Physiology & Behavior 152 (2015) 11–19

Contents lists available at ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/phb

Female thermal sensitivity to hot and cold during rest and exercise

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HIGHLIGHTS

- Females are more sensitive to innocuous cold compared to innocuous heat stimulation.
- Regional differences to cold stimulation occur across the body in females.
- Regional differences are more homogenous to hot stimulation in females.
- Exercise reduces thermal magnitude sensation in both hot and cold stimuli.

ARTICLE INFO

Article history:
Received 22 June 2015
Received in revised form 18 August 2015
Accepted 25 August 2015
Available online 5 September 2015

Keywords:
Females
Body mapping
Exercise
Regional
Thermal sensitivity

ABSTRACT

Regional differences in thermal sensation to a hot or cold stimulus are often limited to male participants, in a rested state and cover minimal locations. Therefore, magnitude sensation to both a hot and cold stimulus were investigated during rest and exercise in 8 females (age: 20.4 ± 1.4 years, mass: 61.7 ± 4.0 kg, height: 166.9 ± 5.4 cm, VO_{2max}: 36.8 ± 4.5 ml·kg^{-1}·min^{-1}). Using a repeated measures cross over design, participants rested in a stable environment (22.3 ± 0.9 °C, 37.7 ± 5.5% RH) whilst a thermal probe (25 cm^2), set at either 40 °C or 20 °C, was applied in a balanced order to 29 locations across the body. Participants reported their thermal sensation after 10 s of application. Following this, participants cycled at 50% VO_{2max} for 20 min and then 30% VO_{2max} whilst the sensitivity test was repeated. Females experienced significantly stronger magnitude sensations to the cold than the hot stimulus (5.5 ± 1.7 and 4.3 ± 1.3, $p < 0.05$, respectively). A significant effect of location was found during the cold stimulation ($p < 0.05$). Thermal sensation was greatest at the head then the torso and declined towards the extremities. No significant effect of location was found in response to the hot stimulation and the pattern across the body was more homogenous. In comparison to rest, exercise caused a significant overall reduction in thermal sensation (5.2 ± 1.5 and 4.6 ± 1.7, respectively, $p < 0.05$). Body maps were produced for both stimuli during rest and exercise, which highlight sensitive areas across the body.

1. Introduction

Central and peripheral thermoreceptors are distributed all over the body and are responsible for both sensory and thermoregulatory responses to maintain thermal equilibrium. Behavioural thermoregulation is the first line of defence against thermal disturbances and this is primarily controlled by peripheral thermoreceptors which provide immediate feedback about the thermal state of the body and initiate a set of desired actions to correct the thermal imbalance [1]. Both Burke and Mekjavić [2] and Nakamura et al. [3] speculated that the central nervous system assigns weighing factors for each body segment and that this is what determines the regional differences in sensitivity rather than receptor density. Regional differences in thermal sensitivity have previously been measured on a limited number of small locations across the body (<5) which then have been interpreted as fully representing that particular area (e.g. legs, arms, front/back torso and face). However, intra-segment variations to a cold or hot stimulus have recently been identified [4,5]. More research is required to fully understand thermal sensitivity across wider areas of the body.

Despite there being a large body of literature exploring thermal sensitivity much of the research is limited to male participants, despite the fact that females have been shown to be more sensitive to a variety of stimuli [6,7,8]. One recent study compared sex difference in response to a hot stimulus (40 °C) across 31 locations on the body and found that

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http://dx.doi.org/10.1016/j.physbeh.2015.08.032

overall females were significantly more sensitive to heat than males [4]. Regional differences in perceptual responses were more prominent in females and thermal hot sensation was greatest at the head, than the torso and declined towards the extremities. Using a similar technique, Ouzzahra et al. [5] assessed regional distribution of sensitivity on the torso to a cold thermal stimulus (20 °C) in male participants. Comparing the findings of these two studies indicates that male regional sensitivity across the torso is not the same when stimulated with cold or hot stimuli. There are more regional differences in response to a cold stimulus whereas the response is more homogenous to a hot stimulus. However in both studies the anterior torso was more sensitive than the posterior torso. To the authors knowledge there is limited research comparing thermal sensitivity to a cold and hot stimulus in female participants across multiple (>5) locations on the body.

Exercise has been shown to alter ones sensory perceptions to a variety of different stimuli [9,10,11,12,13,14]. A large body of literature is available demonstrating the reduction in pain during or after exercise in males and females (see Koltyn [15] for a review). This also includes noxious thermal stimulation and the reduction is associated with exercise induced analgesia (EIA). EIA is associated with the activation of the endogenous opioid system during exercise in which various peptides are released that have a similar effect to that of morphine (i.e. they cause a reduction in pain sensitivity) [16]. Large amounts of research exist regarding EIA and noxious stimulation using magnitude estimation but only two studies have investigated innocuous thermal sensitivity with this technique [4,5].

Ouzzahra et al. [5] found that during exercise thermal sensitivity to a cold stimulus was attenuated in males compared to rest and suggested that the reduction was likely a result of exercise induced analgesia (EIA). Gerrett et al. [4] also found that sensitivity to a hot stimulus (40 °C) was reduced during exercise in both males and females. The response was more prominent in males despite only the females having a significantly elevated T_c temperature during exercise. This was the first study to confirm that exercise caused a reduction in innocuous heat sensitivity. It is believed that during exercise the release of corticotrophin concomitantly with β-endorphin reduces the pain perception thresholds [17,18]. Males have been reported to have significantly higher β-endorphin than females at rest and in response to endurance exercise [19]. This may explain why males had a significantly reduced thermal sensitivity compared to females during exercise. However, whether female sensitivity reduces during exercise to a cold innocuous stimulus has not yet been investigated. It would be of interest to determine whether females experience the same decline in sensitivity to a cold stimulus as to that experienced to a hot stimulus.

The aim of the study is to investigate the regional differences in thermal sensitivity to a hot and cold stimulus in female participants during rest and exercise. It is hypothesised that, similar to males, significant regional variations will exist between hot and cold perceptions in females. It is further hypothesised that exercise will cause a significant reduction in thermal sensitivity to both innocuous cold and hot stimuli.

2. Methods

2.1. Participants

Eight Caucasian females (age: 20.4 ± 1.4 years, mass: 61.7 ± 4.0 kg, height: 166.9 ± 5.4 cm, VO_{2max}: 36.8 ± 4.5 ml·kg^{-1}·min^{-1}) were recruited from the staff and student population of Loughborough University. The selection criteria included only Caucasian females, aged between 18 and 45 years to reduce any systemic errors due to ethnic or age-related differences in thermoregulatory responses. Six of the eight participants were taking oral contraceptives. Menstrual cycle phase was not controlled for during the experimental session. However the stage of menstrual cycle in each participant was noted and a range of stages was tested during the experiment, thus providing a representative sample of menses state in the results.

2.2. Experimental design

The aim of the investigation was to compare regional sensitivity to a hot and a cold stimulus in females during rest and exercise. To achieve these aims a randomised cross over design was opted for, with all participants taking part in both conditions (hot and cold sensitivity) separated by at least 2 days. During both conditions, participants rested and exercised on a cycle ergometer whilst regional thermal sensitivities to a thermal probe were investigated. A total of 29 regional body segments were chosen to ensure that each area of the body was fully investigated (see Gerrett et al. [4]). These included the front and back torso, the arms and legs (upper, lower, front and back), head, face and neck and the extremities. The testing sequence of the segments was randomised to prevent any order effects. However, the order of rest and exercise in the tests was not randomised as rest had to precede exercise due to the elevation of T_c caused by the latter. This increase could have a lasting effect in any following rest exposures. To counteract any order effect, participants were thoroughly familiarised with the procedure before the start of the actual test.

2.3. Experimental protocol

Each participant completed a pre-test session for anthropometric measurements; stature and body mass. They then completed a submaximal fitness test based on the Åstrand Rhyming methods [20]. The test consisted of four progressive exercise stages on an electromagnetically braked cycle ergometer (Lode Excalibur, Groningen, Netherlands) each lasting 5 min. Heart rate (Polar Electro Oy, Kemple, Finland) was recorded during the last minute of each stage. Estimation of $VO_{2\,max}$ was then calculated from the ACSM metabolic equation for cycling [20].

During the test, participants were familiarised with the thermal probe and sensation scales across a number of locations. Participants were then invited back to the laboratory on two different occasions to conduct the main trial with at least 2 days separating trials. For the main trial, pre- and post-test nude weight was recorded. Participants self-inserted a rectal probe 10 cm beyond the anal sphincter. Four skin thermistors (Grant Instrument Ltd, Cambridge, UK) were attached at the chest, upper arm, thigh and calf using 3M™ Transpore™ surgical tape (3M United Kingdom PLC). Mean skin temperature ($\overline{T}_{sk}$) was estimated using the following calculations as proposed by Ramanathan [21]:

$$\overline{T}_{sk} = (0.3 * \text{Tricep}) + (0.3 * \text{Chest}) + (0.2 * \text{Quadriceps}) + (0.2 * \text{Calf}).$$

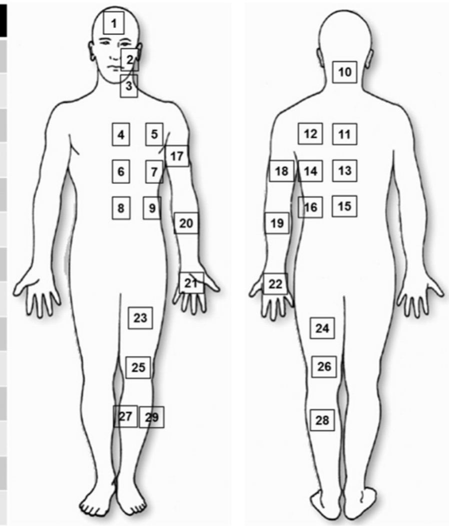
Body temperature (T_b) was estimated using the following calculation of T_c and $\overline{T}_{sk}$ in an 8:2 ratio [22]:

$$T_b = 0.8 * T_c + 0.2 * \overline{T}_{sk}.$$

Markings were made on the body using a washable pen to indicate each measurement site for the application of the thermal probe. The locations of each stimulus application, all taken on the left hand side of the body, are shown in Fig. 1. Dressed in shorts, sports bra, socks and trainers, participants sat in a controlled environment (22.3 ± 0.9 °C, 37.7 ± 5.5% RH) for 15 min to allow physiological responses to stabilise. During the stabilisation period participants were once again familiarised with the sensation scales and allowed to practise rating their sensations to a range of hot and cold stimuli across different regions on the body.

After the stabilisation period, whilst still at rest, thermal sensitivity of each body site along the left hand side of the body to the thermal stimulus was investigated in a balanced order. Each stimulus site was subjected to the following: the measurement of T_{sk} using an infrared thermometer (FLUKE 566 IR THERMOMETER, Fluke Corporation, Eindhoven, Netherlands), immediately followed by probe application for 10 s. The temperature controlled thermal probe was similar to that

Location #	
1	Forehead
2	Cheek
3	Anterior Neck
4	Medial Chest
5	Lateral Chest
6	Medial torso
7	Lateral torso
8	Medial Abdomen
9	Lateral abdomen
10	Posterior neck
11	Upper medial back
12	Scapula
13	Middle medial back
14	Middle lateral back



Location #	
15	Lower medial back
16	Lower lateral back
17	Biceps
18	Triceps
19	Anterior forearm
20	Posterior forearm
21	Hand
22	Palm
23	Quadriceps
24	Hamstrings
25	Anterior knee
26	Posterior knee
27	Medial calf
28	Posterior calf
29	Lateral calf

Fig. 1. Number, name and location of the 29 body sites investigated for thermal sensitivity.

described by Fowler et al. [23] and that used by Gerrett et al. [4] and Ouzzahra et al. [5]. The thermal probe (NTE-2, Physitemp Instruments, Inc., USA) consisted of a 25 cm^2 metal surface that was controlled at either 40 °C (heat sensitivity) or 20 °C (cold sensitivity). These temperatures were selected based on two factors; to not stimulate noxious thermal sensations and to be roughly equal in distance from mean skin temperature. Previous literature suggests that noxious heat and cold occurs at approximately 45 and 15 °C, respectively [6,24,25,26,27,28]. And previous studies in our lab suggested that a mean T_{sk} of 30 °C could be achieved in a semi-nude condition in approximately 20 °C, 40% RH. Therefore stimulus temperatures of 20 and 40 °C would be 5 °C away from a painful stimulus and approximately 10 °C away from mean T_{sk}. A series of pilot tests were conducted across a number of locations on the body to ensure that a noxious thermal sensation was not reported.

The probe was applied to the skin by the same investigator to ensure consistent pressure was applied to each location and individual. The pen markings served as reference points for each location. From pilot testing, the stimulus site temperature was found to be similar to probe temperature after the 10 second application and thus the sensation reported indicated a steady state magnitude sensation. The thermal sensation scale was similar to that used by Gerrett et al. [4] and Ouzzahra et al. [5] with 0 indicating 'no hot/cold sensation' and 10 indicating 'extremely hot/cold' with intermediary values (see Table 1). This scale was an adapted version of a scale for noxious heat stimulation [29]. For magnitude sensation, given that the stimulus was the same in all applications, the higher the number reported the higher the thermal sensitivity.

Following the rest period, participants began cycling for 20 min at 50% of the pre-determined VO_{2max} value; after which the exercise intensity was lowered to 30% VO_{2max} to ensure participants could maintain a high level of concentration on the thermal ratings whilst still exercising and to maintain an elevated but stable physiological state. The test was then repeated in the same order as the rest condition. To reduce any order effects, the order of application between tests (i.e. hot and cold) was randomised for each participant. Any sweat produced due to exercise was briefly wiped away before the probe was applied. During lower limb assessments, participants ceased exercise momentarily whilst the probe was applied and continued pedalling thereafter.

Table 1
Thermal sensation scale used by participants to report thermal sensation to a hot or cold stimulus.

	Thermal sensation
>10	Painfully hot/cold
10	Extremely hot/cold sensation
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	No hot/cold sensation

2.4. Data analysis

Statistical analysis was conducted using Statistical Package (SPSS) version 22.0. Differences in thermal sensation during rest and exercise across different body regions were analysed using a three-way repeated measures ANOVA. The independent variables included; condition (hot and cold), activity (rest and exercise) and location ($n = 29$) with post hoc comparisons. The large number of locations increases the risk of inflating type I errors when doing multiple post hoc zone comparisons therefore Bonferroni corrections were applied to adjust for this. However this also risked inflating type II errors therefore data corrected and uncorrected for multiple comparisons are presented [30] to allow the reader to judge these issues. Unless otherwise stated, all measurements are expressed as means with standard deviations (±SD) and significance is defined as $p < 0.05$.

3. Results

Mean T_c, T_b and $\overline{T}_{sk}$ and mean local T_{sk} of each condition are presented in Table 2. Mean T_c, T_b and $\overline{T}_{sk}$ was not significantly different between

Table 2
Mean T_c, T_b, $\overline{T}_{sk}$ and mean local T_{sk} (±SD) at rest and during exercise for during both conditions in females ($n = 8$). There were no significant difference ($p > 0.05$) between condition (hot and cold) or activity (rest and exercise). † mean local skin temperature data across 29 locations.

	Cold		Hot	
	Rest	Exercise	Rest	Exercise
T_c (°C)	37.5 ± 0.2	37.6 ± 0.2	37.6 ± 0.2	37.7 ± 0.3
T_b (°C)	36.1 ± 0.2	36.3 ± 0.2	36.1 ± 0.2	36.3 ± 0.2
$\overline{T}_{sk}$ (°C)	30.3 ± 0.7	30.8 ± 0.8	30.1 ± 0.5	30.3 ± 0.9
Local T_{sk} (°C)†	30.9 ± 1.4	30.6 ± 1.6	31.1 ± 1.4	30.8 ± 1.6

conditions ($p > 0.05$). Mean T_c, T_b and $\overline{T}_{sk}$ was higher during exercise compared to rest but not significantly different ($p > 0.05$). The local T_{sk} data collected from each of the 29 locations prior to stimulation was averaged and the results were not significantly different between conditions or activity type ($p > 0.05$).

3.1. Regional sensitivity to hot and cold stimuli

Female sensitivity to a hot and cold stimulus during rest and exercise are illustrated in Figs. 2 and 3, respectively. A significant overall effect of condition (hot versus cold) was observed, as females reported a significantly higher magnitude sensation for the cold stimulus in comparison to the hot stimulus (5.5 ± 1.7 and 4.3 ± 1.3, $p < 0.05$, respectively). A significant overall effect of activity was also found as thermal sensation was higher during rest than exercise (5.2 ± 1.5 and 4.6 ± 1.7, respectively, $p < 0.05$). No significant overall effect of location was found ($p > 0.05$). However, when the overall effect of location was analysed for cold and hot stimuli separately, the results indicated no significant overall effect of location for the hot stimulus but a significant overall effect for the cold stimulus (inclusive of rest and exercise). Pairwise comparisons with Bonferroni corrections revealed no significant differences ($p > 0.05$), however without corrections for multiple comparisons significant differences were observed and these are listed in Table 3.

During the cold stimulus, the head region was very sensitive and the cheek was significantly more sensitive than many locations across the body ($p < 0.05$). During rest, the anterior torso was generally more sensitive than the posterior torso but this pattern reversed during exercise. The lateral lower back was significantly less sensitive than most locations across the torso and head region. During both rest and

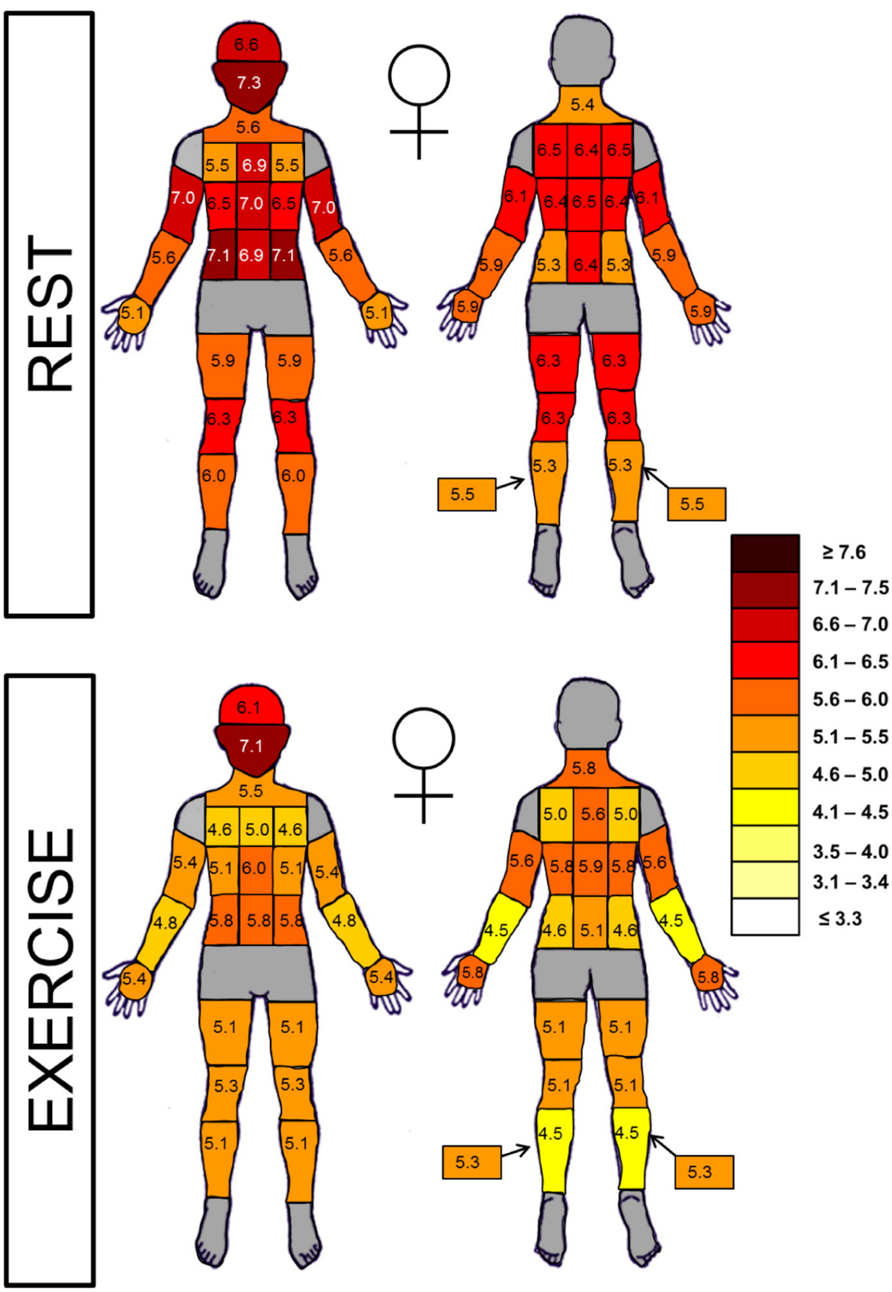


Fig. 2. Female ($n = 8$) regional magnitude sensation to a cold stimulus (20 °C) during rest and exercise. All measurements were taken from the left hand side of the body assuming symmetry [51,52]. Areas in grey were not investigated.

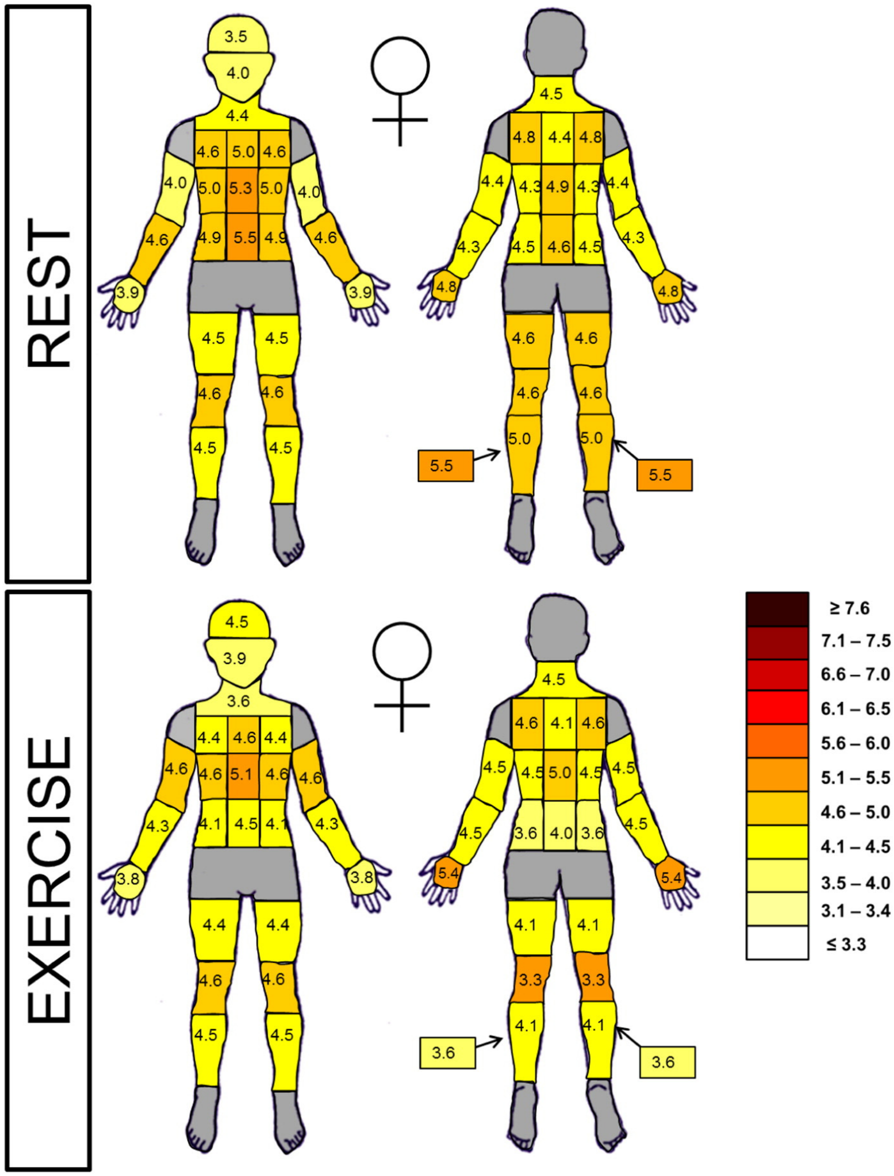


Fig. 3. Female (n = 8) regional magnitude sensation to a hot stimulus (40 °C) during rest and exercise. All measurements were taken from the left hand side of the body assuming [51,52]. Areas in grey were not investigated.

exercise, the upper arms were more sensitive than the lower arms. The anterior legs had no regional differences but the posterior legs were more sensitive proximally.

3.2. The influence of exercise on thermal sensitivity

A significant overall effect of activity was found as thermal sensation was higher during rest than exercise (5.2 ± 1.5 and 4.6 ± 1.7, respectively, $p < 0.05$). There was no significant interaction between location and activity ($p > 0.05$) but a significant interaction between location, condition and activity ($p < 0.05$) was observed. The differences between rest and exercise for each location during cold and hot stimulation and the significant differences are displayed in Table 4; the larger the number the bigger the difference between rest and exercise. Negative numbers in Table 4 indicate where sensitivity increased with exercise, though none of these are significant. Magnitude sensation to cold produced the largest differences between rest and exercise and thus more significant differences (12 of 29) than magnitude sensation to a hot stimulus (4 out of 29).

4. Discussion

The aim of the study was to investigate the differences in thermal sensitivity to a hot and a cold stimulus in female participants during rest and exercise. The study also aimed to provide a detailed description of regional sensitivity from multiple locations across the whole body. Three main findings can be drawn from this investigation; firstly, females demonstrated a stronger thermal sensation (i.e. more sensitive) to a cold stimulus (20 °C) than to a hot stimulus (40 °C). Secondly, regional variations in thermal sensation exist for both temperatures, but it appears more prominent in response to a cold stimulus than a hot stimulus. Thirdly, exercise caused a reduction in thermal sensation to both cold and hot thermal stimuli. These findings will be discussed in detail below.

4.1. Temperature differences

It is clear from the data presented that female sensitivity to innocuous cold stimulation is greater than that experienced during hot stimulation across numerous locations on the body (see Figs. 2 and 3, respectively).

Table 3
Significance of pairwise comparison between locations for female magnitude sensation to a cold stimulus (data is inclusive of rest and exercise).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
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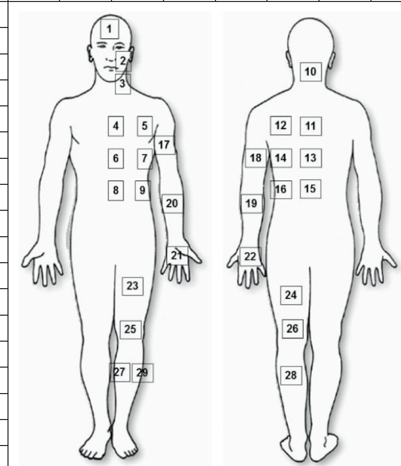

*p < 0.05 without Bonferroni correction.
**p < 0.001 without Bonferroni correction.

Table 4
The differences in magnitude sensation between rest and exercise for each location during cold or hot stimulation. No significant differences with Bonferroni correction.

Location	Δ magnitude sensation (rest–exercise)	
	Cold	Hot
Forehead	0.5 ± 0.7	−1.0 ± 0.5
Cheek	0.1 ± 0.4	0.1 ± 0.1
Anterior neck	0.1 ± 0.0	0.8 ± 0.5
Posterior neck	−0.4 ± 0.4	0.0 ± 0.1
Medial chest	0.9 ± 0.1	0.3 ± 0.3
Lateral chest	1.9 ± 0.4*	0.4 ± 0.3
Medial torso	1.4 ± 0.1*	0.4 ± 0.6
Lateral torso	1.0 ± 0.0*	0.1 ± 0.1
Medial abdomen	1.4 ± 0.7*	0.8 ± 0.2
Lat abdomen	1.1 ± 0.3*	1.0 ± 0.1*
Upper medial back	1.5 ± 0.2*	0.1 ± 0.2
Scapula	0.8 ± 0.9	0.3 ± 0.3
Middle medial back	0.6 ± 0.1*	−0.3 ± 0.3
Middle lateral back	0.6 ± 0.3	−0.1 ± 0.1
Lower medial back	0.6 ± 0.2	0.9 ± 0.8
Lower lateral back	1.3 ± 1.0	0.6 ± 0.0
Biceps	1.6 ± 0.3	−0.6 ± 0.1
Triceps	0.5 ± 0.1	−0.1 ± 0.3
Anterior forearm	1.4 ± 0.5*	−0.3 ± 0.0
Posterior forearm	1.3 ± 0.5	0.4 ± 0.4
Palm	−0.3 ± 0.4	0.1 ± 0.2
Back of hand	0.1 ± 0.1	−0.6 ± 0.2*
Quadriceps	0.8 ± 1.5	0.1 ± 0.6
Front knee	1.0 ± 0.4*	0.4 ± 0.4*
Lateral gastrocnemius	0.9 ± 0.4	0.0 ± 0.5
Hamstring	1.1 ± 0.3*	0.4 ± 0.4
Posterior knee	1.1 ± 0.4*	1.4 ± 0.0
Post. Gastrocnemius	0.8 ± 0.6*	0.9 ± 0.7
Medial gastrocnemius	0.2 ± 0.7	1.9 ± 0.2*
Mean	0.9 ± 0.6	0.3 ± 0.6

* p < 0.05 (without Bonferroni corrections).

Overall females reported a significantly higher magnitude sensation for the cold stimulus in comparison to the hot stimulus (5.5 ± 1.7 and 4.3 ± 1.3, $p < 0.05$, respectively). Whilst this is the first paper to determine such differences in females using magnitude estimation, similar findings have been reported in in both males and females using the method of limits/threshold detection [31,32]. Using this technique, Golja et al. [32] also reported that females were more sensitive than males to cold and warmth and the differences in sensitivity to warm and cold temperatures was more pronounced in females than males. Whilst no gender comparison can be made based on the present study, the data suggests that thermal sensitivity to cold is greater than warmth using magnitude estimation.

Factors that influence thermal sensitivity that may account for differences observed in this study reside in the stimulation of peripheral thermoreceptors. According to Bullock, Boyle and Wang [33], the thermal sensation experienced is dependent upon the direction and magnitude of the change in temperature. In the present study, mean T_{sk} during both conditions was 30.3 ± 0.6 °C and the average local T_{sk} of each site prior to stimulation was 30.8 ± 1.6 °C. As a result the difference in T_{sk} and the temperature of the thermal probe was similar between the two conditions (approximately 10 °C). In addition, the thermal probe was held in place for 10 s before a thermal sensation score was reported in order to achieve a steady state score. This effectively removed the influence of initial T_{sk}, which was found to be similar to probe temperature after the 10 second application in pilot tests. Therefore the differences in thermal sensitivity to a hot and cold stimulus cannot be associated with the magnitude of change in T_{sk}. A more likely explanation is one associated with properties of the receptors being stimulated. Hensel, Andres, and Düring [34] revealed that warm receptors tend to be located deeper in the epidermis than more superficial cold receptors, warm receptors are also outnumbered by cold receptors and their nerves conduct signals at much slower speeds [26]. In recent years the molecular characteristics of these sensory neurons have markedly advanced, of which the transient receptor potential (TRP) family has been identified as thermosensitive fibres [35]. Of the four proposed heat activated sensors and two cold activated sensors, the specific TRP stimulated in this study during hot stimulation was TRPV3 (activated at temperature > 33 °C) and TRPM8 (activated at temperatures <23 °C) [36,35]. Hensel [26] associated cold activated fibres with the thinly myelinated Aδ fibres whose conduction velocities are faster than heat activated fibres along unmyelinated C fibres. Recent research by Caterina & Julius [36] & Patapoutian et al. [35] has associated TRPM8 with both Aδ and C fibres found in animals [37,38] and to some extent in humans [39]. Much of the research associated with the TRP family is still in its infancy and more research is required to enhance our understanding of the TRP family and its relationship with temperature sensation.

As thermoreceptors serve to protect the body for thermal imbalance, the greater number of cold compared with warm thermoreceptors and their faster conducting velocities may suggest we are in more danger from cold exposure than heat. Hypothermia imposes physiological and behavioural responses that are metabolically costly (e.g. shivering, piloerection and movement) and it may be argued that the body is better adapted to heat than cold due to the large number of sweat glands to enhance evaporative heat loss during hyperthermia. As our peripheral thermoreceptors drive our thermoregulatory behaviours, if we are to protect the body against hypothermia or peripheral cold injuries, such as frost bite, then a heightened sensitivity to cold is advantageous. This may explain why females were more sensitive to cold stimulation than heat.

It should also be noted that the stimulation temperature selected may have also impacted the findings. The stimulation temperature were chosen so not to stimulate noxious thermal sensations by being approximately 5 °C away from average noxious thresholds [6,24,25,26,27,28] and 10 °C away from mean T_{sk}. Noxious thermal threshold to heat is consistently reported to occur at approximately 45 °C across numerous locations on the body [6,24]. Cold noxious thermal threshold however can vary across different locations and ranging from 12 to 23 °C [40]. The larger variation to noxious cold threshold may have resulted in some areas being closer to the noxious threshold compared to the hot stimulus and thus not representing and comparable stimulus. Future research in this area could determine individual's pain threshold for different locations and then stimulate each individual location relative to its sensitivity. This may provide more conclusive findings for regional differences to innocuous cold and warm sensitivity.

4.2. Regional differences

The visual presentation of body maps to observe regional differences has become popular in recent thermoregulatory research [41,42,43,5,4] as it allows an easy and clear understanding of regional differences. From Figs. 2 and 3 it is clear to conceptualise the regional thermal sensitivities to a hot but even more so to a cold stimulation. Although no significant overall effect of location was found ($p > 0.05$), when analysed individually the results indicated no significant overall effect of location for the hot stimulus but a significant overall effect for the cold stimulus. Comparing the findings of Ouzzahra et al. [5] and Gerrett et al. [4] on male sensitivity across the torso it is evident that males too do not experience similar regional sensitivity to a cold and to a hot stimulus. Similar to the present observation in females, males also show a more apparent topographical variation in response to a cold stimulus and a more homogenous to a hot one. Interestingly, the more regional differences observed to cold compared to warm innocuous thermal sensitivity in the present study seems comparable to regional noxious thermal sensitivity reported elsewhere [40,6,24]. Previously, in our paper on gender differences in responses to a hot stimulus a significant effect of location was found in females [4] which was absent in the present study. This may be due to the lower sample size of the present study inflating the risk of type II errors. Therefore interested readers may wish to refer to Gerrett et al. [4] for hot thermal sensitivity data based on stronger statistical power.

The current findings support the general consensus of regional sensitivity distribution [44,45,3] which suggests that sensitivity is greatest at the head, followed by the torso and declines towards the extremities. This tends to be the case regardless of methods used (e.g. method of limits [31]; stimulus modality [46] and temperatures explored [3]). The head region was very sensitive and the cheek was significantly more sensitive than many locations across the body ($p < 0.05$). The head has consistently been defined as a sensitive area due to the large number of thermoreceptors and the importance of keeping the brain within a thermo-prescriptive zone [47,45,44,48]. Early research in this area has associated regional differences in thermal sensitivity with thermoreceptor distribution [47]. Whilst the overall pattern observed in the present study supports this theory there are some exceptions to the rule. The hands are thought to be densely packed with various types of receptors, yet the palms of the hands were one of the least sensitive areas during rest to a cold and hot stimulus [49,47]. This was also observed by Gerrett et al. [4]. Perhaps the hands are more sensitive to changes in temperature and would be deemed sensitive using the method of limits/threshold detection. Both Burke and Mekjavić [2] and Nakamura et al. [3] speculated that the central nervous system assigns weighing factors for each body segment and that this is what determines the regional differences in sensitivity rather than receptor density. As the head and torso contain vital organs it is important to maintain thermal homeostasis within these regions, which may explain the regional differences observed.

The anterior torso was generally more sensitive than the posterior torso which has also been observed in males using the same technique and the same temperature (20 °C) [5]. In the present study, the lateral lower back was significantly less sensitive than most locations across the torso and head region, whilst the lateral lower abdomen was one of the most sensitive area on the body. The lateral abdomen areas have consistently been defined as highly sensitive areas in the present study and our previous studies [4,5]. Although this has been linked to enhanced thermal sensitivity there is a possibility that in these areas the sensation magnitude is affected differently by the mechanical component of the stimulus. As the lateral abdomen is often a 'ticklish' area for many individuals, indicating a higher mechanical sensitivity, the influence of mechanoreceptors may be higher there, possibly influencing the sensation. However, against this argument is the fact that sensation magnitude was not recorded until a steady state value was reached, 10 s after application, and keeping the probe still during stimulation.

4.3. Rest and exercise

Exercise induced analgesia (EIA) is a phenomenon whereby exercise causes a reduction in the transmission of sensory information along afferent fibres. The result is a reduction in sensitivity to a variety of stimuli. The majority of research associated with EIA has been associated with noxious stimulation, in particular to thermal noxious stimulation [14,13,12,11,50]. However recent research has demonstrated that EIA is not limited to noxious sensitivity but also affects innocuous thermal sensitivity [4,5]. This has been confirmed in males and females for innocuous heat sensitivity [4] and for innocuous cold sensitivity in males only [5]. In the present study, a significant effect of activity was found as thermal sensation was higher during rest than exercise (5.2 ± 1.5 and 4.6 ± 1.7, respectively, $p < 0.05$). As T_c was not significantly different between rest and exercise in either condition confirms that the thermal state of the body did not influence the thermal sensation reported and the reduction in thermal sensation could be a result of EIA. Although the exercise protocol was designed to elevate T_c and promote a steady state response, T_c was measured using rectal thermometer which may be subjected to time delays. As such, changes to the thermal state of the body may have occurred during exercise and thus influenced the results. Further research in this area may wish to adopt more sensitive measures of T_c, such as oesophageal temperature, which is not subjected to time delays as sometimes observed using rectal thermometer.

Table 4 shows the locations across the body that had significant changes in sensitivity from rest to exercise; the larger the number the bigger the difference between rest and exercise. Magnitude sensation to cold produced the largest differences between rest and exercise and thus more significant differences (12 of 29) than magnitude sensation to a hot stimulus (4 out of 29). The findings of the present study indicate that EIA occurs in females and appears more prominent in cold (mean ± SD at rest = 6.2 ± 1.8 and exercise = 5.3 ± 2.0) than hot (mean ± SD at rest = 4.6 ± 1.4 and exercise = 4.3 ± 1.5) innocuous sensitivity. Even with a larger sample size (n = 12) these differences between hot and cold are still evident as Gerrett et al. [4] reported hot thermal sensitivity during rest (4.9 ± 18) and exercise (4.6 ± 1.8). Gerrett et al. [4] found that areas which displayed no significant differences between rest and exercise generally have a low sensitivity in comparison to other sites, suggesting that EIA is site specific or a given level of response magnitude or sensitivity is required for EIA to have an effect. As cold thermal sensitivity was significantly greater than hot sensitivity (5.5 ± 1.7 and 4.3 ± 1.3, $p < 0.05$, respectively) and more areas were significantly different between rest and exercise during cold stimulation also supports this theory. In the cold the areas which were influenced by exercise were areas of the anterior torso which generally were the most sensitive areas on the body. Therefore it seems that the greater the response magnitude the stronger influence EIA has upon thermal innocuous sensitivity. The authors are unaware of whether this also occurs for noxious thermal sensitivity.

4.4. Application of research

The application of these findings is important for the design of clothing, in particular sports clothing and protective clothing. The data can enhance the evaluation of such clothing using thermal manikins, modelling of human thermophysiological responses, and climate control in cars or buildings in an attempt to avoid T_{sk} fluctuations in areas sensitive to cold and heat. Previous research has shown that data collected on males regarding thermal sensitivity cannot be directly applied to both genders and this paper now adds to the small body of literature on female thermal sensitivity.

5. Conclusions

The main finding of this study is that females are more sensitive (i.e. reported stronger thermal sensation) to innocuous cold (20 °C stimulus) compared to innocuous heat (40 °C stimulus) stimulation. In addition, females display more regional differences in thermal sensitivity to the cold, with the head being the most sensitive, followed by the torso and then the extremities. These finding are consistent with previous literature in the area on other groups. In addition, exercise causes a reduction in magnitude of the thermal sensation in both hot and cold stimuli.

Author notes

The present research was done in the context of an industry-cofunded PhD by Oxylane Research (Decathlon R&D Department) and the Loughborough Design School (Environmental Ergonomics Research Centre). Bernard Redortier and Thomas Voelcker, members of the sponsoring industry (Oxylane Research), contributed to the conception and design of the experiment and contributed to the paper write-up. Nicola Gerrett, Yacine Ouzzahra and George Havenith were fully responsible for the conduct of the trial and the data analysis. The authors declare that they have no conflict of interest.

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