Anthropometric and Demographic Differences in Human Thermophysiology under Light Activity

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Abstract

This paper presents findings on variations in human thermoregulatory response due to demography and anthropometry by studying different subjects during periods of rest, moderate walking and recovery. Sixteen subjects participated in the present study. Controlled experiments were conducted under similar environmental conditions (ambient air temperature and relative humidity). Subjects underwent four phases of experiments: (i) steady-state measurements, (ii) 15-min walk, (iii) 15-min recovery in a sitting position, and (iv) post experiment measurements. There were significant differences in mean skin temperature (Tsk,mean) at rest between genders. However, no significant differences were observed in Tsk,mean between age groups. Core temperatures (Tc) at rest were not significantly different between gender and age groups. Body Mass Index (BMI) and weight were observed to be positively correlated to Tsk,mean of subjects at rest. It was observed that subjects with lower BMI tended to have lower local skin temperatures (Tsk) in their extremities. On the other hand, subjects with higher BMI tended to have slightly lower Tsk in their trunks but higher Tsk in the extremities of their bodies. Elderly male subjects had significantly higher Tsk,mean than other demographic groups in the experiments. Anthropometry of subjects did not influence the change in Tc during moderate walking and recovery period. Although Tsk,mean was observed to generally decrease with BMI during moderate walking, no significant correlation was observed. However, Tsk,mean gain was observed to be marginally dependent on weight and body surface area (BSA) during the recovery period. During the moderate walking phase, subjects with BMI above 23 were observed to have reduced Tsk in a few parts of their body. Conversely, subjects with BMI under 21 experienced increase Tsk across most body parts, especially their extremities. Overall, during moderate walking, sweat rate (SR) was significantly correlated to both BSA and BMI. At similar BMI levels, the SR of males was observed to be greater than that of females. The results show that gender and anthropometric conditions have a significant effect on the thermoregulatory response of subjects at steady-state and during moderate walking. Variation in the Tsk across different demographic and anthropometric groups suggest that these differences have to be considered when considering localized comfort of subjects.

Keywords: anthropometric differences, demographic differences, skin temperature, core temperature, sweat rate

1. Introduction

Thermal physiology plays an important part in the health and quality of life of people. Heat-related discomfort, stress or injuries occur when thermoregulatory processes are unable to regulate body temperatures. These processes, together with the interaction of radiative (R), convective (C) and latent heat (E) exchanges of the human body with its immediate surroundings, govern the thermal balance of the body and can vary to a large degree, and with greater magnitudes in the outdoors. This is because part of the influence on human thermal physiology in the outdoors come from meteorological factors such as air temperature, radiation, wind speed and humidity, which are locally modified by urban factors such as the three-dimensional geometry of street canyons, the orientation of the street canyons and the thermal properties of surface materials (Oke 2006).

Core temperature (Tc), mean skin temperature (Tsk,mean) and sweat rate (SR) are among the variables that moderate a person’s thermophysiological condition (Gagge 1971, Höppe 1993).
The thermal balance of individuals also influences their level of thermal comfort - a subjective perception of satisfaction with the thermal environment - together with some form of psychological effect (Fanger 1970).

Apart from external influences, variation in individual characteristics (such as demography or anthropometry) are also known to result in differing physiological response among people. Individual variation in thermoregulation can come about as a result of behavioral differences, such as choice of activity and/or clothing, or autonomic differences, such as demographic or anthropometric variation in metabolic rate or sweat rate (Hensen 1990).

Various studies have pointed out the thermoregulatory differences between groups of people, such as age differences in metabolic rate (van Ooijen et al. 2004); sweat rate differences as a result of age (Inoue et al. 1995), gender (Wyndham et al. 1965), and metabolic rate (Ooka et al. 2010); the influence of adiposity (body fat composition) on skin temperatures (Nishimura et al. 1993) and overall thermoregulatory response (Takada 2014); noting that some of these studies focus on indoor environments or sedentary subjects. Despite this, many models and studies still employ a “standard male adult”, which is further complicated by ethnic variations, to determine the comfort levels and physiological responses due to different environmental configurations. Relatively few studies (e.g. Nakayoshi et al. 2015) have looked at demographic or anthropometric variations in the thermophysiological condition of people during transient outdoor activity. The above being the case, the experiments in the present study are designed to consider the demographic and anthropometric variations in the thermoregulatory response of subjects under transient thermophysiological state (walking), in moderate simulated outdoor conditions. This is with the aim of adding new knowledge on individual variation in the thermophysiology and thermoregulatory responses.

### 2. Material and Methods

#### 2.1. Experiment subjects and calculation of anthropometric variables

Sixteen subjects participated in the present study (four males in their 20s, four females in their 20s, four males in their 60s and four females in their 60s). Table 1 shows the anthropometric measurements of the subjects in the demographic groups. Apart from giving consent upon hearing the experiment procedure, subjects were required to declare that they had no previous occurrences of heat injuries as that may affect their thermoregulatory response. Blood pressure and pulse rate of subjects were also monitored by a nurse to ensure that subjects were physically healthy during the experiments. Subjects were assumed to have similar fitness levels and habits. During the experiments, all subjects wore identical microfiber polyester T-shirts, to ensure that sweat was quickly evaporated, and long slacks.

Height (Ht) and weight (Wt) of subjects were recorded before the start of the experiments. Body fat or muscle mass not measured directly, instead, body mass index (BMI), which is an approximate measurement of adiposity, was calculated using Equation 1, and body surface area (BSA) was calculated using Equation 2 (Fujimoto 1968).

\[
BMI = \frac{Wt[kg]}{(Ht[m])^2} \tag{1}
\]

\[
BSA[m^2] = Wt[kg]^{0.444} \cdot (Ht[m] \cdot 100)^{0.663} \cdot 88.83[m kg^{-1}] \cdot 10^{-4} \tag{2}
\]

#### 2.2. Statistical methods

The distribution of weight and BMI of subjects were not observed to be significantly different between demographic groups (p=.130 and p=.219 respectively) through ANOVA tests. While the differences in distribution of BSA was marginally significant (p=.044), there was still reason to perform gender and age analysis, although care must be taken when interpreting the results. Test of normality was done using the

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean height (SD)</th>
<th>Mean weight* (SD)</th>
<th>Mean BMI (SD)</th>
<th>Mean BSA (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>Kg</td>
<td>kg m(^{-2})</td>
<td>m(^{2})</td>
</tr>
<tr>
<td>Male 20s (n=4)</td>
<td>1.72 (0.04)</td>
<td>64.719 (3.581)</td>
<td>21.88 (2.03)</td>
<td>1.77 (0.03)</td>
</tr>
<tr>
<td>Male 60s (n=4)</td>
<td>1.69 (0.04)</td>
<td>66.005 (6.027)</td>
<td>23.53 (1.58)</td>
<td>1.75 (0.10)</td>
</tr>
<tr>
<td>Female 20s (n=4)</td>
<td>1.65 (0.09)</td>
<td>56.420 (10.912)</td>
<td>20.48 (1.84)</td>
<td>1.61 (0.19)</td>
</tr>
<tr>
<td>Female 60s (n=4)</td>
<td>1.52 (0.03)</td>
<td>53.366 (5.699)</td>
<td>23.07 (2.12)</td>
<td>1.49 (0.08)</td>
</tr>
<tr>
<td>Range</td>
<td>1.48 – 1.78</td>
<td>42.073 – 72.455</td>
<td>17.74 – 26.04</td>
<td>1.36 – 1.90</td>
</tr>
</tbody>
</table>

*Mean weight is calculated using weight of subjects at the start of each experiment (P1)
Shapiro-Wilk test, with all subjects’ anthropometric variables deemed to be normally distributed as the null hypothesis of normal distribution was not rejected (p > 1).

Two-way factorial ANOVA was used to test for the influence and interaction of the independent variables age and gender on parametric dependent variables of $T_{\text{sk,mean}}$, $T_c$, and SR. In the event of non-normal distribution of a dependent variable, the Kruskal-Wallis test was conducted on each independent variable against the dependent variable in question. Relationships between variables were assessed using the Pearson correlation coefficient and coefficient of determination from ordinary least squares regression. Statistical analyses were performed using the R software environment (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was set at $p < 0.05$.

### 2.3. Experiment flow and conditions

The experiments were conducted in March 2015 in a climate chamber approximately 5m by 5m in floor area at the Institute of Industrial Science, The University of Tokyo. Variables controlled during the experiment were air temperature ($T_a$), at 28.5°C (±0.5°C), and relative humidity (RH), at 37% (±4%), with mean radiation temperature ($T_{\text{mrt}}$) equivalent to $T_a$, and negligible wind speed ($v$). The chamber was made up of two rooms, an anteroom and an experiment room, both of which are sealed from the outside.

Each experiment was made up of four consecutive phases. Phase 1 (P1) was a 15-min period where subjects were rested in the anteroom to obtain baseline conditions and their weight before activity. Phase 2 (P2) was a moderate walking phase during which all subjects walked at a comfortable pace (4 km h$^{-1}$) for 15 minutes (1 km) within the experiment room, led and paced by an experiment assistant. The purpose of the walking phase was to raise the metabolic rate of the subjects and to record their physiological response as conditions changed around them. During Phase 3 (P3) subjects were seated in the experiment room for 15 minutes for the recovery phase. The final phase (P4) was for post-experiment measurements.

Subjects did not use the toilet or to intake any food or fluids between the start of P1 and the end of P4, so as not to affect internal heat production or estimations of sweat rate (SR). SR was estimated by the difference in the weight of subjects before P2 and after P3, scaled to an hour (i.e. g hr$^{-1}$). Environmental conditions of ambient air temperature ($T_a$) and relative humidity (RH) in the climate chamber were kept close to constant as shown in Table 2.

### 2.4. Instrumentation

For logging of physiological response, each subject was equipped with several instruments as shown in Table 3. Nikkiso ear-piece probes (ITP-010-27, Nikkiso co., Japan) were inserted in the left ears of subjects and used to record continuous tympanic core temperature ($T_c$). For mean skin temperatures ($T_{\text{sk}}$, sets of eight Nikkiso skin temperature thermistors (ITP-010-11, Nikkiso co., Japan) were placed at eight parts of the body. Data loggers (N543, Nikkiso co., Japan) were used to log both sets of data. All subjects were equipped with the necessary instruments at least 15 minutes before the start of each experiment. A precision scale (IS150, Sartorius, Germany) was used to measure changes in subject weights before and after the experiments, for the purpose of estimating sweat rate.

### 3. Results

#### 3.1. Anthropometric variation and $T_c$ at steady state

Mean $T_c$ of subjects while in the anteroom (P1) was 36.15 °C (range: 35.77 °C to 36.60 °C). This is

<table>
<thead>
<tr>
<th>Group</th>
<th>Experiment</th>
<th>Date</th>
<th>Mean $T_c$ (SD)</th>
<th>Mean RH (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male 20s</td>
<td>1</td>
<td>3 Mar 2015</td>
<td>28.51 (0.23)</td>
<td>36.82 (1.10)</td>
</tr>
<tr>
<td>Male 60s</td>
<td>2</td>
<td>3 Mar 2015</td>
<td>28.77 (0.21)</td>
<td>36.95 (1.51)</td>
</tr>
<tr>
<td>Female 20s</td>
<td>3</td>
<td>4 Mar 2015</td>
<td>28.43 (0.17)</td>
<td>33.88 (1.29)</td>
</tr>
<tr>
<td>Female 60s</td>
<td>4</td>
<td>4 Mar 2015</td>
<td>28.40 (0.14)</td>
<td>39.64 (0.62)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Instrument</th>
<th>Resolution</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin temperature</td>
<td>$T_a$</td>
<td>Nikkiso thermistor ITP-010-11</td>
<td>0.01°C</td>
</tr>
<tr>
<td>Core temperature</td>
<td>$T_c$</td>
<td>Nikkiso probe ITP-010-27</td>
<td>0.01°C</td>
</tr>
<tr>
<td>Body weight</td>
<td>Wt</td>
<td>Sartorius IS150</td>
<td>0.001 kg</td>
</tr>
</tbody>
</table>
assumed to be representative of steady-state body conditions. BMI was observed to show a positive relationship with steady state $T_c$ while weight and BSA did not have significant correlations with steady state $T_c$ (Table 4). Figure 1 shows the relationship between BMI and steady state $T_c$ of subjects.

### 3.2. Demographic variation and $T_c$ at steady state

Mean steady state $T_c$ of each demographic group is shown in Table 5. Individual values can be found in Figure 1. Elderly subjects were observed to have higher $T_c$ at steady state. Two-way factorial ANOVA tests show that differences in steady state $T_c$ due to age and gender were not significant ($p=.080$ and $p=.439$ respectively).

### 3.3. Anthropometric variation and $T_{sk}$ at steady state

As $T_{sk}$ was measured over 8 parts of the body, variables representing each part of the body are indicated with a subscript (e.g. $T_{sk,head}$). Mean skin temperature for the entire body was calculated with weights in accordance with ISO 9886 (ISO 2004), and represented by the variable $T_{sk,mean}$.

Mean of the steady state $T_{sk,mean}$ of subjects was 33.60 °C (range: 33.07 °C – 34.76 °C). Referring to Table 6, only BMI and weight were observed to have significant positive correlations with steady state $T_{sk,mean}$ of subjects. As the skin temperature of various parts of the body may differ, further analysis showed that $T_{sk,hand}$ was positively correlated with anthropometric variables. However, while $T_{sk,chest}$ was observed to decrease with increasing BMI, weight, and BSA, these relationships were not significant. Dividing the subjects into BMI groups as shown in Figure 2, it was observed that during subjects with lower BMI had generally lower

![Figure 1: Relationship between BMI and $T_c$ during steady state across demographic groups](image1)

![Figure 2: Steady state $T_{sk}$ of different body parts (and mean) averaged across BMI groups](image2)
Anthropometric and Demographic Differences in Human Thermophysiology under Light Activity

Tsk, particularly at their extremities (arms and legs). Subjects with higher BMI had slightly lower trunk Tsk,chest but higher Tsk at their extremities.

3.4. Demographic variation and Tsk at steady state

Table 7 shows the mean values of steady-state Tsk,mean in each demographic group. The Shapiro-Wilk Test shows steady-state Tsk,mean to be non-normally distributed (p<.05) and data transformation could not achieve normality in distribution. The non-parametric Kruskal-Wallis test was used instead to test for differences between groups. Differences in steady state Tsk,mean between age groups were not significant (p=.059), while differences between gender groups were significant (p=.028). The latter was likely contributed by the elderly male group which has a mean steady-state Tsk,mean that was more than 1 °C higher than the other groups (Table 7).

Referring to Figure 3, generally, Tsk of the head and trunk (chest and shoulder) were quite similar across the different demographic groups. The main source of variation was the Tsk in extremities as also observed among different BMI groups. To control the effects of BMI variation, one representative from each demographic group with BMI closest to 21 was chosen (Figure 4). Similar findings results are found, although generally, Tsk values for the elderly groups were slightly lower.

3.5. Anthropometric variation and Tc during activity

Mean Tc of subjects increased to 36.22 °C (range: 35.65 °C to 36.88 °C) in P2 and 36.31 °C (35.74 °C to 36.71 °C) in P3, as compared to during steady state. During the walk (P2), BMI remained similarly correlated to mean Tc as when at steady-state (Figure 5). Referring to Table 8, the strongest relationship was observed between BMI and Tc, while the relationships between weight and BSA against Tc were not significant. During the recovery phase (P3), the correlational strength of all three pairs increased. In particular, a significant positive relationship was observed between BMI and Tc, and a marginally significant positive correlation was found between weight and Tc. Although the correlational strength of BSA and Tc increased, the relationship was not statistically significant.

The mean change in core temperature of subjects (ΔTc) was 0.08 °C (range: -0.25 °C to 0.34 °C) for P2 and 0.11 °C (range: -0.08 °C to 0.23 °C) for P3. During P2, ΔTc was observed not to correlate well with any of the anthropometric parameters. ΔTc was observed to decrease with BMI, weight and BSA during P3 but the relationships are not significant (Table 8).

### Table 7: Mean of steady-state Tsk,mean of each demographic group

<table>
<thead>
<tr>
<th></th>
<th>Male 20s (SD)</th>
<th>Male 60s (SD)</th>
<th>Female 20s (SD)</th>
<th>Female 60s (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean steady-state Tsk,mean</td>
<td>33.46 (0.27)</td>
<td>34.51 (0.26)</td>
<td>33.26 (0.27)</td>
<td>33.33 (0.27)</td>
</tr>
</tbody>
</table>

### Table 8: Correlation coefficients between Tc (at P2 and P3) and anthropometric variables. ΔTc represents the change in Tc between the end and start of a phase.

<table>
<thead>
<tr>
<th></th>
<th>BMI</th>
<th>Weight</th>
<th>BSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Tc during P2</td>
<td>.768**</td>
<td>.461</td>
<td>.306</td>
</tr>
<tr>
<td>Mean Tc during P3</td>
<td>.784***</td>
<td>.569*</td>
<td>.432</td>
</tr>
<tr>
<td>ΔTc during P2</td>
<td>.253</td>
<td>.292</td>
<td>.280</td>
</tr>
<tr>
<td>ΔTc during P3</td>
<td>-.304</td>
<td>-.227</td>
<td>-.173</td>
</tr>
</tbody>
</table>

(* *** p<.001; ** p<.01; * p<.05)
3.6. Demographic variation and $T_c$ during activity

Table 9 shows the mean and standard deviation of $\Delta T_c$ of each demographic group during P2 and P3. The Shapiro-Wilk test failed to reject the null hypothesis that $\Delta T_c$ values were normally distributed ($p > .1$) during P2 and P3. Two-way factorial ANOVA test showed that during P2, $\Delta T_c$ was not significantly different between age groups ($p = .164$) and gender groups ($p = .187$), likely due to high within-group differences. During P3, $\Delta T_c$ differences between age groups and gender groups were not significant ($p = .096$ and $p = .364$ respectively).

| Table 9. Mean and standard deviation of $\Delta T_c$ during P2 and P3 for each demographic group |
|---------------------------------|-----------------|-----------------|-----------------|
|                                 | Male 20s (SD)   | Male 60s (SD)   | Female 20s (SD) | Female 60s (SD) |
| $\Delta T_c$, during P2         | 0.14 (0.07)     | 0.12 (0.19)     | -0.07 (0.15)    | 0.15 (0.11)     |
| $\Delta T_c$, during P3         | 0.17 (0.05)     | 0.08 (0.15)     | 0.13 (0.08)     | 0.03 (0.05)     |

3.7. Anthropometric variation and $T_{sk}$ during activity

Mean $T_{sk,mean}$ of subjects decreased to 33.56 °C (range: 32.98 °C to 34.62 °C) in P2 but increased to 33.84 °C (range: 33.15 °C to 34.67 °C) in P3, as compared to during steady state. As at steady state, mean $T_{sk,mean}$ during P2 was observed to be significantly correlated to BMI and weight but not to BSA. However, during P3, mean $T_{sk,mean}$ was observed to be significantly correlated to weight and BSA, but not to BMI (Table 10).
The mean change in core temperature of subjects ($\Delta T_c$) was 0.03 °C (range: -0.36 °C to 0.31 °C) for P2 and 0.32 °C (range: -0.32 °C to 0.71 °C) for P3. Referring to Table 10, significant relationships between anthropometric variables and the mean of $\Delta T_{sk,mean}$ were not found during P2, although $\Delta T_{sk,mean}$ was observed to decrease with BMI, weight, and BSA. Significant relationships were found between change in $T_{sk}$ and anthropometric variables during P3 for BSA and weight, but not BMI.

Dividing the subjects into BMI groups, as shown in Figure 6, heat gain for subjects with BMI under 21 were mainly from their extremities (hand and calf). For subjects with BMI of between 21 and 23, apart from the hands, they followed similar patterns to BMI under 21. For subjects with BMI above 23, cooling occurred for many parts of their body.

### 3.8. Demographic variation and $T_a$ during activity

Table 11 shows the mean and standard deviation of $\Delta T_{sk,mean}$ of each demographic group during P2 and P3. The Shapiro-Wilk test failed to reject the null hypothesis that $\Delta T_{sk,mean}$ values were normally distributed (p>.1) during P2 and P3. Two-way factorial ANOVA showed during P2, $\Delta T_{sk,mean}$ was not significantly different between either gender or age groups (p=.309 and p=.149 respectively). In the case of P3, $\Delta T_{sk,mean}$ was significantly different between gender groups (p=.041) but not age groups (p=.433).

Referring to Figure 7, young subjects gain most heat in the calves. Apart from that, young males appear to gain heat quite evenly across the body. The elderly mainly gain heat in the lower body but lose heat in other parts of the body. To control the effect of BMI variation, one representative from each demographic group with BMI closest to 21 was chosen (Figure 8). Similar findings results are found, although some differences are found for the elderly male subject who had gained more skin heat than the average elderly male.

Table 10. Correlation coefficients between $T_{sk,mean}$ (at P2 and P3) and anthropometric variables. $\Delta T_{sk,mean}$ represents the change in $T_{sk,mean}$ between the end and start of a phase.

<table>
<thead>
<tr>
<th></th>
<th>BMI</th>
<th>Weight</th>
<th>BSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean $T_{sk,mean}$ during P2</td>
<td>.588*</td>
<td>.552*</td>
<td>.469</td>
</tr>
<tr>
<td>Mean $T_{sk,mean}$ during P3</td>
<td>.527</td>
<td>.670**</td>
<td>.629*</td>
</tr>
<tr>
<td>$\Delta T_{sk,mean}$ during P2</td>
<td>-.334</td>
<td>-.232</td>
<td>-.148</td>
</tr>
<tr>
<td>$\Delta T_{sk,mean}$ during P3</td>
<td>.270</td>
<td>.575*</td>
<td>.594*</td>
</tr>
</tbody>
</table>

Table 11. Mean and standard deviation of $\Delta T_{sk,mean}$ during P2 and P3 for each demographic group

<table>
<thead>
<tr>
<th></th>
<th>Male 20s (SD)</th>
<th>Male 60s (SD)</th>
<th>Female 20s (SD)</th>
<th>Female 60s (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T_{sk,mean}$ during P2</td>
<td>0.10 (0.15)</td>
<td>-0.20 (0.16)</td>
<td>0.09 (0.18)</td>
<td>0.07 (0.26)</td>
</tr>
<tr>
<td>$\Delta T_{sk,mean}$ during P3</td>
<td>0.49 (0.13)</td>
<td>0.47 (0.20)</td>
<td>0.24 (0.41)</td>
<td>0.02 (0.15)</td>
</tr>
</tbody>
</table>

Figure 6. $\Delta T_a$ of different body parts during P2 averaged across BMI groups

Figure 7. $\Delta T_a$ of different body parts during P2 averaged across demographic groups

Figure 8. $\Delta T_a$ of different body parts during P2 for one representative from each demographic group
Table 12 shows the sweat rate (SR) and sweat rate normalized by BSA (normalized SR) of subjects in the experiments. SR of subjects had positive and significant relationships with weight, BSA and BMI (p=.006, p=.021 and p=.027 respectively). However, as skin surface area is an important determinant of sweat production and differences in the distribution of BSA across demographic groups were shown to be significantly different in earlier tests, further analysis was conducted. To control the effect of BSA, the same tests were conducted on SR normalized by body surface area of each subject (g hr$^{-1}$ m$^{-2}$). The normalized SR is the grams of sweat produced per hour per square meter of body surface.

The SR values ranged from 48 g hr$^{-1}$ to 176 g hr$^{-1}$ while normalized SR had a narrower range from 35.4 g hr$^{-1}$ m$^{-2}$ to 98.8 g hr$^{-1}$ m$^{-2}$, as detailed in Table 12. Normalized SR values of subjects had tended to increase with BMI but not significantly so (p=.056). Weight or BSA were also not significantly correlated with normalized SR (p>.1).

Normalized SR values of subjects had tended to increase with BMI but not significantly so (p=.056). Weight or BSA were also not significantly correlated with normalized SR (p>.1).

### 3.10. Demographic variation and sweat rate due to activity

Shapiro-Wilk test failed to reject the null hypothesis that SR and normalized SR are normally distributed (p=.407 and p=.354 respectively). Two-way factorial ANOVA test results showed that SR between gender groups was significantly different (p=.004) but not between age groups (p=.106). There was also no significant effect of age on gender differences in SR (p=.131). Average male SR was 119 g hr$^{-1}$ and average female SR was 81 g hr$^{-1}$, with female SR approximately 68% of male SR. From Figure 9, it can be seen that at similar BMI levels, males have a generally higher SR than females.

Two-way factorial ANOVA test results showed that for normalized SR, there were significant differences between gender groups (p=.039) but no significant differences between age groups (p=.057). There were no significant interactions between the two independent categorical variables of age and gender (p=.346). While the significance of differences between genders was weaker, it can be seen from Figure 10 that the general trend of males having a higher SR than females at similar BMI levels persists.

### 4. Discussion

Core temperatures measured in this experiment were lower than other similar studies (e.g. Takada 2014) but still within reasonable range. Possible reasons for the lower core temperatures are expected differences between tympanic and rectal measurements (Huggin et al. 2012) and possibly seasonal acclimatization in body set-point temperatures as the study was conducted at the beginning of spring. Range of skin temperature values, however, were similar to other similar studies.

Among the anthropometric variables, BMI of subjects has been shown to have the strongest positive influence on Tc during steady state, while walking (P2), and while recovering in a sitting position after walking (P3) (Figure 5). In general, the weight of subjects account for more variance in Tc than BSA but is less significant than BMI. Since BMI is an index to estimate adiposity of subjects based on their weights and heights, it is likely that adiposity is an important factor in determining core body temperature levels. Adiposity as a source of variation in core body temperature was also reported in other studies. Takada (2014) also found that body fat percentage (adiposity) had a strong positive correlation with steady-state core temperature (rectal), more so than weight or body surface area. Apart from anthropometry, elderly subjects were
observed to have significantly higher steady state $T_c$ than the young. Anthropometric variables did not account for $\Delta T_c$, significantly during P2 and P3, although was interestingly observed that $\Delta T_c$ tended to decrease with BMI, weight and BSA during P3. Similarly, no significant differences were observed between demographic and age groups in terms of $\Delta T_c$.

It was observed that BMI of subjects had a significant positive relationship with steady state $T_{sk,mean}$. This is potentially explained by the observation that subjects with higher BMI had more balanced distributions of $T_{sk}$ particularly at their extremities (arms and legs). Conversely, subjects with lower BMI have reduced $T_{sk}$ at their extremities. A point of interest was the tendency for trunk skin temperature (shoulder and chest) to fall with increasing BMI. Nishimura et al. (1993) and Savastano et al. (2009) found that obese subjects had higher hand or finger temperatures but lower trunk temperatures than subjects of normal weight. Takada (2014) also found that adiposity was negatively correlated to trunk skin temperatures. Moderate differences between gender in terms of steady state $T_{sk,mean}$ was observed with the elderly male group exhibiting generally higher skin temperatures for all body parts as compared to other demographic groups. Gender differences in mean $\Delta T_{sk,mean}$ were observed during P3, with men having higher heat gain while recovering after walking. $\Delta T_{sk,mean}$ during P2 was observed to decrease with increasing BMI, weight and BSA although the relationships were not significant. Weight and BSA were observed to be correlated to $\Delta T_{sk,mean}$ in P3. Heat gain for subjects with low BMI occurred mainly in their extremities while subjects with high BMI experienced cooling in many parts of their body during P2, likely due to evaporative cooling of sweat.

Sweat rates measured in the present study were comparable in terms of magnitude with other similar studies (e.g. Ooka et al. 2010). Significant positive relationships were observed between anthropometric variables and SR. However, when SR was normalized by BSA, the relationships between normalized SR and anthropometric variables weakened. Gender differences in SR were also observed. In the present study, females were observed to have mean SR approximately 68% that of male SR. This is consistent with previous studies which suggest that female sweat rates were approximately 70% of male sweat rates (Wyndham 1965, Hoppe 1993). Under similar BMI levels, males still sweat more than females, suggesting underlying gender differences in sweating mechanism.

5. Conclusion

The present study was designed to corroborate and build on existing thermophysiological research. Focus was placed on people engaged in light activity and the study of differences brought about by individual variation. From the experiment results, some influence of anthropometry and demography on the thermophysiology of subjects can be seen. Gender played a small role in differentiating skin temperature and was particularly influential on sweat rates. Skin temperature distribution was shown to vary across different demographic and anthropometric groups, suggesting the importance of weightages used for calculating averaged body skin temperature. Possible effects of individual differences on localized comfort was observed. BMI, which is a proxy measurement of adiposity, had strong relationships with core and skin temperatures, as well as sweat rate of subjects, placing importance on the relevance of adiposity on thermoregulation. These findings suggest the need for the consideration of individual variation when modelling or analyzing thermal physiology and/or comfort.

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References


