

This item was submitted to Loughborough's Institutional Repository (<https://dspace.lboro.ac.uk/>) by the author and is made available under the following Creative Commons Licence conditions.



For the full text of this licence, please go to:
<http://creativecommons.org/licenses/by-nc-nd/2.5/>

Title page

Full Title:

Regional distribution of thermal sensitivity to cold at rest and during mild exercise in males

Authors Names and Affiliations:

Yacine Ouzzahra ^a, George Havenith ^a, Bernard Redortier ^b

^a Environmental Ergonomics Research Centre, Loughborough University, UK

^b Thermal Sciences Laboratory, Oxylane Research, 59665 Villeneuve d'Ascq, France

Corresponding Author:

Professor George Havenith:

Email address: G.Havenith@lboro.ac.uk

Telephone: (+44) 1509 223031

Postal address: Environmental Ergonomics Research Centre

James France Building

Loughborough Design School

Loughborough University

LE11 3TU – Leics

UK

Abstract

Although several studies have compared thermal sensitivity between body segments, little is known on regional variations within body segments. Furthermore, the effects of exercise on the thermal sensation resulting from a cold stimulus remain unclear. The current experiment therefore aimed to explore inter- and intra-segmental differences in thermal sensitivity to cold, at rest and during light exercise. Fourteen male participants (22.3 ± 3.1 years; 181.6 ± 6.2 cm; 73.7 ± 10.3 kg) were tested at rest and whilst cycling at 30% VO_2_{max} . Sixteen body sites (front torso = 6; back = 6; arms = 4) were stimulated in a balanced order, using a 20°C thermal probe (25 cm²) applied onto the skin. Thermal sensations resulting from the stimuli were assessed using an 11-point cold sensation scale (0 = not cold; 10 = extremely cold). Variations were found within body segments, particularly at the abdomen and mid-back where the lateral regions were significantly more sensitive than the medial areas. Furthermore, thermal sensations were significantly colder at rest compared to exercise in 12 of the 16 body sites tested. Neural and hormonal factors were considered as potential mechanisms behind this reduction in thermal sensitivity. Interestingly, the distribution of cold sensations was more homogenous during exercise. The present data provides evidence that thermal sensitivity to cold varies within body segments, and it is significantly reduced in most areas during exercise.

Keywords: cold sensation; body mapping; cycling

1. Introduction

1.1 Distribution of thermal sensitivity across the body

A large body of literature is available regarding regional differences in sensory and regulatory functions of the human thermoregulatory system. This includes research on the distribution of skin temperature (Clark et al., 1977), sweat production (Havenith et al., 2008; Smith and Havenith, 2011), thermal comfort (Nakamura et al., 2008), thermal sensory spots (Strughold and Porz, 1931), thermal thresholds (Lee et al., 2010) and cold sensitivity (Stevens, 1979).

Thermal sensitivity is a general term used in research involving different experimental methodologies. Observations of its distribution across the body will vary greatly depending on the methodology used. Early studies investigating regional thermal sensitivity used the method of sensory spots body mapping, directly exploring the existence of localised sensory spots in the skin. The procedure consists of individually applying a small (usually 1 mm²) thermostimulator in neighbouring points within a small surface area of a body region. For each point, subjects report whether or not the thermal stimulus is perceived (*yes or no score*), allowing calculation of the number of cold and warm “spots” per surface area. Strughold and Porz (1931) found that the average cold spots densities for each segment were as follows (in cold spots per cm²): face (11.3), trunk (9.7), upper limb (5.6) and lower limbs (5.3). This measurement is thought to give a good estimate of thermoreceptors density.

The method of limits, on the other hand, provides a measurement of perceptual thermal thresholds. Lee and colleagues (2010) investigated ethnic differences in thermal thresholds at 12 sites across the body. Regarding regional differences, their results showed that the initial

perception of a cool sensation occurs after different levels of change in skin temperature (*threshold scores*), depending on the body region stimulated. However, only one site was tested on each body segment, except at the hand (dorsal and palmar) and foot (dorsal and plantar).

The distribution of thermal sensitivity has also been investigated with the method of magnitude estimation, consisting of rating the intensity of a thermal sensation resulting from a thermal stimulus (*intensity score*). Stevens (1979) assessed the differences in thermal sensitivity to cold across the body with a 20 cm² temperature regulated stimulator set at different temperatures between 0 and 30°C. Only one site was tested on each body segment, and results showed that the coldest sensations were consistently found on the back, followed by the front torso, the limbs, and the face.

Previous research thus provides inter-segmental comparisons of thermal sensitivity; however little is known on whether test locations chosen in earlier studies were representative for the whole segment, and how large variations within segments may be. For other thermal parameters (e.g.: sweating), vast variations within body segments were previously demonstrated (Havenith et al., 2008; Smith and Havenith, 2011). In terms of application of such knowledge, clothing design comes to mind, where the incorporation of design features (e.g.: ventilation openings) may be guided by regional body maps of thermal sensitivity. With such applications in mind, the present study first aimed to provide a body map of thermal sensitivity to cold at 16 body sites within the front torso, the arms, and the back.

1.2 The effects of exercise on thermal sensitivity

In humans, peripheral thermal stimuli can arouse an affective sensation (e.g.: pleasure, displeasure) as well as an intensity sensation (e.g.: neutral, cool, cold). Regarding the affective sensation, Cabanac (1969) defined thermal alliesthesia as the pleasure/displeasure sensation aroused by a given peripheral thermal stimulus, according to the internal thermal state of a subject. Attia and Engel (1982) investigated the thermal pleasantness of a set of temperature stimuli in different conditions, and found that alliesthesia occurs as a result of both exogenous (i.e. passive thermal exposure) and endogenous (i.e. exercise) thermal loads. In contrast, Mower (1976) showed that the intensity component of a thermal sensation resulting from a thermal stimulus was not affected by passive thermal loads. To the best of our knowledge, no study has investigated the effects of endogenous thermal loads (i.e. exercise) on the intensity of a thermal sensation resulting from a given thermal stimulus. The effects of exercise on thermal sensitivity have however been approached with the method of limits. Kemppainen et al. (1985) measured thermal thresholds at the hand, forearm and leg in three conditions: at rest, whilst cycling (100, 150, 200 and 250 W) and after 15 min of recovery. Results showed that the initial perception of a cool sensation occurred at a lower skin temperature during exercise compared to rest. This effect increased as a function of exercise intensity, and was most marked at the leg and least at the glabrous hand, with an intermediate value found at the forearm. After 15 min of post-exercise recovery, thermal threshold values returned close to the initial resting levels. Kemppainen's results provide thermal threshold scores at rest and during exercise; however, the effects of exercise on thermal sensation intensity scores in response to a given cold stimulus rather than on thresholds remain unknown. Furthermore, the limited number of body locations tested

provides little information on the distribution of the changes in thermal sensitivity resulting from exercise.

The second aim of the present study was therefore to compare thermal sensitivity to cold at rest and during light exercise in 16 body locations, using a stimulus markedly above the thermal threshold.

2. Material and methods

2.1 Participants and pre-experimental session

Following approval of the experimental protocol by the Loughborough University Ethical Advisory Committee, 14 recreationally active Caucasian male participants were recruited from the student population. After providing written informed consent, all participants attended the laboratory on three separate occasions with at least 48 hours between the sessions.

The first session required anthropometric measurements of height, weight, and skinfolds thicknesses. These were taken using the 7-point caliper method (Jackson and Pollock, 1978) specific to the male population for calculation of body fat percentage (BF %). Maximal oxygen consumption ($\text{VO}_{2 \text{ max}}$) was then deduced using a modified version of the Åstrand-Rhyming sub-maximal cycling test (1954). This consisted of analysing the relation between measured heart rate and workload at 4 sub-maximal cycling intensities performed on an electromagnetically braked cycle ergometer (Lode Excalibur, Groningen, The Netherlands). Predicted $\text{VO}_{2 \text{ max}}$ was then calculated from the ACSM metabolic equation for cycling (Franklin et al., 2000). In preparation to the experimental sessions, participants were subsequently familiarised with the testing procedures. A training session was conducted, in which several body sites were stimulated with examples of strong and weak cold stimuli. In the second and third sessions, the thermal sensitivity test was performed at rest and during exercise, in a balanced order.

2.2 Thermal sensitivity experiments

Upon arrival in the laboratory for the second and third sessions, participants changed into shorts, socks and trainers. The investigator marked each of the 16 testing sites on the skin using a washable marker. These were distributed across the upper body as follows: front torso = 6; upper limb = 4; back = 6 (figure 1). All tested sites were medial or on the left hand side of the body, assuming symmetry (e.g.: Claus et al., 1987; Meh and Denišlić, 1994).

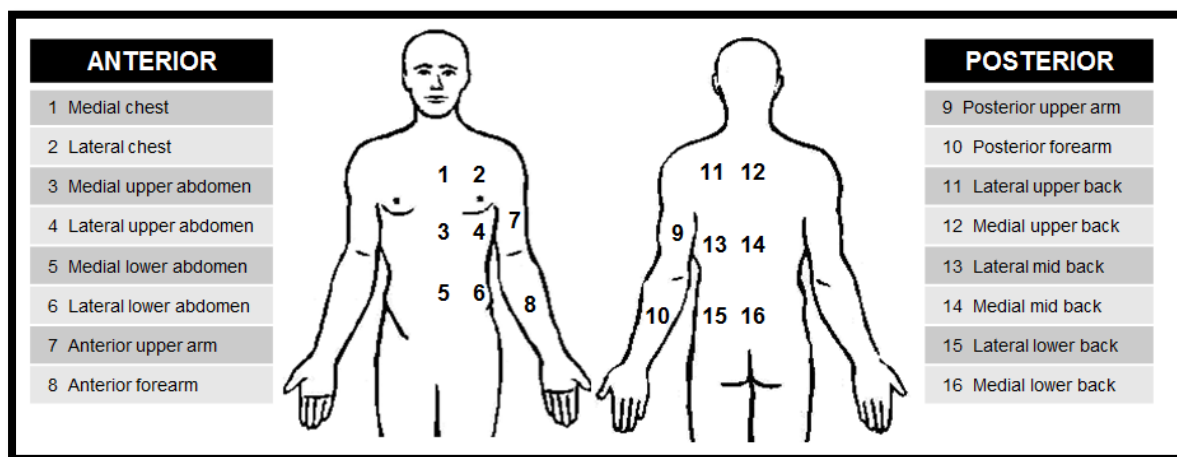


Figure 1 Name and location of the 16 body sites for the measurement of thermal sensitivity

Participants self-inserted a rectal thermometer (Grant Instruments, Cambridge, England) 10 cm beyond the rectal sphincter for measurement of core temperature (T_c). Four skin thermistors (Grant Instruments, Cambridge, England) were taped to the chest, upper arm, thigh and calf for calculation of mean skin temperature (mean T_{sk}) using Ramanathan's weighing formula (1964). Skin and rectal temperature sensors were connected to an Eltek/Grant 10 bit, 1000 series data logger (Grant Instruments, Cambridge, England) recording temperature at 10 second-intervals.

After preparation, participants were taken to the laboratory ($T_a = 21.5 \pm 0.8^\circ\text{C}$; $\text{RH} = 44.2 \pm 4.8\%$) where the initial part of the test consisted of a 20 minutes T_c and mean T_{sk} stabilisation period. During this period and the remainder of the experiment, participants either remained seated (rest condition), or cycled at 60 rpm with a workload corresponding to 30% of their predicted $\text{VO}_{2\text{max}}$ (exercise condition). This low intensity was selected in order to avoid any fatigue during the experiment and to limit the thermal changes to the body. Thanks to the built-in electrical control mechanism, the ergometer maintained work load levels stable regardless of small fluctuations in pedal frequency. In both conditions, another familiarisation to the thermal sensitivity test was performed during the temperature stabilisation period. This was done to ensure that all participants were thoroughly familiarised with the thermal sensitivity test prior to its commencement. The climatic conditions were chosen to provide a single temperature that would allow the body to be close to neutral at rest while not inducing a very high sweat rate during exercise.

Thermal sensitivity to cold was then tested at each of the 16 body sites in a balanced order to prevent any order effects. The 25 cm^2 thermal sensitivity tester (NTE-2, Physitemp instruments Inc., USA) set at 20°C was placed directly onto the skin over the marked site, and participants were instructed to rate thermal sensation at 2 different times: immediately after contact with the probe (transient sensation) and after 10 seconds of stimulation (steady-state sensation). A thermal sensation scale for noxious heat stimulation (Casey and Morrow, 1984) was adapted for innocuous cold stimulation. In this scale, 0 indicated “not cold” and 10 “extremely cold”. After each steady-state sensation rating, the probe was removed from the skin and the site was re-warmed with a hand warmer (Dura-Warm, The Grange, UK) directly applied onto the skin for 10 seconds. The experimenter then moved on to the next body site. Pressure was standardised by using the same experimenter in all tests. To avoid an effect of surprise on the transient cold sensations, a verbal warning of the location of each

out-of-sight body site prior to stimulation (e.g.: “lateral lower back”). In the exercising condition, any sweat present was gently wiped off the skin before each stimulus using a towel. Distractions were minimised throughout the thermal sensitivity test.

2.3 Data Analysis

Statistical analysis was performed using SPSS (Statistical Package for the Social Sciences, version 16.0, Chicago, USA). Mean T_{sk} and T_c at the end of the stabilisation period were compared between rest and exercise using paired-samples t-tests. Thermal sensations were analysed with a 3-way repeated measures ANOVA with body sites, conditions (rest/exercise) and times (transient/steady-state) as within subject factors. In order to identify any statistical differences in mean thermal sensations at individual sites between conditions, a series of paired-samples t-tests was completed. With 16 sites being compared between conditions, and over 100 possible comparisons between zones within subjects, multiple post-hoc comparisons are made with the risk of inflating type I error. This matter has been discussed in the literature (Bender and Lange, 1999; Perneger, 1998). Based on these discussions, it was decided that a Bonferroni would be overly conservative (pushing the limit P value for significance to 0.003 for condition, and below 0.0005 for within-subject comparisons) for the present type of exploratory study, and would dramatically inflate type II error. It was therefore decided to provide uncorrected P values and bring to the reader’s attention that these should be interpreted with multiple comparisons in mind (Havenith et al., 2008). In addition, significance of comparisons which include Bonferroni corrections will also be reported, highlighting the strongest effects.

3. Results

3.1 Regional differences in thermal sensitivity

Participants' characteristics are presented in table 1. In the exercise condition, participants cycled on average at 83.5 W, which resulted in a significant increase of 0.5°C in T_c ($p < 0.05$) but not in mean T_{sk} ($p > 0.05$).

Table 1 Participants' characteristics (n = 14). * indicates a significant difference between rest and exercise ($p < 0.05$)

	Age (years)	Height (cm)	Weight (kg)	BF %	$VO_{2\max}$ (ml kg ⁻¹ min ⁻¹)	T_c rest (°C)	T_c ex. (°C)	Mean T_{sk} rest (°C)	Mean T_{sk} ex. (°C)
Mean	22.3	181.6	73.7	9.3	47.6	37.1	37.6*	30.0	30.4
SD	3.1	6.2	10.3	3.6	9.7	0.3	0.2	0.8	0.9

After grouping sites from each main segment (front torso, back torso, arm), no significant difference in mean cold sensation was found between the front torso and the back torso ($p > 0.05$), whereas the front torso showed a colder mean thermal sensation than the arm ($p < 0.05$). A trend was also found for the back to show a colder mean thermal sensation than the arm, although this did not reach significance ($p = 0.09$). When analysing all sites for the effects of time (transient/steady-state), exercise and site, the repeated measures ANOVA indicated a significant main effect of time, $F(1,13) = 65.76$; $p < 0.001$, with transient thermal sensation being 1.5 units greater (colder) compared to steady-state sensations (mean across all body sites). Furthermore, a clear pattern of distribution was observed across the body.

The coldest scores were consistently observed on the lateral abdomen and lateral mid back. In contrast, areas of particularly low thermal sensations included the medial lower abdomen and the forearm. The repeated measures ANOVA indicated a significant main effect of body site, $F(15,195) = 8.69$; $p < 0.001$, and the post hoc test revealed a total of 60 significant differences between sites ($p < 0.05$). This number was however reduced to 9 after Bonferroni correction for multiple comparisons. Since the present study mainly focused on intra-segmental comparisons, the significance levels are presented separately for sites on the front torso, arm and back (table 2).

Table 2 (A: Front torso; B: Arm and C: Back) Significance levels of the multiple comparisons. * $P < 0.05$; ** $P < 0.01$; * $P < 0.001$; † $P < 0.05$ after Bonferroni correction; § $0.1 > P \geq 0.05$ after Bonferroni correction**

A

	Medial chest	Lateral chest	Medial upper abdomen	Lateral upper abdomen	Medial lower abdomen
Lateral chest	-				
Medial upper abdomen	-	-			
Lateral upper abdomen	**	**	***†		
Medial lower abdomen	*	**	**	***†	
Lateral lower abdomen	**	*	**§	-	***†

B

	Anterior upper arm	Posterior upper arm	Anterior forearm
Posterior upper arm	-		
Anterior forearm	-	-	
Posterior forearm	**	**	-

C

	Lateral upper back	Medial upper back	Lateral mid back	Medial mid back	Lateral lower back
Medial upper back	-				
Lateral mid back	-	*			
Medial mid back	-	-	-		
Lateral lower back	-	-	-	-	
Medial lower back	-	-	*	-	-

For a better visual comparison, body maps of thermal sensations at rest and during exercise were developed (figure 2). These were based on the generally accepted assumption of left-right symmetry in thermal sensitivity (e.g.: Claus et al., 1987; Meh and Denišlić, 1994).

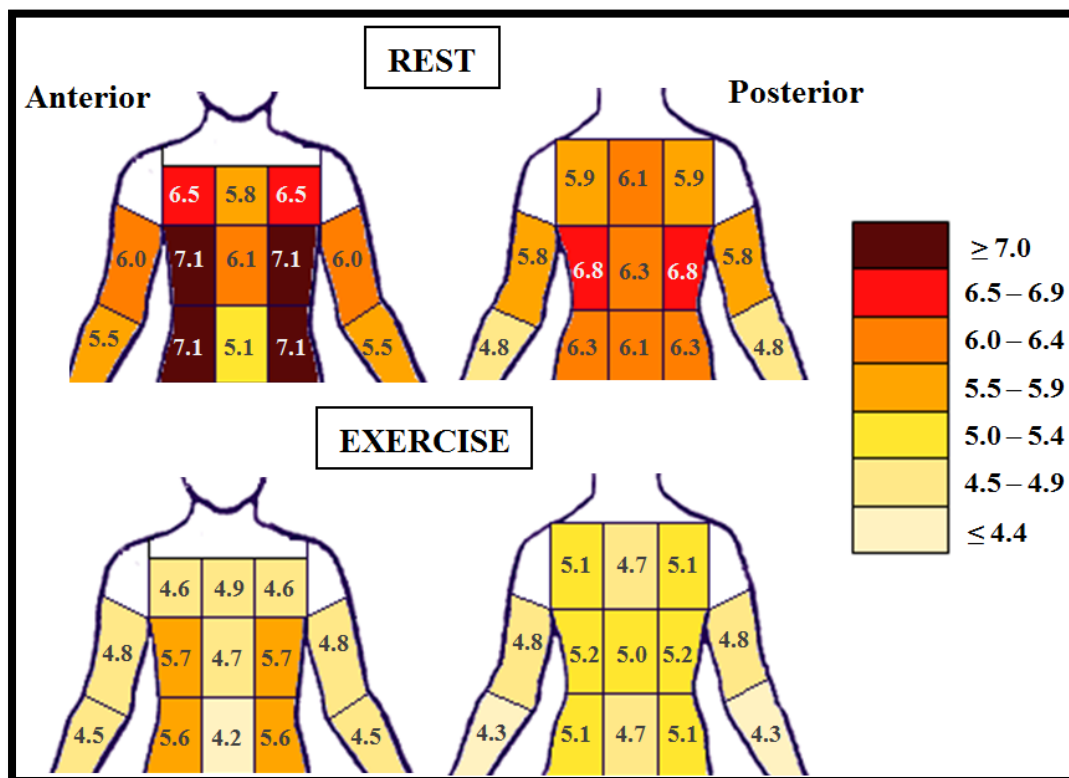


Figure 2 Body map of mean thermal sensations at rest and during exercise ($n = 14$). Values presented are means of transient and steady-state thermal sensations. Cold sensation scale ranged from 0 (not cold) to 10 (extremely cold).

3.2 Rest-exercise comparisons

The ANOVA indicated a significant main effect of exercise, $F(1,13) = 11.61$; $p < 0.01$, with thermal sensation being 1.2 units greater (colder) in the rest condition compared with exercise (mean across all body sites). Paired-samples *t*-tests revealed that thermal sensations were significantly colder at rest than during exercise in 12 of the 16 body sites ($p < 0.05$) with 2 more showing a trend ($p \leq 0.07$), however this difference remained significant only at 2 sites after Bonferroni corrections (table 3).

Table 3 Mean difference in thermal sensation between rest and exercise and significance values. * $P < 0.05$; ** $P < 0.01$; * $P < 0.001$; † $P < 0.05$ after Bonferroni correction**

Body site	Mean difference (rest – exercise)	<i>t</i>	<i>P</i> –value
Medial chest	0.9	2.1	0.054
Lateral chest	1.9	4.9	< 0.0005***†
Medial upper abdomen	1.4	3.2	0.007**
Lateral upper abdomen	1.4	2.8	0.016*
Medial lower abdomen	0.9	2.0	0.070
Lateral lower abdomen	1.5	2.5	0.025*
Anterior upper arm	1.2	2.8	0.015*
Anterior forearm	1.0	2.6	0.021*
Posterior upper arm	1.0	2.7	0.018*
Posterior forearm	0.5	1.4	0.197
Lateral upper back	0.8	1.7	0.122
Medial upper back	1.4	2.8	0.015*
Lateral mid back	1.6	3.8	0.002***†
Medial mid back	1.3	2.5	0.027*
Lateral lower back	1.2	2.6	0.020*
Medial lower back	1.4	2.7	0.020*

4. Discussion

The present data provide the most detailed upper body map of thermal sensitivity to cold available to date, including multiple locations on each body segment. The study also explores differences in thermal sensitivity to cold between a resting and an exercising condition. Two main novel findings arose from the results. Firstly, variations exist in thermal sensitivity between and within body segments at rest. Secondly, the results showed that physical exercise reduced thermal sensitivity to cold. In the present study, a thermally sensitive body site was defined as one with a great cold sensation score in response to the 20°C thermal stimulus.

4.1 Mechanisms for the transient and steady-state thermal sensations

The significant decrease found between transient (immediate) and steady-state (after 10 sec) cold sensations reflects thermoreceptors' dynamic properties. Indeed, it has been demonstrated that cold fibres initially respond with an overshoot in impulse frequency when subjected to an abrupt change in temperature, which is followed by a rapid fading in their activity (Braun et al., 1980; Schäfer et al., 1988). Hensel et al. (1960) investigated the impulse frequency of individual cold fibres when cooling cat's skin, and found that the overshoot only lasted for around 1 second, after which it dropped and reached an almost steady state after around 2 seconds of stimulation. However, it has been suggested that the length of adaptation to a cold stimulus increases with the surface area of the stimulator (Jenkins, 1937). In the present study, the transient to steady-state time duration was chosen

after pilot experiments revealing that thermal sensation stabilised after 10 seconds of stimulation. It is likely that the duration needed for complete adaptation would be different with a stimulus of a different size or temperature.

4.2 Mechanisms for the regional differences in thermal sensitivity

The distribution of thermal sensitivity over the main segments is in agreement to some extent with Stevens (1979) who, comparing one site per body segment, found that sensitivity to cold was greatest at the trunk and lower at the limbs. Novel to the present paper is that regional variations in thermal sensitivity were observed between sites within the same body segment. This was especially true on the abdomen, where the lateral areas were significantly more sensitive than the medial sites. Less variation was found on the back, although the lateral mid back was significantly more sensitive than the medial upper and lower back sites. No significant differences were found between the anterior and posterior sites at the upper arm or forearm, but the posterior forearm was significantly less sensitive than the upper arm sites. Among the variables that have been suggested as causes of regional differences in thermal sensitivity, are the uneven distribution of cutaneous thermoreceptors and the existence of a weighing of thermoafferent information by the integration centre in the central nervous system (Burke and Mekjavić, 1991). Unfortunately, previous cold spot body mapping studies did not compare lateral and medial areas within the front torso or the back, and therefore little is known on the relative distribution of thermoreceptors on different areas of these body segments. It would be of great interest to investigate cold spots densities in those areas in future experiments. The results on the arms are in line with Choi and Seol (2001) who found a greater density of cold spots on the upper arm compared with the forearm.

Another factor which may explain the differences in thermal sensitivity between body sites is the rate of change in skin temperature (ΔT_{sk} rate). Indeed, it is well established that different areas of the body lose their heat content more readily than others. Nakamura et al. (2008) found that applying the same cold stimulus at different areas of the skin resulted in different levels of ΔT_{sk} , and suggested that these regional differences in heat loss are likely caused by differences in skin blood flow due to vasomotor status and tissue vascularity. Moreover, Li and colleagues (2005) found that the lateral chest and lateral abdomen are subjected to the greatest ΔT_{sk} rates when individually exposed to a 20°C ambient air temperature while the rest of the body is covered. Although the present stimulus is much more dominant in defining the T_{sk} drop than Li and colleagues' air exposure, ΔT_{sk} rates may explain some of the variations shown in figure 2.

Furthermore, hair density on the abdominal regions may also be a contributing factor in the regional differences found. Indeed, hair may act as an insulator for the skin and introduce thermal resistance between the stimulus and the skin. Interestingly, Setty (1967) showed that the most common varieties of abdominal hair patterns in Caucasian males consist of hairy central abdominal regions in comparison to lateral areas. This corresponds well with the distribution of thermal sensitivity found on the abdomen. Although participants in the present study were not particularly hairy, the possibility that variations in abdominal thermal sensitivity are linked to levels of hairiness cannot be excluded. Thus, further research is required to examine the effects of hairiness on regional thermal sensitivity.

4.3 Mechanisms for the effects of exercise on thermal sensitivity

The second aim of the current study was to investigate the effects of exercise on thermal sensitivity to cold. Despite the low intensity of exercise, thermal sensitivity decreased in all

of the 16 body sites tested, and this was significant in 12 of them with a trend ($p \leq 0.07$) in a further 2 sites. These results are in line with Kemppainen et al. (1985) who found an increase in the temperature change needed to evoke cool and warm sensations during exercise, compared to resting values. The present results also suggest that the distribution of changes in thermal sensitivity during exercise is not constant across the upper body, with some sites displaying almost no change while others showed large changes in sensation. This resulted in a more homogenous body map during exercise than at rest, especially at the arms and the back.

One logical explanation for the changes in sensitivity could be found in T_{sk} . Indeed, a decrease in T_{sk} in exercise would result in thermoreceptors being stimulated with a smaller ΔT_{sk} , which would decrease the impulse frequency and in turn reduce the intensity of a thermal sensation. This was confirmed in several studies looking at the effects of skin temperature on warm and cool thresholds (Hirosawa et al., 1984; Lele, 1954). This could only affect the transient cold sensation results in the present study. However, the low intensity of exercise selected in the present study resulted in no significant change in mean T_{sk} during exercise ($p > 0.05$). This suggests that T_{sk} is unlikely to be the mechanism behind the reduction in thermal sensitivity. Furthermore, although the present results suggests that a causal relationship may exist between the increase in T_c and the decrease in thermal sensitivity, previous results suggest that this may not be the case. In particular, Mower (1976) found that fluctuations in T_c achieved passively in a bath have an effect on the pleasantness of a thermal stimulus, but not on its intensity. This suggests that the decrease in cold sensation intensity found in the present study is likely to be the result of another physiological change occurring during exercise.

A body of literature has suggested that neural and hormonal mechanisms occurring during exercise are likely to influence the response to both noxious and innocuous stimuli; refer to

Koltyn (2000) for a complete review. Evidence suggests that movement itself can lead to the reduction in transmission of the sensory information to the thalamus and somatosensory cortex. In the awake cat, evoked potentials recorded in response to radial nerve stimulation are reduced during movement of the limb (Coulter, 1974; Ghez, 1972). Psychophysical experiments have also shown that the threshold for detecting cutaneous stimuli rises during active movement of the stimulated area (Coquery et al., 1971; Dyhre-Poulsen, 1978; Garland and Angel, 1974). The mechanism behind this is thought to be the attenuation or interruption of sensory information flow, because an action being performed such as movement renders it irrelevant or misleading (Rushton et al., 1981). This selection of information by the central nervous system results in the disregard of some of the afferent information gathered by the sense organs during active movement.

Regarding the hormonal mechanisms, it has been proposed that exercise-induced stress hormones might play a key role in the reduction of somatic sensitivity by dynamic exercise (Janal et al., 1984; Kemppainen et al., 1985; Pertovaara et al., 1984). The time course of the effects of dynamic exercise on thermal thresholds has been found to be similar to that of endocrine response with a long-lasting after effect (Kemppainen et al., 1985). The activation of the stress analgesia system (Lewis et al., 1984) was therefore deemed to be a possible mechanism to explain the modulation of somatosensory sensitivity. Additionally, it has been demonstrated by Kozyreva (2006) that the acute effects of noradrenaline iontophoresis include a reduction in the number of cold and warm spots on the skin without any change in skin temperature. It is commonly known that exercise induces the release of stress hormones including noradrenaline (e.g.: Floras et al., 1986) and it is therefore credible that the reduction in thermal sensitivity found in the present study reflects the exercise-induced increase in stress hormones levels.

Finally, psychological factors may also play a role in the decreased thermal sensitivity to cold. It has been shown that high levels of arousal may decrease the response of thalamic neurons to the stimulation of skin in the monkey (Casey et al., 1993). Moreover, Bushnell et al. (1985) found that attention influenced noxious and innocuous heat detection in humans and monkeys. Despite the low intensity of exercise used, arousal and attention may have also contributed to the decrease in thermal sensitivity to cold found in the current study.

4.4 Conclusions

The present results extend our knowledge in thermal sensitivity to cold, with the observation of significant *intra-segmental* differences. These results are applicable in several contexts such as the design of car climate control systems and clothing, in an effort to avoid skin temperature reductions in areas of the body which are particularly sensitive to cold. Furthermore, the results also suggest that thermal sensitivity to cold is lower and more uniform during exercise than at rest. Several contributing factors to the decrease in sensitivity were discussed, including neural, hormonal and psychological factors.

Acknowledgements

We would like to thank Professor Mike Tipton for kindly lending his thermal sensitivity equipment for this study. The technical support of Dr Simon Hodder is also greatly appreciated.

References

- Astrand, P. O., & Ryhming, I., 1954. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. *Journal of Applied Physiology*, 7(2), 218.
- Attia, M., & Engel, P., 1982. Thermal pleasantness sensation: An indicator of thermal stress. *European Journal of Applied Physiology and Occupational Physiology*, 50(1), 55-70.
- Bender, R., & Lange, S., 1999. Multiple test procedures other than Bonferroni's deserve wider use. *BMJ: British Medical Journal*, 318(7183), 600.
- Braun, H. A., Bade, H., & Hensel, H., 1980. Static and dynamic discharge patterns of bursting cold fibers related to hypothetical receptor mechanisms. *Pflügers Archiv European Journal of Physiology*, 386(1), 1-9.
- Burke, W. E., & Mekjavić, I. B., 1991. Estimation of regional cutaneous cold sensitivity by analysis of the gasping response. *Journal of Applied Physiology*, 71(5), 1933.
- Bushnell, M. C., Duncan, G. H., Dubner, R., Jones, R. L., & Maixner, W., 1985. Attentional influences on noxious and innocuous cutaneous heat detection in humans and monkeys. *Journal of Neuroscience*, 5(5), 1103.
- Cabanac, M., 1969. Plaisir ou déplaisir de la sensation thermique et homeothermie. *Physiology & Behavior*, 4(3), 359-364.
- Casey, K. L., & Morrow, T. J., 1984. Arousal-related changes in the response of VP thalamic neurons to somatic and spinothalamic stimulation in the awake monkey. *Pain*, 18, S313.

- Casey, K. L., Zumberg, M., Heslep, H., & Morrow, T. J., 1993. Afferent modulation of warmth sensation and heat pain in the human hand. *Somatosensory & Motor Research*, 10(3), 327-337.
- Choi, J., & Seol, H., 2001. Distributions of skin thermoreceptors and clothing weights of Korean urbanites and farmers. *Journal of Physiological Anthropology and Applied Human Science*, 20(6), 375-377.
- Clark, R., Mullan, B., & Pugh, L., 1977. Skin temperature during running--a study using infra-red colour thermography. *The Journal of Physiology*, 267(1), 53.
- Claus, D., Hilz, M. J., Hummer, I., & Neundörfer, B., 1987. Methods of measurement of thermal thresholds. *Acta Neurol Scand*, 76(4), 288-296.
- Coquery, J. M., Malcuit, G., & Coulmance, M., 1971. Altérations de la perception d'un stimulus somesthésique durant un mouvement volontaire. *CR Soc Biol (Paris)*, 165, 1946-1951.
- Coulter, J., 1974. Sensory transmission through lemniscal pathway during voluntary movement in the cat. *Journal of Neurophysiology*, 37(5), 831.
- Dyhre-Poulsen, P., 1978. Perception of tactile stimuli before ballistic and during tracking movements. *Active Touch*. Pergamon Press, Oxford, , 171-176.
- Floras, J., Vann Jones, J., Hassan, M. O., Osikowska, B. A., Sever, P. S., & Sleight, P., 1986. Failure of plasma norepinephrine to consistently reflect sympathetic activity in humans. *Hypertension*, 8(8), 641-649.

Franklin, B. A., Whaley, M. H., Howley, E. T., & Balady, G. J., 2000. ACSM's guidelines for exercise testing and prescription: Testing and prescription Lippincott Williams and Wilkins.

Garland, H. T., & Angel, R. W., 1974. Modulation of tactile sensitivity during movement. *Neurology*, 24, 361.

Ghez, C., & Pisa, M., 1972. Inhibition of afferent transmission in cuneate nucleus during voluntary movement in the cat. *Brain Res*, 40(1), 145-155.

Havenith, G., Fogarty, A., Bartlett, R., Smith, C. J., & Ventenat, V., 2008. Male and female upper body sweat distribution during running measured with technical absorbents. *European Journal of Applied Physiology*, 104(2), 245-255.

Hensel, H., Iggo, A., & Witt, I., 1960. A quantitative study of sensitive cutaneous thermoreceptors with C afferent fibres. *The Journal of Physiology*, 153(1), 113.

Hirosawa, T. I., Dodo, H., Hosokawa, M., Watanabe, S., Nishiyama, K., & Fukuchi, Y., 1984. Physiological variations of warm and cool sense with shift of environmental temperature. *International Journal of Neuroscience*, 24(3), 281-288.

Jackson, A. S., & Pollock, M. L., 1978. Generalized equations for predicting body density of men. *British Journal of Nutrition*, 40(03), 497-504.

Janal, M. N., Colt, E. W. D., Clark, W. C., & Glusman, M., 1984. Pain sensitivity, mood and plasma endocrine levels in man following long-distance running: Effects of naloxone. *Pain*, 19(1), 13-25.

Jenkins, W. L., 1937. Studies in thermal sensitivity: I. adaptation with a series of small circular stimulators. *Journal of Experimental Psychology*, 21(6), 670-677.

Kemppainen, P., Pertovaara, A., Huopaniemi, T., Johansson, G., & Karonen, S. L., 1985. Modification of dental pain and cutaneous thermal sensitivity by physical exercise in man. *Brain Research*, 360(1-2), 33-40.

Koltyn, K. F., 2000. Analgesia following exercise: A review. *Sports Medicine*, 29(2), 85-98.

Kozyreva, T. V., 2006. Adaptive changes in temperature sensitivity in humans under the conditions of cold, heat, and prolonged exercise. *Human Physiology*, 32(6), 721-725.

Lee, J. Y., Saat, M., Chou, C., Hashiguchi, N., Wijayanto, T., Wakabayashi, H., et al., 2010. Cutaneous warm and cool sensation thresholds and the inter-threshold zone in Malaysian and Japanese males. *Journal of Thermal Biology*, 35(2), 70-76.

Lele, P. P., 1954. Relationship between cutaneous thermal thresholds, skin temperature and cross-sectional area of the stimulus. *The Journal of Physiology*, 126(2), 191.

Lewis, J. W., Terman, W., Shavit, Y., Nelson, L. R., & Liebeskind, J. C., 1984. Neural, neurochemical and hormonal bases of stress-induced analgesia. *Advances in Pain Research and Therapy*, 6, 277-288.

Li, J., Wang, Y., Zhang, W., & Barker, R. L., 2005. Cold sensitivity differences between body sections under clothing. *Textile Research Journal*, 75(3), 208-212.

Meh, D., & Denišlić, M., 1994. Quantitative assessment of thermal and pain sensitivity. *Journal of the Neurological Sciences*, 127(2), 164-169.

Mower, G. D., 1976. Perceived intensity of peripheral thermal stimuli is independent of internal body temperature. *Journal of Comparative and Physiological Psychology*, 90(12), 1152-1155.

Nakamura, M., Yoda, T., Crawshaw, L. I., Yasuhara, S., Saito, Y., Kasuga, M., et al., 2008. Regional differences in temperature sensation and thermal comfort in humans. *Journal of Applied Physiology*, 105(6), 1897.

Perneger, T. V., 1998. What's wrong with bonferroni adjustments. *Bmj*, 316(7139), 1236.

Pertovaara, A., Huopaniemi, T., Virtanen, A., & Johansson, G., 1984. The influence of exercise on dental pain thresholds and the release of stress hormones. *Physiology & Behavior*, 33(6), 923-926.

Ramanathan, N. L., 1964. A new weighting system for mean surface temperature of the human body. *Journal of Applied Physiology*, 19(3), 531.

Rushton, D. N., Roghwell, J. C., & Craggs, M. D., 1981. Gating of somatosensory evoked potentials during different kinds of movement in man. *Brain*, 104(3), 465.

Schäfer, K., Braun, H. A., & Kürten, L., 1988. Analysis of cold and warm receptor activity in vampire bats and mice. *Pflügers Archiv European Journal of Physiology*, 412(1), 188-194.

Setty, L. R., 1967. Varieties of the quadrangular abdominal hair pattern of white males. *Journal of the National Medical Association*, 59(1), 45.

Smith, C. J., & Havenith, G., 2011. Body mapping of sweating patterns in male athletes in mild exercise-induced hyperthermia. *European Journal of Applied Physiology*, , 1-14.

Stevens, J. C., 1979. Variation of cold sensitivity over the body surface. *Sensory Processes*, 3(4), 317-326.

Strughold, H., & Porz, R., 1931. Die dichte der kaltpunkte auf der haut des menschlichen korpers. *Z Biol*, 91, 563-571.