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Seeing the body produces limb-specific modulation of skin temperature

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Vision of the body, even when non-informative about stimulation, affects somatosensory processing. We investigated whether seeing the body also modulates autonomic control in the periphery by measuring skin temperature while manipulating vision. Using a mirror box, the skin temperature was measured from left hand dorsum while participants: (i) had the illusion of seeing their left hand, (ii) had the illusion of seeing an object at the same location or (iii) looked directly at their contralateral right hand. Skin temperature of the left hand increased when participants had the illusion of directly seeing that hand but not in the other two view conditions. In experiment 2, participants viewed directly their left or right hand, or the box while we recorded both hand dorsum temperatures. Temperature increased in the viewed hand but not the contralateral hand. These results show that seeing the body produces limb-specific modulation of thermal regulation.

1. Introduction

Vision of the body, even when entirely non-informative about stimulation, has widespread effects on somatosensation, enhancing tactile spatial acuity [1,2], reducing acute pain [3,4], increasing somatosensory intracortical inhibition [5] and reducing perceived tactile distance [6]. While such effects are diverse, they are consistent with effects limited to the central nervous system, for example by visual modulation of GABAergic inhibition in somatosensory cortex [3,5,7]. It is unknown how widespread the effects of seeing the body are and whether they might extend beyond somatosensory processes in the CNS.

We investigated whether seeing a limb modulates temperature regulation in that limb. In *experiment 1*, we used the mirror box illusion [8], asking participants to look into a mirror aligned with their body midline and view the reflected image of their right hand, which appeared to be a direct view of their left hand behind the mirror. We measured skin temperature from the left hand dorsum while participants: (i) had the illusion of directly seeing their left hand, (ii) had the illusion of seeing a non-body object at the same location or (iii) looked directly at their contralateral right hand. In *experiment 2*, we measured skin temperature from both hands while participants looked directly at either one.

2. Material and methods

(a) Participants

Sixty predominantly right-handed individuals participated, 30 in experiment 1, (23 female; age: M = 32 years, s.d. = 7), and 30 in experiment 2 (14 female; age: M = 32 years, s.d. = 13).

(b) Procedure

Both experiments used a non-contact infrared thermometer (Precision Gold N85FR, Maplin Electronics, South Yorkshire) and a box (13 × 7 × 7 cm). Both experiments involved three conditions, each repeated twice. The first three blocks included one

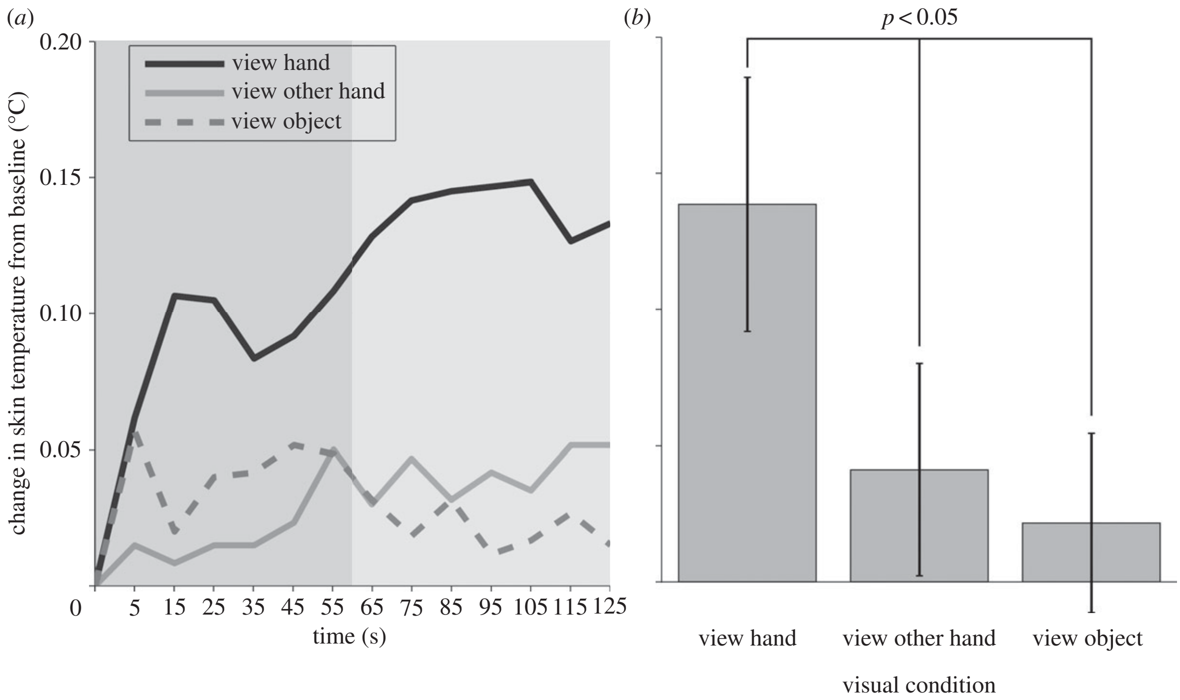

Figure 1. Changes in the left hand dorsum skin temperatures (experiment 1). (*a*) The time course of temperature change compared to the baseline measure taken at the start of each block. The analysis focused on test period (light grey). (*b*) Mean temperature increase in test period across experimental conditions. Error bars are 1 s.e.m.

Table 1. The illusion questionnaire responses. Items 1 and 2 used a Likert scale with +3 being 'strongly agree' and −3 being 'strongly disagree'. Item 3 used a 0–100 scale with 0 being 'strongly left hand' and 100 being 'strongly right hand'.

	questionnaire responses across the conditions (self-reported ratings)		
questionnaire item	view hand mean (s.e.m.)	view object mean (s.e.m.)	view other hand mean (s.e.m.)
It felt that I was directly looking at my hand rather than at mirrored image	1.64** (0.31)	−2.55** (0.20)	3 (0)
It felt like the hand I was looking at was my hand	2.23** (0.25)	—	2.93** (0.03)
Did it feel like the hand you were looking at was right or left hand?	24.40** (4.89)	—	100 (0)

**$p < 0.001$

of each condition, counterbalanced across participants according to a Latin square. The last three blocks were performed in the reverse order.

In *experiment 1*, participants sat at a table with their index fingers on Velcro discs 20 cm on either side of a mirror aligned along their midline and facing their right hand. Across conditions, participants saw: the mirror reflection of their right hand which appeared to be a direct view of their left hand (*view hand* condition), a non-hand object reflected at the same location (*view object* condition) or a direct view of their right hand (*view other hand* condition).

Following baseline temperature measurement, the mirror (or right hand) was uncovered for 2 min and temperature was recorded from the left hand dorsum every 10 s. Participants' subjective experience of the mirror illusion was assessed with a short questionnaire [3,6] after each block. Because it was unclear how long any effect might take to emerge, we classified the first minute as an induction period, analogous to the period of stimulation used to induce the rubber hand illusion [9,10], and excluded it from analyses. Our analyses accordingly focused on the second minute (test period).

In *experiment 2*, participants directly viewed their right hand, left hand or the object for 3 min while temperature was recorded from both hands in alternation. Participants placed their hands with palms down 60 cm apart on marked positions across the table. Two occluders (50 × 30 cm) blocked vision of the right and left hand. After a baseline temperature measurement, the appropriate occluder was removed to allow vision of the right or left hand, or the object was placed directly in front of the participant. Skin temperature was recorded every 10 s, alternating between the right and left hand. As in experiment 1, the first minute was treated as an induction period and excluded from analyses.

3. Results

(a) Experiment 1

The questionnaire data are shown in table 1 and suggest that the mirror box created a compelling illusion of seeing the left hand in the view hand condition.

The temperature data are shown in figure 1. Skin temperature of the left hand (compared with baseline) differed significantly across the three conditions, $F_{2,58} = 3.43$, $p = 0.04$, $\eta^2 = 0.11$. There was a clear increase from baseline in the view hand condition (0.139°C), $t_{29} = 2.97$, $p = 0.01$, $d_z = 0.54$, but not in the view object (0.022°C), $t_{29} = 0.66$, n.s., or view other

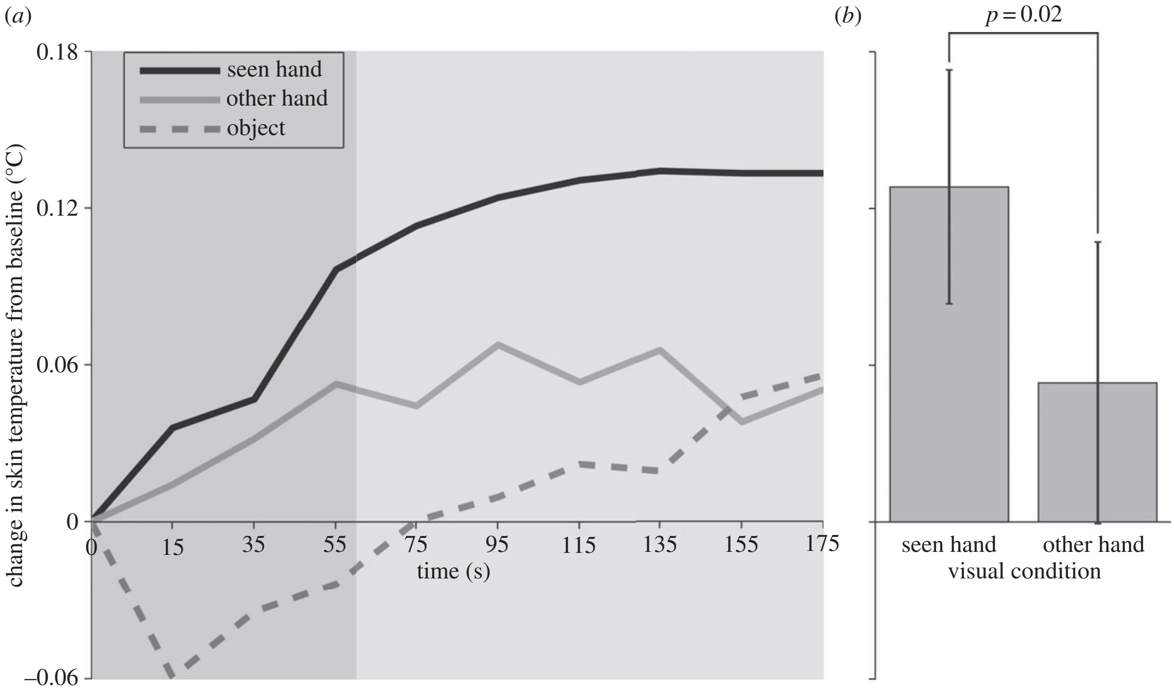

Figure 2. Changes in skin temperature of the right and left hand dorsum (experiment 2). (*a*) The time course of temperature change of the seen same hand, other hand and object conditions compared to the baseline. The analysis focused on test period (light grey). (*b*) Mean increase in temperature of measured hand in the seen hand and other hand conditions. Error bars are 1 s.e.m.

Table 2. Changes in hand dorsum skin temperature. Temperature was recorded from both hands in each experimental condition (experiment 2).

	mean change in skin temperature (°C)	
experimental condition	measured right hand mean (s.e.m.)	measured left hand mean (s.e.m.)
view of the right hand	0.17 (0.05)	0.05 (0.04)
view of the left hand	0.05 (0.08)	0.08 (0.05)
view of the non-hand object (box)	−0.01 (0.06)	0.06 (0.05)

hand (0.041°C), $t_{29} = 1.06$, n.s., conditions. The increase in the view hand condition was significantly larger than that in the view object, $t_{29} = 2.56$, $p = 0.02$, $d_z = 0.47$, and view other hand, $t_{29} = 2.05$, $p = 0.0495$, $d_z = 0.37$, conditions. We found no correlation between the temperature increase in view hand condition and self-rated experience of seeing the left hand in mirror (table 1, Question 1), $r_{30} = -0.06$, n.s.

The baseline temperature showed a slight *decrease* across successive blocks in a regression analysis (mean $\beta = -0.046$°C), though this did not reach significance, $t_{29} = 0.84$, n.s. Data from both experiments are provided in the electronic supplementary material.

(b) Experiment 2

Table 2 suggests that the left- and right-hand temperatures (relative to baseline) were higher when participants viewed that hand compared with looking in a direction of their other hand or box. This is supported by a significant interaction between the visual condition and location of temperature recordings, $F_{2,58} = 5.40$, $p = 0.01$, $\eta^2 = 0.16$ There was no main effect visual condition, $F_{2,58} = 1.10$, n.s., nor a difference in temperatures recorded from the right and left hand, $F_{2,58} = 0.14$, n.s.

To follow up this significant interaction, we ran a 2 × 2 ANOVA on the hand-view conditions including factors 'viewed hand' (right and left) and 'measured hand' (seen hand and other hand). Skin temperature was increased for the seen hand compared with the other hand (figure 2), $F_{2,58} = 6.34$, $p = 0.02$, $\eta^2 = 0.18$. Critically, there was no main effect of right versus left hand, $F_{2,58} = 1.85$, n.s., nor an interaction, $F_{2,58} = 0.62$, n.s., suggesting no laterality in the observed effect. The temperature increase was statistically significant in the seen hand condition, $t_{29} = 2.87$, $p = 0.01$, $d_z = 0.52$, but not when the other hand or box were viewed, $t_{29} = 0.99$, n.s. and $t_{29} = 0.53$, n.s., respectively.

4. Discussion

Looking at your hand increases its temperature, but does not affect the contralateral hand. Moreover, viewing a non-hand object, even if in the exact location of the hand, does not result in temperature increase. These findings demonstrate that vision of the body produces limb-specific modulation of thermal regulation and thus they add to a growing literature reporting the widespread effects of vision on bodily stimuli processing [1–6].

Our findings have intriguing similarities with recent results showing temperature modulation in the rubber hand illusion. In this illusion, touch applied synchronously both to a prosthetic hand and one's own hidden hand produces the compelling feeling that the rubber hand actually is one's hand [9–11]. The experience of ownership over the rubber hand produces a limb-specific temperature drop in the hidden hand [12,13]. Moseley *et al*. [12,14] suggest that the experience of ownership over the rubber hand displaces the actual hand, resulting in 'disownership' and reducing homoeostatic control in the limb. Our results can be interpreted as reflecting the opposite process, an enhanced ownership over the seen limb resulting in increased homoeostatic control and temperature.

Several psychiatric and neurological conditions involving disruptions of body representation have also been found to feature disordered thermoregulation, including complex regional pain syndrome (CRPS) [15,16], schizophrenia [17], phantom limb pain [18] and self-injurious behaviour [19]. CRPS, for example, is associated with increased pain, decreased tactile sensitivity on the affected limb [20,21], somatosensory disinhibition [22] and reduced temperature on the affected limb [15,16]. Intriguingly, vision of the body has the opposite effects in healthy participants, reducing pain [3,4], enhancing tactile sensitivity [1,2], enhancing somatosensory inhibition [5] and increasing limb temperature (this study).

Thus, vision of the body appears to produce real-time enhancement of a coherent constellation of characteristics, which appear to be impaired in CRPS, suggesting that these characteristics may arise from a single cortical network. Moseley *et al*. [14] recently presented the idea of a 'body matrix', a putative cortical network integrating multisensory and homoeostatic functions to represent the body and the space immediately surrounding it. The diverse effects produced by vision of the body could result from limb-specific modulation of body matrix activity. Consistent with this proposal, in a recent fMRI study, we found that seeing the body while receiving painful stimuli increased functional connectivity between visual and posterior parietal areas and both somatosensory cortices (SI and SII) as well as areas known to be involved in homoeostatic control, including the insula and anterior cingulate cortex [23].

The causal mechanism underlying our findings remains uncertain. One possibility is that in addition to modulating somatosensory processing, vision of the body also modulates the autonomic nervous system directly, analogous to the effect reported above in CRPS. Alternatively, seeing the body may modulate activity in motor cortical areas. While seeing the body does not induce obvious movement of the hand, it could produce sub-threshold muscular activation which could drive the effect we report. Future research should investigate this issue.

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References

1. Kennett S, Taylor-Clarke M, Haggard P. 2001 Noninformative vision improves the spatial resolution of touch in humans. *Curr. Biol.* **11**, 1188–1191. (doi:10.1016/S0960-9822(01)00327-X)
2. Harris JA, Arabzadeh E, Moore CA, Clifford CW. 2007 Noninformative vision causes adaptive changes in tactile sensitivity. *J. Neurosci.* **27**, 7136–7140. (doi:10.1523/JNEUROSCI.2102-07.2007)
3. Longo MR, Betti V, Aglioti SM, Haggard P. 2009 Visually induced analgesia: seeing the body reduces pain. *J. Neurosci.* **29**, 12 125–12 130. (doi:10.1523/JNEUROSCI.3072-09.2009)
4. Mancini F, Longo MR, Kammers MPM, Haggard P. 2011 Visual distortion of body size modulates pain perception. *Psychol. Sci.* **22**, 325–330. (doi:10.1177/0956797611398496)
5. Cardini F, Longo MR, Haggard P. 2011 Vision of the body modulates somatosensory intracortical inhibition. *Cereb. Cortex* **21**, 2014–2022. (doi:10.1093/cercor/bhq267)
6. Longo MR, Sadibolova R. 2013 Seeing the body distorts tactile size perception. *Cognition* **126**, 475–481. (doi:10.1016/j.cognition.2012.11.013)
7. Haggard P, Iannetti GD, Longo MR. 2013 Spatial sensory organization and body representation in pain perception. *Curr. Biol.* **23**, R164–R176. (doi:10.1016/j.cub.2013.01.047)
8. Ramachandran VS, Rogers-Ramachandran D, Cobb S. 1995 Touching the phantom limb. *Nature* **377**, 489–490. (doi:10.1038/377489a0)
9. Botvinick M, Cohen J. 1998 Rubber hands 'feel' touch that eyes see. *Nature* **391**, 756. (doi:10.1038/35784)
10. Tsakiris M, Haggard P. 2005 The rubber hand illusion revisited: visuotactile integration and self-attribution. *J. Exp. Psychol. Hum. Percept. Perform.* **31**, 80–91. (doi:10.1037/0096-1523.31.1.80)
11. Longo MR, Schüür F, Kammers MPM, Tsakiris M, Haggard P. 2008 What is embodiment? A psychometric approach. *Cognition* **107**, 978–998. (doi:10.1016/j.cognition.2007.12.004)
12. Moseley GL *et al*. 2008 Psychologically induced cooling of a specific body part caused by the illusory ownership of an artificial counterpart. *Proc. Natl Acad. Sci. USA* **105**, 13 169–13 173. (doi:10.1073/pnas.0803768105)
13. Hohwy J, Paton B. 2010 Explaining away the body: experiences of supernaturally caused touch and touch on non-hand objects within the rubber hand illusion. *PLoS ONE* **5**, e9416. (doi:10.1371/journal.pone.0009416)
14. Moseley GL, Gallace A, Spence C. 2012 Bodily illusions in health and disease: Physiological and clinical perspectives and the concept of cortical 'body matrix'. *Neurosci. Biobehav. Rev.* **36**, 34–46. (doi:10.1016/j.neubiorev.2011.03.013)
15. Moseley GL, Gallace A, Spence C. 2009 Space-based, but not arm-based, shift in tactile processing in complex regional pain syndrome and its relationship to cooling of the affected limb. *Brain* **132**, 3142–3151. (doi:10.1093/brain/awp224)
16. Moseley GL, Gallace A, Iannetti GD. 2012 Spatially defined modulation of skin temperature and hand ownership of both hands in patients with unilateral complex regional pain syndrome. *Brain* **135**, 3676–3686. (doi:10.1093/brain/aws297)
17. Chong TW, Castle DJ. 2004 Layer upon layer: thermoregulation in schizophrenia. *Schizophr. Res.* **69**, 149–157. (doi:10.1016/S0920-9964(03)00222-6)
18. Nikolajsen L, Jensen TS. 2001 Phantom limb pain. *Br. J. Anaesth.* **87**, 107–116. (doi:10.1093/bja/87.1.107)
19. Symons FJ, Sutton KA, Bodfish JW. 2001 Preliminary study of altered skin temperature at body sites associated with self-injurious behavior in adults who have developmental disabilities. *Am. J. Ment. Retard.* **106**, 336–343. (doi:10.1352/0895-8017(2001)106<0336:PSOAST>2.0.CO;2)
20. Moseley GL. 2008 I can't find it! Distorted body image and tactile dysfunction in patients with chronic back pain. *Pain* **140**, 239–243. (doi:10.1016/j.pain.2008.08.001)
21. Gierthmühlen J *et al*. 2012 Sensory signs in complex regional pain syndrome and peripheral nerve injury. *Pain* **153**, 765–774. (doi:10.1016/j.pain.2011.11.009)
22. Lenz M *et al*. 2011 Bilateral somatosensory cortex disinhibition in complex regional pain syndrome type I. *Neurology* **77**, 1096–1101. (doi:10.1212/WNL.0b013e31822e1436)
23. Longo MR, Iannetti GD, Mancini F, Driver J, Haggard P. 2012 Linking pain the and body: neural correlates of visual analgesia. *J. Neurosci.* **32**, 2601–2607. (doi:10.1523/JNEUROSCI.4031-11.2012)