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Visual Distortion of Body Size Modulates Pain Perception

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Abstract

Pain is a complex subjective experience that is shaped by numerous contextual factors. For example, simply viewing the body reduces the reported intensity of acute physical pain. In this study, we investigated whether this visually induced analgesia is modulated by the visual size of the stimulated body part. We measured contact heat-pain thresholds while participants viewed either their own hand or a neutral object in three size conditions: reduced, actual size, or enlarged. Vision of the body was analgesic, increasing heat-pain thresholds by an average of 3.2 °C. We further found that visual enlargement of the viewed hand enhanced analgesia, whereas visual reduction of the hand decreased analgesia. These results demonstrate that pain perception depends on multisensory representations of the body and that visual distortions of body size modulate sensory components of pain.

Keywords

somatosensory perception, pain, body representation, multisensory integration, vision, analgesia

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Pain is a frequent but unpleasant experience with a clearly negative impact on well-being. Pain can be caused by peripheral stimuli (e.g., burning one's fingers), by chronic bodily states (e.g., back pain), or by mechanisms entirely within the brain (e.g., phantom limb pain). The pain level generated by a peripheral stimulus varies dramatically across individuals and across situations, so the subjective aspect of pain cannot be ignored (Eisenberger & Lieberman, 2004; Melzack & Wall, 1965). An important element of pain subjectivity comes from the wide variety of top-down factors that modulate pain (Chen, Williams, Fitness, & Newton, 2008; Gray & Wegner, 2008). Expectation and arousal factors, such as placebo effects and the requirement to focus on an ongoing task, are examples of variables that modulate pain (Wiech, Ploner, & Tracey, 2008).

Simple perceptual factors can also influence pain. For example, both reported intensity of pain and neural responses to painful stimuli are reduced when participants look at their own body, compared with when they view a neutral object (Longo, Betti, Aglioti, & Haggard, 2009). This visually induced analgesia demonstrates that acute pain can be modulated by specific visual contexts, which raises the possibility that manipulating the visual appearance of the body might further modulate pain. Indeed, visually specified size of the body may affect levels of chronic pain in certain clinical populations (Moseley, Parsons, & Spence, 2008; Ramachandran, Brang, & McGeoch, 2009). In the present study, we investigated whether manipulating the visual size of the body modulates experimentally induced pain in healthy participants.

These studies on cross-modal pain modulation generally relied on pain-intensity ratings. Pain ratings reflect a combination of sensory-discriminative and postperceptual affective-motivational components of pain (Auvray, Myin, & Spence, 2010; Melzack & Casey, 1968). In the present study, by contrast, we used a more purely sensory measure of pain perception, contact heat-pain thresholds (Yarnitsky, Sprecher, Zaslansky, & Hemli, 1995). Heat-pain thresholds were measured while participants viewed their own hand or a neutral object in three size conditions: The hand or object appeared visually reduced, actual size, or enlarged.

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Method

Participants

Eighteen healthy, right-handed volunteers (7 males, 11 females; mean age = 27.1 years, *SD* = 4.1) participated for payment. Procedures were approved by the University College London ethics committee.

Thermal stimuli

Thermal stimulation of the dorsum of the left hand, just proximal to the knuckle of the index finger (first metacarpal space), was delivered by a Peltier-type thermode (NTE-2A, Physitemp Instruments Inc., Clifton NJ). The probe was 13 mm in diameter and was held by a mechanical arm to control contact pressure.

Thresholds for pain were estimated with the method of limits (Yarnitsky et al., 1995). The probe temperature was increased from normal skin temperature (constant 32 °C, maintained for 20 s) at 2 °C per second. Participants pressed a foot pedal with their right foot when they first perceived the stimulation as being painful. For safety, maximum temperature was limited to 50 °C.

Procedure

We used the mirror-box technique (Ramachandran, Rogers-Ramachandran, & Cobb, 1995) to induce the impression that the participant's right hand, which was reflected in a mirror aligned with the sagittal plane, was actually the participant's stimulated left hand. Participants sat at a table with the left hand behind the mirror and the right hand in front of the mirror. The tip of each index finger was 20 cm from the mirror. One group of participants (*n* = 9; *hand-view condition*) looked into the mirror toward their left hand and saw the reflection of their right hand, appearing where they felt their left hand to be. A second group (*n* = 9; *object-view condition*) saw the reflection of an occluding hand-sized wooden block that had been placed approximately 3 cm over the right hand. The viewed size of the hand or object was manipulated by exchanging three mirrors (see Fig. 1): a convex mirror giving 2× reduction (0.5× magnification), a normal mirror, and a concave mirror giving 2× magnification. The different visual sizes (reduced, actual size, and enlarged) were tested in separate blocks presented in random order. The hand-view and object-view conditions were tested in separate groups of participants to avoid problems of pain habituation, or sensitization (Green, 2004).

Participants were first familiarized with contact heat through stimulation of a skin region not used in the experiment (the center of the hand dorsum). Next, in each of the three blocks, participants were instructed to look into the mirror and fixate the hand (or object) continuously. After 10 min of fixation (the adaptation phase), a thermode probe applied gradually increasing contact heat to the left hand. Four heat-pain staircase measurements were then obtained at 1-min intervals.

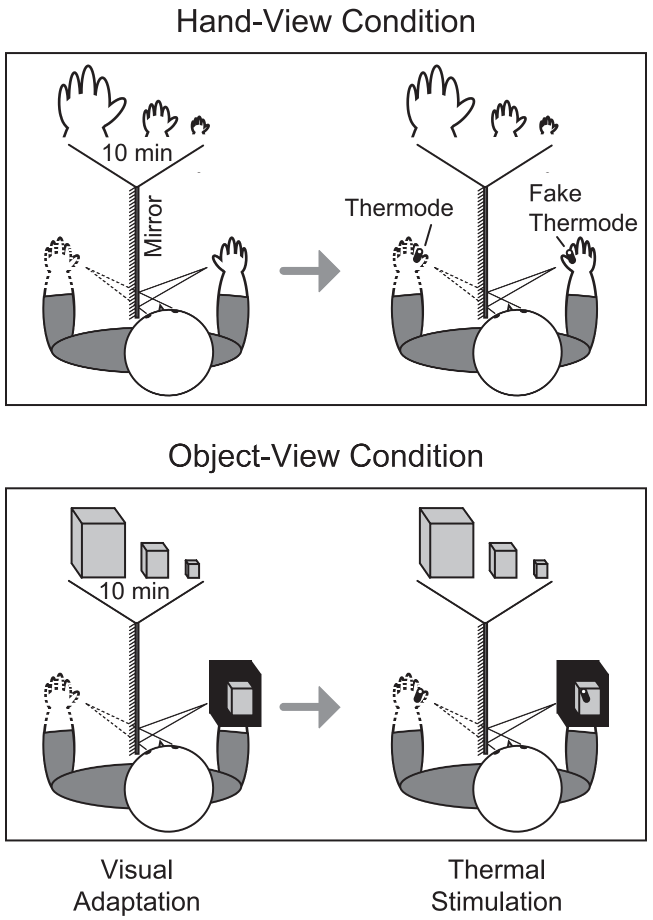

Fig. 1. Stimuli, apparatus, and procedure. Participants gazed toward their left hand. A mirror aligned with the midsagittal plane ensured that they viewed the reflection of either their right hand (which appeared to be their left hand; hand-view condition) or a neutral object (object-view condition) in front of the mirror. The hand or object was viewed reduced, actual size, or enlarged through the use of mirrors with different degrees of magnification in different blocks. After a 10-min adaptation phase, a thermode probe applied gradually increasing contact heat to the left hand. A fake thermode probe was simultaneously applied to the right hand, or to the object, at the location corresponding to where the stimulation was felt on the left hand, to avoid perceptual conflict. Participants pressed a foot pedal when the stimulation of the left hand became painful.

During each staircase, the temperature was increased continuously (2 °C/s) until the probe started to feel painful and the participant pressed a pedal in response. A fake thermode probe was simultaneously applied to the right hand or to the neutral object at the location corresponding to where the stimulation was felt on the left hand, so that participants always saw an object touching the hand or block at the location corresponding to where they felt the heat. Three minutes of rest were allowed between blocks.

Three additional measures were collected. First, we administered an established questionnaire (Longo et al., 2009; see also Fig. 2) to check that the mirror box indeed induced a compelling visual illusion of viewing the left hand directly. Item 1 was given in both the hand-view and the object-view

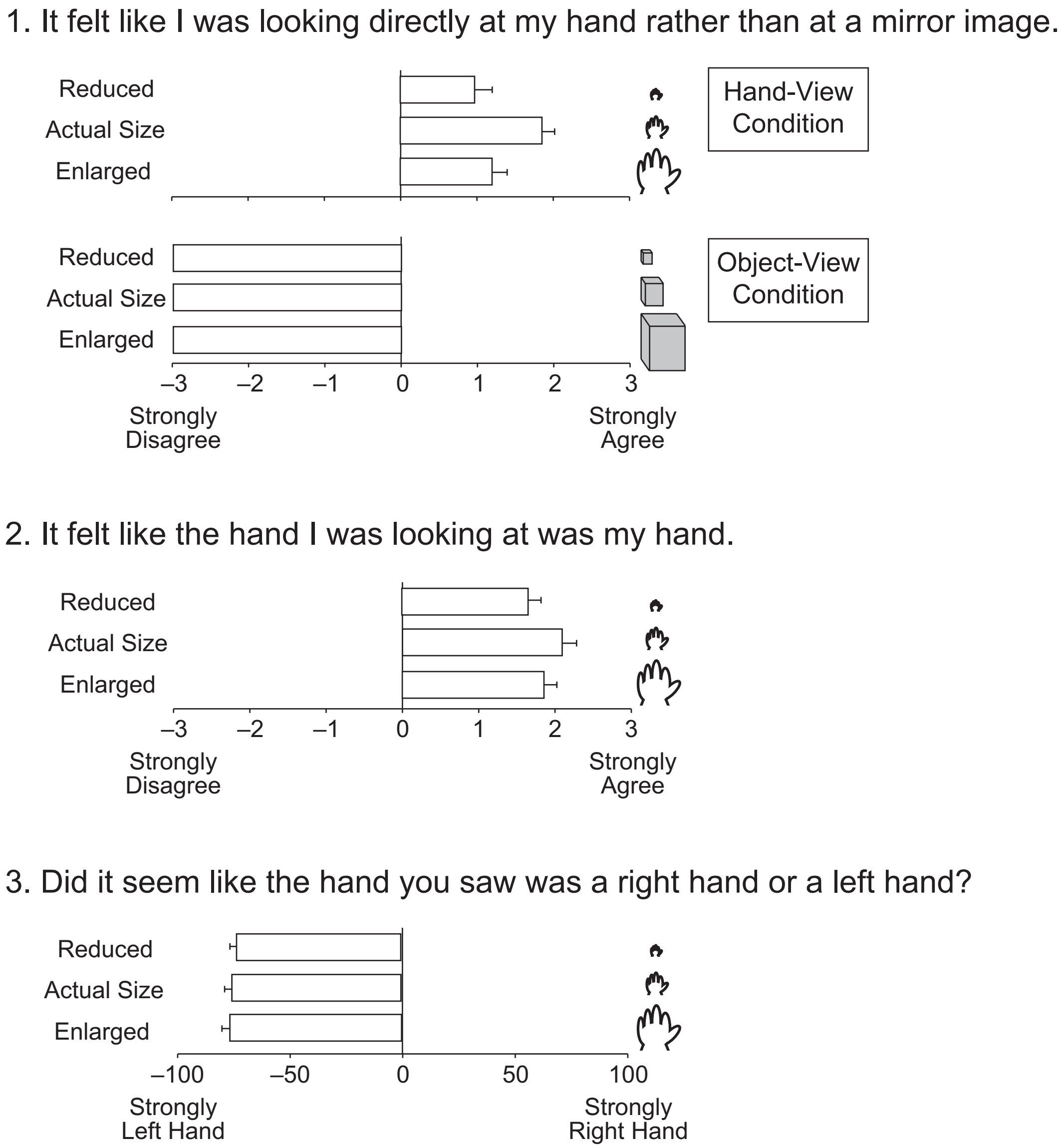

Fig. 2. Responses to the mirror-box questionnaire. Error bars indicate +1 *SE*.

conditions; Items 2 and 3 were given only in the hand-view condition. Participants rated their agreement with Items 1 and 2 using a 7-point Likert scale ranging from +3 (*strongly agree*) to −3 (*strongly disagree*). For Item 3, participants reported whether they felt they were viewing their right or their left hand and then indicated the strength of this feeling using a scale from 0 to 100. Ratings for the right hand were coded as positive values, and ratings for the left hand were coded as negative values, so that the possible range of scores was from −100 (strong feeling of viewing the left hand) to 100 (strong feeling of viewing the right hand).

Second, to check that the visual manipulations of hand size were effective, we asked participants to judge the size they felt their left hand to be, using a specially designed apparatus. Immediately before and after each block, participants adjusted the distance between two visual points to match the perceived distance between the proximal knuckles of their index and little fingers of their left hand.

Finally, to assess whether pain thresholds could have changed because of changes in skin temperature, we used an infrared thermometer to measure skin temperature immediately before and after the visual adaptation phase.

Results

Questionnaire responses

Agreement or disagreement with the three questionnaire items (see Fig. 2) was tested using *t* tests that compared the mean score for each item, averaged across visual size, with 0. In the hand-view condition, for all three items, the mirrors produced the illusion of viewing one's own left hand when viewing the right hand—Item 1: $t(8) = 3.41$, $p = .009$; Item 2: $t(8) = 5.13$, $p = .001$; Item 3: $t(8) = -12.71$, $p < .001$. In the object-view condition, however, all participants strongly disagreed with the statement that they felt they were looking directly at their left hand.

Analyses of variance (ANOVAs) revealed that responses to the questionnaire items were not affected by visual size—Item 1: $F(2, 30) = 1.27$, $p = .297$, $\eta_p^2 = .08$; Items 2 and 3: Fs < 1. Thus, the size manipulation did not influence the illusion of viewing one's hand.

Hand-size estimates

Differences in hand-size estimates before and after visual exposure were analyzed using a repeated measures ANOVA with visual context (hand, object) as a between-subjects factor and size condition (reduced, actual size, enlarged) as a within-subjects factor. Greenhouse-Geisser corrections were used when deviation from sphericity was observed. The ANOVA showed no main effect of visual context, $F < 1$, but a significant effect of size condition, $F(2, 30) = 8.78$, $p = .003$, $\eta_p^2 = .35$, and a significant interaction, $F(2, 30) = 9.95$, $p = .002$, $\eta_p^2 = .38$ (see Fig. 3, left panel). Simple-effects analyses showed that this interaction arose because visual size distortions influenced reported hand size when participants viewed their hand, $F(2, 16) = 13.23$, $p < .001$, $\eta_p^2 = .62$, but not when they viewed the object, $F < 1$. Bonferroni-corrected follow-up tests comparing the visual distortion conditions with the actual-size condition confirmed that seeing the hand as bigger increased reported hand size ($p = .003$), but seeing the hand as smaller shrank reported hand size ($p = .002$). All comparisons between visual size conditions were nonsignificant for the object-view condition (ps > .30). These results indicate that the size at which the body was viewed influenced representations of actual body size.

Pain thresholds

We first investigated whether viewing the hand at its actual size produced a visual analgesia similar to that reported previously (Longo et al., 2009). We confirmed that viewing the hand via the nondistorting mirror indeed increased heat-pain thresholds ($M = 44.90$ °C, $SE = 0.98$), relative to viewing the object ($M = 41.69$ °C, $SE = 1.07$), $t(16) = 2.14$, $p = .048$.

We then explored the effects of visual size of the hand and object. An ANOVA revealed significant main effects of both visual context, $F(1, 16) = 5.20$, $p = .037$, $\eta_p^2 = .24$, and size condition, $F(2, 32) = 4.16$, $p = .025$, $\eta_p^2 = .21$, on heat-pain thresholds. Crucially, there was a significant interaction between these two factors, $F(2, 32) = 4.58$, $p = .018$, $\eta_p^2 = .22$. Simple-effects analyses showed that visual size modulated pain thresholds when participants saw their hand, $F(2, 16) = 10.18$, $p = .001$, $\eta_p^2 = .56$. Bonferroni follow-up tests comparing the visual distortion conditions with the actual-size condition revealed that visual enlargement of size increased the analgesic effect of viewing the body ($p = .032$), whereas visual reduction decreased the analgesic effect ($p = .043$; see Fig. 3, right panel). In contrast, simple-effects analyses showed that visual size of the object had no effect on pain thresholds ($F < 1$).

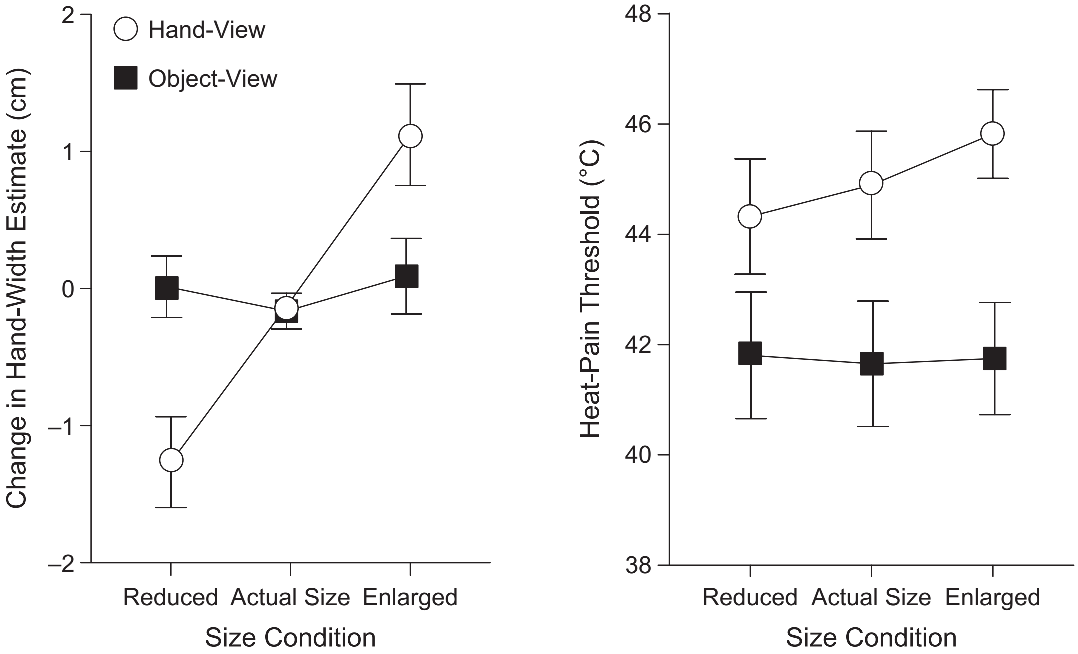

Fig. 3. Mean change in hand-width estimates (after visual adaptation minus before visual adaptation) and mean heat-pain threshold as a function of visual context (hand or object) and visual size condition (reduced, actual size, or enlarged). Error bars indicate ±1 *SE*.

Because pain thresholds depend on baseline skin temperature, we also investigated whether the different visual conditions induced changes in skin temperature and thus influenced pain thresholds indirectly. However, no significant main effects or interaction was found ($F < 1$).

Discussion

This study yielded three main findings. First, viewing the body is analgesic (relative to viewing a neutral object), inducing specific effects on sensory-discriminative processing of pain. Contact heat-pain thresholds are increased by an average of 3.2 °C. Second, the size at which the hand is viewed alters the size at which the hand is mentally represented. Third, viewing one's enlarged hand increases the analgesic effect of seeing the hand, whereas viewing a reduced hand decreases the analgesic effect. In other words, when a stimulus is applied to a body part that is seen as bigger than its actual size, the stimulus needs to be hotter to produce pain than it otherwise would need to be. Conversely, the pain threshold for a stimulus applied to a body part that is viewed as smaller than its actual size is reduced. Our findings cannot be explained by either changes in skin temperature or scale dependence of the mirror-box illusion.

We have thus demonstrated for the first time that viewing one's body modulates the sensory-discriminative components of pain experience. Previous studies of visual analgesia measured pain-intensity ratings (Longo et al., 2009). These are confounded by postperceptual affective-motivational components of pain (Melzack & Casey, 1968), such as task demands and response biases (Iannetti, Hughes, Lee, & Mouraux, 2008). Further, recent reviews have questioned how much of pain is specific to nociceptive stimulation and how much reflects general salience and arousal mechanisms (Iannetti & Mouraux, 2010). However, our results suggest that viewing the body modulates sensory processes specific to pain perception. Previous studies have demonstrated that alterations of afferent input cause changes in the perceived size of affected body parts (Gandevia & Phegan, 1999). Here, we demonstrated an additional causal relationship in the opposite direction: That is, altering the perceived size of a body part causes changes in the sensory processing of pain.

Previously, viewing the body was reported to improve tactile acuity (Kennett, Taylor-Clarke, & Haggard, 2001). This tactile modulation was further enhanced by visual enlargement. Here, we showed a visually induced increase in the heat-pain threshold, which was further enhanced by visual enlargement. It is interesting to note that reduction of visual hand size decreased heat-pain thresholds. This bidirectional modulation rules out explanations based simply on attention, expectations, or novelty. Visual distortion of one's own body is unusual in everyday life, so it might plausibly lead to a nonspecific arousal effect. However, such nonspecific attentional effects should be similar for increased and decreased scales. Our results indicate a specific, proportional relation between visual body size and pain perception.

The fact that viewing the body has similar modulatory effects on touch and pain suggests a common underlying mechanism. For example, visual and multisensory areas that represent one's own body and peripersonal space might modulate networks of inhibitory interneurons in early somatosensory areas (Longo et al., 2009). Previous psychophysical (Kammers, de Vignemont, & Haggard, 2010) and clinical (Ramachandran et al., 2009) studies have confirmed links between body representation and pain sensation. The representation of one's own body is initially created by integrating multisensory inputs. Once established, however, such body representations may attribute, interpret (Tsakiris, Haggard, Franck, Mainy, & Sirigu, 2005), and modulate (Kennett et al., 2001) sensory inputs in order to optimize perception of novel events (Coslett & Lie, 2004) and provide a spatiotemporally continuous sense of self. We suggest that visual analgesia is another example of self-related modulation.

Our results provide an intriguing contrast with modulations of pain caused by viewing another person. In previous work, viewing a stranger's hand did not influence pain levels or the brain's response to painful stimulation (Longo et al., 2009). However, participants who viewed photographs of their partner experienced reduced heat pain (Master et al., 2009). This suggests that visual modulation of pain may always involve recognition of individual personal identity. The present results show that analgesic effects of self-perception depend proportionately on basic metric features of the visual input—in this case, how big one's own body is perceived to be.

Curiously, a previous study of body-size effects on chronic pain reported a result apparently opposite to that found in the present study. Moseley et al. (2008) reported that chronic pain ratings and swelling evoked by movement in patients with complex regional pain syndrome (CRPS) increased when patients viewed the affected limb enlarged and decreased when they viewed the limb reduced. However, different neurophysiological mechanisms underlie acute and chronic pain (Apkarian, Bushnell, Treede, & Zubieta, 2005; Moseley, Sim, Henry, & Souvlis, 2005). The links between the two mechanisms may be inhibitory, with acute pain inhibiting chronic pain (Baliki, Geha, Fields, & Apkarian, 2010). Further, different therapies relieve the two forms of pain (e.g., Chou & Huffman, 2007; Wiffen, McQuay, Edwards, & Moore, 2005). Note also that CRPS alters the territory of the affected limb in somatosensory brain regions (Maihofner, Handwerker, Neundorfer, & Birklein, 2003) and involves a complex pattern of disorders, including impaired body image and sense of ownership (e.g., Lewis, Kersten, McCabe, McPherson, & Blake, 2007). These physiological and psychological aspects of CRPS may mediate the effects of visual size.

In conclusion, we have shown for the first time that noninformative vision of one's own body has an analgesic effect on pain perception. Not only does viewing one's body reduce pain, but also the specific features of the visual content affect pain processing. Specifically, the analgesic effect is directly proportional to the spatial scale at which the body is seen and felt, with visual enlargement increasing analgesia and visual reduction decreasing it. Our results highlight a plastic and flexible link between representation of body size and pain perception. This suggests new possibilities for modulating acute pain cross-modally by manipulating vision of the body. Cognitive therapies that aim to relieve physical pain generally focus on the painful stimulus itself and thus may take the form of modulating expectations regarding pain sources and attention toward them. Here we have shown that the multisensory context in which pain occurs—in this case, the body and its appearance—is also important. Seeing the body enlarged attenuates pain. Consequently, looking beyond the painful stimulus to the body itself may have novel therapeutic implications.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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