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Report

Cooling the Thermal Grill Illusion through Self-Touch

Marjolein P.M. Kammers,[1,*] Frédérique de Vignemont,[2,3] and Patrick Haggard[1]
[1]Institute of Cognitive Neuroscience, University College London, Alexandra House, 17 Queen Square, London WC1N 3AR, UK
[2]Institut Jean-Nicod, CNRS/EHESS/ENS, 29 rue d'Ulm, F-75005 Paris, France
[3]Transitions NYU–CNRS, 4 Washington Square, New York, NY 10003, USA

Summary

Acute peripheral pain is reduced by multisensory interactions at the spinal level [1]. Central pain is reduced by reorganization of cortical body representations [2, 3]. We show here that acute pain can also be reduced by multisensory integration through self-touch, which provides proprioceptive, thermal, and tactile input forming a coherent body representation [4, 5]. We combined self-touch with the thermal grill illusion (TGI) [6]. In the traditional TGI, participants press their fingers on two warm objects surrounding one cool object. The warm surround unmasks pain pathways, which paradoxically causes the cool object to feel painfully hot. Here, we warmed the index and ring fingers of each hand while cooling the middle fingers. Immediately after, these three fingers of the right hand were touched against the same three fingers on the left hand. This self-touch caused a dramatic 64% reduction in perceived heat. We show that this paradoxical release from paradoxical heat cannot be explained by low-level touch-temperature interactions alone. To reduce pain, we often clutch a painful hand with the other hand. We show here that self-touch not only gates pain signals reaching the brain [7–9] but also, via multisensory integration, increases coherence of cognitive body representations to which pain afferents project [10].

Results and Discussion

Central pain is associated with abnormal neural reorganization of the representation of the body in several conditions including phantom limb, complex regional pain syndrome, and dystonia [2, 3, 11–14]. We show here that acute pain can also be modulated by a specific cognitive form of multisensory integration that occurs when one body part touches another. Such self-touch is often thought to underlie the coherence of body representation [4, 15]. Moreover, results in patients [16, 17] and neurophysiological studies [18] confirm that self-touch enhances perceptual and motor processing. We used a well-established neurophysiological model of acute peripheral pain, the thermal grill illusion (TGI) [6], and show that only a full multisensory form of self-touch, with coherent tactile and thermal inputs, can reduce thermal pain. Partial self-touch, touching another person, and touch without full thermal input across all three stimulated fingers on each hand were all insufficient. These results suggest that self-touch reduces thermal pain because it enhances the coherence of cognitive body representation.

The TGI is generally explained by low-level interactions between different afferent pathways: normal discharge of Aδ (signaling coolness coming from the middle object) is reduced due to spatial summation of inputs signaling warmth from surrounding skin regions. Because Aδ input normally inhibits the nociceptive C fiber pathway [19], reduced Aδ firing leads to disinhibition of C fibers that signal pain. Previous TGI studies could not separate tactile from thermosensory perception, because they involved touching warm and cool external objects. We therefore extended the TGI to interoceptive situations where no object is touched. Participants immersed the index and ring fingers of both hands in warm water ($\sim$43°C) and the middle fingers of both hands in cool water ($\sim$14°C) (see Supplemental Experimental Procedures available online). First, participants judged the temperature of the cool middle finger while immersed and matched its perceived temperature with the temperature of a thermode touching their face (Figure 1). We found that the middle finger felt significantly hotter when the outer fingers were in warm water than when they were in neutral water, replicating the original TGI (Supplemental Data; Figure S1).

Next, we investigated the effect of higher-level cognitive body representations on this interoceptive form of TGI by manipulating self-touch. Low-level effects of touch on pain are well established [1]. If one hand is wounded, we reflexively grasp it with the other hand to reduce pain. We hypothesized that self-touch might also reduce pain via an additional, cognitive mechanism. Pressing the two hands against each other not only provides additional proprioceptive, thermal, and tactile input but also provides strongly correlated sensory input across different body parts. These correlations enhance sensory processing [16, 17] and strengthen the association between the touching body parts, thus creating a coherent body representation [4].

Therefore, we next combined the afferent inputs of the TGI with the distinctive experience of self-touch, to increase multisensory integration and coherence of body representation (Figure 1). After induction of the TGI on both hands with warm-cool-warm water, participants removed their hands from the water and pressed the distal and middle fingerpads of the middle three fingers of the right hand onto the distal and middle fingerpads of the middle three fingers of the left hand (test 1, Figure 1C). Interestingly, full self-touch between the two hands resulted in significantly reduced TGI. The target right middle finger now felt cooler, and thus closer to its true temperature, than when touching a neutral external object (test 1 versus control 1, Figure 2), indicating a paradoxical release from the paradoxical heat.

This full self-touch condition involved both thermal and tactile input and coherence between hands in the pattern of both temperature and touch. To investigate the importance of bimanual coherence of thermal input alone to TGI reduction, we had participants press their warm-cool-warm right fingers on their neutral left fingers. No reduction of TGI was now found (test 2 versus control 1). Partial thermal input, by cooling the

*Correspondence: m.kammers@ucl.ac.uk

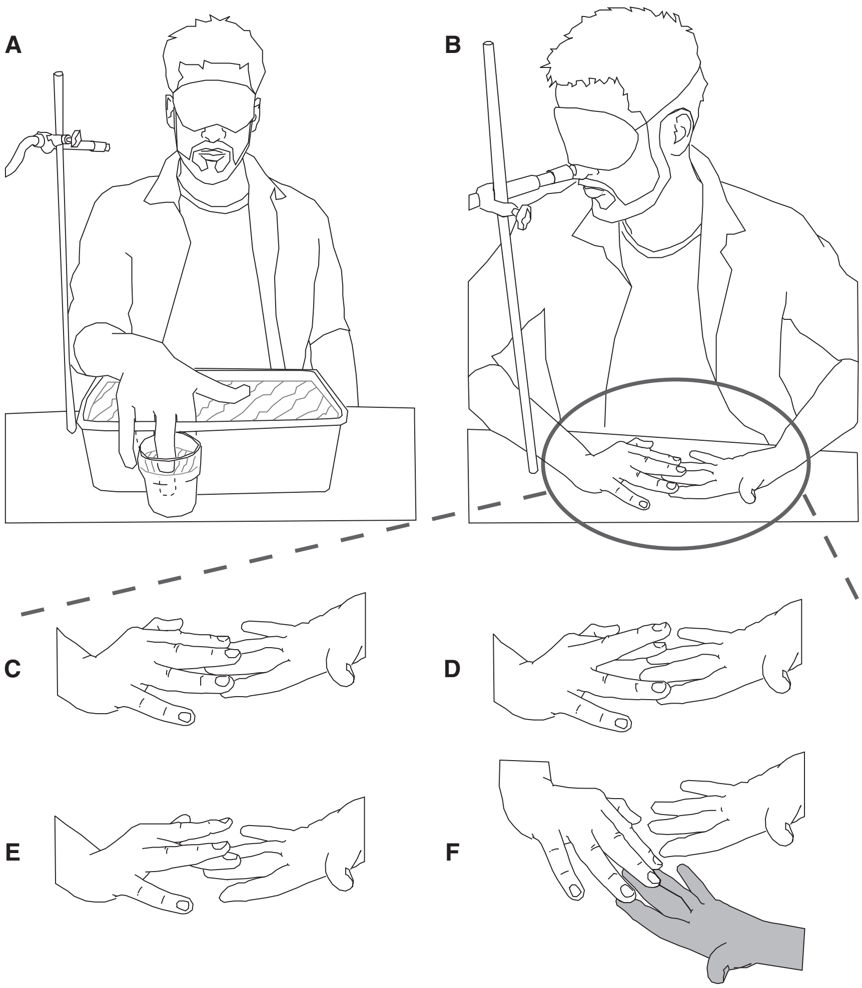

Figure 1. The Thermal Grill Illusion and Self-Touch

The thermal grill illusion (TGI) refers to a paradoxical feeling of painful heat generated when the middle finger is cooled and surrounded by warmed outer fingers.

(A) TGI was induced by immersing the participant's index and ring fingers in hot water and the middle finger in cool water.

(B) Participants reported the perceived temperature of their right middle finger using a method of adjustment, verbally reporting whether a thermode in contact with the nose was warmer or colder. The temperature of the thermode was adjusted until it was perceived to be equal to the participant's right middle finger.

(C–E) Self-touch conditions. After removing their fingers from the water, participants touched their fingers together in a number of different self-touch conditions.

(F) External touch. In two control conditions, participants instead touched their fingers to the experimenter's fingers (gray).

See also Figure S2.

left middle finger only, was also insufficient to cause TGI reduction (test 3 versus test 1) in subsequent self-touch. Hence, TGI reduction with full thermotactile self-touch was not simply due to bimanual improvement in cold perception.

To investigate the importance of bimanual coherence of tactile input alone to TGI reduction, we induced TGI on both hands and asked participants to press either the warm left and right outer fingers against each other or only the cold middle fingers (test 4 versus test 5). Neither of these partial self-touch patterns reduced the TGI. On one view, TGI reduction in full thermotactile self-touch could simply reflect improved information about right middle finger temperature from thermoreceptors in the left middle finger. This explanation would predict TGI reduction when the right middle finger alone touches the left middle finger, but this was not found (test 5). On another view, TGI reduction could arise from reduced spatial summation of the warm input from the outer fingers, thus restoring normal inhibition of C fibers. However, the combination of touch and warm inputs from outer fingers only did not reduce TGI (test 1 versus test 4).

In sum, TGI was reduced only when thermosensory and tactile information from all three fingers was fully integrated. That is, TGI reduction required a highly coherent somatosensory pattern, including coherence between tactile and thermal patterns and coherence of stimuli between the two hands.

Finally, to confirm that TGI reduction required multisensory integration within a coherent body representation, we tested a control condition involving tactile and thermal input to the right hand alone (control 2). We induced TGI on the participants' right hand only and asked them to press against the experimenter's hand, which also had TGI (control 2). Here, the experimenter's fingers provided the same thermal and tactile inputs to the participant's right hand that the participant's own left hand did in the full self-touch condition of test 1. Thus, inputs from the right hand were identical in both conditions, whereas coherent input from the left hand was present in test 1 but not in control 2. No TGI reduction was found in this condition (test 1 versus control 2).

We conclude that TGI reduction requires integration of thermotactile information across both hands. This finding is consistent with an involvement of secondary somatosensory cortex (SII). Neurons in this area show bilateral receptive fields [20], integration across multiple digits [21, 22], and a somatotopic coding of both temperature and pain [23]. Human neuroimaging studies have shown proprioceptive modulation, with increasing convergence of SII sources for the index finger and thumb when these two digits are brought closer together [24], and also modulation of blood oxygen level-dependent responses during bimanual self-touch [9]. Thus, SII appears to house, and integrate, all of the multisensory information present in TGI. Furthermore, this integration appears sensitive to the coherence of overall body form and action.

Another possible cognitive mechanism of acute pain modulation is source attribution. Thermal pain is perceived as more intense if attributed to changes in one's own bodily temperature than if attributed to an external object touching the skin [19, 25, 26]. Could full self-touch in the present experiment trigger a switch from internal to external attribution, producing TGI reduction? That view suggests the brain should reattribute thermal sensation from left to right, as well as from right to left, during self-touch, with each hand appearing as an external object to the other. However, this implies

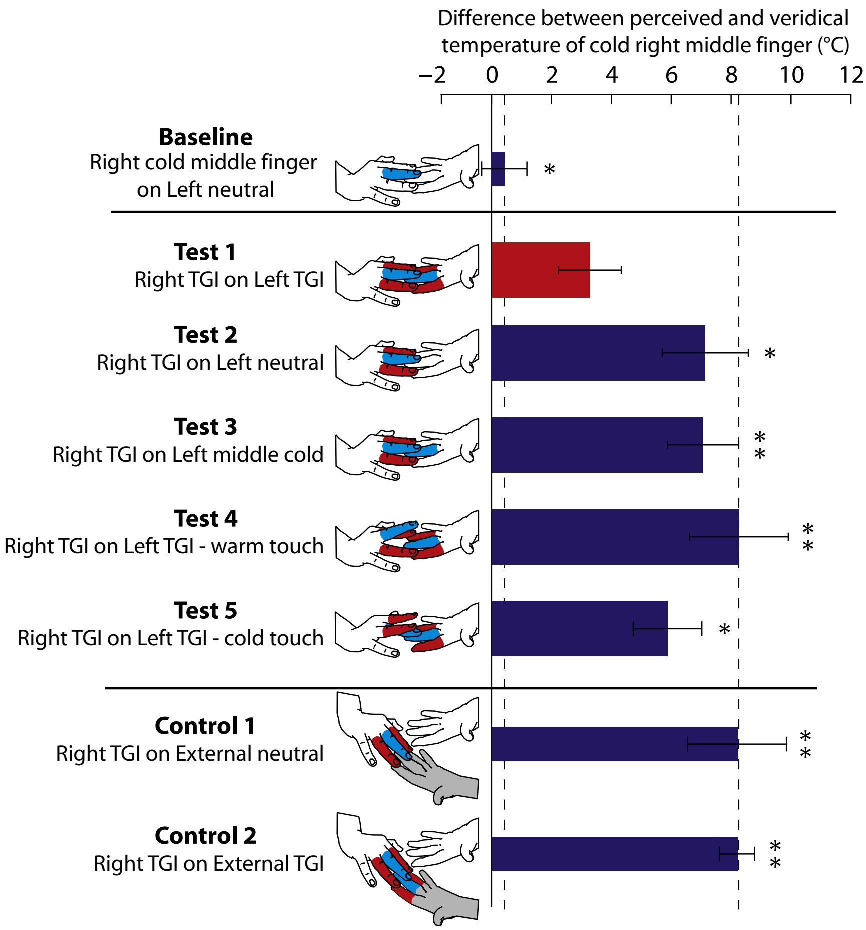

Figure 2. Paradoxical Release from Paradoxical Heat

In normal TGI, a cool middle finger surrounded by warm outer fingers feels painfully hot compared to only cooling the middle finger (control 1 versus baseline; both values also indicated by dashed vertical lines). This feeling of heat is strongly reduced (64% attenuation) when two TGIs on the participant's hand are touched together (test 1 versus control 1). The TGI reduction was not found during self-touch of a neutral hand (test 2), self-touch of a neutral hand with a cold middle finger (test 3), or partial self-touch with two TGIs (tests 4 and 5). Finally, touching a neutral external hand (control 1) or an external hand with TGI (control 2) did not reduce TGI. Red and blue fingers indicate warm and cool fingers, respectively. *$p < 0.05$, **$p < 0.01$ versus test 1 condition (indicated in red) by uncorrected paired-sample t test, with the exception of control 2, which was performed on a separate subject pool and therefore tested by two-sample t test. All comparisons remain significant with a family-wise error rate of 0.05 when corrected for multiple comparisons using Holm-Bonferroni correction [29]. Error bars indicate standard errors of the mean. See also Figure S1 and Table S1.

a fragmentation of body representations during self-touch instead of a multisensory integration, which is inconsistent with previous results [4]. In contrast, only in our critical full self-touch TGI condition did the afferent multisensory information form a coherent bilateral pattern across hemispheres and across sensory modalities. Previous studies have shown that multisensory interactions can modulate acute [14] as well as central [12] pain. Correlated multisensory information is a major source of the sense of one's own body as a coherent "self" [10, 27]. Our results show that coherence between hands, as well as across modalities, may contribute to pain modulation. The present study suggests that multisensory, multieffector information may rapidly boost coherence of cortical activity and thus reduce (thermal) pain.

Hence, we show that touch-temperature interactions such as TGI have a cognitive component. Specifically, they are sensitive not only to low-level multisensory integration but also to the coherence of tactile and thermal input across both hands provided by self-touch. The TGI reduction caused by fully coherent self-touch could not be explained by changes in tactile or thermal input alone. Interestingly, when we hurt our hand, we grasp it with our other hand but are typically reluctant to allow anyone else to touch the wound. We suggest that modulation of acute pain by coherence of body representation during self-touch underlies this surprising difference.

Our findings may have important implications for the treatment of clinical conditions including both central pain and disorders of body representation. For example, altered coherence of body representation in complex regional pain syndrome is often accompanied by changes in the temperature of the affected limb and disorders of body ownership, such as neglect [13, 28]. We speculate that the pain associated with these disorders might be reduced by activities that restore coherence of body representation, such as self-touch.

Supplemental Information

Supplemental Information includes two figures, one table, and Supplemental Experimental Procedures and can be found with this article online at doi:10.1016/j.cub.2010.08.038.

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