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Thermal comfort following immersion

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HIGHLIGHTS

- Swimming is associated with higher thermal comfort than resting in cool moving water.
- Post-immersion, thermal discomfort could be reduced despite cooling skin temperature.
- Thermal comfort regained pre-immersion levels despite poorer thermal profiles.

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ABSTRACT

Unlike thermal comfort in air, little research has been undertaken exploring thermal comfort around water sports. We investigated the impact of swimming and cooling in air after swimming on thermal comfort. After 10 min of swimming-and-resting cycles in 28 °C water, volunteers wearing two types of garments or in swim briefs, faced winds in 24 °C air, at rest or when stepping. Thermal comfort was significantly higher during swimming than resting. Post-immersion, following maximum discomfort, in 45 of 65 tests thermal comfort improved although mean skin temperature was still cooling (0.26 [SD 0.19] $°C \cdot min^{-1}$ — max was 0.89 $°C \cdot min^{-1}$). When thermal comfort was re-established mean skin temperature was lower than at maximal discomfort in 39 of 54 tests (0.81 [SD 0.58] °C — max difference was 2.68 °C). The reduction in thermal discomfort in this scenario could be due to the adaptation of thermoreceptors, or to reductions in cooling rates to levels where discomfort was less stimulated. The relief from the recent discomfort may explain why, later, thermal comfort returned to initial levels in spite of poorer thermal profiles.

1. Introduction

Thermal comfort is an emotional and affective experience, which depends on an individual's history and expectation [1]; it is generally defined as the condition of mind expressing satisfaction with the environmental conditions [2] and refers to the subjective indifference to this environment. It can therefore be characterised by the absence of thermal discomfort. In leisure-type scenarios thermal comfort will become important as it will affect both behaviour and pleasure responses [3]. The aim of this study was to investigate thermal comfort responses during a critical phase in recreational water-based activities: when getting out of the water and facing a wind.

Cold cutaneous thermoreceptors are temperature sensitive nerve endings situated just beneath the skin surface, where they are more densely distributed than the warm receptors [4]. Amongst the three transient receptor potential families thought to act as thermoreceptors, the transient receptor potential cation channel subfamily M member 8 (TRPM8) channel has been shown to be activated by chemical compounds including menthol [5,6] and predominantly involved in the detection of environmental cold, in the range 15 °C to 25 °C [7]. In response to thermal stimuli, afferent neural information is transmitted to the thalamus for integration and to the somatosensory cortex for subjective interpretation [8].

When a sudden thermal stimulus is applied to previously thermoneutral skin, the frequency of discharge of the thermoreceptors reaches a maximum which depends upon the adapting temperature (the steady discharge observed at constant temperatures) [9]. For a given adapting temperature, this dynamic response is more intense when the cooling rate is higher [10,11]. Likewise, the threshold for cold sensation increases with faster cooling rates [12,10]. In humans, this threshold depends upon both the cooling rate and the surface area stimulated [4,13].

Following the dynamic response, the firing frequency of the thermoreceptors rapidly reduces to new static firing rate which is still above the pre-cold exposure thermoneutral static discharge frequency. Thus, the short term adaptation of the dynamic response of the cold receptors produces a new static discharge which itself disappears when the cold

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stimulus is removed and thermoneutrality returns and, the receptor firing frequency returns to the initial static values, corresponding to the adapting temperature [11].

Following immersion in recreational scenarios, deep body temperature is unlikely to change dramatically in the short term and skin temperature will be the primary determinant of thermal sensation and comfort. Indeed, in situations where deep body temperature remains stable, thermal comfort and skin temperature are highly correlated [14]. When wet and facing a wind, an evaporative cooling effect will be perceived, in which evaporation of water cools the skin. The extent to which wind speed will affect skin temperature following immersion may be estimated by existing predictive models [15]. However, the impact such temperature patterns will have on thermal comfort is unknown. Furthermore, little research has examined the impact on thermal comfort when wet skin of the whole body is exposed to the wind, and the effect of a prior immersion on subsequent comfort responses in air remains unexplored. A few studies have looked at human thermal responses to wet and windy environments in extreme conditions which resulted in falling skin and deep body temperatures and intense discomfort [16,17]. It is not known what might happen in a recreational situation where the surroundings and the duration of exposure are less stressful.

Despite extensive research on the relationships between skin temperature and thermal comfort, the effect of the *direction* of change of skin temperature is one factor that has received little attention. Previous pilot experiments (in water) conducted in our laboratory revealed that, with deep body temperature stable, the loss of overall thermal comfort occurred when mean skin temperature fell below approximately 31.5 °C but could be re-established below these levels if mean skin temperature was increasing then slightly increased. This suggests that in some situations absolute skin temperature could be relatively meaningless for the determination of thermal comfort in comparison with the rate of change and/or the direction of the change of skin temperature. Therefore, whether decreasing skin temperature is always experienced as uncomfortable is uncertain, as is whether increasing skin temperature is a requirement for thermal comfort to be re-established following immersion.

Water-based activities are usually associated with exercise. Several studies have investigated the impact of physical activity on deep body temperature in cool and cold water (e.g. [18]) and recent work has explored the impact of physical activity on cold sensitivity [19]. However, it seems that no information is available regarding its effect on thermal comfort in cool water. Non-thermal factors have been proposed to influence subjective or perceptual responses [20–23] but no direct evidence has been provided regarding thermal comfort during immersion. We thus investigated the effect of water-based activity on overall thermal comfort. This study also explores the impact of initial values of mean skin temperature, as well as the rate, the magnitude and the direction of change of these temperatures on thermal comfort responses following immersion. It was hypothesised that following immersion, thermal comfort would only improve when mean skin temperature increases. It was also hypothesised that thermal comfort would be relatively independent of absolute mean skin temperature, and that it would be improved by exercise.

2. Methods

This study was approved by the University of Portsmouth BioSciences Research Ethics committee and was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki (2008). The participants gave their written informed consent to participate.

2.1. Volunteers

Nine male volunteers were recruited for this study (mean [SD]; Age 19.3 [1.4] yrs; height 1.8 [0.053] m; mass 73.4 [11.6] kg). They were instructed to avoid performing any vigorous physical activity and consuming alcohol for 24 h prior to each test, and to avoid caffeine and hot food 3 h before data collection.

2.2. Experimental design

The experiment was a repeated measures design in which each volunteer completed eight tests (Fig. 1), on four separate days (two tests per day). The order of the different experimental conditions followed a counterbalanced Latin square design, to which each volunteer was randomly allocated. The eight tests are shown in Fig. 1, and described in more details in the following paragraphs.

2.3. Clothing conditions

Besides the control conditions where volunteers wore only swim briefs (*Conditions 1* to *4*), the clothing consisted of a long-sleeved top, and shorts, stopping at the knees. The surface area covered was similar between the two clothing conditions, but the design and the fabrics used were different. The first assembly (Garment A) was a single layer of polyamide fabric that allowed water to evaporate easily. The other garment (Garment B) was two layered with a microfleece-type fabric inner layer (polyester) whilst the outer layer was wind and waterproof (polyurethane), hence producing a low evaporative profile. The clothing was not, itself, being tested, it was merely used to produce different cooling and rewarming profiles.

2.4. Pre-immersion period

In the first stage of the experiment volunteers were exposed for 10 min to an air environment, with a temperature of 24 °C, and relative humidity at 60% to 70%. During this pre-immersion air exposure, whilst wearing *Swim briefs* (*Conditions 1* to *4*), volunteers stood still in front of a fan producing a turbulent flow, although air velocities were relatively uniform across the volunteers' height. In *Condition 1*, whilst facing air velocities of 1 $m \cdot s^{-1}$ in *Swim briefs*, volunteers continuously stepped up and down on a 22.5 cm step in pace with a metronome set to stepping rate of 15 complete (up and down) steps per minute. In *Conditions 2*, *3* and *4*, volunteers faced air velocities of 1 $m \cdot s^{-1}$, 2 $m \cdot s^{-1}$ or 4 $m \cdot s^{-1}$ respectively, for 10 min whilst standing at rest. In *Conditions 5* and *7*, they were exposed to 1 $m \cdot s^{-1}$ winds for 5 min immediately followed by 5 min at 2 $m \cdot s^{-1}$. Finally, *Conditions 6* and *8* consisted of 10 min of wind at 4 $m \cdot s^{-1}$. Throughout the air exposure, and in all conditions, volunteers faced the wind.

2.5. Immersion period

In all conditions, following the first air exposure, volunteers immersed themselves up to the neck in a swimming flume (counter-current swimming pool) at a water temperature of 28 °C, and they started alternating between swimming breast stroke and resting, for 10 min (i.e. five 1 minute swimming periods interspersed with 1 minute rest periods). Throughout the immersion period, including the resting stages, the flume speed was 1.6 $km \cdot h^{-1}$.

2.6. Post-immersion period

Following 10 min of immersion, the volunteers got out of the tank and for 25 min faced the same wind speeds as before the immersion. In *Condition 1*, they started stepping up and down on a step, like they did pre-immersion. In the other seven experimental conditions, they stood still until the end of the test (that is for 25 min). Following the first test, volunteers retained their instrumentation in place, but were rewarmed if needed in a warm bath, and then rested for about 1 h in their own clothes, in thermoneutral air. Once rewarmed and rested, they entered the chamber for their second test of the day.