Embodiment of others' hands elicits arousal responses similar to the own hands

Embodiment of others' hands elicits arousal responses similar to one's own hands

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Does 'my' body representation refer only to 'me' or can another person's body parts be incorporated into my own somato-sensory experience? And, if so, does this incorporation elicit physiological reactions similar to those observed for one's own body? The aim of the present study was to test this hypothesis in a monothematic delusion of body ownership, in which brain-damaged patients claim that the examiner's hand is their own [1,2]. By recording the skin conductance response (SCR) during noxious stimulations, we have found that an alien hand can be so deeply embedded into a patient's somato-sensory experience as to elicit physiological reactions of a kind normally specific to one's own hands.

Body awareness can be dramatically impaired after brain damage. In some cases, when the examiner's hand is located in the patient's contralesional (affected) side, in egocentric, body-congruent perspective, patients immediately identify it as their own (see Supplemental Movie S1). Interestingly, when the examiner moves his/her hand, the patients claim that they are moving their own hand (Movie S2), and if painful stimuli are delivered to the examiner's hand, the patients state that they feel pain from that 'alien' hand (Movie S3). A previous study [1] showed that this phenomenon may reflect an embodiment mechanism capable of altering the patients' motor behavior. We focused on the somatosensory domain and we asked whether the pathological subjective experience of feeling pain from an alien (embodied) hand is only a mere verbal confabulation or if it has a physiological counterpart. To this aim, we recorded the SCR, a measure of autonomic arousal which, although not nociceptive-specific (for example [3]), it is known to detect sympathetic responses to the expected noxious stimuli [4–6].

Six right-brain-damaged patients, three with (E+) and three without (E-) the alien-limb-embodiment, and ten age-matched healthy subjects were administered a nociceptive stimulation protocol during SCR recording. Noxious stimuli were overtly applied by using a nociceptive stimulator on both the subject's own and alien hands (either on the right or on the left body side; Figure 1A). The patients had to rate the perceived sensation on a 0–5 Likert scale, with 0 indicating 'no nociceptive sensation' and 5 indicating 'clear nociceptive sensation'. It is important to stress that the patients were only recruited for this study if they perceived somatosensory stimuli on their affected body side (i.e. if they did not have hemianesthesia; Supplemental Table S1). The ethical considerations as well as the methodological, clinical, and anatomical details are described in the Supplemental Information.

If the sense of ownership — the belief that a specific body part belongs to the own body — modulates the arousal responses to noxious stimuli [4–6], we could expect different results in controls (healthy subjects and E- patients) with intact body awareness, and in E+ patients with pathologic delusion of ownership. In particular, significant differences between own and alien hands were expected in the controls, while significant differences between left (embodied) and right (not-embodied) alien hands were expected in E+ patients. Alternatively, according to the empathy-for-pain literature [7], which suggests that, in social contexts, the same mechanisms underpinning the perception of physical pain are also involved in experiencing the pain of others, we should expect to find, in both E+ patients and controls, similar SCR values when the own and alien hands were stimulated.

A 2*2*3 ANOVA with the peak-to-peak SCR mean values (in Z-scores; Supplemental Information) as dependent variable, one between-factor 'Group' (Controls/E-/E+) and two within-factors 'Side' (Left/Right) and 'Ownership' (Own/Alien), showed a significant interaction Side*Ownership*Group: $F(2,13) = 18.2$; $p = 0.0001$. As shown in Figure 1B, both in Controls and E- patients, the SCR amplitude was significantly greater when the stimuli were delivered to the own rather than alien hand, irrespective of the stimulated side ($p < 0.01$, at planned comparisons). On the contrary, in E+ patients, significantly greater SCR values were found when the stimuli were delivered to the embodied (left) with respect to the not-embodied (right) alien hand ($p = 0.00001$). Furthermore, in E+ patients, the SCR value for the own affected hand was significantly lower than that found for both the embodied alien hand and intact own hand ($p < 0.01$). For each group (Controls, E-, E+), an example of the SCR waveforms is shown in Figure 1C. Crawford's tests [8] confirmed the significant difference between each E+ patient's affected side and both sides of the controls (E+1: $p = 0.01$; E+2: $p = 0.02$, E+3: $p = 0.03$ two tailed). Moreover, the SCR values significantly predict the extent to which the patients experienced the noxious stimuli (linear regression: SCR coefficient ± std. error: 2.43 ± 0.46; $R^2 = 0.6$; $p < 0.001$; Figure 1D and Supplemental Information).

These data show that when E+ patients report feeling pain on an alien (embodied) hand, their claim is not a mere verbal confabulation because it has a physiological counterpart in the modulation of the SCR related to the expectancy of noxious stimuli. Moreover, the results are in keeping with the hypothesis that the SCR modulation is exerted by top-down processes related to the sense of body ownership. In the controls, the results showed that the SCR was evocated, only when they received stimuli on their own hands and reported feeling pain on them. As for the E+ patients, SCR comparable to that found for the own intact hand was also found for the alien hand, but only when the patients believed that it was their own hand and claimed to feel pain on it (i.e. when it was located on the affected side, in a body-congruent position; Supplemental Information, Figure S1 and Movie S3). Interestingly, E+ patients also showed, for the own affected hand, lower SCR values with respect to the own intact and alien embodied hand. Although they

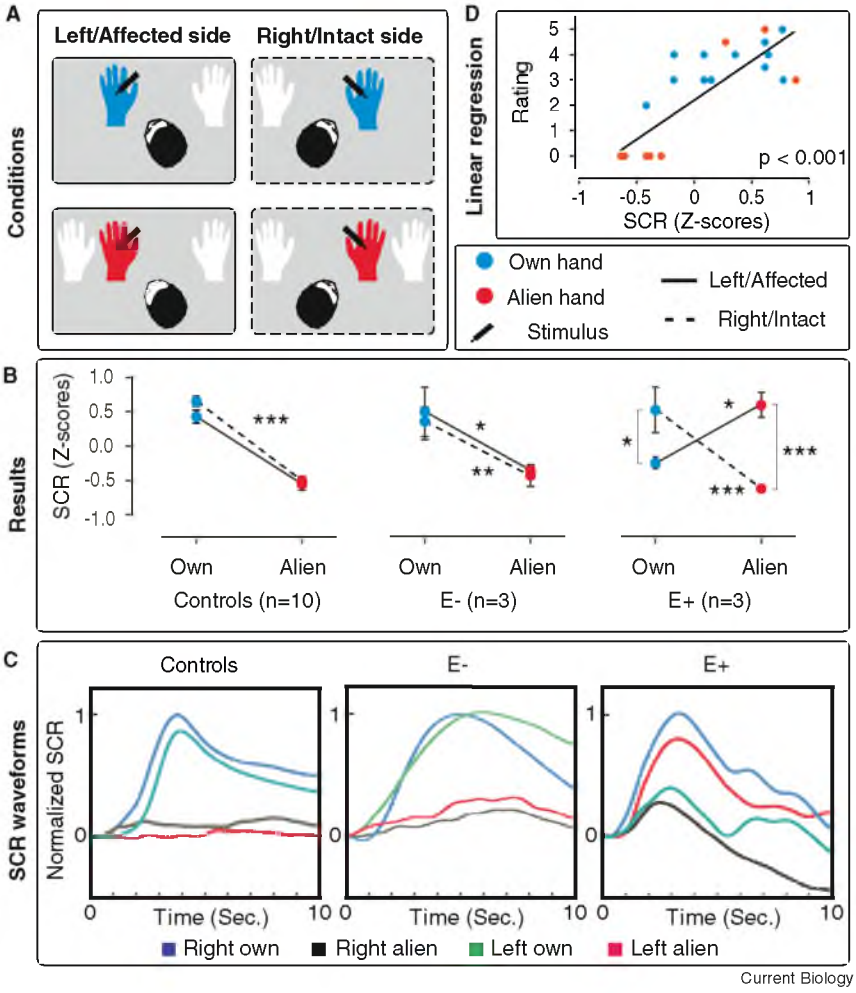

Figure 1. Experimental task and SCR results.
(A) Experimental task. In the 'own' conditions, the participants placed their arms on a table and either the right or the left hand dorsum was stimulated. In the 'alien' conditions, the co-experimenter's arm was placed alongside the participants' arm, either on the right or on the left body side, and the co-experimenter's hand dorsum was stimulated. A sequence of five stimulations per each condition was repeated twice in a counterbalanced order (ABCD-DCBA). (B) SCR ANOVA results. Graphs show the peak-to-peak SCR mean values expressed in Z-scores (with standard errors) for the Controls group (n = 10) and for the two groups of patients without (E-; n = 3) or with (E+; n = 3) the pathological embodiment. * P < 0.01; ** P < 0.001; *** P < 0.0001. (C) Examples of SCR waveforms. An example of the SCR waveform was shown for each group (Controls, E-, E+), normalizing raw data and averaging all the trials (n=10) for each condition. (D) Linear regression "rating by SCR" results. The mean SCR (expressed in Z-scores) value was used as an independent variable to predict the perceived sensation scores reported by the patients on a 0–5 Likert scale. The P value is reported in Figure.

did not deny that the affected hand belonged to their body, the lower SCR values revealed an implicit form of disownership for the affected hand, like in somatoparaphrenic patients [9], who show a reduced SCR when threatening stimuli approach the contralesional hand, and they explicitly consider it as not belonging to themselves [6].

The visual monitoring of an approaching stimuli and the mental representation of one's own body play a crucial role in determining physiological reaction, alerting the subject to a possible danger directed toward the own body and activating defensive behaviors [10]. Our study shows that when the sense of body ownership is altered by brain damage, such an alerting physiological response can be triggered by noxious stimuli delivered to an alien hand that becomes a part of one's own body. According to classical neuropsychological inference, this implies the existence, in the normal functioning of the human brain, of a specific neural process that binds self-awareness to one's own body, as opposed to other bodies.

Acknowledgements
This study was funded by a Compagnia di San Paolo grant and a MIUR-PRIN grant (to A.B.). The authors are indebted to all of the patients involved in the study. We are also grateful to Angelo Marvaita for his suggestions on the first draft of the paper.

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