Consciousness and Cognition 60 (2018) 62–71

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Atypical susceptibility to the rubber hand illusion linked to sensory-localised vicarious pain perception

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ARTICLE INFO

Keywords:
Rubber hand illusion
Vicarious pain perceptions
Shared representations
Body ownership

ABSTRACT

The Rubber Hand Illusion (RHI) paradigm has been widely used to investigate the sense of body ownership. People who report experiencing the pain of others are hypothesised to have differences in computing body ownership and, hence, we predicted that they would perform atypically on the RHI. The Vicarious Pain Questionnaire (VPQ), was used to divide participants into three groups: (1) non-responders (people who report no pain when seeing someone else experiencing physical pain), (2) sensory-localised responders (report sensory qualities and a localised feeling of pain) and (3) affective-general responders (report a generalised and emotional feeling of pain). The sensory-localised group, showed susceptibility to the RHI (increased proprioceptive drift) irrespective of whether stimulation was synchronous or asynchronous, whereas the other groups only showed the RHI in the synchronous condition. This is not a general bias to always incorporate the dummy hand as we did not find increased susceptibility in other conditions (seeing touch without feeling touch, or feeling touch without seeing touch), but there was a trend for this group to incorporate the dummy hand when it was stroked with a laser light. Although individual differences in the RHI have been noted previously, this particular pattern is rare. It suggests a greater malleability (i.e. insensitivity to asynchrony) in the conditions in which other bodies influence own-body judgments.

1. Introduction

The rubber hand illusion (RHI) paradigm (Botvinick & Cohen, 1998) is an established means of investigating and manipulating the sense of body-ownership including body location, image, and agency (Ehrsson, Spence & Passingham, 2004; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008; Tsakiris & Haggard, 2005). In this paradigm, the participant's hand is hidden from view and a dummy hand is placed in view, alongside the real hand. The hidden and dummy hands are then stroked either synchronously or asynchronously. The illusion is significantly stronger in the synchronous condition, when the participant *feels* the touch delivered to the visible dummy hand as if the hand belonged to him/her. Thus, when the illusion occurs, the rubber hand becomes temporarily incorporated in the participant's mental body representation. This is reflected in a perceived shift in the position of one's own hand towards the fake hand, a phenomenon termed proprioceptive drift. The objective measure of proprioceptive drift complements self-reported questionnaire ratings through which participants report their experience of ownership, self-location, and agency over the fake hand.

The RHI arises through the integration of multisensory information with reference to an internal body representation (Costantini

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https://doi.org/10.1016/j.concog.2018.02.010
Received 11 September 2017; Received in revised form 1 February 2018; Accepted 21 February 2018
1053-8100/

& Haggard, 2007). According to this model, visual, proprioceptive, and somatosensory inputs are processed within higher order multimodal integration areas (Ehrsson, et al., 2004; Limanowski & Blankeburg, 2015). As such, the illusion is the strongest when distinct external inputs match each other (as shown by the difference between synchronous and asynchronous stroking, Botvinick and Cohen, 1998) and also when external inputs match internal representations of the body (Tsakiris, 2010). The RHI is greater when the rubber hand looks similar, has same orientation and side as the real hand (e.g. both left or both right) and when the hand is within the peripersonal space (PPS) of the person (Preston, 2013). Thus, the viewed object is tested against an abstract model of one's body for 'fit', to determine whether or not the dummy hand is incorporated within the body model in a process that involves both bottom-up and top-down mechanisms (Tsakiris, Costantini & Haggard, 2008). In some circumstances, the illusion can also occur in the absence of visuo-tactile congruency. The illusion can be induced in a 'light only' condition, when the dummy hand is 'stroked' by a laser-pointer but no light/tactile stimulation is applied to the real hand (Durgin, Evans, Dunphy, Klostermann & Simmons, 2007). Here, participants who report tactile and thermal sensations evoked by the light-beam also report stronger feeling of ownership of the dummy hand.

Atypical performance on the RHI has been linked to various psychiatric and developmental conditions, as well as sub-clinical individual differences. Differences in the RHI are observed in patients with autism (Paton, Hohwy, & Enticott, 2011; Palmer, Paton, Hohwy & Enticott, 2013), schizophrenia (Thakkar, Jimenez, & Costantini, 2011), neurotypical variations linked to schizotypy (Germine, Benson, Cohen, & Hooker, 2013; Kallai et al., 2015), in eating disorders including anorexia nervosa (Eshkevari, Rieger, Longo, Haggard, & Treasure, 2011; Kaplan, Enticott, Hohwy, Castle & Rossell, 2014), and in mirror-touch synaesthesia (Aimola Davies & White, 2013). In the latter, participants report experiencing touch when seeing others touched and, during the RHI paradigm, report ownership of the rubber hand when it is stroked but no physical touch is applied to the participant's own hand. This may occur because the observed touch triggers a synchronised feeling of touch on their own body, analogous to the normal effect of synchrony in the RHI (Aimola Davies & White, 2013). However, it may also reflect more general differences in computing body ownership in this group: in effect, a tendency to misattribute other people's bodies as their own (Ward & Banissy, 2015). In the present study, we extend this to a similar related phenomenon, mirror-pain synaesthesia), namely to individuals who report feeling pain when seeing pain in others.

Seeing someone else in pain activates neural circuitry involved in the physical perception of pain (Jackson, Brunet, Meltzoff & Decety, 2006; Lamm, Decety & Singer, 2011). However, for a subset of the general population this extends to reportable pain-like experiences evoked by observing others in pain (Fitzgibbon, Giumarra, Georgiou-Karistianis, Enticott, & Bradshaw, 2010; Fitzgibbon et al., 2012; Osborn & Debyshire, 2010). These individuals have been called vicarious pain responders, or mirror-pain synaesthetes. Ward and Banissy (2015), in their account of mirror-touch/pain synaesthesia, suggest that this may reflect an over-inclusive body ownership mechanism, in which all observed bodies are matched to the person's own internal body model, or as a failure in a top-down orienting mechanism for selective attention to the self that inhibits representations of the (non-self) other. Whatever the precise mechanism, the prediction is that a greater tendency to treat all observed bodies as self-related will result in an increased tendency to experience the RHI, as well as the tendency to report experiences on their own body as a result of observing these on other people (the defining feature of mirror touch/pain).

One study already tested the performance of vicarious pain responders on the RHI using only subjective reports (not proprioceptive drift). Derbyshire, Osborn, and Brown (2013) showed a greater tendency to incorporate the rubber hand in the pain-responder group when compared to controls and this effect was unusually apparent for the asynchronous stroking condition (which tends not to induce the illusion in controls). We extend this to include five different manipulations of the RHI, including conditions in which the dummy hand is observed without any physical touch, and grouping participants via a new assessment tool for vicarious pain experience (Grice-Jackson, Critchley, Banissy & Ward, 2017a). The Vicarious Pain Questionnaire (VPQ) employs 16 movie clips depicting people experiencing physical pain, and probes the phenomenological characteristics of any felt pain sensations provoked in the observer (e.g. pain quality, pain intensity, pain localisation). Using a bottom-up approach of cluster analysis, three groups are identified: (1) non-responders or controls (who report no pain when watching a video with someone else experiencing physical pain), (2) sensory-localised responders (S/L) (who report a precisely localised feeling of pain at the same location as the person in the video) and (3) affective-general responders (A/G) (who report a generalised and emotional feeling of pain). The validity of these groupings is endorsed by observed difference in structural and functional brain characteristics (Grice-Jackson et al., 2017a, Grice-Jackson, Critchley, Banissy, & Ward, 2017b) and, in the present study, we demonstrate cognitive differences between the groups and provide the first assessment of test-retest reliability of the VPQ.

Using the VPQ to group and recruit participants, we tested both subjective and objective measures of the rubber hand illusion, with five different manipulation. Two of these manipulations were the standard synchronous and asynchronous conditions. Based on published findings (Derbyshire et al., 2013), we predicted that individuals within the responder groups to be less sensitive to synchrony (i.e. they will show the illusion in both conditions). We had no predictions about whether this effect would be found for one or both responder groups. Two further manipulations involved the visual presentation of touch from a paintbrush or light from a laser pointer in the absence of any physical sensation. Here, our prediction was that the sensory-localised group (who feel sensations in the same location that they observe them on others) would show the RHI illusion, as found for mirror-touch synaesthesia (Aimola Davies & White, 2013). The fifth condition involved the reverse scenario of feeling touch while observing an untouched dummy hand. We were not aware of any previous report of this manipulation inducing the RHI, hence, this serves as an important control measure across all groups to assess for a general bias in responding.