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Title: Body mapping of thermoregulatory and perceptual responses of males and females running in the cold

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Keywords: skin temperature; skinfold thickness; exercise; sex; infrared thermography

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Abstract: Thermoregulatory parameters during exercise are typically reported as global responses (Tcore and mean Tsk). In contrast, this study investigated regional skin temperatures (Tsk) over the body, in relation to regional skinfold thickness and regional perceptual responses for both sexes using a body-mapping approach. Nine males and nine females, of equivalent fitness, minimally clothed, ran for 40 minutes at 70% VO2max in a 10°C, 50% rh, 2.8 m.s-1 air velocity environment. Tsk was recorded by infrared thermography and processed to obtain population-averaged body maps. Rectal temperature and heart rate were monitored continuously throughout the running trial. Skinfold thickness was obtained for 24 sites and thermal sensation votes for 11 body regions.
Males and females had similar rectal temperature, heart rate and regional sensations. Whole-body maps of Tsk highlighted the significantly lower regional Tsk for females (-1.6°C overall, $p<0.01$). However, the distribution of Tsk across the body was similar between sexes and this was not correlated with the distribution of skinfold thickness, except for the anterior torso. On the other hand, regional thermal sensation votes across the body were correlated with Tsk distribution during exercise (females: $r = 0.61$, males $r = 0.73$, $p<0.05$), but not at rest.
Our thermographic results demonstrate the similar Tsk distribution for active males and females during submaximal running in the cold, though shifted to a lower mean value for females. This Tsk distribution was associated with regional sensations but not with local fat thickness. The described body-mapping approach can have implications in physiological modelling and clothing design

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Introduction

Temperature regulation is dependent upon ascending sensory information from deep and skin thermoreceptors widely distributed in the body (Werner and Reents, 1980). Core and mean skin temperature ($\overline{T_{sk}}$) are often considered as the regulatory parameters. Body-mapping, i.e the study of thermoregulatory responses for different body regions, has gained attention over recent years after earlier works mainly focussed on global responses. Recent data from studies about sweat mapping (Havenith et al., 2008; Smith and Havenith, 2012) and thermal sensitivity distribution (Ouzzahra et al., 2012) are now used in models of thermoregulation (Fiala et al., 2012) as well as in the design of thermal manikins and clothing (Havenith et al., 2008). Little is known about the spatial distribution of body temperatures, especially skin temperature (T_{sk}). The topography of T_{sk} distribution across the body can have some thermoregulatory and perceptual significance (Candas, 2005). It is even more relevant in cold environments where T_{sk} differences between regions are larger (Werner and Reents, 1980).

In the literature, T_{sk} responses are reported via the dynamics of $\overline{T_{sk}}$ usually computed from several contact point measurements from up to 15 body regions (Choi et al., 2007). However, large point-to-point T_{sk} variations have been highlighted in relatively small areas of the body (Frim et al., 1990) and this questions the representativeness of such contact measurements.

Infrared thermography offers an alternative non-contact method in the evaluation of T_{sk} with the potential of mapping T_{sk} distribution over the whole-body. Several studies have used this method during exercise and specifically whilst running (Clark et al., 1977; Merla et al., 2010). However, no studies have attempted to combine the individual infrared images (thermograms) in order to give a population-averaged pattern of T_{sk} distribution. Moreover, patterns of male versus female T_{sk} distribution have only been described qualitatively for two participants at rest in a 22°C environment (Clark and Edholm, 1985).

Sex-differences in thermoregulatory responses, have mainly been reported as overall responses. During exercise in the cold, $\overline{T_{sk}}$ is 1-2°C lower for females (Graham, 1988) and only one study, using contact sensors, actually compared regional T_{sk} between sexes (Walsh and Graham, 1986). Differences in T_{sk} between sexes have sometimes been attributed to differences in subcutaneous fat (Wagner and Horvath, 1985), acting as a passive layer of insulation impeding heat transfer from the core to the skin. In the cold, peripheral cutaneous vasoconstriction maximises its insulatory benefits. The distribution of subcutaneous fat thickness over the body, also called fat patterning, is different in males and females (Mueller and Joos, 1985). Together with hormonal differences, this corresponds to a true sexual dimorphism that can lead to sex-differences in thermoregulation. These different distribution patterns can locally alter heat transfers, and it is suggested that T_{sk} distribution reflects the regional subcutaneous fat distribution (LeBlanc, 1954), though this has never been verified.

Lastly, the role of T_{sk} in the generation of thermal sensations is well recognized (Candas, 2005) with thermoreceptors responding to static temperature and rates of change of temperature (Hensel, 1973). Although this determinism has been explored for individual regions at rest (Zhang et al., 2010) and overall response during exercise (Gagge et al., 1969), no reports have looked at the relationships between thermal sensations across the body and T_{sk} distribution.

A body-mapping approach was therefore used in the present study in order to investigate different thermoregulatory and perceptual variables. In the context of running in the cold, it was hypothesized that males and females would have different thermographic body maps of T_{sk} due to their differences in fat patterning. Moreover, the expected lower T_{sk} for females may lead to sex-differences in regional thermal sensation responses.

Methods

Nine males and nine females (aged 18-25), all physically active Caucasians, participated in the experiment. All experimental procedures were approved by the Loughborough University Ethical Committee and were fully explained to the participants before obtaining informed written consent and completing a health screen questionnaire.

Height and body mass were obtained as well as skinfold measurements using a Harpenden caliper at 24 locations across the right side of the body (Table 1). The latter provided a detailed body map of skinfold thickness. Skinfolds were also used to calculate body fat percentage (%BF) (Hayward and

Wagner, 2004). Maximal oxygen uptake ($\dot{V}O_{2max}$) was predicted from a sub-maximal test (Whaley et al., 2009) on a treadmill (h/p cosmos mercury 4.0, Nussdorf-Traunstein, Germany). Exercise intensity for the experimental session was set at 70% $\dot{V}O_{2max}$ which was chosen to reflect a common training speed of regular active runners.

Males were provided with swimming trunks and females low-cut running shorts and bras (Decathlon, Villeneuve d'Ascq, France). Rectal temperature (T_{re}) was monitored continuously using a thermistor (Grant Instruments, Cambridge, UK) inserted 10cm beyond the anal sphincter. Heart rate (HR) was recorded using a Polar RS600 monitor (Polar Electro Oy, Kempele, Finland).

The trial was designed to reproduce a typical outdoor running scenario with a selection of four different stages for specific measurements. Following a 10-min period of stabilisation at rest in the 22°C preparation room, participants entered the 10°C climatic chamber, stood at rest for 5 minutes on the treadmill (PRE), ran for 10 minutes (T10) and ran for another 30 minutes to complete the 40-min exercise bout (T40). Exercise was followed by a 10-min recovery period standing on the treadmill (POST). All experiments were conducted in the controlled climatic chamber in a 9.9 ± 0.5°C environment and 54 ± 6% relative humidity. This type of conditions was chosen to induce large T_{sk} variations and were in line with others (Werner and Reents, 1980; Gagge et al., 1969). During exercise, a 2.8 ± 0.3 $m.s^{-1}$ frontal air speed was present. Body sweat loss was calculated from body mass loss adjusted for water intake and corrected for metabolic and respiratory mass losses. Within the group of females, 5 were tested during the follicular phase and 4 during the luteal phase of the menstrual cycle.

Perceptual responses were obtained at the end of each stage with the rate of perceived exertion (RPE) using the 6-20 Borg scale (Borg, 1970) and the overall and regional thermal sensations using an extended Gagge 21-point bipolar scale (from *extremely cold* to *extremely hot*) (Gagge et al., 1969). Eleven regions were investigated, extending the list of Pellerin et al. (2004) and for the limbs separating anterior and posterior to account for effects of the front wind applied: chest, abdomen, upper and lower back, anterior and posterior arms, anterior and posterior hands, anterior and posterior legs, face.

Whole-body T_{sk} was then recorded with the participant standing in an anatomical position using an infrared camera (Thermacam B2, FLIR Systems Ltd, West Malling, Kent, UK, spectral range 7.5 to 13µm, accuracy ± 2°C, thermal sensitivity ± 0.1°C,). A series of five different thermograms (anterior upper body, posterior upper body, anterior lower body, posterior lower body and right side) were taken immediately at the end of each stage (PRE, T10, T40, POST). The HR belt was worn for 5 minutes and removed 5 minutes before each infrared measurement to reduce its influence on heat exchanges at the skin. A reference surface temperature (measured by a thermistor at ±0.1°C) was included in all images for post-calibration of absolute temperature in order to improve the device absolute accuracy. Females removed their bras so that the bare chest could be measured.

Temperature correction was performed on individual infrared images using FLIR ThermaCam Researcher Pro 2.8 to account for various parameters, i.e ambient temperature, reflected temperature, relative humidity, distance (1.9m) and emissivity (0.98) (Steketee, 1973). Image processing was then performed using a custom-made tool under MATLAB R2009a (The MathWorks Inc., Natick, USA) to account for between-subject differences in body size and shape. Following image registration (selection of control points), all thermograms were morphed, i.e. projected, onto a reference body shape chosen as a male and female with median anthropometric characteristics. Morphed individual thermograms were then averaged to obtain population-averaged absolute body maps of T_{sk}. Lastly, relative or normalised T_{sk} body maps were computed by dividing the absolute maps by the group $\overline{T_{sk}}$ at each specific stage, calculated as the arithmetic average of all skin surface pixels except for groin, feet and scalp. Image processing was performed manually based on anatomical landmarks in order to avoid the selection of artefacts pixels caused by the edge effect of the curved human body. The morphing procedure induced pixel distorsion around the body contour depending on body geometry of each individual in relation to the reference body shape. The transformation led to a ±15% difference (expansion or constriction) in effectve body pixel count from morphed vs original thermogram, though this only affected the topographical representations of the T_{sk} patterns (body maps). On the other hand, for quantitative analysis, T_{sk} data were obtained before morphing based on a segmentation in close association with superficial musculature. T_{sk} values for palmar and dorsal hands were included but the hands are not reported in the body map representations due to limited resolution in these areas.

A two-way repeated measures ANOVA (SPSS Inc, Chicago, IL, USA) was used to investigate the main effect of TIME of exposure, and SEX on the different dependent variables: $\overline{T_{sk}}$, regional T_{sk}, T_{re}, HR. Holm-Bonferroni corrections was applied to allow for multiple comparisons when different body sites were compared. Pearson correlation coefficients were obtained following regression analysis between regional T_{sk} and regional skinfold thickness on one hand, and regional thermal sensation and regional T_{sk} on the other.

Results

The following participants characteristics were obtained for females vs males (171 ±3 cm vs 182 ±4 cm, 66.6 ±5.0 kg vs 79.5 ±4.3 kg, $p<0.01$). Females had significantly greater body fat percentage compared to males (21.6 ±2.8 % vs 9.5 ±2.4%, $p<0.01$). Both groups had similar maximal fitness level (females vs males: 50.3 ±5.3 $ml.min^{-1}.kg^{-1}$ vs 53.7 ±4.1 $ml.min^{-1}.kg^{-1}$, NS) and they exercised at a similar running speed (9.5 ±1.1 $km.h^{-1}$ vs 10.2 ±0.9 $km.h^{-1}$, NS) during the experimental trial.

Overall thermoregulatory responses highlighted a significant sex-difference for whole-body $\overline{T_{sk}}$ but no difference in terms of T_{re}, body sweat loss and HR between males and females. Whole-body $\overline{T_{sk}}$ was indeed 1.6°C significantly lower for females (females vs males: 26.9±0.8°C vs 28.9±0.9°C, $p<0.01$ at PRE; 22.4±0.9°C vs 24.0±0.9°C, $p<0.01$ at T10; 21.9±1.1°C vs 23.5±1.5°C, $p<0.05$ at T40; 24.5±1.2°C vs 25.7±0.8°C, $p<0.05$ at POST). Dynamics of $\overline{T_{sk}}$ was however the same between the two groups with no TIME*SEX interaction effect.

There were no sex-differences in the dynamics of T_{re} and their absolute values throughout the whole-protocol including the four specific stages (females vs males: 37.5±0.3°C vs 37.7±0.2°C at PRE, 38.1±0.2°C vs 38.1±0.2°C at T10; 38.5±0.3°C vs 38.5±0.2°C at T40; 37.9±0.4°C vs 38.1±0.2°C at POST, all NS). Moreover, there was no sex-difference in body sweat loss (females 185 ±133g, males 212 ±39g, NS) and no differences in HR and its dynamics with a similar plateau at 150 ±13bpm for females 152 ±9bpm for males.

Overall perceptual responses were similar between females and males considering RPE (females vs males: 11±1 vs 11±2 at T10, 13±2 vs 13±2 at T40, NS) as well as whole-body thermal sensation ranging on average from *cool* at PRE to *neutral / slightly cool* at T40, with a large inter-individual variability in both groups.

The body-mapping approach applied to the evaluation of skinfold thickness is presented in Table 1. A majority of skinfolds sites had a significantly larger thickness for females compared to males. The largest difference was observed at the triceps, thigh and lumbosacral regions with a respectively +121%, +88%, +68% larger skinfold thickness for females.

Females exhibited lower regional T_{sk} at all stages and most of the significant sex-differences in absolute T_{sk} were observed in the anterior and posterior legs, the upper and lower back as observed in the population-averaged body maps of absolute T_{sk} (Figure 1). There was no TIME*SEX interaction effect over the protocol which indicates that sex-differences remained consistent at the different stages. The evolution of regional skin temperatures followed $\overline{T_{sk}}$ dynamics over the four stages. The anterior skin temperatures dropped more during the running than the posterior for both sexes (on average -7°C vs -5°C).

Relative T_{sk} distribution was similar between females and males which represents the main finding of the present study (Figure 1) and this was consistent throughout the protocol. No significant relationship was found between the whole-body T_{sk} distribution and the skinfold thickness distribution across the body (24 sites) for both groups neither at rest nor during exercise (Figure 2A,B). This relationship became significant only when analysed for the variations over the anterior torso separately (8 sites), and solely at T40 (females $r = -0.71$, $p=0.11$; males $r=-0.85$, $p<0.05$).

Despite the significantly lower T_{sk} for females, there were no sex-differences in regional thermal sensation in the eleven body regions throughout the protocol. At T40, the extreme regions were the hands, perceived as *slightly cool*, and the back perceived as above *neutral* for both groups. There was a significant relationship between the distribution of regional thermal sensations and the distribution of regional T_{sk} but only during exercise (Figure 2 C,D).

Discussion

The present study produced for the first time population-averaged whole-body maps of T_{sk} distribution for minimally clothed Caucasian males and females during submaximal running in a 10°C environment. Using a body-mapping approach similar to recent sweat and sensitivity mapping (Havenith et al., 2008; Smith and Havenith, 2012; Ouzzahra et al., 2012), it gives new insights in the spatial resolution of thermoregulatory and perceptual variables with a special emphasis on the influence of skinfold thickness. The main findings of this experiment on a physically active population can be summarised as follows: **(1)** Females exhibited lower $\overline{T_{sk}}$ and regional T_{sk} than males, **(2)** T_{sk} distribution pattern was similar between males and females, **(3)** T_{sk} distribution was not associated with the regional variations of skinfold thickness across the body, **(4)** The regional variation of thermal sensations across the body were positively correlated with T_{sk} distribution during exercise, though different per sex. For a certain sensation, females had a lower T_{sk}.

(1) The present thermographic data support the well documented sex difference in $\overline{T_{sk}}$ based on contact measurements showing an absolute 1-2°C colder $\overline{T_{sk}}$ for females at rest and during exercise in the cold (Graham, 1988; Walsh and Graham, 1986). In agreement with others (Walsh and Graham, 1986), T_{sk} in the limbs and trunk, especially at the back, were colder for females compared to males.

(2) Despite the absolute T_{sk} differences, our population-averaged relative body maps highlighted the similar topography of regional T_{sk} distribution between females and males (Figure 1). Specific exercise-related features in the body maps were observed such as the warmer skin overlying active gastrocnemii and hamstrings muscles. Other thermographic studies also documented this feature whilst running but on only one representative participant (Clark et al., 1977; Merla et al., 2010). Interestingly, the T_{sk} body maps paralleled the body maps of glucose metabolism obtained after running by 3D positron emission tomography using ^{18}F-2-fluoro-2-deoxyglucose (Iemitsu et al., 2000), emphasizing the important influence of regional heat production on regional T_{sk}, overpowering the increased convective heat loss in the swinging lower limbs.

The colder Y-shape area over the abdominal, hypogastric and pectoral regions is in line with observations at rest (Clark and Edholm, 1985) or after running (Clark et al., 1977; Merla et al., 2010) on individual athletes. Higher breast temperatures for females were caused by the insulation provided by the bra and prevented the definition of a plain Y-shape as observed in males. This could not be avoided as running without a bra was not acceptable at these running speeds. In the posterior torso, the Y-shape region of higher T_{sk} was noticeable and similar to that found for an individual male and female at rest (Clark and Edholm, 1985) and close to the T-shape of a single male runner (Clark et al., 1977). The body maps also allowed the identification of a warm "core" (Clark and Edholm, 1985) including the face, sternal and neck regions. Lastly, the distribution of T_{sk} in the limbs partly challenges the classical observation of a "cephalo-caudal distribution" (Candas, 2005) of T_{sk}, i.e colder towards the extremities, which may only apply during prolonged rest.

(3) The body-mapping analysis revealed that within each sex, T_{sk} distribution did not reflect the regional variations of skinfold thickness across the body, as firstly hypothesised. The gynoid (females) vs android (males) fat distribution (Mueller and Joos, 1985) did not impact the spatial variations of T_{sk}. Studies classically reporting an effect of fat thickness on T_{sk} were focused on inter-individual variations for single body regions (Frim et al., 1990; LeBlanc, 1954). Our body-mapping approach explored the variations between body regions over the body. Despite some regions with thicker fat deposits (e.g thigh) being indeed one of the coldest, there was no topographically consistent determinism over the whole body. Within the anterior torso however, skinfold thickness variations appeared to influence T_{sk} distribution for both groups during exercise. It can be hypothesized that insulation of the moderately perfused pectoral and abdominal muscles (Veicsteinas et al., 1982) may also have contributed to the specifc Y-shape region of colder $T_{sk.}$

All T_{sk} determinants must be taken into account in the description of the thermal patterns. The exposition of the anterior torso to strong convective heat exchange (relative wind) may partly explain the colder T_{sk} compared to the posterior torso.

The role of cutaneous perfusion is also highly important in the thermal patterns (Hunold et al., 1992) as it modifies the tissue heat conductance. Vasomotor tone is autonomously controlled and dynamically dictates tissue insulation as opposed to the passive influence of fat thickness which refers to fixed body characteristics. The influence of cutaneous perfusion may also vary from site to site (Park et al., 1997). Following a period of cold and exercise-induced vasoconstriction at the start of the trial (Johnson, 1992), some reflex active vasodilation and more superficial blood flow may have limited the temperature drop in the posterior torso, especially along the spinal arteries, or in the regions overlying the aortic arch and the routes of the carotid and brachial arteries (Figure 1). Cutaneous blood flow measurements during exercise were deemed impractical so the male and female results cannot be compared to this effect. However, based on literature results, it may be assumed that sex differences in skin blood flow would be limited (Park et al., 1997) and regional differences in blood flow have also been found to be relatively small between the trunk, arms and legs in various environments (Werner and Reents, 1980). Baroreceptor unloading induced by the transition from running to standing may have caused some reductions in regional blood flow (Crandall et al. 1996; Mack et al., 2001) and regional sweat rates (Mack et al., 2001) though the influence of baroreceptor unloading on sweat rate is yet not fully understood. Moreover, the cessation of exercise was also associated with a sudden reduction in evaporative and convective heat loss due to the cessation of the running motion and relative air velocity. Regional T_{sk} was the result of the concomitant contribution of these internal and external phenomenons.

(4) In terms of perceptual responses, regional thermal sensations were similar between males and females despite the lower absolute T_{sk} for females. In the context of our study, rate of changes in $\overline{T_{sk}}$, regional T_{sk} and T_{re} were similar between sexes and may partly explain this perceptual outcome (Zhang et al., 2010). Interestingly, mapping perceptual responses revealed that regional sensations across the body were associated with their corresponding absolute regional T_{sk} during exercise only, though the relation was different for each sex. To our knowledge, no other studies have explored this spatial feature.

The above findings have been obtained from a population of physically active males and females with a relatively narrow range of body fat within each group. Our body-mapping method offers novel insights in the exploration of sex-differences but it can also be valuable in the spatial comparisons of various interventions or populations on one occasion or longitudinally.

Conclusions

A body-mapping approach was able to discriminate spatial thermoregulatory and perceptual responses. In the context of running in the cold, females exhibited lower T_{sk} compared to males. However, the relative distribution of regional T_{sk} was similar between sexes as highlighted by our population-averaged relative body maps. The regional T_{sk} distribution was not explained by the regional variations in skinfold thickness, except within the anterior torso. A dynamic interplay between regional heat production, heat transfer to the surface and heat loss influences regional T_{sk} and some determinants have been discussed especially the vasomotor adjustments induced by exercise. Moreover, males and females had similar overall and regional thermal sensations despite the lower T_{sk} in the females. Unlike fat thickness, these regional sensations proved to be associated with the regional T_{sk} during exercise, but not rest. The present body-mapping data can be useful to increase the resolution of multi-nodal temperature regulation models and it can have practical implications for the design of sport or cold protective clothing.

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Legends

Table 1. Body-mapping of 24 regional skinfold thicknesses (group average, range) across the whole-body for males (n=9) and females (n=9)

Figure 1. Group averaged body maps of absolute (left panel) and relative (right panel) skin temperature after 40 minutes of running at 70% $\dot{V}O_{2\max}$ in a 10°C environment for males (♂) (n=9)and females (♀) (n=9) after morphing individual images of the participants in each group onto a reference body shape. Relative maps are obtained by dividing the absolute body map by the group $\overline{T_{sk}}$ at this specific stage. A value of 1 therefore corresponds to the group $\overline{T_{sk}}$

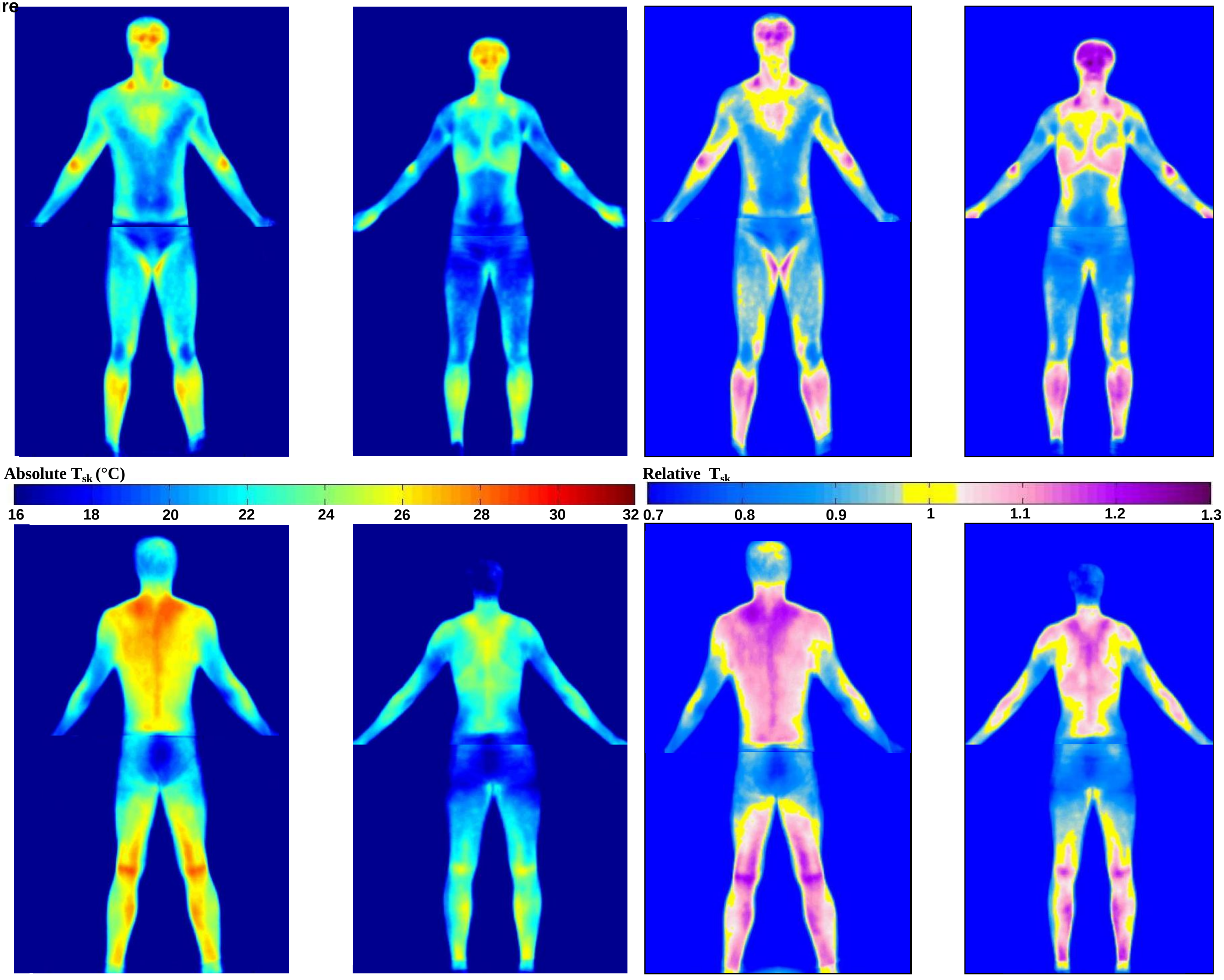
Figure 2. Analysis of regional data distribution across the body. Each data point represents the group average for a single body region. Regional skin temperature (°C) in relation to regional skinfold thickness (mm) 5 minutes after entering the 10°C environment (A) and after 40 minutes of running at 70% $\dot{V}O_{2\max}$ in the 10°C environment (B). Regional thermal sensation votes in relation to regional skin temperature (°C) at rest (C) and at the end of exercise (D) . *significant at $p<0.05$

Table

	FEMALES		MALES			FEMALES		MALES	
Regions	skinfold thickness (mm)	range	skinfold thickness (mm)	range	**Regions**	skinfold thickness (mm)	range	skinfold thickness (mm)	range
anterior forearm	7.3	(4.6-9.8)	5.4*	(4.3-7.6)	**thigh**	24.3	(15.5-39.1)	12.9**	(9.5-22.1)
biceps	6.9	(4.3-9.1)	4.9*	(2.5-7.1)	**suprapatellar**	7.2	(4.5-11.3)	6.2	(5.0-8.2)
shoulder	7.8	(4.5-9.9)	6.6*	(4.6-9.0)	**calf**	12.1	(8.9-15.2)	10.0	(4.5-16.9)
clavicular	7.6	(5.3-10.1)	4.9**	(4.0-6.2)	**posterior forearm**	6.2	(4.3-8.7)	4.5**	(3.6-5.6)
pectoral	8.6	(5.7-11.7)	7.7	(4.9-10.2)	**triceps**	16.6	(10.8-22.9)	7.5**	(5.3-11.1)
chest	11.8	(9.3-14.9)	6.1**	(4.5-7.4)	**neck**	14.3	(11.5-17.5)	9.9**	(8.1-12.5)
nipple	8.7	(6.7-10.6)	8.5	(6.0-11.2)	**suprascapular**	10.5	(7.9-13.3)	9.9	(7.6-13.9)
midaxillary	10.8	(7.5-14.2)	7.7**	(6.1-9.1)	**scapular**	11.6	(7.8-13.9)	11.5	(8.4-16.5)
upper abdominal	13.1	(8.1-19.4)	13.6	(9.0-27.3)	**subscapular**	12.6	(8.2-17.8)	10.0*	(8.2-12.3)
external oblique	11.9	(7.7-18.5)	10.0	(7.5-21.0)	**infrascapular**	12.9	(8.1-18.3)	10.6	(8.7-13.1)
suprailiac	18.7	(13.1-25.3)	13.7*	(7.7-25.9)	**lumbar**	19.7	(9.9-30.9)	13.6*	(9.0-24.3)
abdominal	13.7	(12.2-14.9)	14.8	(11.4-23.3)	**lumbosacral**	18.6	(9.1-27.5)	11.1**	(7.6-16.2)
sum of 24 skinfolds	293	(224-362)	222**	(177-324)					

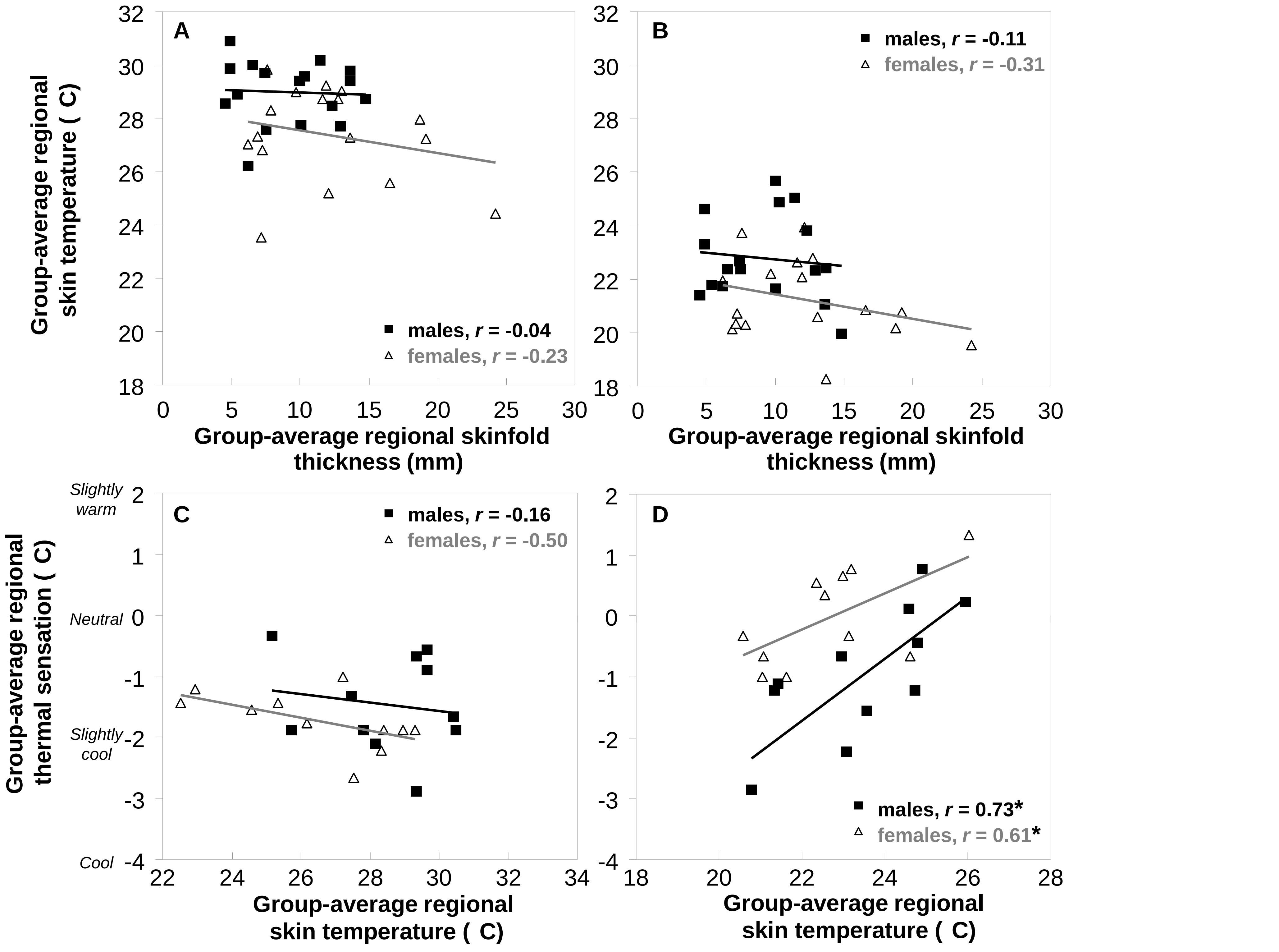
* significantly different from females at p<0.05; ** significantly different from females at p<0.01

Figure



Absolute T_{sk} (°C)
16
18
20
22
24
26
28
30
32
Relative T_{sk}
0.7
0.8
0.9
1
1.1
1.2
1.3

Figure2


A
B
C
D
Group-average regional skin temperature (C)
Group-average regional skinfold thickness (mm)
Group-average regional thermal sensation (C)
Group-average regional skin temperature (C)
males, r = -0.04
females, r = -0.23
males, r = -0.11
females, r = -0.31
males, r = -0.16
females, r = -0.50
males, r = 0.73*
females, r = 0.61*
Slightly warm
Neutral
Slightly cool
Cool

Highlights

- Females exhibited lower $\overline{T_{sk}}$ and regional T_{sk} than males
- T_{sk} distribution pattern was similar between males and females
- T_{sk} distribution was not associated with the distribution of skinfold thickness, except for the anterior torso
- Thermal sensation distribution was associated with T_{sk} distribution during exercise