DIFFERENCES IN FEMALES' REGIONAL THERMAL COMFORT DURING EXERCISE IN WARM CONDITIONS

Gerrett Nicola[1], Redortier Bernard[2] , Voelcker Thomas[2], and Havenith George[1]

[1]: Environmental Ergonomics Research Centre, Loughborough Design School, Loughborough University, UK, [2]: Oxylane Research, Villeneuve d'Ascq, Lille, France

Email: n.gerrett@lboro.ac.uk

INTRODUCTION

An increase in core and skin temperature causes an increase in sweat production to facilitate heat balance. This mechanism maintains skin temperature and thermal sensations at favourable levels, yet discomfort increases. This increase in discomfort has been attributed to the amount of moisture present on the skin surface, namely skin wettedness (w) which was first introduced by Gagge in 1937. Skin wettedness refers to the extent of moisture present on the skin surface and is a ratio between actual sweat evaporation and the maximal evaporation possible in a given climate. Skin wettedness (nd) ranges from 0.06, termed insensible perspiration, to a maximum value of 1.00, when the skin surface is saturated with a layer of sweat. Since its introduction, a value of 0.3 has been prescribed at the thermal comfort limit and has been widely supported in the literature as a strong predictor of whole body thermal comfort (Gagge et al., 1969, Nishi & Gagge, 1977; Fukazawa & Havenith, 2009). However, temperature sensation and thermal comfort have been shown to vary across the body even in the same environmental conditions. Sweat gland distribution and sweat production also vary across the body and between individuals (Smith & Havenith, 2011). As a result, Fukazawa & Havenith (2009) conducted research to established regional differences in terms of sensitivity to local skin wettedness (w_{local}). They were able to identify the extremities as highly sensitive areas despite being areas of low sweat production. Even though w_{local} and w_{body} have been proven to predict thermal comfort, research in this area was so far limited to conditions of low sweat production. Alongside this, Fukazawa & Havenith (2009) established sensitivity according to the transitions away from comfort and this was therefore limited to low ratings of discomfort. Recent research by Gerrett et al. (2011) has shown a plateau in w_{local} and w_{body} during periods of high sweat productions but a continual increase in discomfort. Therefore, when the degree of discomfort is high the likelihood of w_{body} and w_{local} predicting thermal discomfort is lessened. As a result an alternative measure for the prediction of discomfort has been proposed: galvanic skin conductance (COND) (Gerrett et al., 2011). COND indicates the ability of the skin to transmit an electrical current which is enhanced by the presence of sweat. Darrow (1964) found an increase in COND before sweat was present on the skin surface. Therefore, COND is assumed to represent sweat gland activity, sweat within the skin and sweat on the surface. It has also been suggested that the production of sweat causes swelling of the epidermis, which increases the sensitivity of the receptors (Berglund & Cunningham, 1986; Berglund, 1995). As a result COND may predict thermal discomfort at high levels of sweat production and at greater degrees of discomfort. This is particularly relevant when exercising at higher metabolic rates and/or when exercising in warm-hot conditions where sweat production will be high. Gerrett et al. (2011) has shown COND can predict thermal comfort in such conditions on male participants but differences in sweat production between genders have been reported (Havenith et al., 2008). Alongside this there is currently limited data regarding female sensitivity to sweat. As a result, this study aims to compare COND and w_{local} as predictors of local thermal comfort in female participants. Alongside this, differences in regional sensitivity to the presence of sweat will be investigated.

METHODS

Following ethical approval and informed consent, ten physically active, Caucasian females were recruited (22 ± 5 years, 163.9 ± 5.0 cm, 59.12 ± 6.3 kg). Prior to the main investigation all participants were required to visit the laboratory during which all participants completed a sub maximal fitness test to determine $\dot{V}O_{2max}$. On a separate day, participants visited the lab to compete the main trial whereby they were required to rest for 15 minutes in a thermoneutral environment (20°C, 40% RH) to collect baseline measurements and ensure a state of thermal comfort was achieved. Following this they ran for 45 minutes at 70% $\dot{V}O_{2max}$ in 25°C, 30% RH. During the trial each participant was equipped with humidity sensors (MSR electronics GmbH, Switzerland) to measure w_{local} and electrodes (Biopac Systems Inc. USA) to measure COND. These sensors were attached at four locations; chest, upper arm, upper back, and upper leg. Core temperature was measured via rectal thermometer. All physiological data were averaged per five minute period which coincided with the rating of local discomfort scores on a unipolar Likert scale (0 = comfortable, -2 = slightly uncomfortable, -4 = uncomfortable, -6 = very uncomfortable). Clothing for all experiments was standardised for each participant and consisted of a 100% polyester long sleeve top and trouser ensemble with a high permeability for heat and vapour transfer with intrinsic local thermal resistance (0.154 m^2 K W^{-1}) and intrinsic local water vapour resistance (29.1 m^2 K W^{-1}). w_{local} was calculated using the following equation:

$$w = \frac{Csk - Ce}{Csk,s - Ce}$$

Where C_{sk} =water vapour pressure at the skin, $C_{sk,s}$ = saturated water vapour pressure at the skin and C_e = water vapour pressure of ambient air. COND was estimated as a change from baseline (Δconductance).

Differences between rest and values from the end of exercise were analysed using paired samples t-test. A one-way repeated measures ANOVA was performed to analyse regional differences and adjusted using Bonferroni correction for multiple comparisons. Regression analysis was performed to assess the relationship between individual physiological parameters on perceptual thermal comfort.

RESULTS

w_{local} began to increase after 10 minutes of exercise and displayed a plateau in w_{local} after 20 minutes of exercise with values minimally increasing (see Figure 1). w_{local} was significantly higher at the end of exercise for all locations compared to rest ($p<0.05$). During the experiments, it was observed that certain areas were saturated with sweat; particularly the upper back yet w_{local} did not exceed values of ~0.80. The upper back and chest reached the highest values, whilst the upper legs were significantly lower ($p<0.05$). COND began to increase 5 minutes into exercise and the values did not plateau but continued to increase (see Figure 2). Paired t-tests revealed significant differences from rest to the end of exercise ($p<0.05$). Similar to w_{local}, the upper back and chest had higher COND values, whilst the upper legs had the lowest values. The upper back was significantly higher than the upper arms and upper legs.

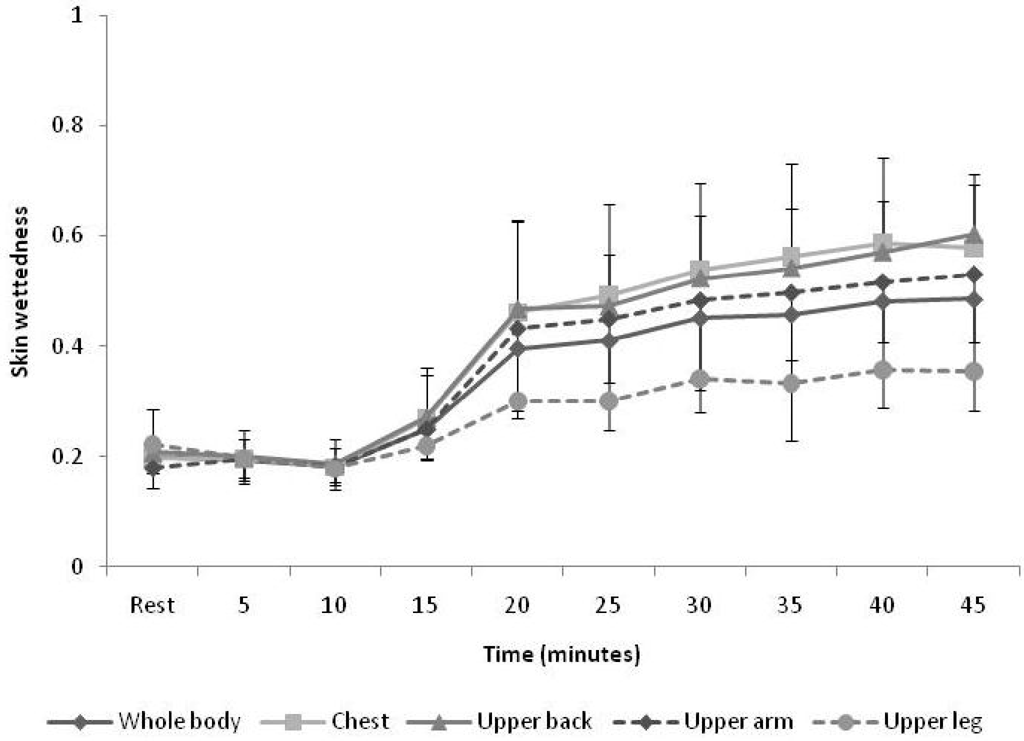

Figure 1: Mean (±SD) values of w_{local} over time for the four local measurements and the whole body average.

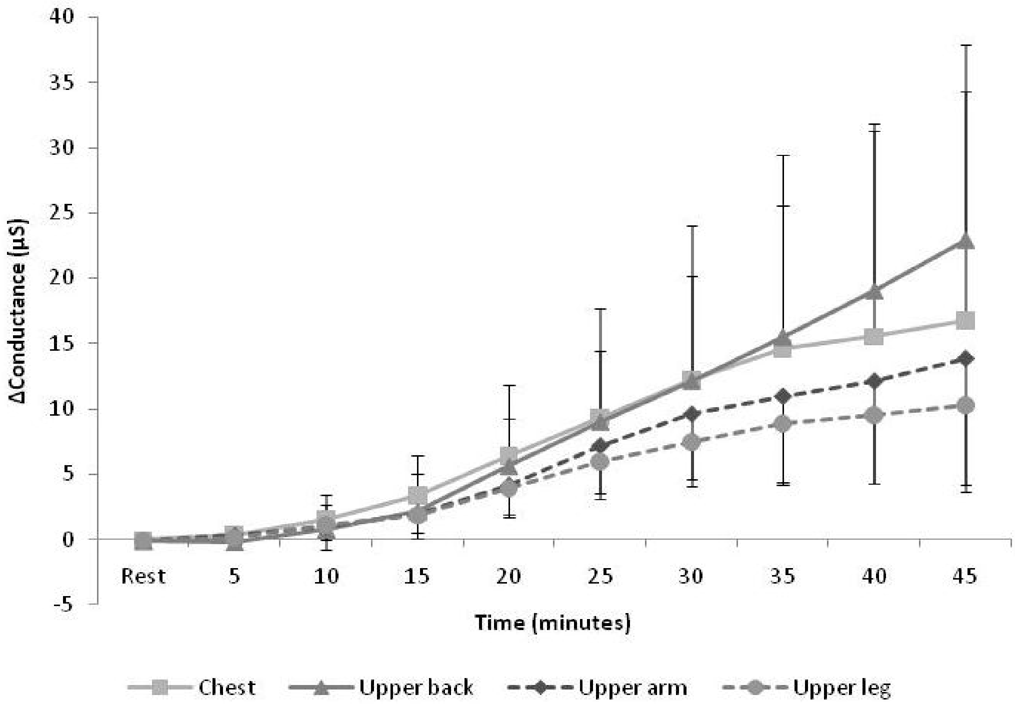

Figure 2: Mean (±SD) values of Δconductance over time for the four local measurements.

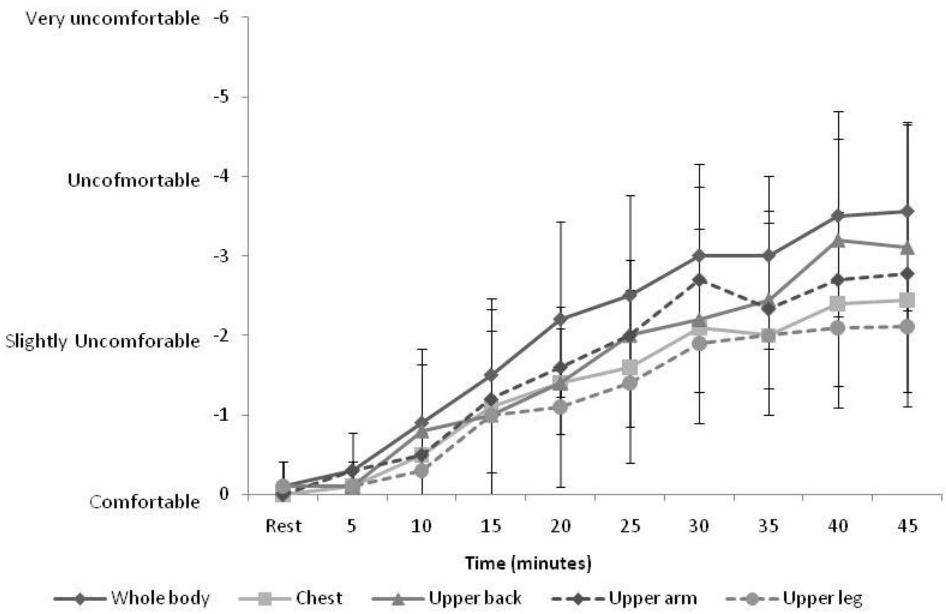

Figure 3: Mean (±SD) local thermal comfort over time for four local measurements and the whole body average.

Thermal discomfort significantly rose from rest to the end of exercise for all locations. The degree of discomfort experienced ranged from slightly uncomfortable (-2 vote) for the upper legs and chest to uncomfortable (-4 vote) for the whole body and upper back (figure 3). The relationship between local thermal comfort and COND and w_{local} respectively are illustrated in Figure 4 and Figure 5. Local thermal comfort had a stronger relationship with COND than w_{local} at the chest (r^2= 0.95, r^2=0.94), upper back (r^2=0.94, r^2=0.89) and upper leg (r^2=0.96, r^2=0.89) respectively. However, w_{local} had a stronger relationship at the upper arm (r^2=0.91, r^2=0.96). The onset of discomfort occurred at the following w_{local} and COND values for each local area respectively: chest; 0.25 and 4.0 μS, upper back; 0.30 and 4.0 μS, upper arm; 0.30 and 3.0 μS, upper leg; 0.26 and 4.0 μS.

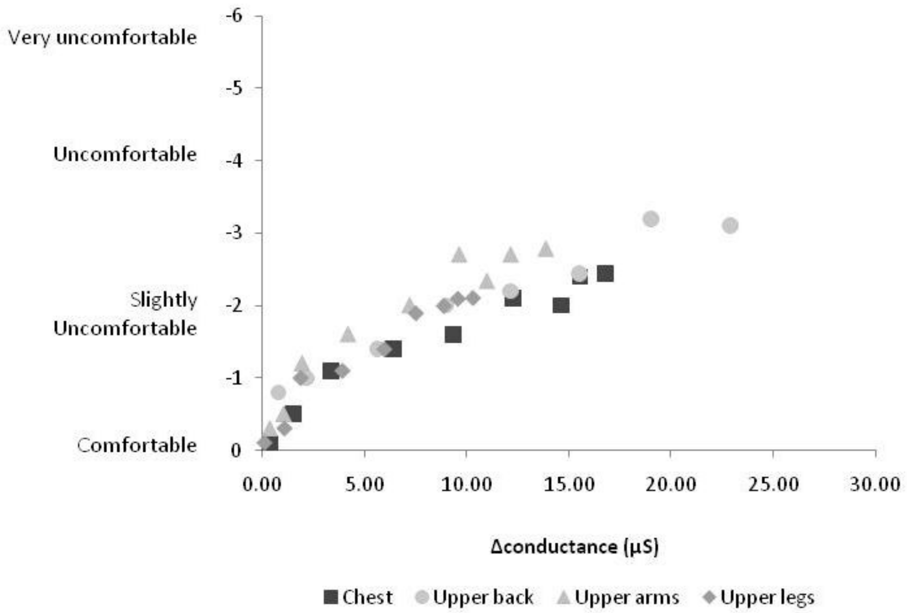

Figure 4: The relationship between local thermal comfort and local COND for the four local measurements

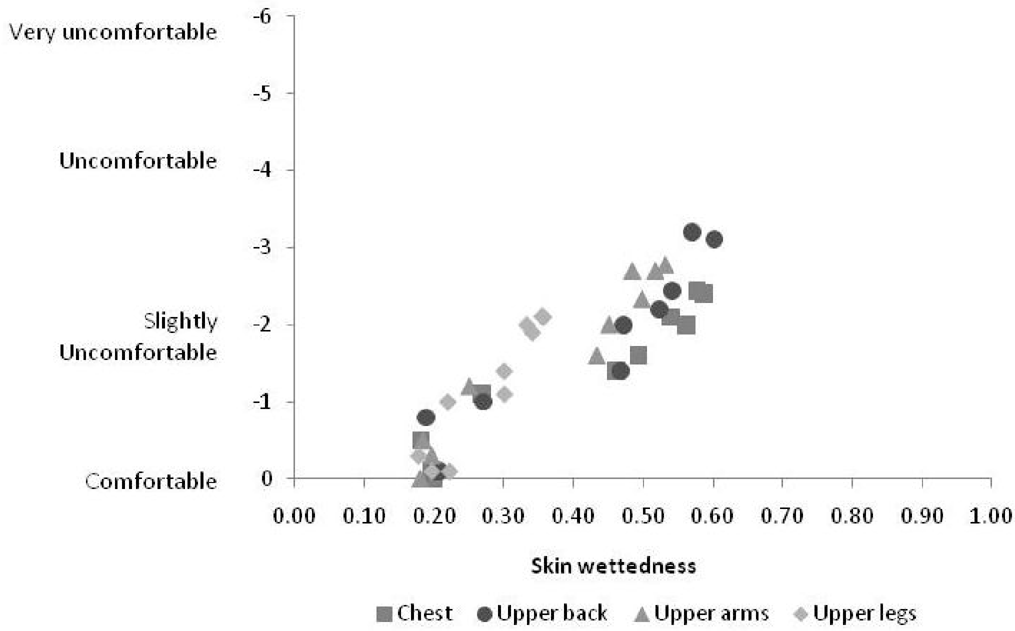

Figure 5: The relationship between local thermal comfort and w_{local} for four local measurements

DISCUSSION

w_{local} and COND reflected high sweat production from the upper back and chest and lower values at the extremities, particularly the upper legs. This supports research of regional sweat rates (Smith & Havenith, 2011) and suggestions that the legs have the lowest sweat gland density and less active sweat glands per square cm of skin than any other location across the body (Krause 1844, cited by Kuno, 1956). The torso has frequently been reported as an area of high sweat production, with a large amount of sweat being produced from the back region in males and females (Machoado-Moreira et al., 2008; Havenith et al., 2008; Smith & Havenith, 2011). Therefore in comparison to data from the literature, w_{local} and COND are representative of regional sweat production.

Notably w_{local} and COND demonstrated very different responses during the experiment. COND began to increase 5 minutes into exercise, whilst w_{local} did not increase until 10 minutes. The earlier increase in COND is representative of the filling of the sweat glands and sweat within the skin as previously reported by (Darrow, 1964). w_{local} reflects the amount of sweat on the skin surface, hence the delayed response and showed a tendency to plateau until the end of the experiment. However, following the experiment, some areas, particularly the back appeared to be completely saturated yet w_{local} did not reach the theoretical maximum (1.0). This suggests a measurement artefact or an inability to physiological achieve a maximum. However, COND gradually increased throughout the experiment and began to increase at the onset of exercise. COND is more representative of sweat gland activity as it increases when the glands fill with sweat and when the skin is hydrated with sweat. As a result the presence of sweat within the skin influences the measurement and thus can be used at very high sweat rates as observed in this study.

Both variables are strong predictors of thermal comfort ($r^2>0.89$, $p<0.05$), yet COND was slightly stronger for all locations except the upper arms. Discomfort began to increase 5 minutes into exercise which coincides with the increase in COND, whereas w_{local} increase 10 minutes into exercise. According to w_{local} data, the onset for discomfort suggested that the chest and upper legs are the most sensitive areas as a lower w_{local} were required for the participants to no longer feel comfortable. However the degree of discomfort experienced was greatest at the upper back as it became 'uncomfortable' at the end of the experiment whilst the chest and upper leg were only 'slightly uncomfortable'. As the chest and upper back had similar w_{local} and COND values this would suggest that the upper back is a highly sensitive area. According to COND data, the onset for discomfort occurred at similar values for each location, indicating no differences in the thresholds for discomfort. COND is expressed as a change from baseline and therefore the local discomfort experienced by each location may be relative to the amount of sweat it produces. These differences are representative of the two different techniques; where w provides information regarding sweat on the skin surface, COND reflects not only on what is happening on the skin surface but also within the epidermis where the receptors are located. As stated earlier, the production of sweat causes swelling of the epidermis, which is suggested to increase the sensitivity of the receptors and this may explain why COND is a stronger predictor of discomfort than w.

The tendency of w_{local} to plateau when sweat production is high and the inability to detect saturated skin makes it advisable to have an alternative measurement to predict thermal comfort. The use of COND provides a credible solution based on the strength of its relationship with thermal comfort.

REFERENCES

Berglund, L. (1995) Comfort criteria – humidity and standards. Proceedings of the Pan Pacific Symposium on Building and Urban Environmental Conditioning in Asia, Japan. 2; 369–382.

Darrow, C. W. (1964) The rationale of the galvanic skin reflex in the light of its relation to quantitative measures of perspiration. Psychological Bulletin, 31; 607-698.

Fukazawa, T & Havenith, G. (2009) Differences in comfort perceptions in relation to local and whole body skin wettedness. European Journal of Applied Physiology, 106; 15-24.

Gagge, A.P. (1937). A new physiological variable associated with sensible and insensible perspiration. American Journal of Physiology, 20; 277-287.

Gagge, A.P., Stolwijk, J.A. & Nishi, T. (1969).The prediction of thermal comfort when thermal equilibrium is maintained by sweating. ASHRAE Transactions, 75; 108-121.

Gerrett, N., Redortier, B., Voelcker, T. and Havenith, G. (2011). Skin conductance as an indicator of thermal comfort during exercise in warm conditions. In Kounalahis, S. & Koskolou, M. (eds) XIV International Conference of Environmental Ergonomics, Greece.

Havenith, G., Fogarty, A., Bartlett, R., Smith, C. & Ventenat, V. (2008) Male and female upper body sweat distribution during running measured with technical absorbents. European Journal of Applied Physiology, 104; 245-255.

Kuno, (1956). Human Perspiration. Thomas , USA. Pp 64.

Machado-Moreira, C.A., Smith, F.M., Van den Heuvel, A.M.J., Mekjavic, I.B., and Taylor, N.A.S. (2008) Sweat secretion from the torso during passively-induced and exercise-related hyperthermia. European Journal of Applied Physiology. 104; 265-270.

Nishi, Y. & Gagge, A.P. (1977) Effective temperature scale useful for hypo- and hyperbaric environments", Aviations, Space and environmental physiology, 48; 97-107.

Smith, C.J. & Havenith, G. (2011) Body mapping of sweating patterns in male athletes in mild exercise-induced hyperthermia. European Journal of Applied Physiology, 111; 1391-1404.