# The Influence of Regional Insulation on the Initial Responses to Cold Immersion

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TIPTON MJ, GOLDEN FSTC. *The influence of regional insulation on the initial responses to cold immersion.* Aviat. Space Environ. Med. 1987; 58:1192–6.

**Twelve healthy male subjects performed three 10-min head-out immersions in water at 10°C. The responses of the subjects to immersion were recorded under three conditions: a) Control condition (CC)—torso and limbs exposed; b) Torso protected/limbs exposed condition (TPC); and c) Limbs protected/torso exposed condition (LPC). Results showed that the LPC significantly reduced the heart rate ($p < 0.01$), minute ventilation ($p < 0.05$), and respiratory frequency ($p < 0.05$) during the first minute of immersion compared to the CC. Subjects also found the LPC the most comfortable. The TPC significantly reduced minute ventilation ($p < 0.01$) and respiratory frequency ($p < 0.01$) on immersion compared to the CC, but did not significantly lower the heart rate response. A comparison of the LPC and TPC revealed no significant difference in minute ventilation and respiratory frequency recorded on immersion. The LPC however, produced significantly lower heart rates on immersion ($p < 0.05$) than the TPC. It was concluded that the limbs may be more important than the torso for the initiation of cardiac response to cold water immersion.**

THE TERM 'COLD SHOCK' has been applied to the initial reflex responses associated with cold water immersion. They are mediated by the sympathetic nervous system and include an increase in heart rate, an uncontrollable hyperventilation, intense vasoconstriction, and hypertension (8).

Such responses can constitute a serious threat to survival, particularly in individuals with underlying cardiovascular disease or even in fit, healthy individuals who, in order to avoid inhaling water, must voluntarily control ventilation. Tetany has been reported (5) in a subject as a result of hyperventilation during the initial minutes of immersion in cold water; this would seriously compromise survival should it occur following accidental immersion.

Studies examining the reflex responses to cold water immersion, and protection from such responses, have used either naked or fully clothed subjects. No studies have been solely concerned with the importance of different body surface areas in the initiation of the 'cold shock' responses. As part of a wider study, Keatinge and Nadel (8) examined the importance of different regions of the body in initiating a reflex ventilatory response to sudden cooling of regions of the skin. A 15°C spray was limited to nine regions of the trunk and limbs, and always produced an increase in the average minute ventilation of the subjects.

The greatest ventilatory response was obtained from the front and back of the trunk. A smaller response was initiated by the extremities, even though the surface areas showered were larger than those of the torso.

This finding could have implications on the design of protective clothing for helicopter passengers on short duration inter-rig flights. In the event of a helicopter 'ditching,' these individuals are at risk from 'cold shock,' but are likely to be rescued before becoming seriously hypothermic. The cost and logistic difficulties associated with wearing full immersion suits for such flights has led to the question of whether a less-cumbersome and cheaper garment which protects specialised regions of the body might provide adequate protection against cold shock. This experiment was designed to examine the relative contribution of different body areas to the initiation of some of the cardiorespiratory reflex responses to cold water immersion.

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This manuscript was received for review in September 1986. The revised manuscript was accepted for publication in December 1986.

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## METHODS

Twelve healthy males, aged between 24 and 37, acted as volunteers. They were fully informed in accordance with the code of ethics of the World Medical Association. The age, height, weight and percentage of fat (%fat) of each subject was recorded. Fat percentage was calculated from subcutaneous fat thicknesses measured with calipers at four sites (4).

Each subject performed three 10-min head-out immersions in stirred water at 10°C. They were immersed at the same time of day on each occasion, but with different clothing assemblies. These are shown in Fig. 1 and are described below:

1. Control Condition (CC)—swimming trunks only (worn in all conditions).
2. Torso protected/limbs exposed condition (TPC)—a sleeveless cotton T-shirt and sleeveless thick woolen pullover were worn under a waterproof polyurethane-coated nylon survival suit with the short sleeves and legs taped to the skin with waterproof tape.
3. Limbs protected/torso exposed condition (LPC)—the limb sections of cotton thermal underwear, long woolen socks, and the sleeves of a thick woolen pullover were worn underneath the sleeve and leg portions of a survival suit. Again water was prevented from entering beneath the clothing by waterproof tape.

Both clothing assemblies kept the protected parts of the body completely dry and adequately insulated for the duration of the experiment, as demonstrated by the dryness of the underclothing and by skin temperatures.

The order of immersions was counterbalanced, and 2 d were left between successive immersions to reduce the influence of habituation.

Each experimental condition involved a 10-min resting period in thermoneutral air (26.1°C ± 1.5°). Then the subject was lowered in a reclining attitude into stirred water at 10°C. Lowering was effected with a double harness and electronic winch, which ensured the subjects were immersed at a rapid, reproducible rate.

Rectal temperature ($T_{re}$) was monitored throughout each experiment using a rectal thermistor probe (Yellow Springs Instrument, Series 400 Probe) inserted 15 cms into the rectum. Heart rate ($f_H$) was measured from an electrocardiogram (ECG) obtained by telemetry (Siemens Telecust 36). Skin temperatures ($T_{sk}$) were recorded every 5 min using Edale Instruments EU thermistor probes. Mean skin temperature ($\overline{T}_{sk}$) was calculated from an unweighted division of six skin sites (chest, upper arm, hand, lower back, thigh, and foot). The mean temperature of exposed skin ($\overline{T}_{skexp}$) was calculated by an unweighted division of the skin temperatures recorded from uncovered skin sites. Oxygen uptake ($\dot{V}O_2$), minute ventilation ($\dot{V}_E$) and respiratory frequency ($f_R$) were measured during the last 5 min of the rest period, and during the first minute and last 5 min of the 10-min immersion period.

$\dot{V}O_2$ was assessed by open-circuit spirometry where expired air was collected in Douglas bags and analysed for fractional oxygen (Beckman OM11 oxygen analyser) and carbon dioxide (Beckman LB2 carbon dioxide analyser) concentrations. Volumetric measurement was made using a Parkinson and Cowan CD4 gas meter. The values obtained for $\dot{V}_E$ were checked, after appropriate correction, against inspiratory volume ($\dot{V}_I$) obtained from a heated pneumotachograph (P. K. Morgan) placed on the inspiratory side of a low-resistance mouthpiece. $f_R$ was also obtained from the pneumotachograph. $T_{re}$, $\dot{V}_I$, $f_R$ and the ECG were recorded on a Gould 2600S six-channel direct-writing recorder.

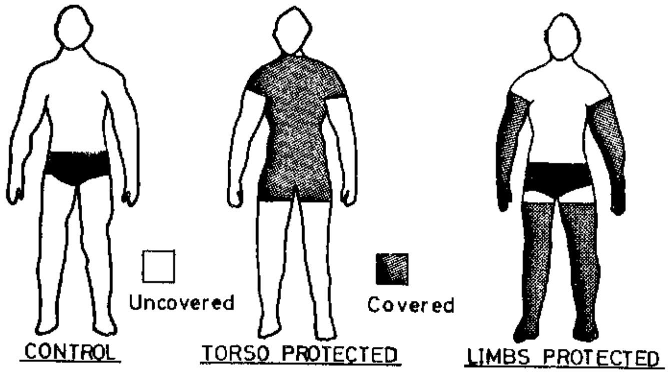

Fig. 1. Clothing assemblies.

Subjective assessments of comfort were obtained using a sliding unmarked scale following 5 min at rest, and after the first and ninth minute of cold water immersion. After their final immersion, each subject was asked to rank, in order of preference, each clothing assembly and give a reason for the decision. Ambient air temperature in the vicinity of the subject was kept constant for each subject during each immersion. The subjects abstained from food and drink for at least 2 h before an immersion.

*Statistical analysis:* An analysis of variance, incorporating a Latin square design to allow for adjustments due to previous immersions, was performed on the data. It was decided prior to the experiment that, if the analysis of variance procedure yielded significant differences between conditions, assessments would be made of pairwise differences between CC & TP, CC & LP, and TP & LP. The overall significance level of 5% was split equally between these comparisons. Where any significant differences were found, these are quoted at this level; if differences were found to be very significant, they are quoted at the 1% level of significance. The Friedman test was performed on the subjective assessment data.

## RESULTS

Mean (S.D.) subject data were: Age 31 (5) years, Height 180 (7) cms, Weight 83 (11) kg, and %fat 18.2 (4.7). Mean data (+ range) for all 12 subjects under each condition is presented in the tables.

Just prior to cold immersion, there were no significant differences between conditions in any of the variables being recorded except $\overline{T}_{sk}$ (Table I).

*Body temperatures:* Just before immersion, $\overline{T}_{sk}$ was found to be significantly lower ($p < 0.05$) in the CC compared to the other two conditions. A separate analysis of variance revealed that this variation in $\overline{T}_{sk}$ had no significant effect on the responses obtained on immersion. By the end of immersion, $\overline{T}_{sk}$ was significantly lower ($p < 0.05$) in the CC than in the other two conditions. $\overline{T}_{skexp}$ was not, however, found to differ between conditions. At no time during the immersion period was $T_{re}$ found to differ significantly between conditions (Tables II, III).

*Heart rate:* The LPC produced significantly lower heart rates on immersion than either the TPC ($p < 0.05$) or CC ($p < 0.01$). There were no significant differences in the heart rates recorded on immersion between the CC and TPC.

*Respiratory variables:* $\dot{V}_E$ and $f_R$ showed the same trends. The TPC produced significantly lower $\dot{V}_E$ and $f_R$ on immersion compared to the CC ($p < 0.01$). The LPC also produced significantly lower $\dot{V}_E$ and $f_R$ on immersion ($p < 0.05$) compared to the control condition. No significant differences were found between the TPC and LPC in the $\dot{V}_E$ and $f_R$ recorded on immersion.

*Oxygen consumption:* No significant differences were found between conditions in the $\dot{V}O_2$ of subjects on immersion. However, by the last minute of immersion, $\dot{V}O_2$ was significantly lower ($p < 0.05$) in the TPC and LPC than in the CC (Table III). No differences were found between the TPC and LPC.

*Subjective data:* The subjective data revealed a preference for the LPC followed by the TPC, with the CC subjectively the worst. The LPC was found to be significantly more comfortable than the CC ($p < 0.01$).

## DISCUSSION

No attempt has been made in this study to control the total area of exposed skin between conditions. To make such a control, one must assume that the peripheral cold receptors responsible for initiating the reflex responses to cold water are not only equally distributed throughout the body surface but are also all of equal sensitivity. Electrophysiological studies on cats (6), monkeys, and humans (3) suggest this is not so. It was estimated that the LPC exposed approximately 43% of the body surface area to cold water; in the TPC, the figure was about 48%.

Studies in which subjects have been immersed in thermoneutral and cold water (2) have shown that significantly greater increases in pulmonary ventilation are produced on immersion in cold water. Other work (9) has provided similar findings for $f_H$, $f_R$ and $\dot{V}O_2$ on cold, compared to thermoneutral, immersion.

The immediate respiratory and heart rate responses to cold water immersion are presumably initiated by afferent sensory information arising in the periphery. There is some doubt as to whether the ventilatory response to cold is initiated by cold receptors in the skin alone or whether it is

TABLE I. MEAN (+ RANGES) DATA AT THE END OF THE REST PERIOD.

| Variable | Control Condition | | Torso Protected Condition | | Limb Protected Condition | |
|---|---|---|---|---|---|---|
| $f_H$ (Bts·min$^{-1}$) | 79 | (58–108) | 74 | (41–105) | 74 | (59–98) |
| $\dot{V}_E$ (L·min$^{-1}$) | 11.7 | (7.4–14.8) | 11.0 | (7.6–16.6) | 10.6 | (6.2–16.3) |
| $f_R$ (Brths·min$^{-1}$) | 13 | (10–16) | 13 | (7–17) | 12 | (6–16) |
| $\dot{V}O_2$ (L·min$^{-1}$) | 0.337 | (0.274–0.394) | 0.352 | (0.269–0.471) | 0.326 | (0.235–0.457) |
| $T_{re}$ (°C) | 37.5 | (37.2–37.9) | 37.7 | (37.1–38.0) | 37.6 | (37.1–37.8) |
| $\bar{T}_{sk}$ (°C) | 33.0 | (31.7–33.8) | 33.7 | (35.2–31.8) | 33.9 | (35.0–32.1) |
| $\bar{\bar{T}}_{skexp}$ (°C) | 33.0 | (31.7–33.8) | 32.8 | (31.1–34.7) | 33.2 | (31.4–35.2) |

See text for significance levels.

TABLE II. MEAN (+ RANGES) DATA DURING THE FIRST MINUTE OF COLD IMMERSION.

| Variable | Control Condition | | Torso Protected Condition | | Limb Protected Condition | |
|---|---|---|---|---|---|---|
| $f_H$ (Bts·min$^{-1}$) | 109 | (58–148) | 102 | (64–150) | 89 | (72–123) |
| $\dot{V}_E$ (L·min$^{-1}$) | 62.1 | (28.1–137.9) | 46.1 | (19.2–115.0) | 51.3 | (24.4–131.2) |
| $f_R$ (Brths·min$^{-1}$) | 31 | (11–67) | 24 | (14–38) | 26 | (13–47) |
| $\dot{V}O_2$ (L·min$^{-1}$) | 0.990 | (0.808–1.279) | 0.916 | (0.697–1.159) | 0.882 | (0.676–1.179) |
| $T_{re}$ (°C) | 37.5 | (37.2–37.9) | 37.7 | (37.1–38.0) | 37.6 | (37.1–38.0) |
| $\bar{T}_{sk}$ (°C) | 14.3 | (12.9–15.8) | 19.6 | (16.3–21.5) | 25.2 | (22.8–28.8) |
| $\bar{T}_{skexp}$ (°C) | 14.3 | (12.9–15.8) | 13.9 | (12.3–14.7) | 14.0 | (11.7–16.5) |

See text for significance levels.

TABLE III. MEAN (+ RANGE) DATA AT THE END OF THE 10-MIN IMMERSION PERIOD.

| Variable | Control Condition | | Torso Protected Condition | | Limbs Protected Condition | |
|---|---|---|---|---|---|---|
| $f_H$ (Bts·min$^{-1}$) | 80 | (49–108) | 74 | (41–105) | 73 | (50–98) |
| $\dot{V}_E$ (L·min$^{-1}$) | 22.4 | (10.4–35.4) | 17.7 | (9.4–44.2) | 20.4 | (9.3–57.7) |
| $f_R$ (Brths·min$^{-1}$) | 14 | (8–23) | 14 | (7–20) | 13 | (5–21) |
| $\dot{V}O_2$ (L·min$^{-1}$) | 0.777 | (0.418–1.553) | 0.501 | (0.340–0.890) | 0.614 | (0.342–1.239) |
| $T_{re}$ (°C) | 37.4 | (36.7–37.8) | 37.6 | (37.0–37.9) | 37.3 | (36.8–37.8) |
| $\bar{T}_{sk}$ (°C) | 13.4 | (12.5–14.8) | 18.3 | (15.1–20.3) | 24.3 | (21.3–28.4) |
| $\bar{\bar{T}}_{skexp}$ (°C) | 13.4 | (12.5–14.8) | 13.1 | (11.9–13.9) | 13.3 | (11.4–15.3) |

See text for significance levels.

due, in part, to receptors sensitive to the increase in muscle tension associated with cold immersion. In this study, both the variation and the speed of onset in the ventilatory and heart rate responses, despite insignificant differences in $\dot{V}O_2$ on immersion, suggest that the neuronal pathways associated with cold reception may play a more important role in the ventilatory response to cold. Work on decerebrated cats (8) has led to the suggestion that the ventilatory response to cold is initiated by cold receptors in the skin and is mediated at midbrain level. In man, higher centres may have an influence on the magnitude of the response (2). The rapidity with which the responses to cold immersion are initiated suggest that they are neurogenic in origin. Perhaps the most interesting findings of this study involve the differences in the ventilatory and heart rate responses to immersion between clothing assemblies. There were no significant differences, on immersion, in the ventilatory responses between the TPC and LPC; both significantly reduced the ventilatory response compared to the control condition.

This result conflicts with the earlier findings of Keatinge and Nadel (8), who found that a smaller ventilatory response was elicited by cooling the extremities. These authors suggested that the smaller response was due to both habituation of these frequently cold-exposed areas of the body and to the paucity of cold receptors in these regions. This latter suggestion was based on the psychophysical evidence of cold-spot identification. This technique does not necessarily give a good indication of the number of cold receptors in an area of the body. At a given temperature, for example, many cold receptors may be firing at rates below the threshold of conscious sensation. Electrophysiological studies have demonstrated constant cold receptor discharge at perceptual thermoneutrality (7).

A difference between the study of Keatinge and Nadel (8) and this study is the area of the skin exposed to the cold stimulus. In the present study, larger areas were exposed to the cold stress. Any differences in the sensitivity of the subregions of the extremities to cold may thus have been hidden due to spatial summation of the afferent input.

The heart rate response to cold water immersion was significantly lower in the LPC than in either of the other conditions. The TPC and CC produced heart rate responses not significantly different. The variation in the pattern of the heart rate and ventilatory responses suggests that they were not produced by identical neuronal pathways.

Variations in receptor distribution, receptor sensitivity, and the degree of facilitation and inhibition placed on afferent information by central processing mechanisms, make it impossible to identify where these differences lie. But the conditions in which the subjects felt most uncomfortable were those in which the limbs were exposed. In these conditions, subjects experienced intense pain in their hands, forearms, and feet. This may have been ischaemic pain associated with intense vasoconstriction. Alternatively, it may indicate that cold nociceptors in the extremities were being directly stimulated by the cold.

If this were so, then it might be postulated that the heart rate response to cold water immersion is determined to a larger extent by activity in the neuronal pathways associated with cold nociception, rather than in those associated with cold reception. Furthermore, the insignificant difference in the heart rate response on immersion between the CC and TPC suggests that some difference may exist between the torso and limbs with regard to cold nociception.

That the ventilatory response to cold immersion was lowest when the limbs were exposed and pain was experienced suggests that this response may not be influenced by cold nociception pathways to the same extent as the heart rate response. This may also be due to variations in the controlling mechanisms of the two responses—variations that are exemplified by differences in the amount of conscious control that can be placed upon the two responses.

The oxygen consumption on immersion is primarily determined by an increase in muscle tension caused by cold shock. That there were no significant differences between conditions in $\dot{V}O_2$ on immersion suggests that, after a certain percentage of the body surface has been exposed to a cold stimulus, further increases in the area exposed do not result in greater oxygen consumption. Presumably, this percentage is less than the lowest percentage (43%) exposed in this study.

After the initial response, $\dot{V}O_2$ during the rest of the immersion will have been determined by the absolute, as well as the rate of change, of skin and core temperatures. It is not surprising, therefore, to find that the two clothed conditions produced significantly lower oxygen consumptions during the final minutes of immersion, as both of these resulted in higher $\overline{T}_{sk}$ during this period. This also highlights a difference between the 'cold shock' and 'thermoregulatory' $\dot{V}O_2$ responses; whilst the former appears to require exposure of only a percentage of the body surface area to cold in order to evoke a maximal response, the latter is thought to be determined by inputs from the whole body (1).

In conclusion, although both the TPC and LPC reduce the initial responses to cold immersion, in some individuals these responses can still reach potentially hazardous levels (see ranges in Table II). It would appear that there is little to choose between the two areas of the body exposed in this study (limb and torso), with regard to their importance for the initiation of the responses associated with cold shock. These areas may vary, however, in their relative importance for initiating specific heart rate and ventilatory responses. This point requires further detailed investigation.

## ACKNOWLEDGMENTS

The authors thank the volunteers for their reliability and courage, the members of the I.N.M. Survival and Thermal Medicine Department for their invaluable assistance, Dr. R. Plethybridge for his assistance with the statistical analysis, and Shell U.K., which helped fund the project.

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