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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.

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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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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