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Perception of Transient Thermal Environments: pleasure and alliesthesia

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Abstract

Recent research indicates that dynamic thermal environments can potentially deliver higher levels of occupant satisfaction than static, homogenous indoor environments. The physiological concept of alliesthesia presents a coherent framework for investigating *thermal pleasure* arising from environmental or metabolic transients. This project investigated the relationship between core and skin temperatures and thermal pleasure in transient thermal environments. Pilot studies recorded skin temperature (T_{sk}) and core temperature (T_c) of six healthy males through a series of environmental and metabolic changes. Preliminary results indicate that sudden changes in ambient temperature were rated pleasantly whenever a positive alliesthesial effect was induced (i.e. opposite polarity of T_{sk} and T_c). This decayed as the subject returned to thermoneutrality. The same environmental step change invoked a displeasure response when the core temperature was stable. It is possible that higher levels of occupant satisfaction in transient or textured thermal environments may be explained by the hedonic overtones from the alliesthesial effect.

Keywords: alliesthesia; thermal pleasure; transient; core temperature; skin temperature.

Introduction

International comfort standards encourage exclusive reliance on HVAC usage by largely restricting thermal asymmetries and transients within indoor environments as potential sources of discomfort. Such thermal homogeneity is at odds with comfort research that suggests dynamic environments can maintain and, in some cases, enhance occupant comfort (de Dear & Brager 2002; Nicol & Humphreys 2002, Candido et al 2010). Moving beyond prescriptive thermal homogeneity towards more textured alternatives involves both spatial and temporal domains. Traditional heat balance models are widely acknowledged as inadequate in evaluating the effects of asymmetrical or transient environments on comfort. However recent advances have been made in multi-node thermophysiological models (Fiala et a 2001; Tanabe et al 2002; Huizenga et al 2001; Zhang et al 2010). Whilst these models can accurately simulate thermophysiology, the realm of thermal perception is inadequately understood. We don't know *why* certain environments are pleasant sometimes, and distinctly unpleasant other times.

The renewed interest in thermal alliesthesia seems timely given the recent advances in modelling and global uptake of adaptive comfort principles. There have been some theoretical discussions (Kuno 1995; de Dear 2010) since the pioneering work of Cabanac (1971), but there are scant empirical data on the hedonic tone of thermal comfort. This is partly due to the complexity of the body's thermoregulatory systems. The signal from a thermal environmental stimulus is two-dimensional in its message: descriptive (magnitude, intensity) and affective (pleasure, usefulness). There has been a lot of attention given to assignation of behavioural and autonomic responses to a stimulus to particular areas of the body (Attia 1981; Zhang et al, 2010). Most point to a central integration, where an evaluation of 'usefulness' is made according to the thermal state of the body (Cabanac, 1992). Using an alliesthesial framework to understand this literature suggests that while the descriptive dimension can remain the same across different scenarios, a stimulus can be perceived as either pleasant or unpleasant depending on its potential to restore the body to a 'normal' thermal state. This may present an opportunity for investigating the immediate sensations of *thermal pleasure* that arise from environmental or metabolic transients.

Thermal pleasure and the built environment

Thermal stressors are ranked according to their impact on homeostasis in order to prioritize behavioural responses. This lead Cabanac (1992) to suggest that such a system of negotiation requires a common currency to evaluate each instance of conflicting stimuli. The currency he proposed was pleasure. In his interpretation priority is given to any behavioural response that maximises pleasure (or minimises displeasure) with minimal regulatory strain. Pleasure is deemed greatest immediately after a successful response, continually diminishing until a new equilibrium is reached, and at this point in time pleasure disappears altogether. Unfortunately we have little more than conceptual models of the temporal dimension of pleasure.

Thermal pleasure in psychometry lacks experimental evidence, with a few notable exceptions (Mower 1976; Winslow et al 1937; Attia & Engel 1981). Connotations of the word 'pleasure' are likely to vary between individuals and between pleasant and unpleasant (Cabanac 1972). An experimenter cannot know when pleasure should or should not be experienced, as it requires an introspective evaluative process on the subject's behalf. It is, however, a ubiquitous, communicable experience. When sharing stories of a vacation, people can relate to the pleasure of lying on the sand and basking in the sun. Rarely does one describe that experience as ‘too hot’; more common are words with hedonic overtones such as ‘pleasant’, ‘basking’ or ‘luxuriating’. Alternatively, the displeasure of a cold wind on a winter’s morning is something most people understand. Heschong (1979 pp 18) eloquently explains:

When the sun is warm on my face and the breeze is cool, I know it is good to be alive.

Experience of pleasure in our thermal environment is an everyday occurrence that we routinely share and appreciate, but surprisingly little is known about the casual process at play.

If either the environment or the subject is static, there is no opportunity for the body to interpret the ‘usefulness’ of a stimulus for thermoregulation. Thermal pleasure can therefore only be experienced in transient states (Cabanac 1992). From this comes one of the most prominent criticisms of alliesthesia: displeasure must occur in order to experience pleasure. Whilst a reasonable critique, it is unreasonable to suggest that we should not, or do not, experience displeasure. Indeed, we seek out thermal extremes lying on the beach in summer or swimming in ice water in winter. We are routinely exposed to environments that upset our thermal balance - commuting to and from work; travelling between levels or buildings; sitting in a car with strong solar ingress. Pleasure is more rare than displeasure simply because any stimulus experienced in excess becomes unpleasant (Cabanac, 1979). But the result of this uneven distribution is a heightened sense when we *do* experience pleasure - the greater the displeasure experienced, the stronger the resulting pleasure (Kuno, 1995). It is possible to design spaces that leverage this balance to create something more than just comfort – alliesthesia seems to explain the phenomenon of thermal delight (Heschong, 1979).

If we look further afield, a similar discourse is taking place in product development and user experience evaluation where pleasure has emerged as the design goal. Coelho & Dahlman (2002) suggest that concepts of comfort and pleasure overlap, but pleasure holds dimensions that are not included in comfort. In this sense it is not a cause-and-effect relationship; comfort is an aspect of pleasure. In relation to thermal perception, Kuno’s two-dimensional model (1995) has pleasure and displeasure merging into indifference along a central gradient, analogous to neutral on the familiar comfort scale. The inclusion of both comfort and pleasure in the same model, along with Cabanac’s definition, suggests that semantic and etymological differences are great enough to warrant separate but linked use. To summarise: the inherent difficulties of pleasure are recognised, and this is an area of research that needs to be developed further. It is not the aim of this paper to define pleasure, nor to suggest we abandon conventional comfort, but rather to explore some of the causal mechanisms and temporal characteristics of thermal alliesthesia.

This paper presents the results of a pilot study looking at the relationship between T_{sk} and T_c and subjective thermal pleasure during environmental and metabolic transients.

Subjects were exposed to both an up-step and down-step in temperature from a neutral state. By repeating the same temperature step changes after exercise, it was possible to test the alliesthesial model and the hedonic effects of transients.

Methods

Experiments were conducted under field-laboratory conditions that allowed an exploration of the primary alliesthesial hypothesis. Limited control over the thermal environments made it difficult to maintain constant conditions within each exposure. However, transitions were of similar magnitude across all experiments.

Subjects

Six healthy male subjects were tested individually. Subjects had an average height of 1.81m (sd = 0.04m), weight of 74.50kg (sd = 6.69kg), and 23.33 years old (sd = 1.75). All wore a standardised ensemble consisting of a cotton t-shirt, athletic shorts, sneakers with anklet socks and their own underwear. The insulative value of this uniform was estimated to be 0.25clo. Subjects were advised to refrain from strenuous exercise and the consumption of alcohol, tobacco, or caffeine during the 12 hour period prior to the experiment.

Research design

Individual experiments were conducted during consecutive mornings. This was in consideration of circadian rhythms in core temperature, as well as the influence of prevailing weather on expectations and adaptation. Sedentary subjects were exposed to a 30-minute 23°C preconditioning period at the beginning of each experiment. Following this was a series of six temperature step-changes between three rooms (16°C; 23°C; 30°C), interspersed with two periods of increased metabolic activity in the neutral room. Transitions included (1) *neutral to warm,* (2) *neutral to cool,* (3) *warm to neutral,* (4) *cool to neutral,* (5) *neutral* (*cycling) to warm,* and (6) *neutral* (*cycling) to cool*. Air movement was below 0.15m/s in all rooms and radiant loads were minimal. Cycling intensity was determined by resting heart rate and expressed as a heart rate ratio (observed heart rate / resting heart rate). Subjects kept a heart rate ratio (HRR) of 1.7 (sd=0.05) during both cycling sessions i.e. maintaining a 70% increase in heart rate from rest. This experimental protocol was designed to induce alliesthesial effects, as the same environmental changes (neutral to warm and neutral to cool) occur with and without an elevated core temperature. Figure 1 summarises the research design and the conditions of each zone.

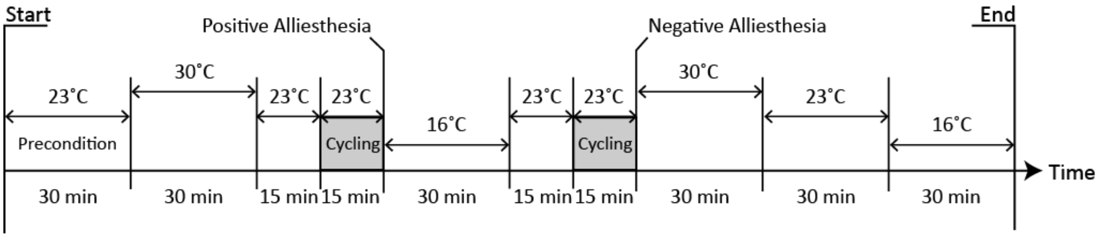

Figure 1. Experiment design. The transitions designed to induce positive and negative alliesthesia are marked, as are the periods of increased metabolic activity.

Thermal perception

Three separate Likert scales were used to rate thermal pleasure, whole-body thermal sensation, and thermal preference (see Figure 2). The widely accepted 7-point thermal sensation scale was used (ASHRAE 2001), and McIntyre's 3-point thermal preference scale ranging from -1 (cooler), 0 (neither warmer nor cooler), and warmer (+1). Both thermal sensation and preference were evaluated every 5 minutes throughout the 4-hour experiment. A 7-point scale was developed to rate 'thermal pleasure'. Whilst functionally identical to the widely used sensation scale, the scale ranged from very pleasant (+3) to very unpleasant (-3), similar to the 5-point scale used by Winslow et al (1937) and the 9-point version used by Mower (1976). Thermal pleasure was evaluated every minute throughout the 4-hour experiment. Each transition was timed so the subject cast their vote on all three scales once seated immediately after a transition.

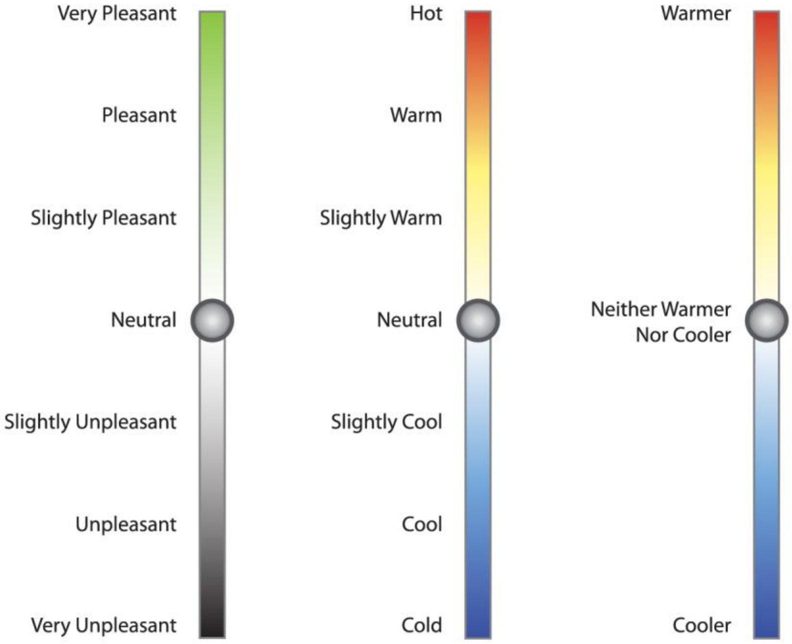

Figure 2. Scales of thermal pleasure, thermal sensation, and thermal preference as they appear in the iPad application.

A native iPad© application was developed to administer the three psychometric scales on a fast 60-second turnaround. All votes were saved to the internal memory of the iPad in a time-stamped comma separated file. After each vote was submitted a countdown timer was displayed, terminating with an audible cue to prompt the subject to make the next vote. If a question was missed, a no-vote was recorded and the next scale displayed. The slider returned to the neutral (0) position after each vote was submitted so subjects were not reminded of their previous rating. Furthermore, the slider has to be touched for a valid vote to be submitted.

Although all scales had a fixed number of points, the slider did not 'snap' to whole integers; it could be stopped at any location along the scale and report the nearest number down to thirds.

Physical measurements

Basic anthropometric data (age, height, weight) were recorded prior to each experiment. Constant measurements of air temperature and relative humidity were made in each of the rooms. Spot readings of air speed were used to ensure the subjects were not exposed to draft sensation from the air-conditioning units.

Physiological data included body core temperature, local skin temperature, and heart rate. Core temperature and heart rate were measured and wirelessly recorded every 20 seconds using an ingestible telemetric thermistor (HQInc CorTemp) and heart rate monitor (Polar T31 transmitter). This method of core temperature observation has been used extensively in sport science and considered a suitable replacement for rectal or oesophageal measurements (O'Brien et al, 1998; Byrne & Lim 2006). The single-use pill was administered 10-hours before the start of the experiment to ensure it was in a thermally stable location within the digestive system. The subject was instructed not to ingest solids in the morning, and was given a small liquid meal immediately before the pre-conditioning session. Water was administered ad libitum.

Skin temperature measurements were made every 5 seconds at 7 sites across the body in order to calculate mean skin temperature according to the formula in Hardy & duBois (1937). Maxim iButtons, a stainless steel, hermetically sealed, self-sufficient temperature logging system with accuracy of ±0.2ºC were used instead of wired thermistors. They have been used in the same application in many other studies and considered to be sufficiently low in thermal mass for skin thermometry (Harper Smith et al, 2010; van Marken Lichtenbelt et al, 2006).

Results and Discussion

Analysis of the data stemming from this preliminary study is focused on the physiological parameters of skin and core temperatures and their time derivatives, and alliesthesial dependent variable, thermal pleasure.

Core (T_c) and skin temperature (T_{sk})

The physiological responses to transients represent the independent variables in the alliesthesial model of thermal pleasure. Figure 3 shows the group mean skin temperature, mean core temperature, mean body temperature and mean thermal pleasure vote for all six subjects during the 4-hour experiment. T_{sk} observations were excluded from the preconditioning period at the beginning of each session because the thermistors had only just stabilised in a few of the subjects. Subjective voting started 5 minutes before the first transition.

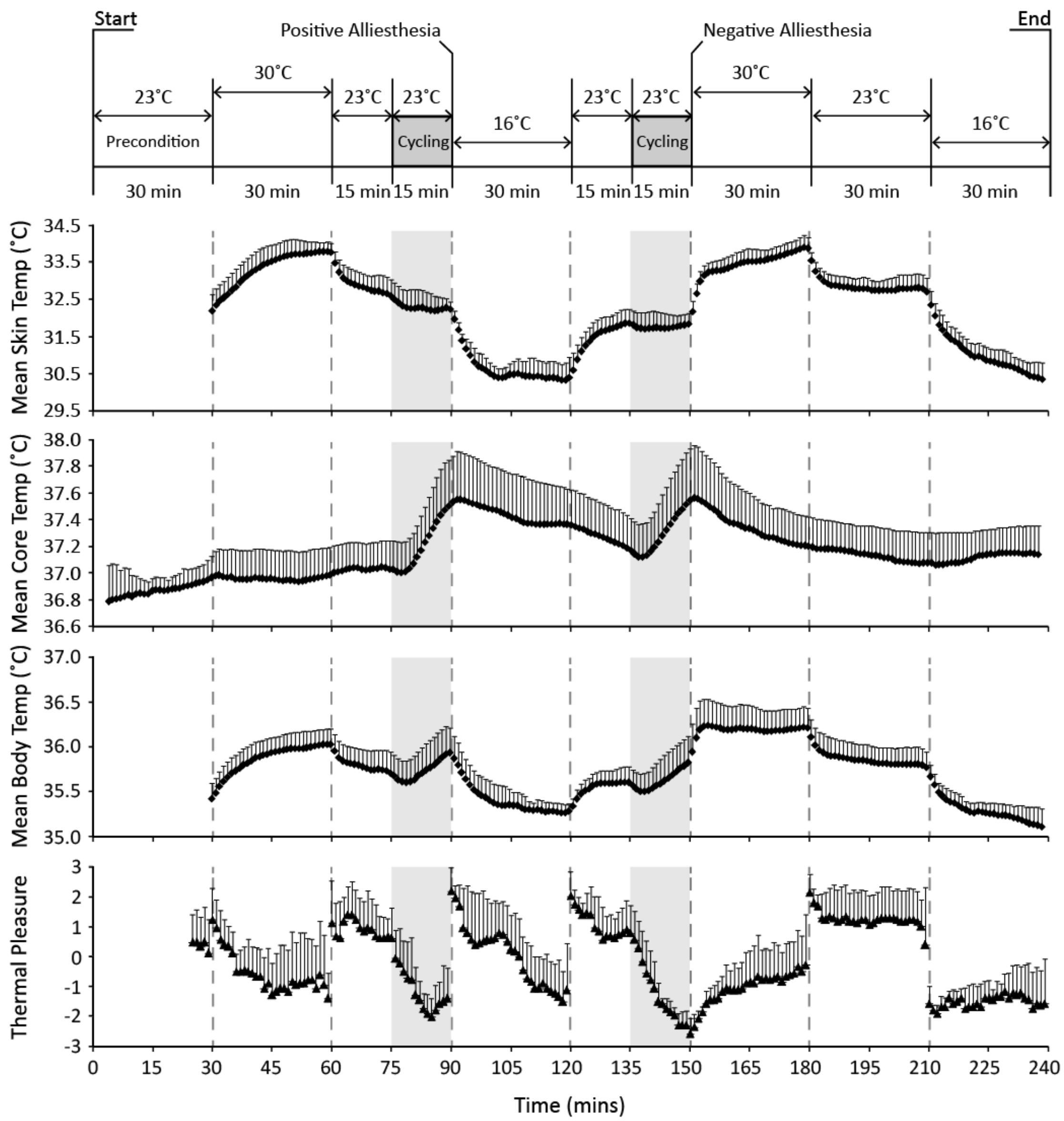

Figure 3. Group mean (n=6) of physiological and subjective measurements taken every minute during the 4 hour experiment. Each environmental transition is marked with a dotted vertical line, and the periods of increased metabolic activity are shown in grey. Error bars show the standard deviation for each variable.

Small standard deviations indicate that mean skin temperature is similar for all subjects. Periods of rapid change immediately after transitions correspond with minimal inter-individual variance.

Despite larger inter-individual variance in core temperature, there is agreement in general trend throughout the experiment. Strong variance in the heat accumulation and decay in relation to cycling was observed. For example, T_c increased by nearly 1°C for one subject, but only increased 0.4°C for another under the same metabolic regime. Differences between subjects slowly reduced as body core returned to its original temperature during sedentary. There is also a slight increase in core temperature over the course of the experiment phases. The cool environment slowed the decay of metabolic heat accumulated during cycling or increased core temperature when sedentary through vasoconstriction. Most subjects' T_c never returned to the value observed at t_0 even though subjects reported feeling neutral in the later stages of the experiment. This is perhaps a diurnal variation similar to that observed by Cabanac et al (1976), or simply residual heat from earlier periods of increased metabolism. As a result, the calculation of T_c setpoint proved difficult and was excluded from the analysis.

Mean body temperature (T_b) was calculated according to the formula suggested by Burton (1934):

$$T_b = (T_c \times 0.7) + (T_{sk} \times 0.3) \quad \text{[Equation 1]}$$

Where T_c is core temperature and T_{sk} is skin temperature.

T_b has been shown to correspond well with thermal perception (Flouris & Cheung 2009). Evaporative cooling from sweating stabilised T_{sk} during periods of exercise whilst T_c increased steadily. The weighting of mean body temperature towards the core ensures an increase in body temperature continues throughout these periods. Similarly the cycling-to-warm transition (t_{150}-t_{180}) shows a stable T_b because the slowly decreasing T_c is offset by an increasing T_{sk}.

A sudden change in thermal pleasure immediately after a transition was observed in almost all cases in Figure 3. Variance between subjects was lowest at this point, but gradually increased with time after the transition whilst sedentary. With the exception of the neutral-to-cool transition (t210), all transients induced positive pleasure. Both periods of cycling were considered unpleasant. The strongest change in thermal pleasure votes, both positive and negative, involved the cool room. The heightened sensitivity to temperature down-steps corroborates the findings of de Dear et al (1993). The constant displeasure induced by the neutral-to-cool transition (t210) suggests an ambient temperature of 16°C was too low during an Australian summer and induced a sense of "thermal shock".

Altered thermal perception from changes in core temperature

Both an up-step and down-step were experienced after the subject had been sedentary in a neutral room for 30-minutes. The same environmental temperature transients were repeated immediately after cycling for 15 minutes. Figure 4 shows the mean body temperature and thermal pleasure vote for each of the four transitions.

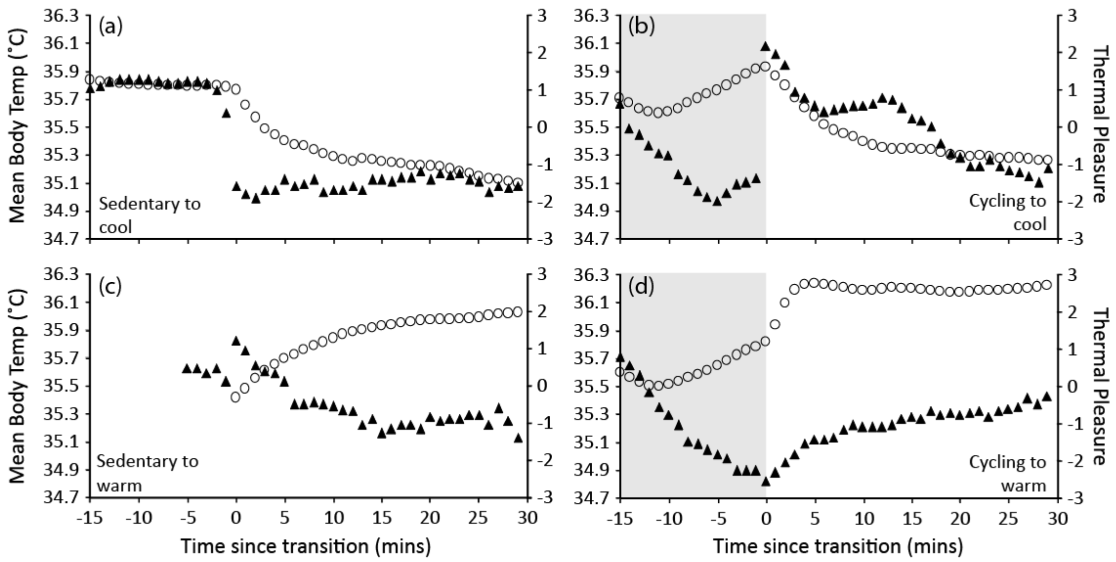

Figure 4. Changes in mean body temperature (○) and thermal pleasure vote (▲) during each transition. 15 minutes of the previous environment is shown. Periods of cycling are shaded.

Comparisons of figures 4a with 4b, and 4c with 4d clearly illustrate that the same stimulus can feel pleasant or unpleasant, depending upon the internal thermal state of the subject. Both mean body temperature and subjective pleasure were stable whilst subjects were sedentary in a neutral environment (Figure 4a). Immediate displeasure was elicited by the temperature down-step and sustained throughout the 30-minute exposure as skin temperature decreased steadily and core temperature remained stable. The same environmental temperature transient elicited positive thermal pleasure when the body temperature was elevated by the metabolic heat gained from 15 minutes of cycling (Figure 4b). Instantaneous and strongly positive alliesthesia resulted from a negative dT_{sk} and the elimination of further metabolic heat gain. Pleasure appears to correlate with the rate of change in mean body temperature, eventually reaching a level of displeasure similar to that experienced in the sedentary-to-cool (Figure 4a) transition. The plateau in thermal pleasure after the initial decrease corroborates the overshoot observed by de Dear et al (1993) in their study of thermal sensation after temperature down-steps.

Temperature up-steps were designed to test a negative alliesthesial effect. The transition from a sedentary neutral environment (Figure 4c) was immediately favourable (positive pleasure rating), a surprising result given the magnitude of the step-change. Even though it was a relatively small effect, and temporary, it is possibly indicating the beneficial properties of thermal environmental dynamics, where the stimulation helps to break any 'thermal boredom'. Apparently this is conditional on the direction and magnitude of the temperature step-change, as shown by the 'thermal shock' of the sedentary to cool transition (Figure 4a). In the sedentary-to-warm transient (Figure 4c) mean body temperature continually increased for the duration of the warm exposure, driven largely by an increasing T_{sk}. In the negative alliesthesial transition (Figure 4d), displeasure was already experienced due to the heat load of cycling before the transition. Despite the elevated T_c and increasing dT_{sk}, pleasure votes reached a level similar to that observed in the earlier temperature up-step (Figure 4c) after only 10 minutes. In this particular transition, displeasure seems to subside with the increasing usefulness of the change in removing excess metabolic heat. The temperature up-step would have served to induce autonomic responses of both vasodilation and further sweating, thereby increasing heat loss. Active thermoregulation driving the immediate adaptive process appears to mediate the displeasure aroused by the negative alliesthesial change in environment.

The immediacy of the change in pleasure response suggests that the hedonic dimension of a stimulus delivered by an environmental step-change is cutaneous in origin. The much slower rate of change in core temperature does not seem to fit the volatility of pleasure votes. However, the direction and magnitude varies with both the nature of the environmental change and its disposition with respect to the core temperature of the subject. A generalised pattern can be discerned in Figure 5, where the larger rates of change of skin temperature elicit the strongest subjective votes of pleasure or displeasure. Typically these are experienced in the first few minutes after the environmental transition. We think that instances of strong (dis)pleasure under small temperature changes in Figure 5 is attributable to the thermal mass in iButtons causing a slightly delayed response time (iButtons used to record skin temperature). The concentration of votes at slightly unpleasant is expected given both environments were designed to be outside comfortable indoor conditions.

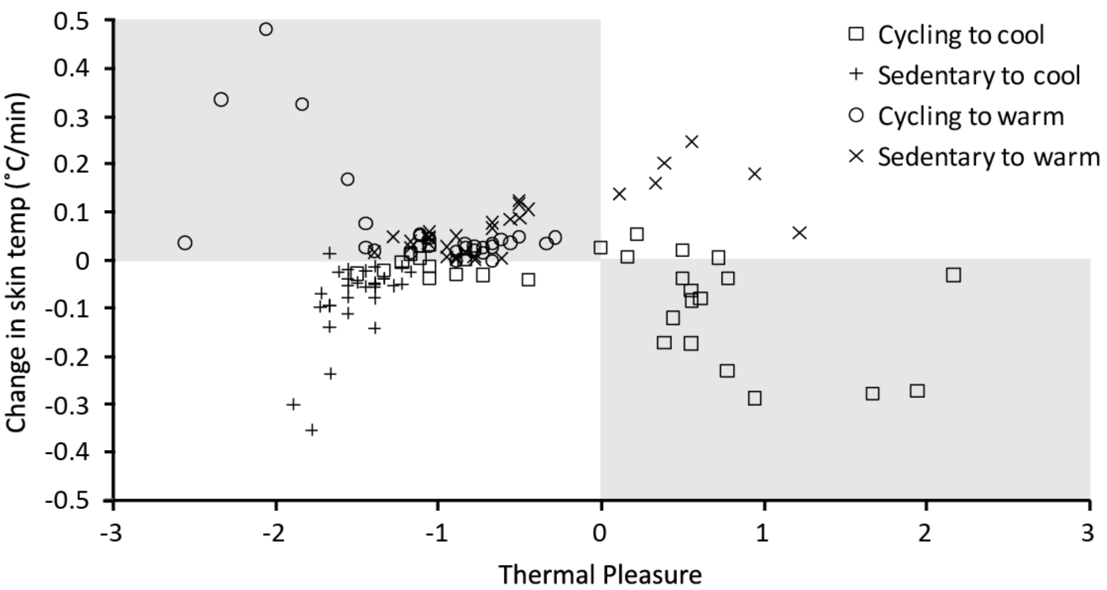

Figure 5. Pleasure votes plotted against the rate of change of skin temperature (dT_{sk}) after an environmental transient.

It is possible to summarise the immediate subjective response to a thermal transient in a generalised alliesthesial hypothesis (shown in figure 6**)**. Two scenarios are presented: elevated and depressed core temperature. When core temperature is raised, any stimulus leading to a rapid reduction in skin temperature will be perceived as thermal pleasure. The same stimulus will be unpleasant if the core temperature is depressed. The opposite is true with an increasing skin temperature. There is no mention of ambient temperature, as its role in this hypothesis is to influence skin temperature. Differences in the curves are from asymmetrical responses in perception to temperature up-steps and down-steps.

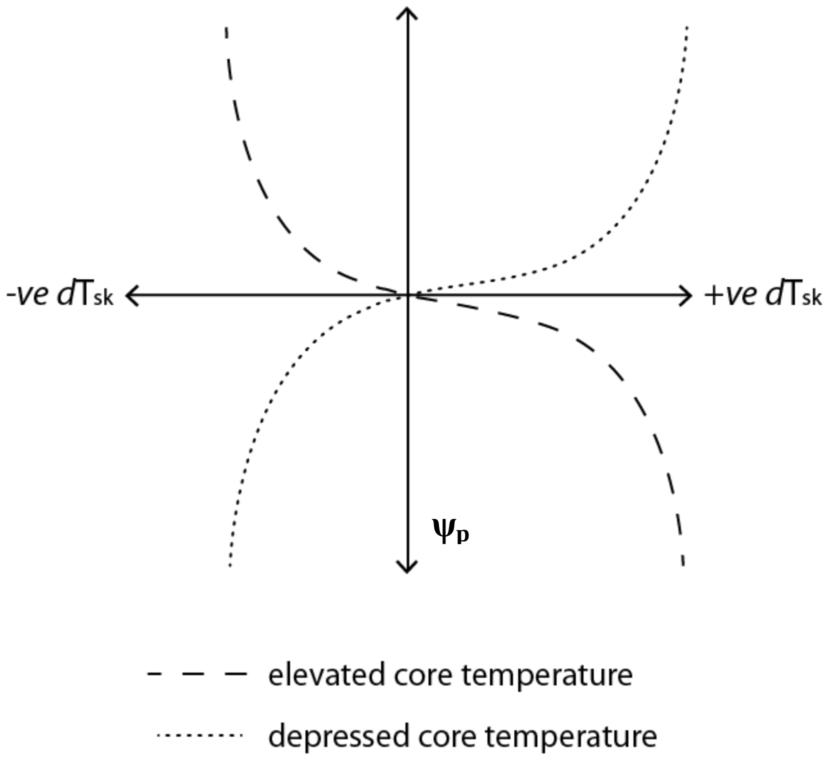

Figure 6. A generalised alliesthesial hypothesis, where rate of change of skin temperature (dT_{sk}) influences thermal pleasure (ψ_p) according to the body core temperature.

Alliesthesia has a particular relevance to transitional spaces that act as the intermediary between the relative extremes of the outdoors and the conditioned spaces afforded within the built environment. As we travel through it we experience a series of different thermal exposures, sometimes referred to as Lagrangian. Parallels can be drawn between the present matrix of experiments and real-world exposures. An obvious example is the daily commute to work. We are late to leave our comfortable house and have to hurry to the train. The cooling is pleasant at first, as the slight sweat on the forehead helps to reduce the heat accumulated from walking. The excess cooling quickly becomes unpleasant, and we feel a sudden hedonic impulse as we leave the carriage into the warm underground platform. After rushing to arrive on time, the dry air from the heating feels very unpleasant because of the metabolic heat gain. Another simpler example is the typical Australian shopping mall that lures passing pedestrians with blasts of cool, conditioned air seeping out onto the footpath though storefront sliding doors on a hot summers day. After the immediate respite we experience upon entering the store, we begin to feel slightly cool when our metabolic rate approaches sedentary. Kuno (1995) offers numerous examples, including the open-air spa (honsen) typically found across Japan.

Conclusion

The findings of this preliminary study suggest that an alliesthesial model of pleasure may help to explain occupant acceptance of dynamic indoor environments. The same change in ambient temperature was both pleasant and unpleasant according to the thermal state of the subject. Thermal perception appears to be influenced by changes in skin temperature, particularly when they serve to address an environmentally or metabolically induced thermal imbalance. Pleasure depended on the nature of the physiological change caused by transitions, and only lasted for short periods immediately after. Further work is required in exploring the temporal dimension of alliesthesia in order to compliment the existing research on its spatial effects (e.g. Attia 1981; Zhang et al, 2010).

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