Physiology & Behavior 151 (2015) 426–440

Contents lists available at ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/phb

Investigation of gender difference in human response to temperature step changes

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HIGHLIGHTS

- Women lowered oral temperatures more intensively than men after up-step of S15.
- Men witnessed a more remarkable decrease in RMSSD after up-step of S15 than women.
- Men regulated skin temperatures more robustly and swiftly than women.
- Women felt lower temperature cooler and higher temperature warmer than men.

ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form 22 July 2015
Accepted 29 July 2015
Available online 8 August 2015

Keywords:
Temperature steps
Gender difference
Subjective perception
Biomarkers
Physiological parameters

ABSTRACT

The purpose of this study was to examine gender difference in human response to temperature step changes. A total of three step-change conditions (S5: 32 °C–37 °C–32 °C, S11: 26 °C–37 °C–26 °C, and S15: 22 °C–37 °C–22 °C) were designed and a laboratory experiment with 12 males and 12 females was performed. Results of this study support our hypothesis that females differ from males in human response to sudden temperature changes from the perspectives of psychology, physiology and biomarkers. Females are more prone to show thermal dissatisfaction to cool environments while males are more likely to feel thermal discomfort in warm environments. It is logical that men have a stronger thermoregulation ability than women as male skin temperature change amplitude is smaller while the time to be stable for skin temperature is shorter than that of females after both up-steps and down-steps. In S15, males witnessed a more intensive decrease in RMSSD while females underwent a remarkable instant reduce in oral temperatures after the up-step. Marginal significance was observed in male IL-6 before and after the up-step in S15 while female IL-6 prominently increased after the down-step in S15.

1. Introduction

Human beings are often likely to expose themselves to sudden temperature changes in daily life. For example, people will encounter temperature steps when entering or exiting air-conditioned buildings and getting on or off planes. Many studies have been carried out to examine human subjective and objective responses to transient thermal environments. However, most of them did not consider gender difference as some studies only enrolled males in their experiments [1–6], and some even did not give subjects' gender information [7,8]. Moreover, although some dynamic thermal environment research did recruit both males and females as subjects [9–12], only Chen discussed gender difference from the aspect of thermal sensation and skin physiology [12], followed by Zhai presenting a simple gender comparison in thermal sensation and dissatisfaction [13]. No circumstantial analysis on gender difference in human response to temperature step changes has been published.

As far as thermal perceptions are concerned, Karjalainen conducted a detailed review comprising chamber studies and field surveys, and gave a synopsis of thermal comfort experienced by men and women, which concluded that females were more likely than males to express thermal dissatisfaction; however, no significant gender difference was found in neutral temperatures in most studies; females are more sensitive than males to a deviation from an optimal temperature and express more dissatisfaction, especially in cooler conditions [14]. Nevertheless, as the review shows, most studies focus on human thermal comfort under steady environments rather than transient environments and could not reflect human dynamic response. In addition, objective measures like physiological parameters and biomarkers are applied more

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http://dx.doi.org/10.1016/j.physbeh.2015.07.037
0031-9384/

Nomenclature

S5, S11, S15 experiment conditions (S5: 32 °C–37 °C–32 °C, S11: 26 °C–37 °C–26 °C, and S15: 22 °C–37 °C–22 °C)
S5-M, S11-M, S15-M male response to S5, S11 and S15, respectively
S5-F, S11-F, S15-F female response to S5, S11 and S15, respectively
TS thermal sensation
TC thermal comfort
TA thermal acceptability
ANOVA analysis of variance
IL-6 Interleukin-6, ng/L
HSP70 heat stress protein 70, ng/L
T_{skin} mean skin temperature, °C
T_{oral} oral temperature, °C
SPO_2 blood oxygen saturation, %
RR respiratory rate, bpm
ECG electrocardiograph
HRV heart rate variability
HR heart rate, bpm
mRR the average of the beat intervals, ms
SDRR standard deviation of the beat intervals, ms
RMSSD the square root of the mean of the sum of the squares of differences between adjacent beat intervals, ms
TP (5 min total power) the variance of NN intervals over temporal segment, ms^2
LF_{norm} LF power (0.04–0.15 Hz) in normalized units; LF / (TP − VLF) ∗ 100, n.u.
HF_{norm} HF power (0.15–0.4 Hz) in normalized units; HF / (TP − VLF) ∗ 100, n.u.
LF/HF ratio LF/HF
Δ instant change which was defined as the first value after temperature steps minus the last value before temperature steps (e.g. ΔTS, ΔTC, ΔHR, ...)

and more widely in thermal environment studies [15–18], but few gender difference analyses were delivered and even much less studies on the bodily reaction to temperature steps between different gender groups were performed.

The purpose of this study was to investigate gender difference in human response to the alteration in thermal environment. We hypothesized that females are different from males in their responses to different temperature steps from the perspectives of psychology, physiology and biomarkers.

2. Material and methods

2.1. Subjects

Twenty four healthy undergraduate students (half males and half females) with an average age of 22 ± 1 years were recruited in the study. Preliminary evaluation of applicants was conducted to exclude those who might suffer cardiovascular disease, respiratory disease and skin disease which might interfere with the physiological and biochemical measures used in this experiment. Table 1 is the summary of their anthropometric information. Every subject's body mass index rates in the normal range [19]. Skin surface area was calculated based on the Chinese formula [20]. Table 1 also shows profound gender differences in height, weight and skin surface area. Participants were required to wear short-sleeved T-shirts, short trousers and slippers. All of them were asked to avoid caffeine, alcohol, and intense physical activity at least 12 h prior to each experiment. All protocols were approved by the university's ethics committee. Verbal and written informed consents were obtained from each subject prior to participation.

Table 1
Anthropometric information of subjects participating in the study.

Gender	Number	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	A_s (m^2)
Male	12	22 ± 1	176.8 ± 4.9	66.5 ± 6.3	21.3 ± 2.3	1.90 ± 0.08
Female	12	22 ± 1	164.1 ± 5.7	55.1 ± 4.0	20.5 ± 1.3	1.69 ± 0.08
P	–	0.122	<0.001***	<0.001***	0.270	<0.001***

Note: BMI, body mass index and A_s, body surface area calculated by formula for Chinese adults [20].
*** $P < 0.001$.

2.2. Measurements

2.2.1. Thermal environment measurement

The experiment was conducted in a climate chamber which contained two adjacent rooms (Room A: 3.8 m ∗ 3.6 m ∗ 2.65 m, Room B: 3.8 m ∗ 3.8 m ∗ 2.65 m) connected by an internal door. The step changes in air temperature of heat exposure were supposed to range from 5 °C (small) to 11 °C (medium) to 15 °C (large). Room A was set at 37 °C to represent the outdoor temperature while Room B was set at 22/26/32 °C to represent the typical temperature levels found in air conditioned and naturally ventilated environments in summer. By this means, three temperature step conditions, namely, S5: 32 °C–37 °C–32 °C, S11: 26 °C–37 °C–26 °C, and S15: 22 °C–37 °C–22 °C, were developed.

The measurement site was placed at the center of each room. The air temperature and relative humidity were recorded every 10 s at 0.1 m and 1.1 m height. The air velocity was also monitored. The mean radiant temperature was computed from the globe temperature. All apparatus used in the experiment are listed in Table 3. The measured physical parameters describing the indoor environment are summarized in Table 2. The relative humidity in all rooms was controlled in the range of 30% to 70%. The air speed was kept under 0.1 m/s. The mean radiant temperature was close to air temperature during the experiment.

2.2.2. Subjective measurement

In this study, psychological measurements consist of health self-reported symptoms, fatigue, thermal perceptions and endurance. Subjects were asked to answer whether or not they were suffering from health symptoms like perspiration, dizziness, accelerated respiration, eyestrain and accelerated heart rate at present time. Fatigue was assessed using the Japanese subjective fatigue symptoms (2002 version) [21]. The fatigue check-list contains 25 items and is divided into 5 subtypes. The participants answered each item using a five-point discrete scale from +1 (none) to +5 (extremely severe). In addition, subjects gave their subjective thermal feelings on ASHRAE continuous voting scales and endurance status on a four-point scale (Fig. 1).

2.2.3. Biochemical and physiological measurements

When encountering a temperature step, many biochemical and physiological variations would occur for humans to adapt themselves to the stress. In this study, parameters that can reflect temperature step effects on the human immune system (IL-6 and HSP70), heat metabolism system (T_{skin} and T_{oral}), respiratory system (SPO_2 and RR) and cardiovascular system (ECG) were recorded. Devices used for measurements are summarized in Table 3.

Venous blood was sampled four times during the experiment for the test of IL-6 and HSP70. Each time, each subject provided about 2 ml of blood. The samples were then centrifuged for 15 min at the speed of 2000 RPM. After separation from blood cells, serum was stored in a freezer at −20 °C before being sent for analysis. The analysis was performed by an external specialized laboratory using ELISA (enzyme-linked immunosorbent assay) kits.