BODY MAPPING OF SWEATING IN MALE ATHLETES

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INTRODUCTION

A large body of literature is available regarding both gross and regional sweat rates. Regional variation between large body segments has long been recognised (Weiner, 1945; Kuno, 1956; Hertzman, 1957; Cotter *et al*., 1995). Recent research on the foot (Taylor *et al*., 2006), torso (Havenith *et al*., 2008; Machado-Moreira et al., 2008a), head (Machado-Moreira *et al*., 2008b), and hands (Smith *et al.,* 2007; Machado-Moreira *et al*., 2008c) have demonstrated large intra regional variation. However, these studies are conducted in differing conditions, during differing exercise modes and intensities, and cover only a small surface area on a limited number of sites, thus not providing a detailed whole body map. The ventilated capsule method adopted in the majority of these studies, although having the distinct advantage of measuring sweat rate continuously over time, only cover an area of skin 2-9 cm^2 per capsule, typically less than 3% of the body area studied The absorbent method of sweat collection used in the current study aimed to cover large areas of the skin simultaneously to allow detailed analysis of inter and intra regional variation in sweat rate over the whole body in male athletes. Preliminary data from a whole body sweat map is presented in the current paper, describing regional sweat rates over the upper body (torso and arms). A whole body sweat map of male athletes will be presented at ICEE 2009.

METHODS

Ten male participants (age: 23 ± 3 years, height: 179 ± 4.1 cm, weight: 73 ± 5.0 kg, body fat: 11 ± 5 %, $\dot{V}O_{2max}$: 70 ± 13 $ml.kg^{-1}.min^{-1}$) who were regular runners attended the Environmental Ergonomics Laboratory for two sessions. The first session required anthropometric measurements of height, weight, and body dimensions used for the calculation of absorbent pads (Tech Absorbents product 2164). Skinfolds were taken using a 7 point calliper method (Jackson and Pollock 1978) specific to male athletes for calculation of body fat percentage. The second session was an experimental session which was conducted in a climate controlled room at 25.6 ± 0.4°C and 44 ±.8 % relative humidity. Following the measurement session, two sets of absorbent pads were produced for each participant. These were weighed (Sartorius YACOILA, Sartorius AG, Goettingen, Germany) inside labelled airtight bags, in which they were stored until testing. A total of 28 pads were used, covering the anterior and posterior torso and arms. All pads were attached to custom made plastic sheeting for application to the body and to prevent the evaporation of sweat during the testing.

On arrival to the experimental session participants were provided with shorts and t-shirt and then weighed. Infra red images (Thermacam B2, FLIR Systems Ltd., West Malling, Kent, UK) of the nude, dried, skin were taken prior to testing, before and after each pad application, and immediately after testing to monitor skin temperature (T_{sk}). Resting heart rate and sublingual temperature were taken before participants warmed up, with heart rate monitored throughout the experiment at 15 second intervals. Core temperature (T_{core}) was measured using a Vitalsense Integrated Physiological Monitoring System (Mini Mitter Company, Inc. Bend, Oregon, USA). Participants swallowed a CorTemp™ ingestible temperature pill 5 hours before testing. T_{core} was registered from the 'temperature pill' up to 4 times per minute. The participant ran for a total of 60 minutes, running at two incremental exercise intensities. The participant could drink water freely during the experiment, which was recorded, to prevent dehydration. The target heart rate of the participant was 125-135 and 150-160 beats per minute (bpm) for intensity 1 (I1) and intensity 2 (I2) respectively, which was set to control workload at a fixed percent of $\dot{V}O_{2max}$ (I1

50%, I2 70%). Sweat samples were taken at 30 and 60 minutes during the experiment for a duration of 5 minutes. The participants removed their shirt and towelled their skin dry immediately prior to pad application to ensure only sweat produced during the sample period was collected. Pads were applied and held in place using a stretch zip t-shirt. All of the pads had an impermeable backing to prevent evaporation. Immediately following the sample period the pads were returned to their airtight bags and sealed. Following the 60 minute run, the weight and sublingual temperature of the participant were recorded. On completion of the experiment all pads were reweighed inside their airtight bags. The pad surface area was calculated from the dry weight of each pad and the weight per unit of surface area of a piece of control material. The sweat rate (SR) was calculated in grams per meter square per hour ($g.m^{-2}.h^{-1}$) using the weight change of the pad, the pad surface area, and the duration of application to the skin.

Paired samples t-tests were performed both with and without Bonferroni correction to analyse right-left differences in sweat rate and changes with exercise intensity. A one-way repeated measures ANOVA was performed to analyse regional differences within each intensity, presented both with and without Bonferroni correction. A Pearson's r correlation coefficient was preformed to assess correlations between regional SR and T_{sk}. It was decided to use medians for the presentation of the data to reduce the effect of extreme values.

RESULTS

Median sweat rates of the torso and arms are presented in Figure 1. Regional SR data was grouped for corresponding right-left zones since only a small number of significant differences were present ($p < 0.05$; shoulder, anterior upper arm, anterior lower arm). These differences were not constant across exercise intensities or apparent following Bonferroni correction. Despite large individual variation in absolute SR, a clear pattern of distribution was observed within all participants. The highest values were consistently observed on the posterior torso, in particular on the central upper, central mid, and lower back. The anterior torso and shoulders followed as areas of next highest sweat production, yet values were over half that of the posterior torso. A medial to lateral decrease was observed across the torso, which was more prominent on the posterior and exacerbated by an increase in exercise intensity. Detailed regional sweat data and the significance level of I1 and I2 comparison are presented in Table 1. All regions increased significantly with exercise intensity, with exception to the posterior lower torso, reflecting the large standard deviation. To assess sweat distribution over all participants, absolute sweat rates were normalised using the surface area weighted average of all tested regions. Notably, the distribution over the arms showed no change with exercise intensity and only 4 regions significantly altering on the torso. No differences in distribution between exercise intensities were present following Bonferroni correction.

Significance levels of region comparisons of absolute sweat rates are presented in Table 1a and 1b for I1 and I2 respectively. The most pronounced differences were between the arms and posterior torso, indicating the high and low sweat regions. Considerably fewer significant differences were present following Bonferroni correction due to the conservative nature of the adjustment and the large number of regions. Data are presented both without and without correction at an alpha level of $p < 0.05$, $p < 0.01$, and $p < 0.001$. P values between 0.05 and 0.1 are additionally presented due to inflation of type II error with Bonferroni correction, but with the conservative approach in mind when considering the data.

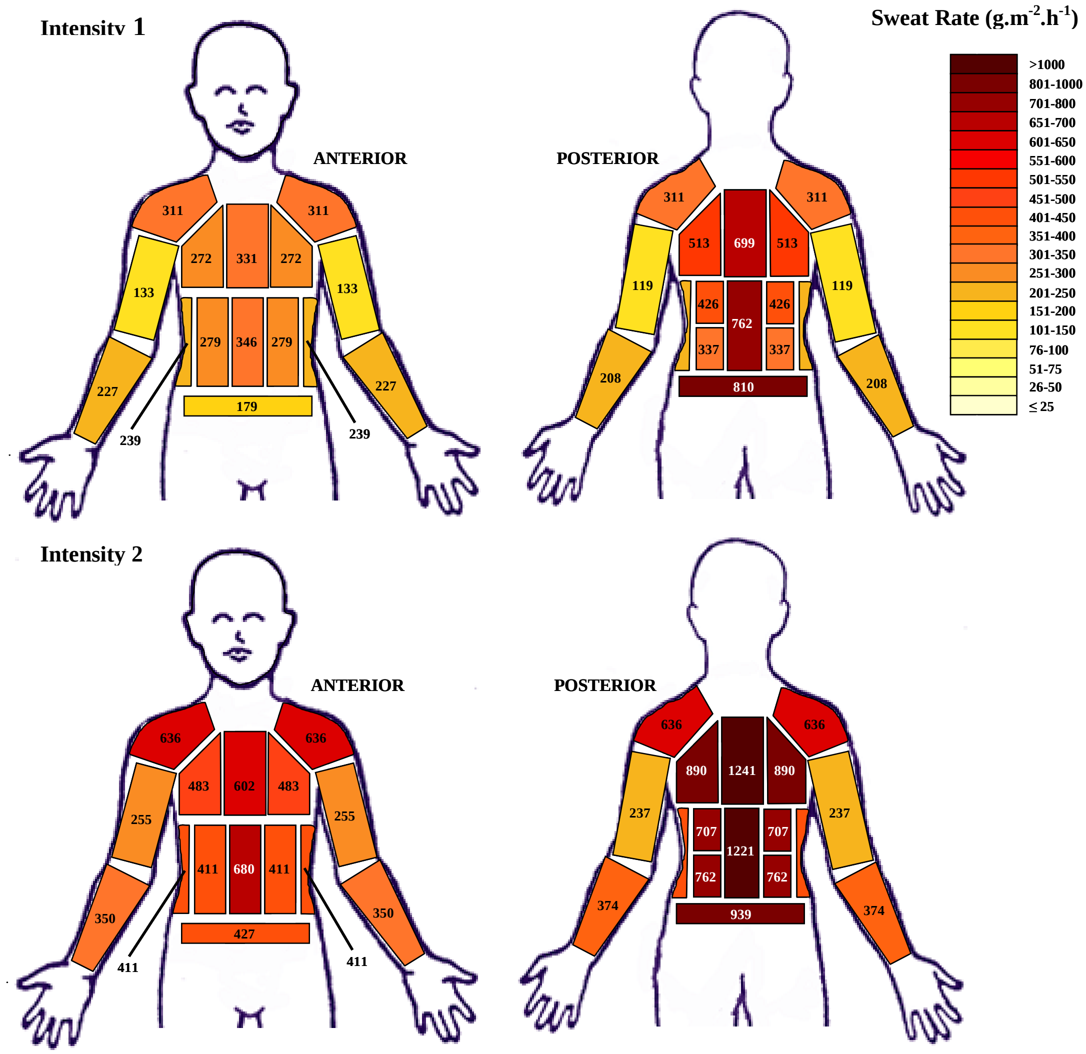

Figure 1. Regional sweat rates of the upper body at Intensity 1 and Intensity 2 in male athletes.

A significant increase in T_{sk} was observed in a few zones following the application of pads at I1 ($\Delta T_{sk} \leq 1.6$°C) followed by a significant decrease in most regions once the pads had been removed ($\Delta T_{sk} \leq 1.6$°C). A significant increase in skin temperature following the second sample period occurred in only 7 regions ($\Delta T_{sk} \leq 2.4$°C, decreasing to only 3 following Bonferroni correction. Within participant correlations were performed for T_{sk} and *SR* due to between participant factors confounding regional skin temperature and sweat rate. A weak, non significant correlation was observed in all participants ($r < 0.5$) except m5.

Table 1a. Significance levels of comparison of absolute sweat rates at Intensity 1.

	shoulders	lat upper chest	centre ant upper	lat mid chest	centre ant mid	sides	ant lower	lat pos upper	centre pos upper	lat pos M-U	lat pos M-L	centre pos mid	pos lower	ant upper arm	pos upper arm	ant lower arm
lat upper chest	-															
centre ant upper	-	*														
lat mid chest	-	-	-													
centre ant mid	**	*	-	**												
sides	-	-	-	-	**											
ant lower	**	-	-	*	**	*										
lat pos upper	***$	**	**	***	**	***	***$									
centre pos upper	***#	***$	***$	***$	**	***#	***$	**								
lat pos M-U	*	**	*	**	-	**	**	**	***#							
lat pos M-L	-	-	-	*	-	**	**	***	***#	-						
centre pos mid	***$	***#	***$	***$	***	***$	***#	**	-	***	***					
pos lower	*	*	*	*	*	**	**	-	-	*	**	-				
ant upper arm	**	*	**	**	**	*	-	***##	***##	***##	***	***##	**			
pos upper arm	**	-	**	*	**	*	-	***##	***##	***##	***$	***##	***	-		
ant lower arm	-	-	-	-	*	-	-	***#	***##	***#	*	***#	**	**	***$	
pos lower arm	-	-	-	-	*	-	-	***##	***##	***	*	***#	**	**	***	-

Table 1b. Significance levels of comparison of absolute sweat rates at Intensity 2

	shoulders	lat upper chest	centre ant upper	lat mid chest	centre ant mid	sides	ant lower	lat pos upper	centre pos upper	lat pos M-U	lat pos M-L	centre pos mid	pos lower	ant upper arm	pos upper arm	ant lower arm
lat upper chest	-															
centre ant upper	-	-														
lat mid chest	*	-	-													
centre ant mid	-	*	-	***$												
sides	**	-	-	-	***#											
ant lower	***$	-	-	-	***#	-										
lat pos upper	**	**	**	***	-	***#	***$									
centre pos upper	***	***	**	***#	**	***#	***$	*								
lat pos M-U	-	*	-	**	-	**	**	**	***$							
lat pos M-L	-	-	-	*	-	*	*	-	**	-						
centre pos mid	**	**	**	***	**	***$	***$	*	-	**	***					
pos lower	*	*	**	*	-	**	**	-	-	*	-	-				
ant upper arm	***	*	**	**	***#	**	-	***##	***##	***###	***#	***##	***			
pos upper arm	***	*	**	*	***#	**	-	***###	***##	***##	***#	***##	***	-		
ant lower arm	**	*	*	**	***#	*	-	***#	***##	***##	**	***#	**	**	*	
pos lower arm	**	-	*	-	***	-	-	***##	***##	***##	**	***#	**	***#	***#	-

No correction: *P ≤ 0.05; **P ≤ 0.01; ***P ≤ 0.001;

Bonferroni correction: # P ≤ 0.05; ## P ≤ 0.05; ### P ≤ 0.001; $ 0.1 > P ≥ 0.05

CONCLUSIONS

The current study aims to provide a whole body sweat map of male athletes. The preliminary data presented in this paper confirm large intra segmental variation on the torso and arms. Considerable variation in absolute regional sweat rate was observed both within and between male athletes yet consistent patterns of distribution were observed. A significant increase in sweat rate occurred in all regions with increased exercise intensity but showed little change in distribution. The central and lower back consistently showed the highest sweat rates over the body at both intensities in comparison to the lowest sweat rates being observed on the extremities. These observations are in agreement with regional sweat data from other authors (Weiner, 1945; Kuno, 1956; Hertzman, 1957; Cotter *et al.*, 1995; Havenith *et al.*, 2008a). The medial to lateral decrease across the torso has been reported by some authors (Ogata, 1935; Kuno, 1956; Hertzman, 1957; Havenith *et al*., 2008; Machado-Moreira *et al*., 2008a), but was either absent or progressed towards unity with increasing exercise intensity in other studies (Cotter et al., 1995; Hertzman, 1957). Regional sweat distribution does not necessarily correspond to eccrine sweat gland density (Ogata, 1935). Cadavar data by Szabó (1962) found the highest densities (± SE glands.cm^{-2}) on the soles (620 ± 120), forehead (360 ± 50), and cheeks (320 ± 60). Conversely, SRs were highest on the central back and lower on the extremities in the current study. It would therefore seem logical to consider the number of active sweat glands, output per gland, and sudomotor sensitivity. Machado-Moreira *et al.* (2008a) calculated intra segmental sudomotor sensitivity, with results relating closely to the regional variation in SR observed in the current study. They reported these differences not to be significant, failing to adequately explain regional variation in SR.

Comparison between the present absolute data and the relevant literature is problematic since differing temperature and exercise protocols have been adopted. Discrepancies in data may also arise from methodological issues since some techniques promote complete evaporation at the skin (ventilated capsules) which may artificially elevate SR whilst others prevent evaporation, potentially causing increases in T_{sk} and therefore SR (absorbents) or inducing hidromeiosis. It is worthy of note that any method employed in sweat measurement will interfere to some degree with the microclimate of the skin and hence the sweat rate.

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