Correspondences

Induction of mirror-touch synaesthesia by increasing somatosensory cortical excitability

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Understanding others' tactile sensations is a fundamental component of social behaviour. This complex process is most likely supported by a 'mirror' network for touch, which allows for an automatic and unconscious simulation of others' somatic states [1]. In everyday life, we are typically unaware of this process, because the system is physiologically active below the threshold of perceptual awareness. In a minority of persons with synaesthesia, however, the sight of a touch on another person elicits conscious tactile experiences on their own bodies — mirror-touch synaesthesia [2]. This peculiar crossmodal experience has been attributed to an unusual activation of the mirror mechanisms for touch — a visual stimulus that elicits a tactile sensation [3] — but this hypothesis requires empirical support. Here, we report the existence of a causal brain-behaviour relationship between increased excitability of two key areas of the tactile mirror system and the emergence of synaesthesia-like effects in non-synaesthetes. Furthermore, we show that individual differences in empathic capacity may modulate the ability to resonate with others' somatic feelings.

We used transcranial direct current stimulation (tDCS), a non-invasive brain stimulation technique that, when delivered with anodal polarity, can increase cortical excitability [4]. We combined tDCS with a vision–touch interference task specifically developed for studying mirror-touch synaesthesia [2]. In the vision–touch task, participants view a touch to a body part, or to an object, while simultaneously receiving a tactile stimulus; they are then asked to report the location of the felt touch, ignoring the viewed touch. Synaesthetes are typically less accurate and slower at identifying the site touched on their body, when the actual touch is spatially incongruent with the viewed touch compared with congruent trials. This implies that synaesthetes mistake synaesthetic touch (the viewed touch) for real touch. These effects are specific for the touch of human body parts and do not extend to objects. This crossmodal interference is absent in non-synaesthetes [2]. We hypothesised that, by increasing the excitability of the tactile mirror system via anodal tDCS, crossmodal interference effects may be revealed in non-synaesthetic individuals.

Non-synaesthetic individuals participated in two versions of the vision-touch interference task, one showing a touch to human hands (Figure 1A), and one showing a touch to an object (lamp), while receiving anodal or sham tDCS to the primary somatosensory cortex (S1) or to the premotor cortex (PM) of the right (N = 16) or of the left (N = 16) hemisphere (see Supplemental Information for details). Both of these areas are part of the tactile mirror system and may be over-active in mirror-touch synaesthesia [3]. Analysis of variance (ANOVA) of the reaction times, with Hemisphere (right/left) as the between-subjects factor, and Task (hand/object), tDCS (Sham/S1/PM), Side (ipsilateral/contralateral to tDCS) and Stimulus (unimodal touch/congruent/incongruent vision-touch) as the within-subject factors, showed a significant Task by tDCS by Side

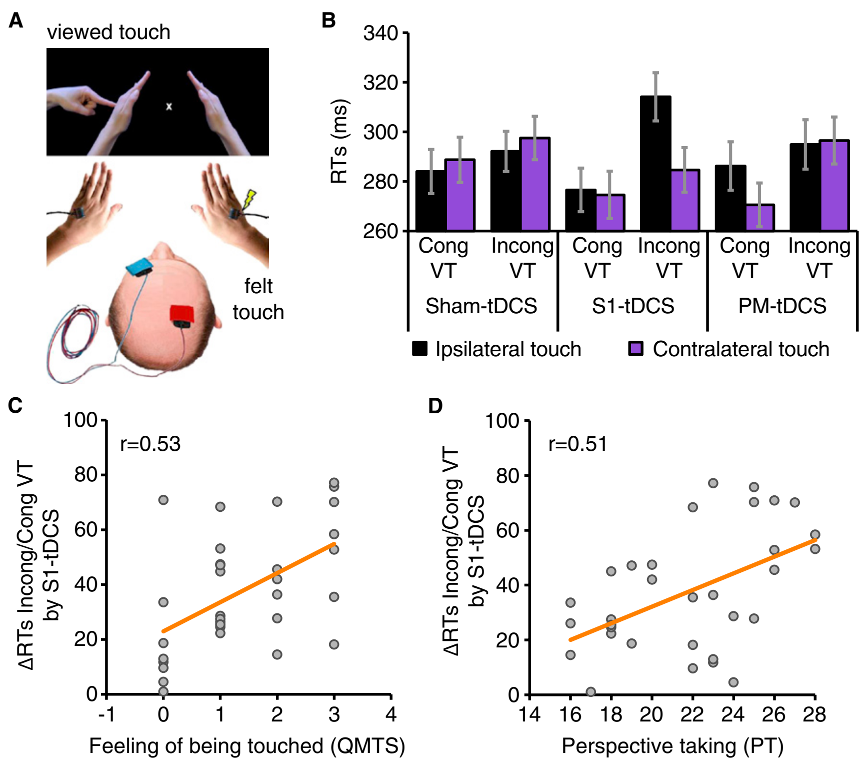

Figure 1. Induction of mirror-touch synaesthesia by transcranial electrical stimulation.
(A) An incongruent visuo-tactile (VT) trial of the Hand task. The task (~6 min) was to report the site of the actual touch on the hand, while ignoring the viewed touch at the same (Congruent VT) or opposite location (Incongruent VT). In counterbalanced sessions, anodal or sham tDCS (1.5 mA, ~16 min) to S1 or PM of both hemispheres was delivered with a pair of surface electrodes (Red electrode = anodal, blue electrode = reference). (B) The graph depicts the tDCS effect on reaction times in visuo-tactile trials in the Hand task only, highlighted by the Task by tDCS by Side by Stimulus interaction ($P < 0.0001$). Error bars = S.E. (C) Correlation scatterplots ($P < 0.01$) for the subjective synaesthetic feeling of being touched during the Hand task (abscissa) from the Questionnaire of Mirror Touch Synaesthesia (QMTS), and (D) for the IRI's Perspective Taking subscale (abscissa), displaying the S1-tDCS effect in the Hand task (ordinate, Incongruent/Congruent VT difference; positive values, slower responses in incongruent trials).

by Stimulus interaction ($F_{4,120}$ = 11.99, $P < 0.001$): the enhancement of S1 excitability by anodal tDCS promotes the emergence of synaesthesia-like effects, without hemispheric asymmetries.

Hence, non-synaesthetes became slower at localizing a site touched on their hands when they simultaneously viewed a touch to the opposite hand (Figure 1B). This result mimics the behavioural pattern characteristic of mirror-touch synaesthesia [2]. Moreover, the crossmodal interference was specific for images of touch to a human, being absent when the hands were replaced by lamps, and it occurred only when the visual touch was spatially incongruent to the actual touch, namely the visual touch on the side contralateral to the tDCS and the actual touch ipsilateral to tDCS [2,3,5,6]. This side-specificity may be attributed to the fact that the visual stimuli presented in the contralateral hemifield are relayed to the hemisphere processing enhanced by tDCS, bringing about the synaesthetic effect. Additionally, our visual stimuli might have maximised the self-attribution of the observed touch to the observer's own body because they depicted a hand being touched by an index finger, as viewed from an egocentric perspective, therefore favouring an anatomical mapping of the observed touch, as observed in mirror-touch synaesthesia [2].

Although during S1-tDCS participants did not report any change in their perceptions, the crossmodal interference induced by S1-tDCS was associated with their self-reports of synaesthetic sensations ($r = 0.53$, $P < 0.01$, Figure 1C) and of difficulty in localising touches in incongruent trials ($r = 0.56$, $P < 0.01$), as assessed with an ad-hoc questionnaire (see Supplemental Results).

Considering that mirror-touch synaesthetes report subjectively higher levels of affective empathy [2], and mirror-like somatosensory activations are linked with inter-individual differences in cognitive aspects of empathy [7], we assessed the association between the tDCS-induced synaesthetic-like effects and empathic abilities of non-synaesthetes. We found that the greater was the participant's ability to adopt the subjective perspective of others, namely the empathy subscale 'Perspective Taking' of the Interpersonal Reactivity Index (IRI) [8], the greater was the crossmodal interference induced by S1 stimulation ($r = 0.51$, $P < 0.01$, Figure 1D). This suggests that mirror-touch synaesthesia may represent an extreme manifestation of a physiological process involved in understanding others' somatic sensations [1]. Notably, in non-synaesthetes, different aspects of empathy seem to depend on discrete neural substrates: affective empathy may be elicited when seeing others in pain, and it is associated to the activation of the insula and of the sensorimotor areas [1], while cognitive empathy seems more involved when watching others being non-painfully touched, and involves S1 activity [7].

Conversely, increased excitability in the PM facilitated the integration of spatially congruent viewed and felt touches, contralateral to the site of tDCS, without inducing synaesthesia-like effects (Figure 1B). This finding supports the role of the PM in multisensory integration of bodily signals, a process that may also produce touch referral [9]. Interestingly, the crossmodal facilitation induced by PM-tDCS was not associated with empathy, thereby confirming the functional dissociation between S1 and PM within the tactile mirror system.

Thus, increasing the activity of somatosensory areas that contain shared representations for viewing and experiencing touch favours the emergence of synaesthetic-like phenomena in non-synaesthetes. Simulation of others' somatic sensations in S1 may underpin our ability to empathise with others, and thus may be important for social behaviour. Mirror-touch synaesthesia reflects general crossmodal mechanisms associated with empathetic abilities, rather than an anomaly resulting in the breakdown of modularity [10].

Supplemental information

Supplemental Information includes results, experimental procedures, one figure, one table and one movie and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2013.03.036.

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