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Research report

Common and distinct neural mechanisms associated with the conscious experience of vicarious pain

Thomas Grice-Jackson [a,b,*], *Hugo D. Critchley* [b,c], *Michael J. Banissy* [d] and *Jamie Ward* [a,b]

[a] *School of Psychology, University of Sussex, UK*
[b] *Sackler Centre for Consciousness Science, University of Sussex, UK*
[c] *Brighton and Sussex Medical School, University of Sussex, UK*
[d] *Department of Psychology, Goldsmith's College, University of London, UK*

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ABSTRACT

Vicarious pain perception has been an influential paradigm for investigating the social neuroscience of empathy. This research has highlighted the importance of both shared representations (i.e., involved in both experiencing first-hand physical pain and observing pain) and mechanisms that discriminate between self and other. The majority of this research has been conducted in healthy younger adults using a group-average approach. There are, however, known inter-individual differences that can contribute to vicarious experience. One factor relates to the degree to which individuals experience reportable pain-like sensations/feelings in response to seeing others in pain. Here we conduct the first systematic investigation of the neural basis of conscious vicarious pain in a large sample of participants. Using cluster analysis, we firstly demonstrate that consciously experiencing the pain of others is surprisingly prevalent and, exists in two forms: one group experiences sensory and localised pain whilst the other group report affective and non-localised experiences. Building on this, we used electroencephalography (EEG) and structural brain imaging to examine the neural correlates of vicarious pain in the three different groups. We find that the dominant electrophysiological marker used to index vicarious pain in previous studies (mu and beta suppression) was only found to be significant in the sensory and localised pain responder group (with a sensitive null result in the 'neurotypical' group). Finally, using voxel-based morphometry (VBM) we identify a common differences in the two pain responder groups relative to typical adults; namely increased grey-matter in insula and somatosensory cortex and reduced grey matter in the right temporo-parietal junction (rTPJ). We suggest that the latter reflects a reduced ability to distinguish bodily self and other, and may be a common factor distinguishing conscious from unconscious vicarious experience.

* *Corresponding author*. School of Psychology, University of Sussex, Pevensey 1, Room 2C2, Falmer, East Sussex, BN1 9QH, UK.
E-mail address: t.grice-jackson@sussex.ac.uk (T. Grice-Jackson).

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Our capacity to share the experiences of others is a critical aspect of human social behaviour. One characteristic considered to be important to this process is the ability to match observed states of other people onto representations of our own body. This process has been referred to under several names in the literature including empathy, simulation, contagion, and vicarious perception/experience. There is now good evidence of a near universal tendency for humans to vicariously perceive the actions, emotions, and sensations displayed by others. This evidence has most commonly been provided by human brain imaging experiments that have shown that passively observing experiences (e.g., touch, pain, disgust, actions) recruits similar brain regions to those that become active when we experience the states ourselves (Molenberghs, Cunnington, & Mattingley, 2012). While most of us do not feel pain when observing pain to others, some individuals do experience overt sensations of pain when observing it in others (Fitzgibbon et al., 2012; Giummarra et al., 2014; Osborn & Derbyshire, 2010; Vandenbroucke et al., 2013). The source of such inter-individual difference in vicarious experience remains unknown. To explore this question, the current set of studies contrasts people who report experiencing the pain of others against the more typical scenario of those who do not. Whilst the latter participants could be construed as having an implicit simulation of pain, this notion is controversial as it relies on an assumption of reverse inference (i.e., inferring mental operations from brain activity). Crucially, our approach does not hinge on this assumption as we ask participants to report their state rather than infer it in this way.

Prior findings indicate that observing pain results in brain activity in neural regions that partial overlap with those involved in experiencing first-hand pain. Moreover, the central processing of first-hand experience of pain takes place in a widely distributed and nonexclusive network of regions known as the 'pain matrix' (Rütgen, Seidel, Silani, & Rie, 2015; Melzack, 1999; *for critical response see*; Iannetti & Mouraux, 2010). The primary and secondary somatosensory cortices and the posterior insula have been associated with the processing of the sensory qualities of pain and regions such as the cingulate cortices and the anterior insula have been associated with its affective processing. Functional magnetic resonance imaging (fMRI) findings have shown that the perception of pain (or empathy for pain) also involves activity within this network (Lamm, Decety, & Singer, 2011). This is most commonly linked to brain activity within the anterior insula and mid-cingulate, but the somatosensory cortices are also recruited when body parts are observed in pain, as opposed to simply knowing about the presence of pain. Further evidence for the involvement of sensory processes in vicarious pain has been provided by electroencephalographic (EEG) and non-invasive brain stimulation findings showing the suppression of neural activity, known to emanate from sensorimotor cortex, during the observation of pain (Avenanti, Minio-Paluello, Minio Paluello, Bufalari, & Aglioti, 2006; Bufalari, Aprile, Avenanti, Di Russo, & Aglioti, 2007; Cheng, Yang, Lin, Lee, & Decety, 2008; Martínez-Jauand et al., 2012; Yang, Decety, Lee, Chen, & Cheng, 2009).

While of clear importance, these influential studies have not considered whether individuals are consciously experiencing the pain of others or not, despite other research showing that consciously experienced vicarious pain may be as common as 15–30% (Fitzgibbon et al., 2012; Giummarra et al., 2014; Osborn & Derbyshire, 2010; Vandenbroucke et al., 2013), and are linked to different profiles of brain activity when observing pain in other people (Osborn & Derbyshire, 2010). The studies, however, have been limited in a number of important ways. The cut-off score on the screening procedures are arbitrary and, hence, the prevalence rates themselves are not independently derived. Finally, qualitative differences in the nature of conscious vicarious pain perception (e.g., 'stinging', *vs* 'wincing') have not been used to discriminate people. The novel approach taken here addresses these issues by using a data-driven approach (a k-means cluster analysis, Zhang, Ramakrishnan, & Livny, 1996) such that the diagnostic cut-off (hence, prevalence) and the groupings reflect the individual differences inherent in the data rather than being set by the experimenter.

Why is it that some people might report conscious vicarious pain experiences and for others do not? There are several possibilities. One is that the same neural mechanisms are used for both groups of individuals but that, in the case of conscious vicarious perception, the level of activity exceeds a threshold for perceptual awareness (so-called Threshold Theory, *see* Ward & Banissy, 2015). Another possibility is that different regions within the pain matrix discriminate between these different modes of vicarious perception (de Vignemont and Jacobs, 2012). For instance, the sensory regions of the pain matrix may be crucial for conscious vicarious pain (Osborn & Derbyshire, 2010). A final possibility is that it is regions outside of the pain matrix (i.e., that do not normally respond to physical pain) that underpin this difference. In addition to shared representations, recent accounts of empathy highlight the importance of mechanisms for discriminating self and other (to avoid self-other confusion), which determines whether feeling states are attributed externally or internally (Bird & Viding, 2014; Decety & Jackson's, 2004). This has frequently been linked to the right temporo-parietal junction (rTPJ). This region may provide flexibility in terms of the degree of vicarious perception that takes place (e.g., resulting in a greater vicarious pain response to racial in-groups, Avenanti, Sirigu, & Aglioti, 2010) and a disruption of this cognitive flexibility may result in an over-reliance on shared representations and a tendency to consciously experience the pain of others (so-called Self-Other Theory, Ward & Banissy, 2015). The rTPJ has a particularly important role to play in embodiment: tDCS stimulation of this region can lead to a reduced tendency to imitate (Santiesteban, Banissy, Catmur, & Bird, 2012), and disturbed body ownership (Tsakiris, Costantini, & Haggard, 2008), including out-of-body experiences (Blanke et al., 2005).

The current studies aim to identify, characterise and profile conscious vicarious pain and to assess the neurological basis of this experience using a multi-method approach. Study 1 presents evidence for three qualitatively different forms of vicarious pain perception using a new measure, the VPQ (Vicarious Pain Questionnaire) along with a two-step cluster analysis to produce data driven groups based on VPQ responses. Study 2 examines vicarious pain in the sensorimotor cortices observed via suppression of EEG oscillations in