the alterations that result in this habituation occur centrally (Tipton et al. 1998a). In addition, the process of habituation is not strictly temperature dependent, in that the rate of change of skin temperature (T_{sk}) initiated by immersion in water at 15 °C has been found to be a sufficient stimulus to reduce the response to immersion in water at 10 °C (Tipton et al. 1998b). These studies indicate that a habituation of the cold shock response could be obtained through an acceptable regime of repeated immersions in cool water for individuals who are at particular risk of accidental immersion.

The value of such a regime will be directly related to the length of time the habituation lasts, once established. The permanence of the habituation of the cold shock response is not known, although previous unpublished data on two subjects indicate that the attenuation may last for up to 6 months (Tipton 1986). The hypothesis of the current investigation was that habituation of the cold shock response to immersion in water at 10 °C would be retained for several months after the habituation was produced.

Methods

The methods for this experiment have been described previously (Tipton et al. 1998b). The experimental protocol was approved by the ethics committees of the Universities of Surrey and Ljubljana. Twelve healthy male volunteers aged 18–32 years participated in the experiment after passing a medical examination and giving their informed written consent. None of the subjects had previously participated in cold-water immersions, and they were not acclimatised to cold.

The subjects were randomly divided into two groups, a control (C) group ($n = 4$), and a habituation (H) group ($n = 8$). In October, each subject undertook two 3-min head-out seated immersions into stirred water at 10 °C wearing swimming trunks. These immersions took place at the same time of day and with 4 days separating the two immersions (day 1 and day 5). In the intervening period, the C group were not further exposed to cold water, but the H group undertook two 3-min, head-out seated immersions into stirred water at 15 °C on each of the intervening days, one in the morning and one in the afternoon (a total of six) to produce an habituation to the responses to immersion in water at 10 °C. Two months (December; 64 days), 4 months (February; 120 days), 7 months (May, 226 days) and again 14 months (January, 453 days) after their first immersion, each subject undertook another 3-min head-out seated immersion into stirred water at 10 °C.

Prior to immersion, the subjects rested in air at a temperature of 26.3 ± 1.2 °C. One minute before immersion the chair was suspended 50 mm above the water surface, the subjects were then lowered into the water to the level of the laryngeal prominence at a rate of 0.2 $m \cdot s^{-1}$ using an electric winch. Throughout the immersions the subjects were instructed to relax and to breathe freely.

The subjects wore a nose clip and breathed through a mouthpiece throughout each experiment. Inspiratory minute volume ($\dot{V}_I$), respiratory frequency (f_b) and tidal volume (V_T) were measured continuously using a pneumotachograph and integrator unit (Morgan, Kent, UK) or spirometric module (KL Engineering, California, USA) placed on the inspiratory side of the respiratory tubing. Heart rate (f_c) was monitored continuously from a hard-wire 3-lead electrocardiogram (Schiller, Switzerland). $\dot{V}_I$ and f_b were recorded on a pen recorder (Gould Series 2600S recorder, Ohio, USA).

T_{sk} was measured using skin thermistors (Yellow Springs Instruments, Ohio, USA) that were attached to the skin with adhesive tape at four sites: chest, arm, thigh and calf. T_{sk} data were recorded and stored at 30-s intervals using a Hewlett Packard data acquisition system (Hewlett Packard, Massachusetts, USA), controlled by a microcomputer (Apple Macintosh, California, USA) with LabView software (National Instruments, Austin, Tex., USA).

Percentage body fat was calculated from the sum of skinfold thickness at the biceps, triceps, suprailiac and subscapula, according to the method described by Durnin and Womersley (1974).

Data analysis

As there appeared to be a biphasic response to each immersion, the results were analysed over two time periods, from 0 to 30 s and from 30 to 180 s. Statistical significance was examined using a repeated-measures analysis of variance (ANOVA) model that included linear additive terms for group, immersion occasion effects, and the interaction between these two factors (between-group comparison). Data analyses were conducted using GENSTAT (statistical language, commercially available from NAG, Oxford, UK). Missing data values were estimated within the GENSTAT ANOVA routine. Any differences identified were examined further using the Scheffé method of contrasts (within-subject comparison). A probability level of 5% ($P < 0.05$) was considered as statistically significant.

Results

The mean (SD) physical characteristics of the subjects were similar ($P > 0.05$) for both groups [C group: age 21.3 (1.3) years; height 1.83 (0.09) m; body mass 80.5 (8.1) kg; body surface area 1.96 (0.22) m^2; body fat 13.3 (3.3)%. H group: age 21.8 (0.5) years; height 1.85 (0.05) m; body mass 78.9 (8.0) kg; body surface area 1.98 (0.19) m^2; body fat 14.0 (2.3)%].

Only four subjects in the H group were able to undertake all six immersions in water at 10 °C. One subject missed the immersions on days 64 and 120; two subjects missed the immersion on day 226; and one subject missed the last two immersions (days 226 and 453). All of the subjects in the C group completed their six immersions.

The magnitude of the initial responses to cold-water immersion varied considerably between individuals; numerically the H group appeared to show greater mean responses on the first immersion, but these differences were not significant ($P > 0.05$). Since this individual variability in response, and the fact that we were interested in the change in response over the 14-month period, the data were analysed using a within-subject design.

The rate of fall in T_{sk} on immersion in water at 10 °C did not differ significantly between groups, and averaged 0.42 $°C \cdot s^{-1}$.

Control (C) group

The C group showed no significant differences in f_b between immersions on days 1, 5, 64, 120, 226 and 453

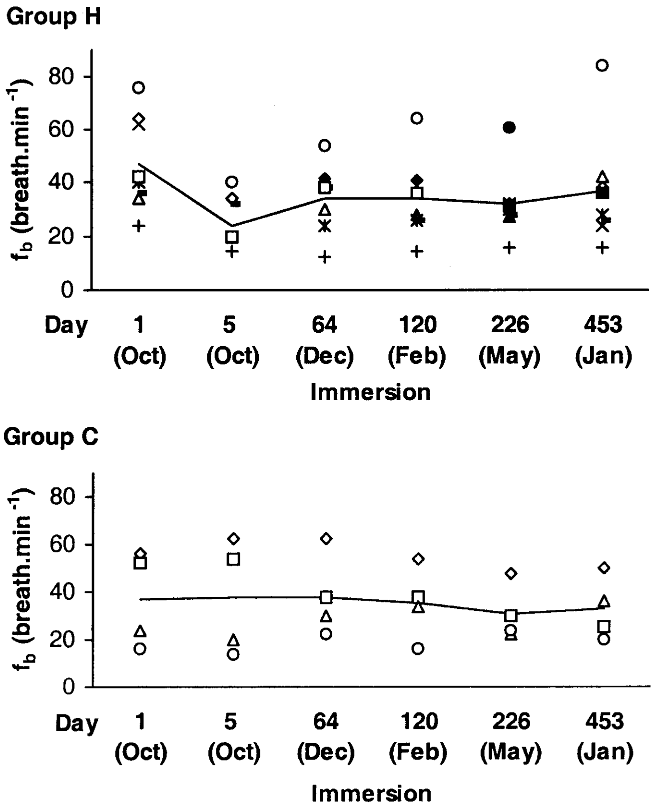

Fig. 1 Respiratory frequency of the H group (*top graph*, $n = 8$) and C group (*bottom graph*, $n = 4$) during the first 30 s of immersion in water at 10 °C. Habituation to cold-water immersion took place between days 1 and 5. The data from each subject are distinguished by a different symbol, a *filled* symbol indicates that data is missing for this immersion and the data have been estimated using GENSTAT. The *line* indicates the arithmetic mean for the group

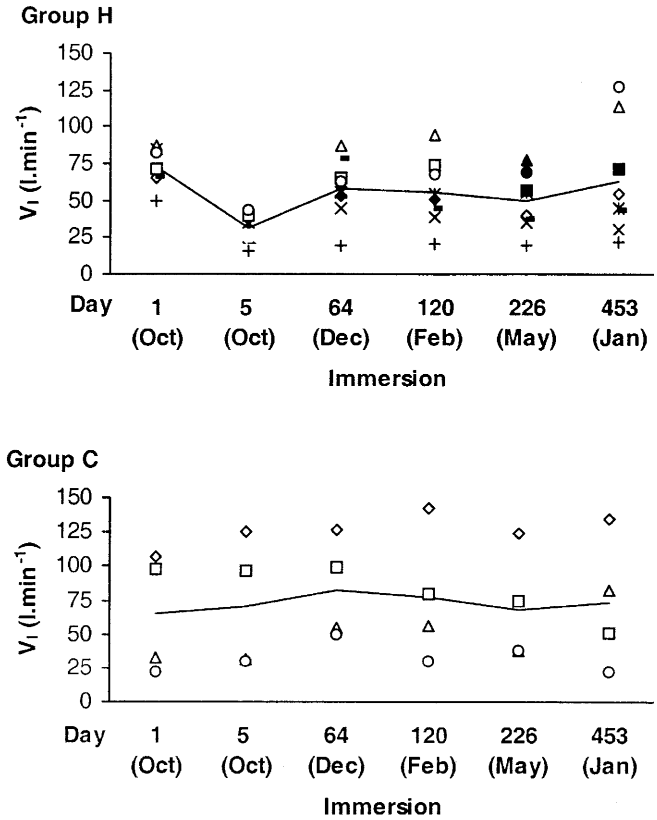

Fig. 2 Inspiratory minute volume of the H group (*top graph*, $n = 8$) and C group (*bottom graph*, $n = 4$) during the first 30 s of immersion in water at 10 °C. Habituation to cold-water immersion took place between days 1 and 5. The data from each subject are distinguished by a different symbol, a *filled* symbol indicates that data is missing for this immersion and the data have been estimated using GENSTAT. The *line* indicates the arithmetic mean for the group

(Fig. 1). Over the first 30 s of immersions, the $\dot{V}_I$ and V_T responses remained unchanged over the 14-month period (Fig. 2; $P > 0.05$). During the latter 150 s of immersions, both the $\dot{V}_I$ and V_T responses were lower ($P < 0.05$) during the last three immersions (days 120, 226 and 453) compared to that observed during the first three immersions (days 1, 5 and 64; Table 1). The f_c response was not altered in the first 30 s of immersions (Fig. 3), but was reduced ($P < 0.05$) over the last 150 s on days 5–453 compared to that observed on day 1 (Table 1). This reduction was similar to that seen in the H group.

Habituation (H) group

After repeated immersion in water at 15 °C the H group showed a habituation of the responses to immersion in water at 10 °C. The f_b (Fig. 1), $\dot{V}_I$ (Fig. 2) and f_c (Fig. 3) responses to cold-water immersion were attenuated on

Table 1 Mean responses of both groups during the last 2.5 min of 3-min immersions in water at 10 °C. The range is given in parentheses (H group $n = 8$; C group $n = 4$). (f_b Respiratory frequency, $\dot{V}_I$ inspired minute ventilation, V_T tidal volume, f_c heart rate)

Variable	Time	Day 1	Day 5	Day 64	Day 120	Day 226	Day 453
f_b (breaths · min^{-1})	Group H	32 (12–54)	18 (9–30)	22 (9–36)	22 (10–36)	21 (10–34)	20 (10–29)
	Group C	29 (10–52)	27 (12–40)	29 (16–36)	23 (14–32)	19 (15–22)	18 (13–26)
$\dot{V}_I$ (l · min^{-1})	Group H	56.8 (25.5–78.0)	17.5 (8.5–22.4)	29.4 (13.8–57.3)	28.6 (12.9–64.0)	25.1 (11.8–49.0)	25.4 (12.1–55.7)
	Group C	58.8 (16.7–92.8)	47.3 (15.1–76.5)	65.2 (38.8–95.5)	35.5 (21.2–51.0)	30.2 (18.1–55.4)	29.6 (14.4–52.9)
V_T (l)	Group H	1.85 (1.23–2.79)	1.10 (0.53–1.95)	1.42 (0.99–2.38)	1.33 (0.76–2.46)	1.15 (0.71–1.90)	1.18 (0.78–1.93)
	Group C	2.00 (1.60–2.80)	1.65 (1.24–2.32)	2.23 (1.42–2.65)	1.54 (1.33–1.89)	1.55 (1.18–2.56)	1.54 (1.11–2.50)
f_c (beats · min^{-1})	Group H	116 (91–138)	90 (61–110)	90 (64–103)	94 (60–110)	77 (55–94)	84 (63–115)
	Group C	104 (87–115)	89 (64–100)	96 (78–106)	84 (57–103)	75 (64–93)	80 (64–100)

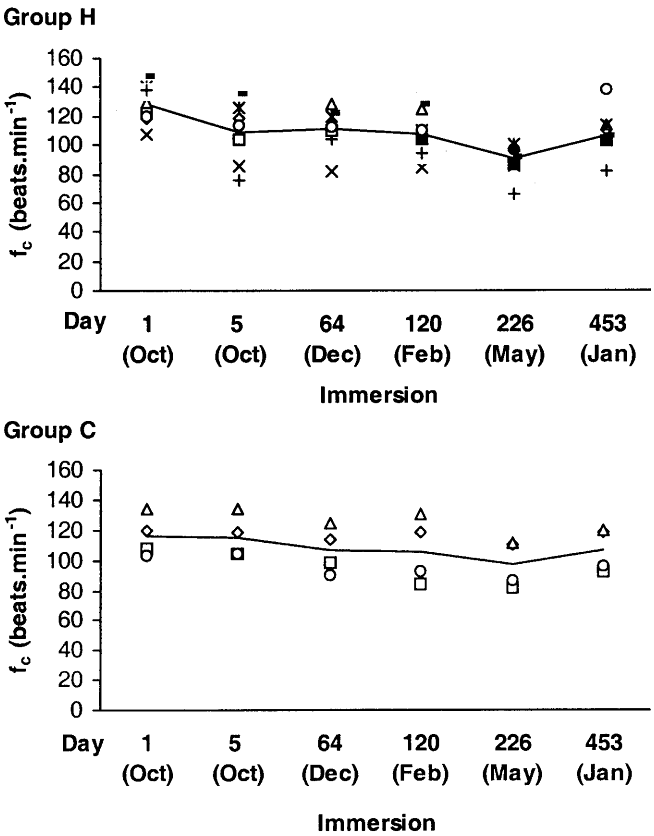

Fig. 3 Heart rate of the H group (*top graph*, $n = 8$) and C group (*bottom graph*, $n = 4$) during the first 30 s of immersion in water at 10 °C. Habituation to cold-water immersion took place between days 1 and 5. The data from each subject are distinguished by a different symbol, a *filled* symbol indicates data is missing for this immersion and the data have been estimated using GENSTAT. The *line* indicates the mean for the group

day 5 compared to day 1 ($P < 0.05$ over both time periods; Table 1). Up to 7 months (day 226) after the habituation process, these responses remained lower than those seen on day 1 ($P < 0.05$). After 14 months (day 453), f_c was significantly reduced ($P < 0.05$), but the decrease in f_b and $\dot{V}_I$ over the first 30 s of immersion was no longer statistically significant ($P < 0.1$). The f_b, $\dot{V}_I$ and f_c responses during the latter 2.5 min of immersion remained reduced 14 months after the first immersion ($P < 0.05$; Table 1). The V_T response on days 1 and 5 did not differ over the first 30 s, but was reduced ($P < 0.05$) during the last 150 s of immersion (Table 1).

Discussion

We have reported previously that repeated immersion in water at 15 °C can reduce the responses to immersion in water at 10 °C (Tipton et al. 1998b), this paper focuses on the permanence of this habituation.

An earlier unpublished preliminary investigation using only two subjects (Tipton 1986), indicated that the cold shock response remains attenuated for up to 6 months after the initial period of habituation. The results of the present investigation confirm that the permanence of this habituation is measurable in months rather than days; the responses that showed a habituation remained attenuated 7 months after the habituation was established. It appears from the data (Figs. 1, 2, 3) that most of the loss of habituation that occurred following repeated immersions, did so in the first 2 months. Between 2 and 14 months there was then a slower rate of loss of the habituation in the majority of subjects.

Taking the average f_b, $\dot{V}_I$ and f_c responses over the first 30 s of immersion to represent the cold shock response, the reductions in this response during 10 °C immersion compared to pre-habituation were: 40% immediately after habituation (day 5); 20% 2 months after habituation (day 64); 23% 4 months after habituation (day 120); 31% 7 months after habituation (day 226); and 18% 14 months after habituation (day 453). These figures represent a significant reduction in the respiratory drive, and therefore the threat associated with initial immersion. This finding suggests that at least half of the habituation developed by the repeated immersions was relatively "permanent".

Examination of the individual data revealed that one of the subjects in the H group showed a progressive increase in his responses following habituation (day 5, Fig. 1 top graph). It could be that for this individual the threshold for producing a "permanent" habituation was not reached; although repeated immersions in water at 15 °C reduced his initial responses, the magnitude of his response on day 5 was still greater than that of the other subjects. Another subject in group H also showed an increase in his response at month 14 compared to day 1. It is notable that both subjects were unable to undertake their immersions at month 7, and suggesting that this influenced their responses at month 14. Thus, the two subjects who had 10 months between immersions lost their habituation. This raises the questions of inter-subject adaptability and whether periodic immersions are required to maintain the habituation.

Periodic immersions in water at 10 °C did not alter any of the responses of the C group during the first 30 s of immersion. However, in the remaining 150 s, reductions were observed in $\dot{V}_I$, V_T and f_c. Thus, the periodic immersions of C group did not alter the magnitude of the responses, but may have reduced their duration such that they returned towards baseline levels more rapidly. Following habituation, the H group showed both a reduction in the magnitude of the response initiated and a faster return towards baseline levels. Following accidental immersion of an otherwise healthy individual into cold choppy water, both the magnitude and duration of the initial respiratory drive and the associated ability to control breathing will determine the risk of drowning.

Studies of peripheral acclimatisation to cold support the hypothesis that cold-induced alterations in function may last some considerable time. Eagan (1963) reported that Eskimos showed a higher finger blood flow than mountaineers and office staff on exposure to cold, and that this difference was still evident after 9 months in a temperate environment. Similarly, LeBlanc (1966) reported that Gaspé fishermen showed a reduced vasoconstriction during cold-water immersion of the hand, and this effect lasted for approximately 15 years after they had stopped fishing. It is possible that these responses and those of the present study are all the result of a decreased activation of the sympathetic nervous system following repeated exposure to cold; such a reduction has been reported in the literature (LeBlanc 1978). However, it is also possible that the alterations observed in the earlier studies of peripheral blood flow were pathophysiological rather than adaptive in nature.

Studies in animals have also indicated that adaptation to cold can have a long-lasting effect. Repetitive exposure of rats to cold (5 °C for 4 h per day for 2 weeks) was found to improve cold tolerance and increase non-shivering thermogenesis (Doi and Kuroshima 1979). This adaptation was found to last for 4 weeks when produced in adult rats, and 18 weeks when produced in infancy. The longer-lasting effect observed in infantile rats would suggest an adaptation of the developing central nervous system.

It is concluded that habituation of the cold shock response can last, at least in part, for many months, although periodic cold exposures may be necessary to maintain it. The relative permanence of the habituation means that it may be a practical, cheap and physiological method of those at risk of immersion in cold water.

Acknowledgements The authors would like to thank the subjects for their reliability and courage, Dr. R. Pethybridge for assistance with the various statistical analyses, and Dr. C. Higenbottam and Dr. F. Golden for their help and support. This work was funded by TG5 of the MoD Corporate Research Package.

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