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Thermal comfort zone of the hands, feet and head in males and females

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ABSTRACT

Introduction: The present study compared the thermal comfort zones (TCZ) of the hands, feet and head in eight male and eight female participants, assessed with water-perfused segments (WPS).
Methods: On separate occasions, and separated by a minimum of one day, participants were requested to regulate the temperature of three distal skin regions (hands, feet and head) within their TCZ. On each occasion they donned a specific water-perfused segment (WPS), either gloves, socks or hood for assessing the TCZ of the hands, feet and head, respectively. In the absence of regulation, the temperature of the water perfusing the WPS changed in a saw-tooth manner from 10 to 50 °C; by depressing a switch and reversing the direction of the temperature at the limits of the TCZ, each participant defined the TCZ for each skin region investigated.
Results: The range of regulated temperatures (upper and lower limits of the TCZ) did not differ between studied skin regions or between genders. Participants however maintained higher head (35.7 ± 0.4 °C; $p < 0.001$) skin temperature (Tsk) compared to hands (34.5 ± 0.8 °C) and feet (33.8 ± 1.1 °C).
Conclusions: When exposed to normothermic conditions, distal skin regions do not differ in ranges of temperatures, perceived as thermally comfortable.

1. Introduction

The first deliberations regarding the senses are attributed to the Greek philosophers Aristotle and Galen (cf. [4]), the former defined the senses as components of the sensation of touch, and the latter considered the sensations to also include that of cold and heat. Electrophysiological evidence of the manner in which cutaneous sensors react to thermal stimuli was provided by Zotterman [37] and Hensel and Zotterman [19], demonstrating the static and dynamic characteristics of the cold and warm sensors [38]. Information from cutaneous thermoreceptors provides two conscious assessments: whether the stimulus applied to the skin is hot or cold, and whether it is considered thermally comfortable or uncomfortable. Early investigations reported that skin temperatures above 35 °C and below 29 °C were considered unpleasant [32], and that thermal comfort was associated with a skin temperature of 33 °C [17]. Gagge et al. [14] suggested that a zone of thermal comfort existed, representing a range of ambient temperatures in which the responses of autonomic temperature regulation were inactive, this being 28 to 30 °C for a naked man at normal core temperature. It has also been demonstrated that changes in core temperature can modify the peripheral perception of temperature and its subjective rating of comfort [6,8].

Regional differences in temperature sensitivity are due to the differences in receptor density, and this prompted Penfield and Boldrey [27] to represent these regional differences in cutaneous sensitivity with a homunculus; a humanoid form with the relative size of different regions representing the sensitivity of a region, as well as the size of the sensory cortex devoted to the integration of the thermoafferent information from these regions. The varying temperature sensitivity of different regions has been mapped, indicating that the face and mouth are most sensitive [12], whereas the extremities are the least sensitive to thermal stimuli [31]. As concluded by Burke and Mekjavic [5], who investigated regional cutaneous cold sensitivity, a greater cold sensitivity of a region may indicate that this region has a greater density of cold receptors, or a greater influence centrally.

Similarly, on the basis of the regional differences in temperature sensitivity, several studies have suggested that the subjective assessment of thermal comfort also varies among regions [2,22,23,31,36]. Using visual analog scales (VAS), it has been demonstrated that the torso region strongly influences overall sensation of temperature and perception of thermal comfort [2,16,22], in contrast to the limbs and extremities, which contribute less [23].

Common to these studies is the manner in which thermal comfort was assessed. During the trials, participants provided ratings of thermal comfort using VAS, at regular intervals. By definition [14], behavioural thermoregulatory actions are initiated in response to the perception of

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thermal discomfort, and these actions attempt to re-establish thermal comfort and defend internal body temperature [30]. As such, studies using VAS are not monitoring actions to re-establish thermal comfort, minimise/eliminate thermal discomfort, or defend core temperature. Instead, these studies assume that the ratings of thermal comfort provided by participants correspond to behavioural actions that would be undertaken, were the participants able to do so. It has to be noted that behavioural responses may vary depending on the method adopted (i.e. regulation of ambient air temperature, water temperature, water-perfused suit temperature etc.).

Researchers conducting animal studies, not being able to administer VAS to their experimental subjects, have to rely on innovative methodological approaches to quantify behavioural thermoregulatory responses to changes in thermal and non-thermal factors. Human studies, by comparison, are seldom designed to assess behavioural actions, but out of convenience rely on subjective ratings. A departure from this norm in human experimentation was reported by Collins et al. [11] who assessed the temperature preferred by elderly participants, by actually providing them with the ability to regulate the temperature of a climatic chamber in which they were accommodated. We recently modified this approach [9,34] by having participants regulate the temperature of a water-perfused suit, so that the temperature was maintained within the thermal comfort zone (TCZ). During the experimental trials, the temperature of the water-perfused suit would, by default, vary in a saw-tooth manner from 10 to 50 °C, if left free-running. Participants were instructed to change the direction of the temperature change when they perceived the temperature to be uncomfortable. In this manner, we were able to establish the range of temperatures considered as thermally comfortable. Using this methodological approach, we wished to confirm the regional differences in thermal comfort previously obtained using VAS [10], by having participants regulate the temperature of the water perfusing individual skin regions (arms, legs, front and back torso). Our results indicated that there was no significant difference in the TCZ for these regions. Assuming that the neurophysiological response characteristics of thermoreceptors in these regions are similar, several explanations could be offered for our observations, as discussed below.

Although temperature sensitivity is primarily a function of sensor density, thermal comfort is a subjective assessment of the quality of the stimulus. Cabanac [7] coined the phrase “alliesthesia” (from the Greek *esthesia* meaning sensation, and *allios* meaning changed) to define an external stimulus that can be perceived as pleasant or unpleasant depending on the signals from within the body, that initiates behaviour to avoid a state of unpleasantness. In the case of temperature regulation, thermal discomfort initiates actions to maintain the temperature of the “milieu interieur” stable. In the absence of any experimental evidence that regional discomfort would initiate appropriate behaviour to counteract the discomfort, it is perhaps unwarranted to define regional thermal comfort zones on the basis of subjective ratings.

The present study extends the findings of our previous study, evaluating the thermal comfort of the arms, legs, front and back torso, by evaluating the thermal comfort of distal regions, namely the hands, feet and head. With the exception of the feet, these distal regions are commonly exposed directly to the ambient conditions, and might become habituated to a lower temperature, resulting in an attenuated response for the same thermal stimulus compared to a region that has not been subject to such habituation. Whereas the heat loss from all skin regions can be continually modified with clothing layers, the feet are normally subject to a constant insulation provide by the footwear during the day. With regards to the contribution of different skin regions to thermal comfort, it has been reported that when immersed in cold water, the chest and the lower back are responsible for the onset of thermal discomfort, not the hands and feet [16].

For the purpose of the present study it was hypothesised that: 1) TCZ of distal regions would be lower (lower regulated temperatures) compared to that of the body (including arms, legs and torso); 2) participants would regulate higher temperature of the head compared to the extremities, in accordance with the skin temperature distribution noted in a room temperature ambient; 3) thermal comfort of different skin regions is achieved at ranges of temperatures deemed thermally comfortable, defined as the TCZ.

Determination of the nature of TCZ is essential in the design of heating, ventilation and air conditioning systems for spaces in which humans of different age (schools, homes for the elderly), and gender work (i.e. offices, manufacturing plants, etc.), recover from illness (hospitals) and play (i.e. fitness centres, gyms, etc.). Provision of thermal comfort is also important for clothed individuals, especially when wearing personal protective clothing in extreme environments. Design of such suits must be appropriate to allow work to proceed unhindered by perceptions of thermal discomfort established by the conditions within the protective clothing microclimate.

2. Methods

2.1. Participants

Sixteen healthy Caucasian males (n = 8) and females (n = 8) participated in the study (Table 1). Participants were all physically active and participated in at least one physical activity several times per week. They were not included in the study, if they had been exposed to a hot or cold ambient conditions one month before entering the study, or if they were involved in occupations that required exposures to extreme temperature conditions. Following familiarisation with the equipment and study protocol, participants gave their written consent for participating in the study, approved by the National Committee for Medical Ethics at the Ministry of Health of the Republic of Slovenia. Before entering the study, they were requested that prior to each experimental trial they should not: i) participate in any heavy exercise, ii) have a large meal, iii) smoke, iv) drink coffee, and v) drink alcohol a day before the experiment. Due to the fluctuation of body temperature during the menstrual cycle, females provided information regarding their menstruation in order to avoid the period immediately after ovulation, when higher levels of progesterone induce elevations in the internal temperature [3]. They were tested for three consecutive days, starting with the first day after completing their menstruation.

Table 1
Participants' physical characteristics.

	Age	Weight	Height	Body surface area (m^2)*
Males				
S1	24	88	187	2.14
S2	30	76	179	1.95
S3	23	84	178	2.02
S4	28	77	169	1.88
S5	22	68	171	1.80
S6	23	70	172	1.83
S7	25	73	179	1.91
S8	27	72	178	1.89
Average	25	76	177	1.93
SD	3	7	6	0.11
Females				
S9	27	53	167	1.59
S10	23	50	163	1.52
S11	26	58	165	1.63
S12	22	65	168	1.74
S13	25	59	163	1.63
S14	25	72	160	1.75
S15	19	63	162	1.67
S16	33	58	164	1.63
Average	25	60	164	1.65
SD	4	7	3	0.08

* Significant gender difference ($p < 0.001$) in body surface area, calculated by Du Bois and Du Bois [13] formula.