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Thermoregulatory behaviour in response to switching thermal environments – a pilot experiment prior to a mild warm acclimation study

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Abstract

The indoor climate is an important factor with respect to human health and comfort since we spend most of our time, no matter if awake or asleep, in the built environment. Building occupants influence their thermal environments to maximize thermal comfort by inducing thermoregulatory behaviour. In the last decades, overheating of cities and buildings became an important issue. However, the effect of a mild hot environment on human thermoregulatory behaviour remains unclear.
To study the effects of a mild warm environment we propose a mild warm acclimation study. Part of this study is to investigate the effect of an alternated thermal environment on thermo-physiology and thermoregulatory behaviour before and after acclimation. In this paper we address the first results of a pilot study. The pilot aimed to elucidate interactions between human thermo-physiology, thermoregulatory behaviour and thermal comfort in response to altering thermal environments, the so-called SWITCH protocol. The pilot measurements demonstrate that thermoregulatory behaviour is initiated upon decreasing levels of thermal sensation and thermal comfort. Furthermore, we found indications for distinct thermoregulatory mechanisms in the three tested subjects, based on behaviour and skin temperatures.

Keywords: Thermoregulatory behaviour, thermal sensation, thermal comfort, mild heat acclimation, passive acclimation

1. Introduction

Human beings are almost constantly exposed to indoor climates and in the last decades, overheating of buildings has become an important issue. As, in the western world, heating, ventilating and air-conditioning of residential, commercial and public buildings consumes a lot of energy, this reveals the importance to reduce this energy use. A lot of progress has been made towards highly effective construction materials, which provide high standards of airtightness and insulation. However, as a result buildings might be at risk for overheating. Furthermore, global warming is progressing slowly but surely (IPCC, 2013).
The indoor climate of a building has an important impact on human metabolism: uncomfortable warm environments might cause sleepiness and restrict productivity, although this is not absolutely certain (de Dear et al., 2013). On the other hand, building occupants influence their thermal environment to maximize their individual

comfort: they open a window or put on a heater. Changes in skin and core temperature as well as conscious perception of thermal sensation and thermal comfort seem to drive this thermoregulatory behaviour (Chatonnet et al., 1966). A recent investigation by Schlader *et al.* (Schlader et al., 2013) indicates, that skin temperature plays the main role in initiating behaviour, whereas core temperature remains stable upon alternating exposure to cold (8˚C) and heat (46˚C). However, which parameters actually control thermoregulatory behaviour, which role local perception plays and which thresholds must be exceeded before individuals change their behaviour, still remains largely elusive.

Regarding the above stated environmental alterations, reactions and adaptions of the human metabolism upon (mild) hot environments are of significant interest. It is generally known that heat can cause stress to the human body, ranging from mild heat exhaustion to heat stroke. In order to prevent heat-related illness, plenty of studies investigated heat acclimation models. Importantly, the term *acclimation* stands for metabolic adaption due to artificial temperature stimuli and should not be mixed up with the term *acclimatization* that represents naturally induced adaptions. Heat acclimation leads to several adjustments at various levels in the body (i.e. subcellular, cellular and organ level), which results in superior ability to dissipate heat. These adjustments can affect core temperature, sweat rate, the cardiovascular system and other metabolic functions. The adjustment is largely dependent on climatic conditions, duration and intensity of the thermal stimulus (Hori, 1995). Currently, acclimation models are mainly developed for athletes or the military. The majority of these models are active acclimation models: they use exercise-induced hypothermia in combination with elevated ambient temperatures. This is a logical consequence in consideration of the original application but it is complicated to distinguish between temperature and exercise-related adaptions. It is desirable to improve knowledge on heat acclimation due to passive (mild) heat exposure and the influences on human metabolism and thermoregulation, since evidence is limited and becomes important with respect to the issue of overheating. It is hypothesized, that prolonged exposure to mild heat causes alterations in thermoregulatory physiology (as widely accepted), and influences behavioural set points of thermoregulation and shift the perception of thermal comfort to higher ambient temperature.

We are planning to investigate the link between changes in physiology and human thermal comfort and thermoregulatory behaviour upon mild heat acclimation. Therefore, we performed a pilot experiment to investigate the relationships between thermoregulatory behaviour, thermo-physiology and thermal comfort, first without the influence of acclimation. The data of this pilot experiment is presented below.

2. Methods

Three subjects participated in the behavioural pilot experiment where they could switch between a cold and a hot condition. Their characteristics are summarized in Table 1.

2.1 Subjects

All subjects were healthy, normotensive, non-obese, non-smokers and not taking any medication, which might alter the cardiovascular or thermoregulatory responses. Subjects were only included if they were on oral contraceptives in order to prevent thermoregulatory influences of the menstrual cycle. The volunteers were given detailed information regarding the purpose and the methods used in the study, before written informed consent was obtained.

Table 1. Subject Characteristics.

	Subject 1	Subject 2	Subject 3	Mean ± SD
Age (years)	23	24	24	23.67 ± 0.58
Height (m)	1.65	1.70	1.73	1.69 ± 0.04
Mass (kg)	58	62	59	59.67 ± 2.08
BMI (kg/m^2)	21.30	21.45	19.71	20.82 ±0.96

Subjects refrained from eating and drinking of alcoholic and caffeinated beverages in the evening and morning prior to the test. After arrival at the laboratory, they put on standardized clothing. Clo values were determined using EN-ISO 9920 (2009) and McCollough *et al.* (McCullough, 1989). The total thermal resistance of the clothing ensemble, including desk chair, was calculated to be 0.4 clo. Twenty-six iButtons were attached to 14 ISO-defined and 12 more spots and recorded skin temperature in 1-minute-intervals**.**

2.2 Experimental protocol.

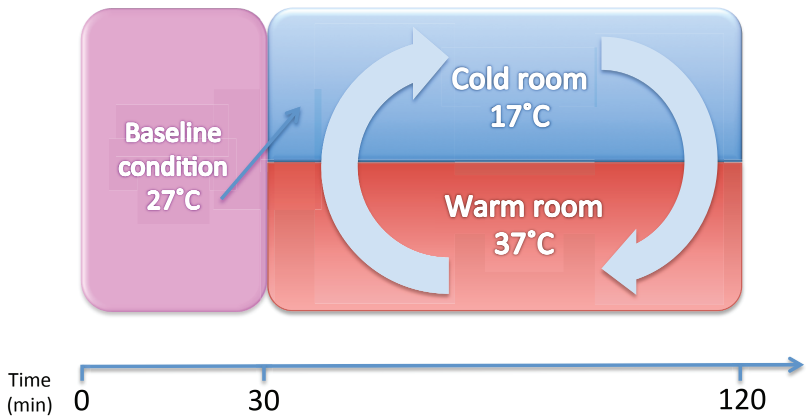

Figure 1. The SWITCH protocol: After 30 minutes of baseline, participants were free to change the conditions; there is no limit in time or frequency.

The SWITCH protocol (figure 1) consisted of a behavioural experiment in which the subjects chose between a hot (37˚C) and a cold (17˚C) condition. Subjects started in the baseline condition room (27˚C ambient temperature). Throughout the whole experiment, participants sat at a desk on a chair and were allowed to read a book or a magazine. Subsequently to the 30 minutes of baseline, subjects were brought to the hot room where they sat at a desk again. After the baseline period, participants were given the freedom to indicate thermoregulatory behaviour as indicated by switching between the two conditions (either cold or warm). After they indicated their desire by ringing a bell, they were replaced to the alternative room. This procedure was continued for 90 minutes. Importantly, subjects were told that the experiment should clearly be no competition of temperature perseverance, that they should try to behave in a natural way and that they should not hesitate to ring the bell when they would want to switch, whenever and as often as they would want to.

2.3 Measurements

Counting the switches and timing the duration (minutes) of persistence in one of the two alternative conditions indicated thermal behaviour. Twenty-six calibrated iButtons (DS1923, Maxim, USA) were attached to the skin with semi-adhesive tape (Fixomull stretch, BSM medical GmbH, Germany) at ISO-defined spots and recorded skin temperature in 1-minute intervals (accuracy ±0.125˚C). Ambient temperature was recorded by an iButton at 1.1m height next to the subject. TS and TC were assessed using our TherMU-VAS, which were completed using a web browser on tablet computer. The questionnaires were presented in Dutch language. During the baseline period, subjects completed the TherMU questionnaire, consisting of a 7-point VAS thermal sensation scale and thermal comfort VAS, on 15-minute intervals and on 6-minute intervals during the rest of the SWITCH protocol. An extra questionnaire was completed just before they switched the conditions, unless they completed one of the regular questionnaires immediately before the switch. Amongst others, the questionnaire included 7-point interval scales to assess global and local thermal sensation and thermal comfort (ISO, 2005). Microsoft Excel was used for data compilation and analysis.

3. Results

The main outcomes of this study were thermal behaviour, ambient and skin temperatures, thermal sensation and thermal comfort. The results per outcome are presented below.

3.1 Thermal behaviour

Thermal behaviour of the three subjects in the cold (C) and in the hot (H) has been indicated by the total amount of switches and the time (min) until the decision to switch. Subject 1 spent about two-thirds of the total exposure time in the cold condition (C=57min vs. H=33min). Subject 2 decided to stay two-thirds of the time in the hot condition (C=30min vs. H=60min). Subject 3 spent approximately the same amount of time both conditions (C=46 vs. H=44min). Subject 1 changed the rooms once (C→H) after 30 minutes of cold exposure. Subjects 1 and 3 decided to switch more often (3 vs. 6 times). The sequencing of switching, as well as, corresponding ambient temperature and skin temperature trends are depicted in figure 2.

The duration from entering the chamber until deciding to switch was longer at C→H (30 and 27 min C→H vs. 14 min H→C) in subject 1. Subject 3 spent more time in H before she decided to switch to C (18, 16 an 10 min H→C vs. 5, 5 and 4 min C→H). Since subject 2 switched one time only, it is not possible to make a statement on the time before decision between cold and hot.

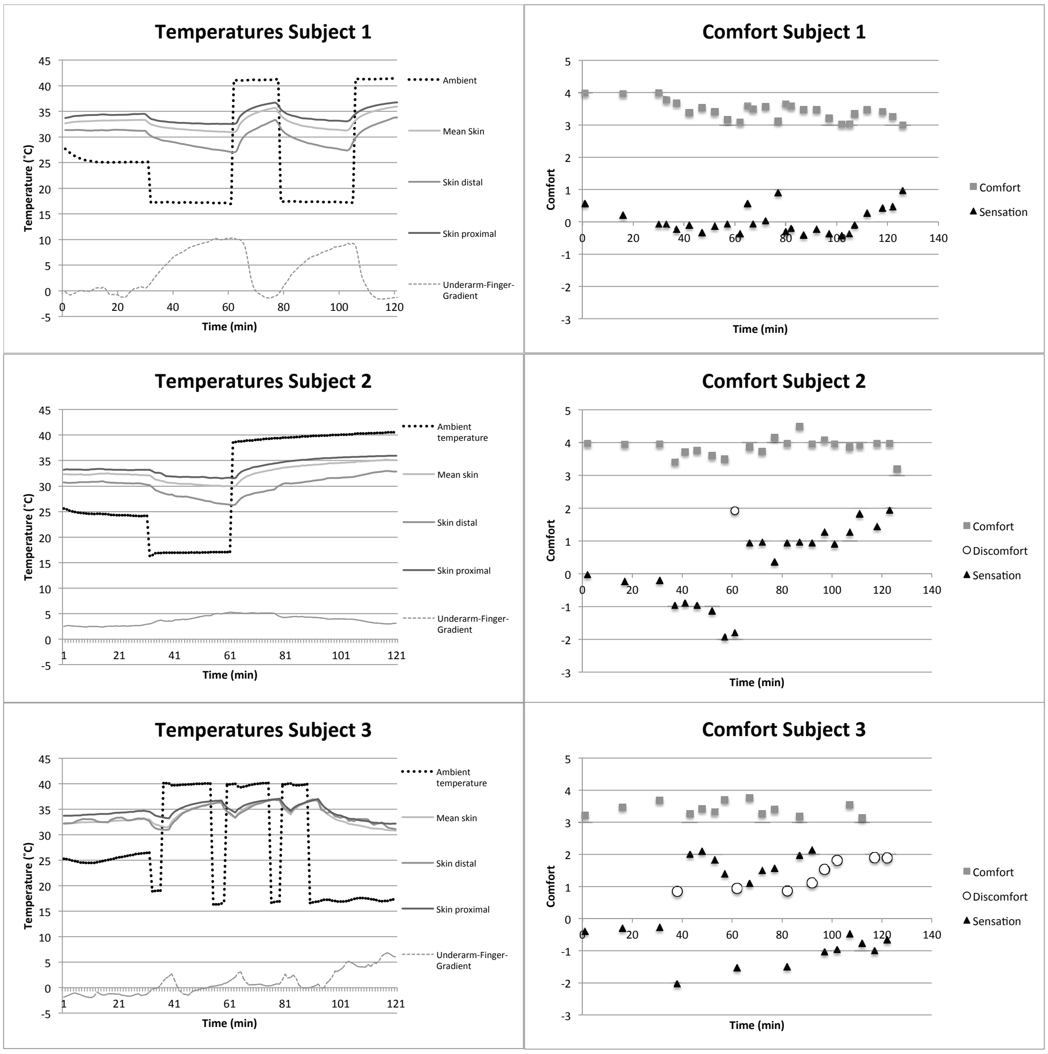

Figure 2. Ambient/skin temperatures, thermal comfort/discomfort and thermal sensation of subject 1, subject 2 and subject 3 during SWITCH. Ambient temperature also indicates switches between the conditions. Underarm-finger-gradient indicates the difference between distal skin temperatures (skin distal) and proximal skin temperatures (skin proximal). Thermal sensation data is represented on the 7-point thermal sensation scale ranging from -3 (cold) to +3 (hot). Thermal comfort data is represented on a 4-point scale; 0=very uncomfortable, 1=uncomfortable, 2=just comfortable, 3=just comfortable, 4=comfortable, 5=very comfortable.

3.2 Temperatures

Ambient temperature during baseline was 25.11±0.49˚C, 40.28±0.82˚C in the hot room and 17.09±0.17˚C in the cold. Skin temperatures of all three subjects during hot and cold conditions are presented in Figure 2 and Table 2.

Table 2. Skin temperatures (averages) during baseline, cold and hot condition. Values are presented as mean±SD and are averages over all time spent in the respective condition.

Baseline	**Subject 1**	**Subject 2**	**Subject 3**	**SD (between subjects)**
Mean skin (˚C)	33.1	32.3	32.6	0.4
Skin distal (˚C)	31.3	30.7	32.8	1.1
Skin proximal (˚C)	34.3	33.2	34.2	0.6
Skin gradient proximal-distal (˚C)	3.0	2.6	1.3	0.9
Underarm-finger gradient (˚C)	-0.1	-2.1	-1.4	1.0
Cold				
Mean skin (˚C)	31.8	30.5	33.5	1.5
Skin distal (˚C)	28.6	27.8	33.8	3.3
Skin proximal (˚C)	33.2	31.9	34.3	1.2
Skin gradient proximal-distal (˚C)	4.6	4.2	0.5	2.3
Underarm-finger gradient (˚C)	7.0	1.9	2.7	2.7
Hot				
Mean skin (˚C)	34.6	33.8	34.9	0.5
Skin distal (˚C)	31.7	30.7	34.8	2.1
Skin proximal (˚C)	35.7	34.9	35.6	0.4
Skin gradient proximal-distal (˚C)	4.0	4.2	0.8	1.9
Underarm-finger gradient (˚C)	1.7	1.2	0.8	0.5

In subjects 1 and 2, mean skin temperature decreased in C and increased in H, compared to baseline. In subject 3, the average of mean skin temperature during C and H were higher compared to baseline levels. Subject 3 exhibited the highest distal skin temperatures during all three conditions. Furthermore, subject 3 had the smallest differences between proximal and distal skin temperatures during baseline, H and C. Underarm-finger-gradient (UFG) can be considered as an indicator for vasodilation (negative values and values tending towards 0) and vasoconstriction (positive values). UFG shifted most between baseline and C measurements in subject 1, which is clearly visible in figure 1 as well.

3.3 Thermal Sensations and Thermal Comfort

During the pilot experiment, subjects had to rate thermal sensation (TS) and thermal comfort (TC) continuously. TS was rated on a continuous 7-point ASHRAE scale ranging from -3 (very cold) to 0 (neutral) and to 3 (very hot). TC was indicated on a split visual analogue scale to distinguish between comfort and discomfort (0-2 for discomfort and 3-5 for comfort). Thus, high values reflected high levels of thermal comfort.

The trends of TS and TC during the experiment of all three subjects are provided in figure 2. Whereas subject 1 always marked TS between “a little hot” and “a little cold” and never indicated the feeling of discomfort throughout the whole experiment, subject 3 fluctuated between “hot” and “cold” and indicated discomfort in 8 (of 21) questionnaires. Subject 2 also indicated TS between “hot” and “cold” but discomfort was stated once only.

4. Discussion

The present pilot study aimed to test a protocol on thermoregulatory behaviour and thermal comfort. Subjects underwent an experimental setting with two distinct thermal conditions of approximately 17˚C and 40˚C. Subjects were given the freedom to switch between these two conditions without any given limits in time or frequency.

4.1 Thermal behaviour and thermal comfort

Since all subjects switched at least once, we suppose that the two temperatures were extreme enough to allure thermoregulatory behaviour. Although all subjects were of comparable age, height and weight, they exhibited different behaviour upon the provided thermal environments. Subject 2 seemed to be content with a wide range of temperatures, since she switched only once after a relatively long stay in H. In contrast, subject 3 decided to change the conditions for six times in 90 minutes of exposure.

Thermal comfort seemed to be appropriately related to thermoregulatory behaviour, indicated by the extent of discomfort (figure 2). Subject 2 switched only once and indicated the feeling of discomfort immediately before changing the conditions. Subject 3, who performed most switches, also indicated discomfort in eight of the 21 questionnaires. Although subject 1 did not report the feeling of discomfort, a trend towards decreasing thermal comfort in the minutes just before she switched were evident. The same trends can be observed in thermal sensation (TS) among all three subjects. If TS tended to increase or decrease towards “cool” (-2) or “warm” (2), subjects were prone to switch. These findings suggest that, on the one hand, subjects experience the thermal environment differently. Time spent in one condition seems to be an important factor since subjects perceived discomfort after different time spans (subject 3 felt uncomfortable very quickly; subject 1 did not felt uncomfortable at all). On the other hand, all subjects tended to perform behaviour (in form of switching), when TS reached the feeling of “hot” or “cold”. Our findings therefore partially agree with other studies that conducted similar behavioural protocols. Schlader *et al.* demonstrated before, that the feeling of “discomfort” is important in the conductance of behavioural thermoregulation (Schlader et al., 2013). The results furthermore suggest that the subjects have individual thermal-comfort-ranges. Recently, Jacquot *et al.* (accepted for publication) indicated, that individuals could be categorized based on their individual thermal preference (Jacquot et al., 2014). Jacquot found significant differences between individuals with “broad range of temperatures preference” and “narrow range of temperatures preference”. These categories seem to be applicable for the three subjects of the pilot-measurement as well: roughly, we could classify subjects 1 and 2 as individuals with a broad range of preferred temperatures and subject 3 as an individual with a narrow range of preferred temperatures.

4.2 Thermal behaviour and physiological responses

Interestingly, the three subjects seemed to have distinct reactions of skin temperature upon thermal exposure.

In subject 1 and 2, mean skin temperature shifted alongside with ambient temperature but in subject 3, mean skin temperature was higher in both H and C compared to baseline. This might be due to the fact, that in the first 60 minutes of SWITCH, subject 3 remained longer in the hot room than in the cold and thus, skin temperature did not decrease remarkably compared to baseline. It is furthermore noticeable, that based on figure 2, skin temperatures of subject 1 and 2 immediately decrease or increase upon ambient temperature change, whereas subject 3 seems to have a sort of delay in adaptions of skin temperature. Taking all these findings into account, the three subjects seem to have distinct physiological reactions upon thermal environmental changes.

In the future, we are going to measure more physiological indicators such as energy expenditure, skin conductance and sweat rate to provide insight into the relationships between physiological parameters and behavioural thermoregulation.

6. References

CHATONNET, J., THIERS, H., CABANAC, M. & PASQUIER, J. 1966. [On the origin of conscious impression of thermal comfort]. *Lyon Med,* 216**,** 1387-92.

DE DEAR, R. J., AKIMOTO, T., ARENS, E. A., BRAGER, G., CANDIDO, C., CHEONG, K. W. D., LI, B., NISHIHARA, N., SEKHAR, S. C., TANABE, S., TOFTUM, J., ZHANG, H. & ZHU, Y. 2013. Progress in thermal comfort research over the last twenty years. *Indoor Air,* 23**,** 442-461.

HORI, S. 1995. Adaptation to heat. *The Japanese journal of physiology,* 45**,** 921-946.

IPCC 2013. Climate change 2013 - The physical science basis. *In:* STOCKER, T. F., QIN, D., PLATTNER, G.K., TIGNOR, M.M.B., ALLEN, S., BOSCHUNG, J., NAUELS, A., XIA, Y., BEX, V., MIDGLEY. P.M. (ed.) *Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Switzerland: Intergovernmental Panel on Climate Change.

ISO 2005. *7730 Ergonomics of the Thermal Environment - Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices And Local Thermal Comfort Criteria,* Geneva, International Standards Organization.

ISO, I. S. O. 2009. EN-ISO 9920: Ergonimics of the thermal environment - estimation of thermal insulation and water vapour resistance of a clothing ensemble.

JACQUOT, C. M. C., SCHELLEN, L., KINGMA, B. R. M., BAAK, M. & VAN MARKEN LICHTENBELT, W. D. 2014. Influence of thermophysiology on thermal behavior: the essentials of categorization. *Physiology & Behavior,* in press.

MCCULLOUGH, E. A. 1989. A data base for determining the evaporative resistance of clothing. *ASHRAE Trans,* 95**,** 316-328.

SCHLADER, Z. J., PERRY, B. G., JUSOH, M. R., HODGES, L. D., STANNARD, S. R. & MUNDEL, T. 2013. Human temperature regulation when given the opportunity to behave. *Eur J Appl Physiol,* 113**,** 1291-301.