THE ROLE OF LOCAL SKIN TEMPERATURE IN DETERMINING THE PERCEPTION OF LOCAL AND WHOLE-BODY THERMAL STATE.

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INTRODUCTION

Humans have very poor natural insulation, yet possess powerful physiological and behavioural thermoregulatory mechanisms, which permit sustained tolerance to severe thermal stress. The thermal inputs which drive these responses arise from both internal and cutaneous thermoreceptors. Whilst behavioural thermoregulation depends mainly on the former source (1), it is the cutaneous afferent input which dominates the whole-body thermal sensation (2). Extensive literature exists on the nature of the interaction between cutaneous temperature alterations and thermal sensation, and on their contributions to thermal comfort and behaviour. However, other than the observation that the head has a relatively high thermal sensitivity (3) and drive for whole-body comfort (4), the possible differential thermosensitivity of the skin has not been adequately partitioned. Thus the aim of this study was to partition the skin for both localised cutaneous thermal sensitivity and drive for whole-body thermal sensation and comfort, using warming and cooling of ten localised skin regions.

MATERIALS and METHODS

Twelve habitually active males experienced three local skin temperature (T_{skl}) manipulations, at each of ten skin regions, using equivalent ΔT_{skl}s and surface areas (274 cm^2). A climate chamber (mean $\pm$sd; T_A=35.8 $\pm$0.2°C, rh=55.2 $\pm$0.2%) was used in combination with a water-perfusion suit (T_{water} =36.7°C; Webb and Associates, Yellow Springs) to clamp the mean core ($\bar{T}_c$= (rectal + oesophageal + aural)/3) and mean skin temperatures ($\bar{T}_{sk}$; area weighting of 15 non-treated sites) above the sweat threshold: 36.9 $\pm$0.2°C and 36.2 $\pm$0.2°C, respectively (5). Separate perfusion patches, consisting of a flexible grid of parallel polyvinyl tubes, were used to alter the T_{skl} at each of ten right-side skin regions, in balanced order: head (bilateral face+forehead), lateral upper arm, lateral forearm, fingers+dorsal hand, chest, abdomen, lateral thigh, lateral leg and toes+dorsal foot. Using approximate square wave changes in patch water temperature, three ΔT_{skl}s were applied to each region: (i) an increase of 4°C (mean of 5 thermistors) over 10 min ($W_{+4°}$; T_{water}=48.3 $\pm$0.2°C); (ii) followed immediately by an 11°C decrease from this plateau over 5 min ($C_{-11°}$; T_{water}=11.5 $\pm$0.2°C); and (iii) a decrease of 4°C over 10 min ($C_{-4°}$; T_{water}=25.9 $\pm$0.2°C). We have shown these thermal clamps to be effective across time, and shown the ΔT_{skl}s to be isolated to the treated skin regions (5). Treatments (i) and (iii) were always preceded by a 10-min pre-treatment baseline period (T_{skl}=36.3 ±0.1°C). Three trials of 135-190 min, were necessary to complete the 30 treatments per subject, with at least 5 days between trials.

Tissue temperatures were obtained using thermistors (types 401, FF and EU YSI, Yellow Springs Instruments, Ohio; Edale Instruments Ltd, Cambridge, U.K.), and recorded at 0.2 Hz (Squirrel, 1206; Grant Instruments; U.K.). Local and whole-body thermal sensation (1=unbearably cold, to 13=unbearably hot) and discomfort (1=comfortable, to 5=extremely uncomfortable) were obtained 60 s prior to treatment onset, and at 4 min post-onset. Local thermal sensation was also obtained at 40 s and 9.5 min post-onset. Subjects were trained in the use of these scales. After first expressing the local and whole-body thermal sensations and discomforts as difference scores (treatment minus pre-treatment baseline), and normalising for the concurrent absolute ΔT_{skl} ($|\Delta T_{skl}|$), the main effects of treatment and region were examined using *ANOVA* for repeated measures (α =0.05). Local sensation was also examined for a time by region interaction. Significant differences were isolated using Tukey's$_{HSD}$ *post hoc* procedure. Results are presented as means ±SEM.

RESULTS

The mean pre-treatment baselines for local and whole-body thermal sensations were slightly warm-to-warm (8.58 ±0.17), which were rated as comfortable-to-slightly uncomfortable (1.42 ±0.10). The changes in thermal sensation and discomfort are summarised for the three treatments in Figures 1A-D. When averaged across treated regions, each of the three treatments ($W_{+4°}$, $C_{-11°}$ and $C_{-4°}$) induced significant and concordant changes in both local and whole-body thermal sensations. Similarly, local and whole-body discomforts were significantly increased during $W_{+4°}$, and decreased during $C_{-11°}$, but only local comfort changed during $C_{-4°}$ ($p<0.05$).

Significant inter-regional differences in local thermal sensation and discomfort were apparent for both $W_{+4°}$ and $C_{-11°}$. The foot, head and hand were consistently the most sensitive regions (Figures 1A and 1C). The head showed a significantly lower local thermal adaptation, in that it maintained its cool sensation more so than did the thigh, during the $C_{-4°}$ treatment ($p<0.05$).

The inter-regional ΔT_{skl}s did not differentially affect whole-body thermal sensation or discomfort, except within the $C_{-11°}$ treatment, where head cooling induced lower whole-body thermal sensation and discomfort votes than did cooling the forearm, hand (discomfort only), calf or foot ($p<0.05$; Figures 1B and 1D).

DISCUSSION

The present study is unique, in that local and whole-body thermal sensations and discomforts were simultaneously investigated, while ten skin regions were treated, with deep body and the remaining skin thermal inputs held constant. Since changes

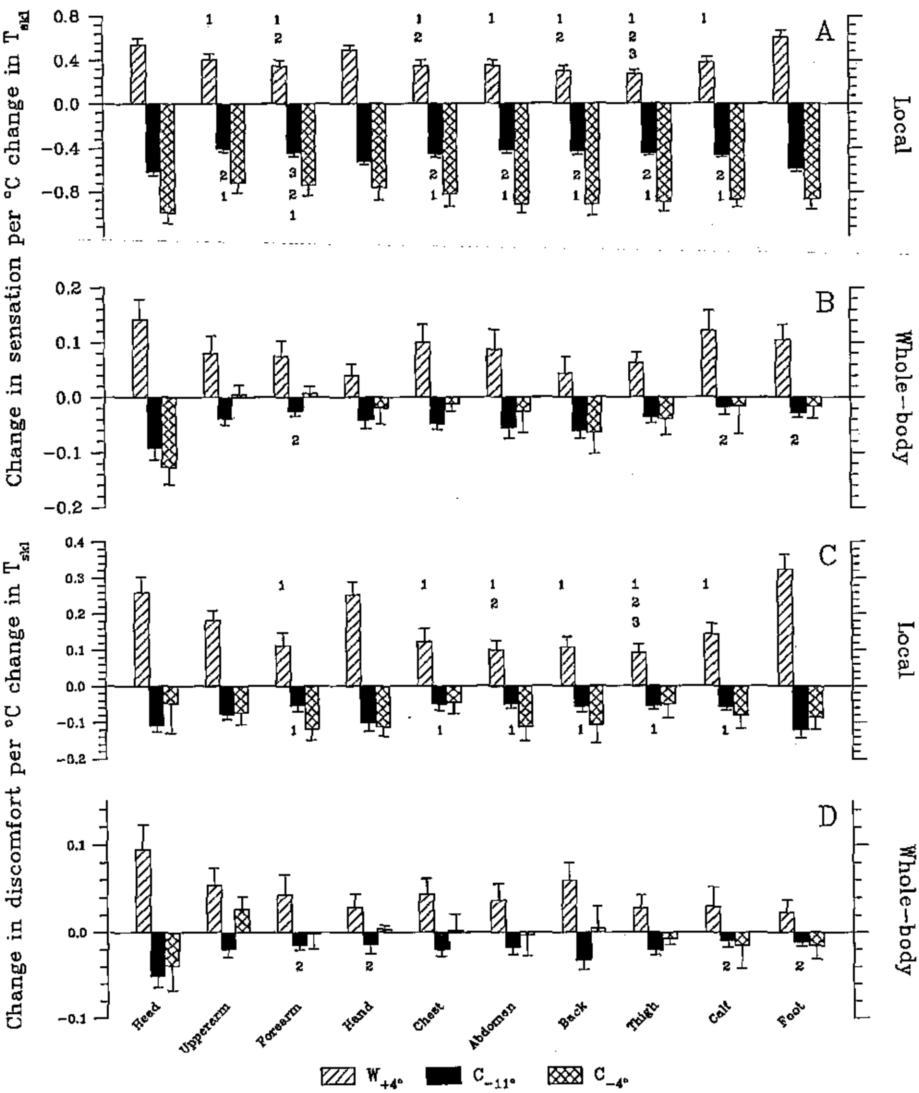

Figure 1. Change (±SE) in local (A) and whole-body (B) thermal sensation, and local (C) and whole-body thermal discomfort (D), during thermal stimulation of each of ten skin regions. Data were obtained 4 min after the onset of mild warming ($W_{+4°}$), mild cooling ($C_{-4°}$) and moderate cooling ($C_{-11°}$), with change scores being divided by the absolute T_{skl} change. '1', '2' and '3' = significantly lower than the foot, head and hand, respectively ($p < 0.05$).

in whole-body discomfort require deep body temperature to be sufficiently displaced from thermoneutrality, whole-body thermal strain was clamped above the sweat threshold, permitting T_{sk} manipulations to affect whole-body discomfort.

Taken collectively, the present data support previous assertions that the skin has a relatively uniform thermal sensitivity, except for a high sensitivity at the face (3). Nevertheless, three trends are immediately evident. First, the hand and foot possessed high local sensitivities and discomforts, however, they exerted minimal impact upon whole-body thermal sensation or discomfort. Therefore, while these high local sensitivities are important to clothing design, they are presumably of minimal importance to behavioural thermoregulatory responses.

Second, the head displayed this relatively high local thermal sensitivity, but also dominated whole-body thermal sensation and discomfort. Such regions, which impact upon whole-body discomfort warrant special consideration from a thermoregulatory perspective, since increasing whole-body discomfort will elicit behaviours aimed at minimising thermal strain (1,2). While this high facial thermal sensitivity has been alluded to previously, the current data are believed to be the first inter-regional partitioning, obtained for relatively steady-state thermal displacements, during which deep body and the non-treated skin temperatures were clamped.

Third, within treatment sites, there may exist differences in sensitivity to warming and cooling, such that sites which display a trend for eliciting whole-body sensation for cooling, are not equally warm-sensitive (*e.g.* back, calf and foot; Figure 1B).

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