Thermal Comfort: Multisensory Interactions?

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Abstract Experimentally, the effects of environmental conditions upon human capabilities have been studied most often through the imposition of a single stressor in isolation. Although it seems to be a common belief that thermal comfort can be influenced by concomitant stimulation of non-tactile sensorial modalities, few studies have succeeded in delineating non-tactile stimulations, which interact with thermal sensation and thermal comfort. Here we briefly overview neurophysiological and behavioural findings in multisensory influences on thermal sensation and thermal comfort. *J Physiol Anthropol Appl Human Sci* 24(1): 33–36, 2005 <http://www.jstage.jst.go.jp/browse/jpa>

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Introduction

Human temperature regulation is a mechanism which is solicited everyday when the body heat balance presents disequilibrium. Costly physiological reactions may be involved: shivering or voluntary heat metabolism production increases when cold stimulations occur; sweating may be triggered when heat accumulation arises. There is, however, a range in which some physiological adjustments also occur (vasoconstriction or vasodilatation) which enable heat redistribution inside the body without high physiological costs. Furthermore, behavioural temperature regulation takes place almost constantly (e.g., body movements, clothing adjustment). These voluntary actions originate from thermal stimuli which are perceived at the periphery, integrated at the central level and lead to actions or reactions. It is well known that the central nervous system integrates all physiological inputs, at various sites, and that the resulting sensation may be more or less complex (some are even described as “paradoxical”). For many years, thermal comfort has been extensively investigated, with experiments giving conflicting results, although non-thermal environmental factors were not comparable or even not controlled. We briefly report previous studies on interactions between thermal and non-thermal stimulation in the judgement of thermal comfort.

Multisensory integration: Neurophysiological data

Thermal sensation involves different cortical and sub-cortical regions which are a part of the somatosensory pathway (medial dorsal midbrain, thalamus, cingulate cortex, S2 and S1 cortex, and insula) (Casey et al., 1994). While many studies have shown multisensory integration between touch, vision and hearing in different areas of the brain (e.g., Falchier et al., 2002; Foxe et al., 2002; Giard and Peronnet, 1999; Rockland and Ojima, 2003; Yaka et al., 1999), few studies have highlighted multisensory regions in the cerebral cortex which involve thermal sensation. It seems not unreasonable to hypothesise that neurophysiological findings on visuo-tactile and auditory-tactile integration might be generalized to thermal sensation, which is a particular component of tactile sensations. Neurophysiological studies on unanaesthetized monkeys, however, have shown that only about 13% of the somatosensory neurons in the cortical area 7b, had thermoreceptive properties (Dong et al., 1994) and only a small proportion of them were multimodal neurones (i.e., responding to visual and thermal stimulation). More evidence is needed before we can evaluate whether multimodal cerebral structures also integrate thermal sensations.

Colour and thermal comfort: The hue-heat hypothesis

The belief that colour can impart such effects as apparent warmth and weight is widespread and ancient. A popular hypothesis is that lights or surfaces whose dominant frequencies are toward the red end of the visual spectrum are “warm” and those toward the blue end are “cool”. This hypothesis involves the concept of one set of environmental parameters, namely thermal comfort, interacting with another, namely hue. There have been a number of experimental studies aimed at determining whether colours can in fact impart such effects. Morgensen and English (1926) had subjects judge the warmer of two thermally equal cylinders each of which were covered with one of six saturated coloured papers. The authors felt that colour preference rather than judgment of warmth might be acting, showing no evidence for the hue-heat hypothesis. Berry (1961) performed a study wherein room lighting was provided by five hues (amber, yellow, white,

green, and blue) on separate occasions. Subjects, who were engaged in an irrelevant task, decided when they were “uncomfortably warm” as the temperature was increased. Differences between the mean room temperatures means for the hues were insignificant. Bennet (1972) made subjects rate thermal comfort while wearing red, blue and clear goggles while air conditions were “comfortable” and wall temperatures were varied from about 60°F to 100°F and back. Analysis of subjects’ change in their thermal comfort judgment from one category to another revealed no major hue effects or interactions. The authors concluded that hue produces a strictly intellectual effect, a belief that one is warmer or cooler but does not affect one’s thermal comfort. Fanger and al. (1977) found in 16 subjects that a slightly lower ambient temperature was preferred in extreme red light compared to extreme blue light. These authors concluded, however, that this colour effect was too small to have any physiological or practical significance.

Illumination and thermal comfort

Considerable effort has been expended by researchers interested in studying the physiological and behavioural effects of photic stimulation on both humans and nonhumans. Most of this effort has focused on the circadian effects of photic stimulation (phase shifting). Immediate non circadian effects of photic stimulation on human physiology and behaviour have also been documented. The primary finding is that photic stimulation suppresses the synthesis and release of the pineal hormone melatonin (Lewy et al., 1980; McIntyre et al., 1989a; McIntyre et al., 1989b). Another prominent finding is the elevated body temperatures obtained when subjects are exposed to bright light, relative to dim light, during the night time hours (Badia et al., 1991; French et al., 1990). This bright light effect on body temperature is observed during the night time hours when melatonin levels are high but not during the daytime hours when melatonin levels are low (Badia et al., 1991). Myers and Badia (1993) suggested that melatonin may be involved in mediating the effects of light on temperature and that 500 lx may be near the threshold for significant melatonin suppression and temperature enhancement. Furthermore, Morita et al. (1995) found that nocturnal core temperature was influenced differently by different wavelengths. The authors suggested that the nocturnal core temperature fall was suppressed through the relationship of melatonin and the thermoregulatory centres of the hypothalamus. There seem to be significant differences in preferred ambient temperature in relation to body temperature, particularly between the high phase (late afternoon) and the low phase (end of sleep stage) body temperature. Humans seem to prefer a comparatively higher ambient temperature when body temperature is the lowest and a comparatively lower ambient temperature when the body temperature is the highest (Pollmann, 1994; Shoemaker and Refinetti, 1996). These observations suggest that the photic stimulation plays an

indirect role in thermal comfort, its primary effect being directed on melatonin synthesis and release.

A particular aspect of illumination is colour temperature. The colour temperature of room lighting sources has been discussed mainly from the viewpoint of subjective feelings of atmosphere. One of the well-known studies in this field is the work of Kruithof (1941). He drew two curved lines on the colour temperature-illuminance co-ordinates and divided three zones of feelings. The zone within the two lines was supposed to be the zone of a desirable combination of illuminance and colour temperature. In the zone below the lower curve the illumination would give an impression of “dim” (at low colour temperature) or “cold” (at high colour temperature). The zone above the upper curve would also cause some unpleasant feelings. However, Kruithof gave no information about the criteria for determining pleasantness or unpleasantness. Kanaya and Kichize (1977) suggested that the colour temperature would scarcely influence subjective feelings if a constant kind of lamp was used as the light source. On the other hand, Wake et al. (1977) obtained a similar conclusion to Kruithof’s study on the relationship between illuminance and colour temperature upon pleasantness. Similarly, Willoughby (1974) recommended a colour temperature of 4000°K to be the most suitable for pleasant interior light sources.

In a recent study (unpublished data) we tried to delineate more precisely the effect of colour temperature on thermal comfort. Forty eight subjects were placed under two levels of colour temperature (2700°K and 5000°K) during 2 hours in slightly warm environments and were asked to evaluate their thermal comfort. Results revealed a small but a significant increase in thermal comfort when subjects were placed under 5000°K, $F_{[1,44]}=4.47$, $p<0.05$ (Fig. 1).

Illuminance and colour temperature effects may be mediated by physiological responses to illumination and colour temperature as found by Kobayashi and Sato (1992). The

Fig. 1 Mean thermal comfort ranking on a 0–100 scale (very uncomfortable—very comfortable) as a function of colour temperature (2700°K and 5000°K) obtained with different fluorescent lamps.

authors observed that diastolic blood pressure was significantly affected by the colour temperature level and increased under 7500°K. Modulation of skin blood flow in the forearm has also been found when illumination was decreased from 700 lx to 70 lx. This physiological response was correlated with the preferred wearing of heavier clothing in 70 lx than in 700 lx. Vasodilatation under high illuminance or high temperature colour environments may slightly lower core temperature, which may act on thermal comfort.

Air pollution, noise and thermal comfort

While the individual effects of elevated temperature and acoustic level have been well documented, their combined impact upon thermal comfort is much less clear. In the few studies which have investigated the combined effects of heat and noise, some synergistic, additive, antagonistic or negligible interactions have been reported (Fanger et al., 1977; Hancock and Pierce, 1985; Pellerin and Candas, 2003). Understanding these conflicting results depends upon the recognition of differing intrusive factors. Of particular importance is the precise specification of the performance task, whether requiring physical activity, skilled neuromuscular coordination, or simple mental response. Early research on physiological responses to acoustic stimulation has shown that high noise level can cause vasoconstriction (Heinecker, 1959; Jansen, 1966) and it might also increase muscle tension and therefore metabolic rate. This observation led several authors to hypothesize a combined effect of noise and temperature on human performance or subjective judgments of thermal comfort. While noise and temperature seem to act independently on human performance (Hancock and Pierce, 1985), thermal comfort judgment seems to be concurrently influenced by these two parameters. In a recent study (Pellerin and Candas, 2003), we investigated the trade-off between noise and temperature and their combined effects on discomfort on 108 lightly clothed subjects, individually exposed for 2 hours in a climatic chamber. Every 10 minutes of the first hour, subjects could modify the experimental conditions by deciding a change in temperature or noise. However, every change in one parameter was experimentally associated with a fixed change in the other parameter. Results showed that females accepted noisier environments than males, suggesting that thermal comfort is dominant for women. Noise was rated as the most unpleasant factor when initial conditions were noisy whereas temperature was the most disturbing factor when subjects began the experiment with thermal conditions far from thermoneutrality. Finally, although the combined effects of noise and temperature did not influence the physiological data, our results suggest that noise may alter thermal pleasantness in warm conditions. Combined effects of air pollution, thermal load and noise were studied by Clausen et al. (1993). They found that in an operative range of 23–29°C, a 1°C change in operative temperature had the same effect on human comfort as a change in perceived air quality of

2.4 decipols or a change in noise level of 3.9 dB. For levels of perceived air quality up to 10 decipols, a 1 decipol change in perceived air quality had the same effect on human comfort as a change in noise level of 1.2 dB. Although acoustic (noise) and odour (air quality) stimulations do not seem to interact with either thermal sensation or thermal comfort per se, their combined effect on global comfort seems to follow specific rules.

Temperature and thermal comfort

There is a great evidence showing that thermal comfort and thermal sensation are related to body temperature. Thermal comfort, however, is not strictly associated with a given thermal sensation. For instance, as mentioned above, the core temperature may be increased (or decreased) without perceived thermal stimulation and thermal preferences may be for a cooler (or warmer) environment respectively (Cabanac, 1969). In addition, the threshold for thermal sensation may be dependant upon initial skin temperature: Kenshalo (1970) clearly showed that thermal sensation and its expression may vary following the initial adapting skin temperature. This effect is assumed to rely on the properties of thermal sensors whose activity is a function of thermal stimulation.

It can be concluded that, since man no longer has fur, thermal components are very dominant factors in determining global comfort. One simply cannot avoid thermal stimuli, unlike stimulations by other sensory modalities (noise, light, odours). To minimize the thermal disturbances, the human being, in many instances, has to protect himself by reconstructing a microclimate around himself to avoid discomfort.

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