WOMEN HAVE HIGHER SKIN TEMPERATURE ON THE BACK DURING TREADMILL EXERCISE IN A HOT, HUMID ENVIRONMENT

Adam Steven Venable

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APPROVED:

Brian K. McFarlin, Major Professor
David W. Hill, Committee Member
Jakob L. Vingren, Committee Member
Sam Atkinson, Chair of the Department of Biological Sciences
Mark Wardell, Dean of the Toulouse Graduate School

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A common measurement of body temperature during exercise in a hot, humid environment is mean skin temperature collected from 3-12 sites on the body. However, such an approach fails to demonstrate localized differences in skin temperature that are likely to exist as a function of gender. The purpose of this study was to examine potential differences in skin temperature between men and women at 17 different locations on the body. Young women (21 ± 1 y; n = 11) and men (23 ± 3; n = 10) were recruited to complete a 60-min walk/jog interval protocol in a hot (34 ± 1 °C), humid (64 ± 8%) environment while skin temperature was measured. Data was analyzed using a repeated-measures ANOVA ($p < 0.05$) and location of interaction effects determined using a Fisher's least squares difference test. We observed a higher change ($p < 0.05$) from baseline skin temperatures (ΔT_{sk}) for women in three locations: left upper back (women: avg. ΔT_{sk} = 4.12 ± 0.20 °C; men: avg. ΔT_{sk} = 2.70 ± 0.10 °C), right upper back (women: avg. ΔT_{sk} = 4.19 ± 0.07 °C; men: avg. ΔT_{sk} = 2.92 ± 0.05 °C), and right mid-back (women: avg. ΔT_{sk} = 4.62 ± 0.14 °C; men: avg. ΔT_{sk} =3.55 ± 0.09 °C). Individual time differences between genders occurred after 7- (left upper back) and 15-min (right upper back, right mid-back) of exercise and were maintained until the end of exercise. Women have a greater increase in skin temperature at three locations on the back following the onset of exercise in a hot, humid environment. This report provides important information regarding the implications of women exercising in a hot, humid environment.

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INTRODUCTION

Exercising in hot, humid environments is commonplace for many individuals during the summertime months, but in extreme cases can pose a risk of incurring a heat-related illness. Thus, understanding these individuals' thermoregulatory response may contribute to clothing preference and design, hydration strategies, exercise type, and selecting the time of day when the exercise is completed. Previous research has focused on understanding the changes in body temperature response in men and women during exercise (Avellini, Shapiro, Pandolf, Pimental, & Goldman, 1980; Gagnon, Dorman, Jay, Hardcastle, & Kenny, 2008; Gagnon & Kenny, 2012; Gerrett et al., 2014; Havenith, Fogarty, Bartlett, Smith, & Ventenat, 2008; Havenith & vonMiddendorf, 1990; McLellan, 1998; Shapiro, Pandolf, Avellini, Pimental, & Goldman, 1980; Smith & Havenith, 2012; Weinman, Slabochova, Bernauer, Morimoto & Sargent, 1967; Wyndham, Morrison, & Williams, 1965). Most commonly, core body temperature (Anderson, 1999; Avellini et al., 1980; Gagnon et al., 2008; Gagnon & Kenny, 2012; Gerrett et al., 2014; Havenith, 2001a; Havenith, 2001b; Havenith, Coenen, Kistemaker, & Kenney, 1998 Havenith, Luttikholt, & Vrijkotte, 1995; Havenith & vonMiddendorf, 1990; McLellan, 1998; Moran, Shitzer, & Pandolf, 1998; Shapiro et al., 1980; Weinman et al., 1967; Wyndham, Morrison, & Williams, 1965) and skin temperature (Avellini et al., 1980; Gagnon et al., 2008; Gagnon & Kenny, 2012; Gerrett et al., 2014; Havenith & vonMiddendorf, 1990; McFarlin, Venable, Williams, & Jackson, 2015; Shapiro et al., 1980; Smith & Havenith, 2011; Weinman et al., 1967) are used as a means of monitoring body temperature during exercise; however, skin temperature measurements inconsistently demonstrate differences between men and women. For example, Del Coso et al. (2011) reported no difference in mean skin temperature as a function of gender when exercising at equivalent workloads under hot conditions (36 ± 1 ºC; 25 ± 2% RH; Del Coso et al., 2011). Moreover, mean skin temperature under room temperature conditions have failed to show a difference between genders (Gagnon et al., 2008). In contrary, Gagnon and Kenny (2012) found that mean skin temperature was significantly greater in women than in men when exercising at equivalent absolute workloads and in a hot, humid environment (40.1 ± 0.2 ºC; 24 ± 2% RH; Gagnon & Kenny, 2012).

In previously published research, 3-12 skin temperature sites are measured and a collectively expresses as a weighted mean skin temperature (Burton, 1935; Hardy & Dubois, 1938). Most studies use the following 12-sites described by Hardy and Dubois (1938; all sites expressed as location (coefficient)): forehead (0.05), forearm (0.14), hand (0.05), foot (0.07), 2 shin locations (0.13), 2 thigh locations (0.19), and 4 torso locations (0.35). Weighted coefficients were determined based on the average contribution to the overall body surface area. The summation of these weighted sites provides the calculation of mean skin temperature. While mean skin temperature provides one representation of the change in skin temperature, it unfortunately eliminates the ability to examine individual skin temperatures at specific anatomical sites. Given gender differences in a variety of physiological and anatomical factors, it is plausible that gender differences may only be revealed when examining individual rather than mean skin temperature.

To our knowledge, one gap in the present literature is a comprehensive comparison of the change in skin temperature at several different locations as a function of gender. The notion that regional differences in thermoregulation may exist between men and women has gained recent attention (Smith & Havenith, 2011; Smith & Havenith 2012); however, these focused primarily on sweat rates and subjective thermal sensation rather than systemic heat exposure and local skin temperature measurements. The purpose of the present study was to compare skin temperature at

17 anatomical locations between men and women during 60 minutes of treadmill exercise in a hot, humid environment.

METHODS

Subjects

This study was conducted in accordance with the guidelines given in the Declaration of Helsinki. Prior to any testing, the proposed methods were reviewed and approved by the University of Houston committee for the protection of human subjects. Subjects gave their written consent after a member of the study staff explained the risks and benefits associated with participation in this study. A total of 21 individuals (Table 1; 10 men and 11 women) participated.

Table 1

Subject Characteristics

Variable	Men (n=10)	Women (n=11)
Age (y)	21 ± 1	23 ± 3
Mass (kg)[a]	75.1 ± 10.3	62.2 ± 6.9
Height (m)[a]	1.8 ± 0.1	1.6 ± 0.1
BMI (kg/m^2)	23.7 ± 2.5	23.3 ± 2.6
BSA (m^2)[a]	1.9 ± 0.1	1.7 ± 0.1
%BF[a]	13.6 ± 4.4	27.1 ± 6.0
VO_2max	52.4 ± 7.7	49.7 ± 9.4

BMI – Body Mass Index; BSA – Body Surface Area; %BF – Percent Body Fat; VO_2max – Maximal oxygen uptake.
[a] Significant main effect (p<0.01) between genders. Mean ± SD.

Procedures

Subject screening. Subjects were presumed to be apparently healthy, according to the American College of Sports Medicine (ACSM, 2013), after initial screening consisting of a medical history questionnaire, body composition analysis, and VO_2max testing. Interested individuals with any contraindications to exercise were excluded after completing the medical history questionnaire. After completing the questionnaire, subjects underwent a body composition analysis (% body fat; DXA; Discovery W; Hologic, Inc.; Bedford, MA) and determination of VO_2max (Parvomedics; Salt Lake City, UT) from a standard graded exercise test on a treadmill that our laboratory has used previously (Carpenter, Breslin, Davidson, Adams & McFarlin, 2013).

Pre-exercise hydration testing and clothing. Subjects reported to the laboratory and were asked to provide a urine sample to test their hydration status (Atago; Livermore, CA). A urine specific gravity <1.025 mg/mL was required before exercise in hot, humid conditions. If needed the subject was asked to consume water until their urine specific gravity was <1.025. Prior to the exercise trial, each subject was asked to change into clothing provided by the laboratory. At the end of exercise, the shorts and shirts were washed at the laboratory and given to the following day's subjects.

Exercise trial. Subjects were then escorted into a heated (34 ± 1 °C) and humidified (64 ± 8%) environmental chamber and asked to complete four, 15-minute treadmill exercise intervals (7-minutes walking - men: 3.9 ± 0.3 mph, women: 3.7 ± 0.3 mph; then 8-minutes of jogging – men 5.4 ± 0.5 mph, women: 4.8 ± 0.4 mph). Skin temperature at each of the 17 sites was automatically recorded at the conclusion of each stage (see below for additional information). Core body temperature and heart rate (HR) were recorded 1-minute prior to the end of each stage (7, 15, 22, 30, 37, 45, 52, 60 minutes). Subjects were allowed to consume water ad libitum, but to refrain from pouring water over themselves during exercise, as this would interfere with skin temperature measurements. Energy expenditure during the exercise trial was calculated based on energy expenditure at a given workload during the VO_2max test. Individual equations were generated for women (Figure 1A) and men (Figure 1B). Energy expenditure for each walk/run interval were calculated and summated to give overall energy expenditure (kcal) during the exercise trial.

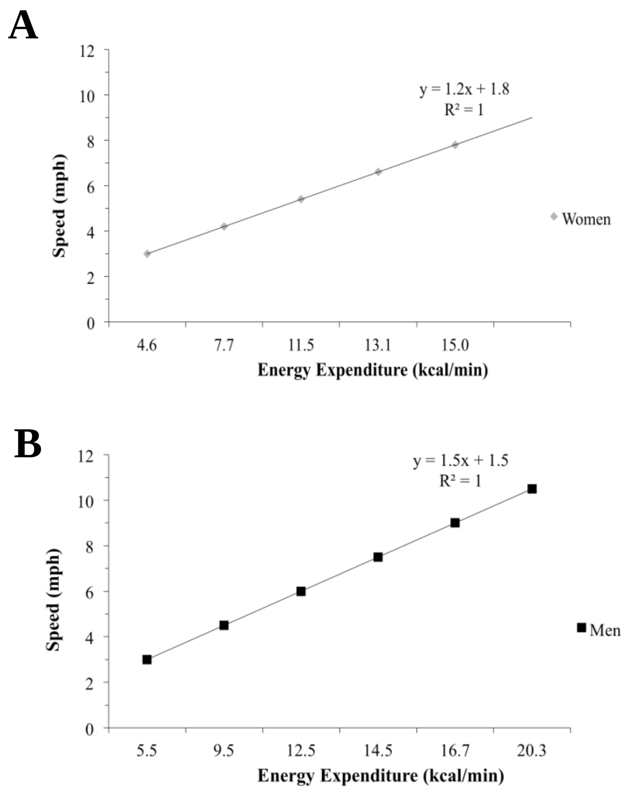

Figure 1. Energy expenditure lines for women (1A) and men (1B) at a given treadmill speed.

Skin temperature measurement. Skin temperature was recorded continuously (1 minute intervals) at 17 sites (back of the neck (BN); right and left: upper chest (RUC, LUC), mid-chest (RMC, LMC), lower chest (RLC, LLC), upper back (RUB, LUB), mid-back (RMB, LMB), lower back (RLB, LLB), upper arm (RUA, LUA), and lower arm (RLA, LLA)) (Figure 2) using skin electrode data loggers (iButtons – DS1921H; Maxim Integrated; San Jose, CA), which were mounted to the skin with breathable adhesive tape (Cover-Roll; BSN Medical; USA). According to the manufacturer, the data loggers are accurate within 1 °C and can record temperatures with 0.13 °C resolution. Data loggers were placed on women so that they were not covered or pressed into the skin by a sports bra. Although skin temperature was measured continuously, only the temperature at the end of each exercise stage was used in further analyses. Our laboratory has previously reported that skin electrode data loggers provide an accurate measurement of skin temperature during exercise in a hot, humid environment (McFarlin et al., 2015). In order to assess gender differences, the change in skin temperature from the baseline (pre-exercise) value for each individual skin temperature location was subtracted from the skin temperature at the given time point (ΔT_{sk}). The change in skin temperature was used to compare responses.

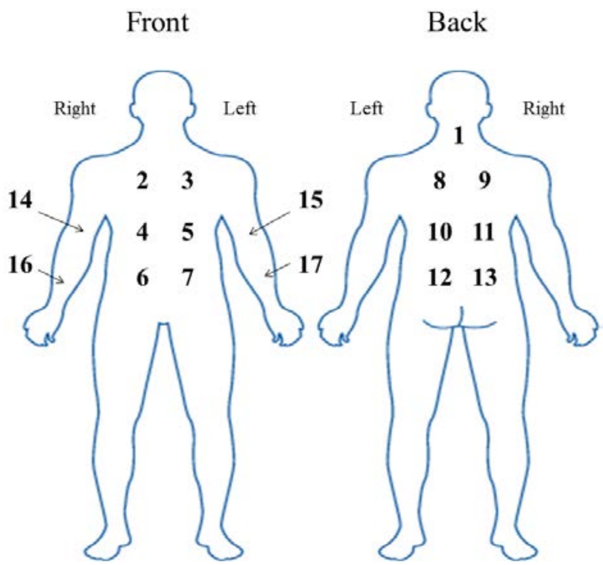

Figure 2. Placement of skin temperature electrodes on the front and back in men and women: 1-BN; 2-RUC; 3-LUC; 4-RMC; 5-LMC; 6-RLC; 7-LLC; 8-LUB; 9-RUB; 10-LMB; 11-RMB; 12-LLB; 13-RLB; 14-RUA; 15-LUA; 16-RLA; 17-LLA.

Mean skin temperature. As stated previously, the calculation of mean skin temperature (MT_{sk}) incorporates the measurement of skin temperature at 12 different location into a weighted equation based on skin surface area (Hardy & Dubois, 1938). This equation was modified to reflect the measurement location uses in the present study. The original equation has coefficients of 0.14 and 0.35 for the arms and torso, respectively. In modifying the original equation, we placed the same weight on each site relative to each other; in other words, the forearm coefficient is 40% of the torso coefficient (Eqn 1).

Eqn 1.

$$Adj\ MT_{sk} = 0.7143[(BN + RUC + LUC + RMC + LMC + RLC + LLC + RUB + LUB + RMB + LMB + RLB + LLB)/13] + 0.2857[(RUA + LUA + RLA + LLA)/4]$$

Core body temperature. Rectal core body temperature was determined using a disposable core thermistor (Temperature Sensor-402; Measurement Specialties; Hampton, VA), which was inserted approximately 10 cm past the anal sphincter. The thermistor was connected to a digital meter (TSYS02D; Measurement Specialties) that provided continual monitoring of core body temperature. According to the manufacturer, the digital meter is accurate within ± 0.20 °C and can record temperatures with 0.01 °C resolution. Core temperature was recorded pre-exercise and 1-minute prior to the end of each walk/run stage.

Heart rate. All subjects were fitted with a Polar heart rate monitor (T31; Polar Electro Inc.; Lake Success, NY) prior to exercise. Heart rate was monitored continuously and recorded pre-exercise and 1-minute prior to the end of each 15-minute stage (walk/run).

Statistical Analysis

All statistical analyses were conducted using SPSS (v. 21.0; IBM; Chicago, IL). Using the EXPLORE function in SPSS outliers were identified and excluded from analysis. Energy expenditure was analyzed using a univariate analysis of variance (ANOVA) to evaluate differences between genders. The change in skin temperature for each site, adjusted mean skin temperature, core body temperature, and heart rate were analyzed using a 2 (Gender: Male or Female) x 8 (Exercise Time: 7, 15, 22, 30, 37, 45, 52, and 60 minutes) ANOVA with repeated measures on the second factor. The time points selected for analysis were at the conclusion of each stage (walk/run) of exercise. Location of significant interaction effects were completed post-hoc using Fisher's least squares difference test. Data is presented as mean ± SE. Pearson's coefficient was used to correlate skin temperature measurements to body temperature.

Significance was set at $p < 0.05$ for all statistical testing.

RESULTS

Energy Expenditure

Total energy expenditure (Figure 3A) was significantly lower ($p < 0.001$) in women (420.91 ± 20.97 kcal) than men (513.96 ± 25.44 kcal). However, when relative energy expenditure (Figure 3B) is calculated, there are no differences between women (6.64 ± 0.18 kcal/kg body weight) and men (7.11 ± 0.26 kcal/kg body weight).

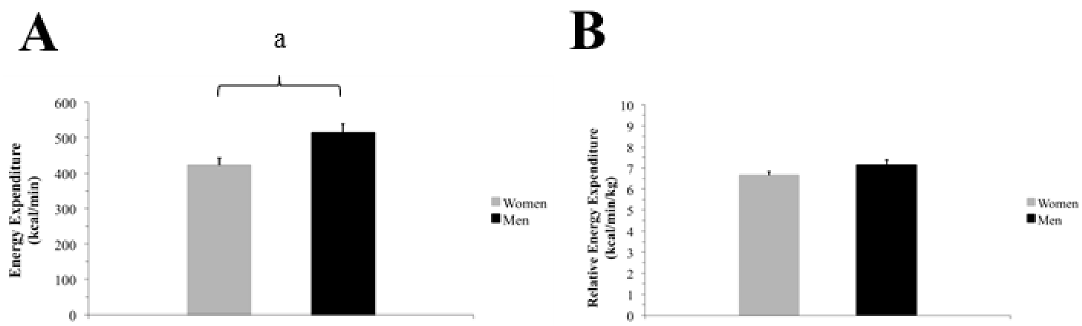

Figure 3. Absolute (A) and relative (B) energy expenditure for men and women during 60-min of exercise in a hot, humid environment. [a] significant main effect ($p < 0.01$) between genders. Mean ± SE.

Skin Temperature

There was a significant Gender x Time interaction for three locations on the back. At each location, women demonstrated a significantly greater change in skin temperature than men. For the left upper back (Figure 4A; $p < 0.001$), the gender difference was present beginning at 7 minutes and continuing through 60 minutes of exercise; the increase in left upper back skin temperature remained higher in women (avg. ΔT_{sk} 4.12 ± 0.20 °C) than in men (avg. ΔT_{sk} 2.70 ± 0.10 °C). For the right upper back (Figure 4B; $p = 0.002$), the gender difference was present beginning at 15 minutes and continuing through 60 minutes of exercise. The increase in right upper back skin temperature remained higher in women (avg. ΔT_{sk} 4.19 ± 0.07 °C) than in men (avg. ΔT_{sk} 2.92 ± 0.05 °C). For the right mid-back (Figure 4C; $p < 0.37$), the gender difference was present beginning at 15 minutes and continuing to 60 minutes. The increase in right mid-back skin temperature remained higher in women (avg. ΔT_{sk} 4.62 ± 0.14 °C) than in men (avg. ΔT_{sk} 3.55 ± 0.09 °C). The left mid-back (Figure 4D) ΔT_{sk} showed similar gender differences between women (avg. 4.35 ± 0.21 °C) and men; however, it remained a trend toward significance ($p = 0.058$). A post-hoc sample size analysis demonstrated that an additional 4 subjects would have been sufficient enough to resolve the difference between women and men on the left mid-back, making the finding statistically significant.

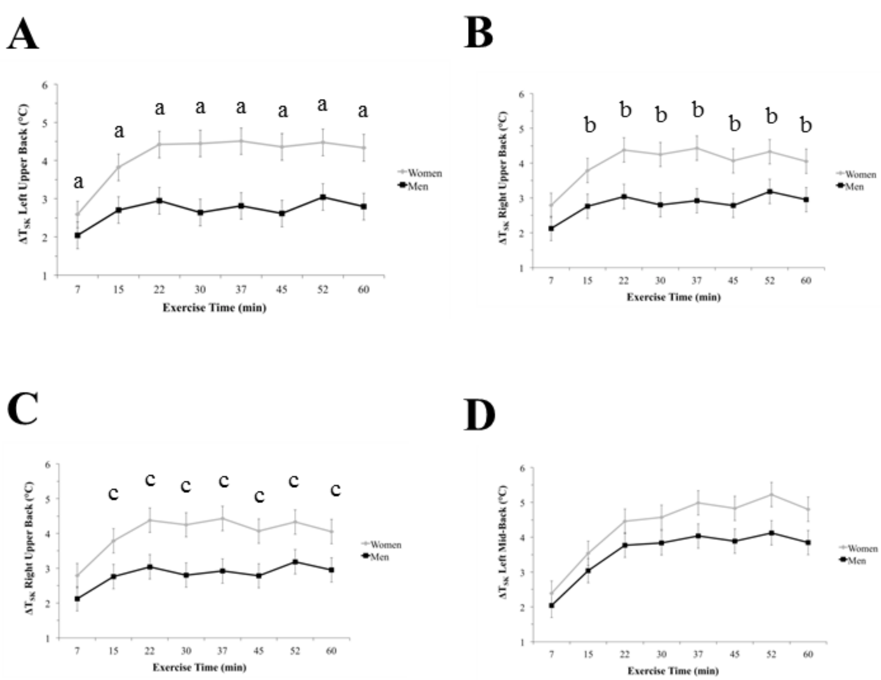

Figure 4. Interaction effect (gender by time) of change in skin temperature between men and women at four locations: left upper back (A); right upper back (B); right mid-back (C); left upper-back ($p = 0.058$; D). Note: [a] – left upper back, indicates $p < 0.001$. [b] – right upper back, indicates $p < 0.01$. [c] – right-mid back, indicates $p < 0.05$. Mean ± SE.

Mean Skin Temperature

Adjusted mean skin temperature displayed a main effect for time ($p < 0.001$) as expected. There were no significant Gender x Time interactions.

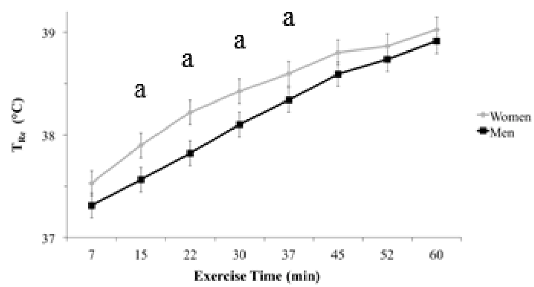

Figure 5. Interaction effect (Gender x Time) of core body temperature. Note: [a] – Indicated $p < 0.05$. Mean ± SE.

Core Body Temperature

A significant gender x time interaction was found for core body temperature ($p = 0.030$). Post-hoc analysis revealed gender differences in core temperature at 15, 22, 30, and 37-minutes of exercise (Figure 5) with an average core body temperature at the time points of significance of 38.08 ± 0.09 °C and 37.76 ± 0.11 °C for women and men, respectively.

Heart Rate

Heart rate demonstrated the typical exercise response for time ($p < 0.001$), but no significant Gender x Time interactions were observed.

DISCUSSION

The present study demonstrates that there are local differences in the change in skin temperature between women and men while exercising in a hot, humid environment. The increase from baseline skin temperature at the left upper back, right upper back, and right mid-back was higher in women than in men beginning after either 7 or 15-minutes of exercise. Moreover, a trend towards significance (p = 0.058) was seen at the right mid-back, localizing the gender difference to the upper half of the back. These findings agree with previous research showing that the change in skin temperature in women exercising in a hot, humid environment is higher when compared to men exercising under the same conditions (Gagnon & Kenny, 2012); however, these researchers relied on mean skin temperature to determine differences in skin temperature. More commonly, mean skin temperature shows no differences between the genders (Gagnon et al., 2008; Shapiro et al., 1980; Weinman et al., 1967). We approach the measurement of skin temperature differently (Gagnon et al., 2008; Gagnon & Kenny, 2012; Gerrett et al., 2014; Shapiro et al., 1980; Smith & Havenith, 2012; Weinman et al., 1967) by separating each measurement site into its own outcome measure. Our adjusted equation for mean skin temperature revealed no difference between women and men at any time point during exercise. Our hypothesis that the calculation of mean skin temperature excluded potential differences between genders appears to be supported by the findings of the present study. Regional gender differences have been reported (Gerrett et al., 2014) but only in response to localized and not whole body heating. Thus, to our knowledge the present study is the first to demonstrate gender differences in the change in skin temperature when examining individual anatomical sites rather than mean skin temperature.

Consistent with gender differences in skin temperature, gender differences were also present for core body temperature. Specifically, women were significant hotter that men at 15-minutes and remained until elevated until 37-minutes of exercise. These differences may account for the higher skin temperature in women up until 37-minutes of exercise; however beyond 37-minutes of exercise, elevated core temperature is a less likely explanation. This later interpretation suggests that another factor beyond just the accumulation of core body temperature may explain gender differences in skin temperature on the back.

Several different factors have been proposed to play a role in explaining the differences in the change in body temperature (skin and core) between men and women. Body surface area has previously demonstrated to be negatively correlated to rises in temperature (Anderson, 1999; Del Coso et al., 2011; Havenith, 2001a; Havenith, 2001b; Shapiro et al., 1980). In the current study, the women (1.7 ± 0.1 m^2) had a significantly lower body surface area compared to men (1.9 ± 0.1 m^2). Body surface area and is known to play a role in evaporative heat loss (Gagnon et al., 2008). In addition to body surface area, lean body mass may also play a role in gender differences of body temperature (Anderson, 1999; Gagnon & Kenny, 2012; Havenith & vonMiddendorf, 1990; Shapiro et al., 1980). Lean mass has been demonstrated to have a higher specific heat than fat mass. In other words, it requires more energy to raise 1 g of lean mass by 1 ºC than to elicit the same response in fat mass (Anderson, 1999). Women in the present study had lower lean mass than men, thus the potential for increased body temperature was greater in women than in men. Gagnon et al. (2009) found that women (lean body mass = 46.2 ± 4.7 kg) had a lower change in esophageal temperature than men (lean body mass = 66.6 ± 6.9 kg). These differences were not apparent rectally or with mean skin temperature (Gagnon et al., 2008).

Some consideration must be taken to explain the isolation (upper back) of the differences in the change in skin temperature between women and men. It is presumed that differences in body surface area and lean mass are the same on the front for both men and women, so those points fail to provide sufficient clarification for the regionalized difference. On the other hand, differences between women and men in local sweat rate. Overall sweat production is demonstrated to be lower in women than in men at three different locations on the mid-back (right, left, and mean mid-lateral; Havenith et al., 2008). Moreover, overall back sweat production has also been determined to be higher in men than in women (Gagnon & Kenny, 2012). Increased sweat production at these locations in men may produce greater evaporative heat loss, causing a subsequent decrease in skin temperature.

CONCLUSION

In summary, the present study indicates that there are gender differences in skin and core body temperature response to exercise in a hot, humid environment. The findings of the present study can be partially explained by examining gender differences in body surface area and body composition. The key findings of the present study are likely to have applications associated with design of gender specific clothing for thermoregulation. Also, female athletes may benefit from added focus on post-exercise heat-loss from the back by the placement of fans and other devices designed to assist cooling. Future studies should also attempt to identify and examine other physiological/anatomical factors that may explain the gender differences in back temperature that we observed.

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