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Feeling the burn: When it looks like it hurts, and belongs to me, it really does hurt more

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ABSTRACT

We examined changes in pain sensitivity in the rubber hand illusion (RHI). Experiment 1 investigated changes in pain tolerance immediately after a "healthy" and "wounded" RHI when immersing the hand in a cold pressor ice bath. There was 19% increased pain tolerance and increased perception detection threshold after the healthy RHI, but 11% reduction after the wounded RHI. Experiment 2 examined pain experience during the wounded RHI with capsaicin-induced hyperalgesia. Pain intensity and unpleasantness was higher on the illusion arm during the synchronous RHI, compared with asynchronous trials. There was no change in pain experience on the control arm, and both arms had similar pain sensitivity after the experiment. Our results highlight the impact of embodying a substitute limb on pain, with increased tolerance and reduced tactile sensitivity when the fake limb is healthy and apparently pain-free, but increased pain sensitivity when the self-attributed limb appears to be wounded.

1. Introduction

Some multisensory illusions, such as the rubber hand illusion (RHI), generate the experience that a fake hand belongs to oneself when it is stroked in synchrony with one's own hidden hand (Austen, Soto-Faraco, Enns, & Kingstone, 2004; Pavani, Spence, & Driver, 2000). The illusion purportedly results from an increased weighting towards visual information, over proprioceptive cues, inducing a remapping of perceived touch onto the visual location of the rubber hand (Posner, Nissen, & Klein, 1976). The illusion appears to result in alterations in physiological regulation with reduced limb temperature (Hohwy & Paton, 2010; Moseley et al., 2008), increased flare to histamine (Barnsley et al., 2012), and disturbance in sensory processing (Moseley et al., 2008) in the corresponding real limb. Although some of these effects have not been replicated (e.g., Hohwy & Paton, 2010; van Stralen et al., 2014), the illusion appears to reduce sensory processing in the corresponding limb, and may be a candidate for pain modulation. It is also an excellent paradigm for examining the impact of alterations in self-attribution on sensory processing.

To date there are inconsistent findings on the impact of the RHI on pain (Mohan et al., 2012; Valenzuela-Moguillansky, Bouhassira, & O'Regan, 2011). Some studies find that noxious sensations seem to simply be displaced onto the self-attributed rubber hand without changing intensity (Mohan et al., 2012), and one study reported that pain threshold was reduced during

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the RHI (Osumi, Imai, Ueta, Nobusako, & Morioka, 2014). However, others have shown that the RHI, virtual arm illusion and full body illusions (Hegedus et al., 2014; Martini, Perez-Marcos, & Sanchez-Vives, 2014) increase thermal and pressure pain thresholds (Hansel, Lenggenhager, von Kanel, Curatolo, & Blanke, 2011). Together, these effects may arise from reduced awareness and disownership of one's own body parts (McCabe, 2011) by attending to and perceiving ownership over healthy pain-free limbs.

While body illusions appear to show promise for generating analgesia, pain experience may also be *increased* when we see painful injuries. Changing the appearance of the fake arm during the RHI, such as making it appear to be red, which could give the illusion that it is acutely injured, *reduces* pain threshold (Martini, Pérez Marcos, & Sanchez-Vives, 2013). Similarly, projecting red and blue lights onto an embodied fake arm elicits warm and cool sensations, respectively (Durgin, Evans, Dunphy, Klostermann, & Simmons, 2007). More recently, Osumi et al. (2014) found that inducing an injured rubber arm illusion *reduced* thermal pain *threshold*. These findings are consistent with the fact that seeing painful images primes spinal nociceptive responses (Vachon-Presseau et al., 2011), and activates somatosensory and motor brain regions and pathways involved in pain experience (Lamm, Decety, & Singer, 2011). In fact, just thinking about pain activates affective pain processing brain regions such as the anterior cingulate cortex, medial prefrontal cortex and anterior insula (Lamm et al., 2011). Taken together, multisensory body illusions disrupt the processing and localisation not only of innocuous, but also noxious, bodily sensations in peripersonal space. However, nearly all of the previous studies looked exclusively at pain threshold, and not the intensity or unpleasantness of a standard painful stimulus.

It is yet to be determined whether such illusions of injury will modulate pain *tolerance* and subjective experience of pain intensity and unpleasantness. In particular, pain tolerance is clearly very different to simple thresholds with the latter relating to when an experience becomes painful, whereas tolerance relates to how long a painful experience can be endured. The implications for identifying whether techniques like the RHI play a role in increasing pain tolerance are therefore vastly different to simply understanding whether these techniques can increase or decrease the arbitrary point at which an experience *becomes* subjectively painful. To fill this gap, we undertook two experiments that investigated the effect of a regular "healthy" RHI and "wounded" RHI on pain tolerance. In a second experiment we investigated whether (a) the experience of concurrent capsaicin-induced hyperalgesia would increase the intensity of the RHI, compared with the intensity of the wounded RHI prior to topical application of capsaicin, and (b) the intensity and unpleasantness of capsaicin-induced hyperalgesia would be heightened during the wounded RHI (i.e., synchronous stroking trials) compared with an asynchronous stroking condition. The study results have important clinical implications for understanding the impact of awareness and self-attribution of injury on pain experience.

2. Experiment 1

The first experiment examined changes in pain tolerance and touch sensitivity after the RHI. Pain tolerance was tested using the cold pressor test, and touch sensitivity was assessed using Semmes Weinstein monofilaments, which measure tactile pressure sensitivity. We hypothesised that after the RHI we would see an increase in pain tolerance and perception detection threshold (PDT), and that these effects would be correlated with the intensity of RHI ownership. The wounded rubber hand, however, was expected to implicitly increase sensitivity to pain and to be followed by reduced pain tolerance and perception threshold.

2.1. Method

2.1.1. Participants

A total of 22 healthy participants were recruited from university advertisements, assuming that at least 3–4 participants would be excluded from data analysis based on upper limits in tolerance time. An a-priori exclusion criterion of 5 min tolerance time in the cold pressor test was applied as 5–10% of individuals acclimatise to the cold pressor (e.g., see Wolff, 1984), and therefore do not show variability when investigating pain tolerance. This sample size was expected to provide 80% power to detect a moderate effect size (partial eta = .45) on pain tolerance at $\alpha = .05$.

The final sample comprised 15 participants (9 male; aged 19–43; $M = 30$ years of age, SD = 6 years) after excluding 6 who exceeded the 5-min tolerance time for the cold pressor test. One female participant was also excluded because she had a disproportionately higher increase in pain tolerance from pre- to post-RHI in the healthy RHI session, and a higher reduction in pain tolerance from pre- to post-RHI test compared with all other participants. Although her data brought about a greater apparent effect, we felt that this probably exaggerated the effects that were typical. Participants were instructed to abstain from cigarettes and caffeine for two hours prior to testing. Participants were excluded if they reported any psychiatric, mood (e.g., anxiety or depression), cardiovascular or central nervous system disease (e.g., epilepsy); acute or chronic pain; or conditions that might interfere with the detection of pain sensations such as peripheral neuropathy (e.g., due to diabetes), Reynaud's disease, or arthritis, or any prior experiences or trauma that may result in a negative reaction to pain.

2.1.2. Study design

The study was approved by the university ethics committee, and participants provided informed consent before attending the laboratory twice, two weeks apart ($M = 13$ days; SD = 3 days). In each session, participants underwent baseline PDT