Sensations Evoked in Patients With Amputation From Watching an Individual Whose Corresponding Intact Limb Is Being Touched

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Background: After amputation of a limb, the majority of patients experience phantom sensations, such as phantom pain. Such patients provide an opportunity for the exploration of the perceptual correlates of recently discovered "mirror neurons," which fire not only when individuals move their own limb but when they watch the movements of the corresponding limb of another person. Similar neurons exist in the secondary somatosensory cortex for touch: they fire when the individual is touched or simply watches another person be touched. While these neurons cannot by themselves discriminate between the two, the mind is aware of the difference between feeling and watching; one does not confuse empathy with actual experience.

Objective: To investigate whether patients with amputation experience the sensations of another person in their own phantom limb during the mere observation of someone else being touched, owing to removal of the inhibition of the mirror neuron system that would have occurred had the limb been intact.

Design: Case report.

Setting: University campus, academic setting.

Patients: Four patients with upper-limb amputation.

Main Outcome Measures: The subjective reports of patients.

Results: We report that 4 individuals with arm amputation, the mere watching of the intact hand of another being touched evokes vivid, precisely localized sensations in their own phantom hands.

Conclusions: We suggest these evoked sensations are owing to removal of neural signals from the hand that would have ordinarily inhibited the response of the mirror neurons and prevented their activity from reaching the threshold of conscious awareness.

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NEURONS IN THE PREFRONtal cortex send signals down the spinal cord that orchestrate skilled and semi-skilled movements such as putting food in the mouth, pulling a lever, pushing a button, etc.[1] These are "ordinary" motor command neurons, but some of them, known as mirror neurons, also fire when one merely watches another person perform a similar act. It is as if the neuron (or, more strictly, the network of which the neuron is part) used the visual input to do a sort of "virtual reality simulation" of the actions of the other person. This allows one to empathize with the other person and view the world from his or her point of view.[2-5]

There are also "touch mirror neurons" in the secondary somatosensory cortex that fire not only when the skin is touched but also when one merely watches someone else being touched.[5,6] This raises an interesting question: how does the neuron know what the stimulus is? Why does the activity of these neurons not lead one to literally experience the touch delivered to another person? How does "oneself" know who is being touched? One possibility is that the tactile receptors in the skin tell the other touch neurons in the cortex (the nonmirror neurons) that they are not being touched, and this null signal prevents touch sensations from reaching the threshold of conscious awareness. The net result is that one empathizes with but does not actually experience the touch quale.

This hypothesis, even though it is speculative, makes a straightforward but counterintuitive prediction. If one's arm is amputated, one should suddenly start to experience the sensations of the same-side arm of other people[7] when one watches them. We had earlier seen pre-

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liminary hints of such a finding and now report the results of systematic experiments.

METHODS

Four patients (referred to herein as patients 1-4) with upper limb amputations who reported having experienced vivid phantom limb sensations were recruited for the experiment.[8-10] One of the patients had been studied previously by V.S.R. and a colleague.[9]

Patient 1, age 22, had undergone amputation above his left elbow 11 months previous to testing, following a crushing injury. Patient 2, age 21, had undergone amputation 7.62 cm below the right elbow 12 months previous to testing. His arm had been severed in an army vehicle accident. Patient 3, age 50, had undergone amputation above the left elbow following a sarcoma 4 years previous to our work with him. Patient 4, age 40, had had a left brachial avulsion 24 years previously and amputation 12 years previously. All were mentally lucid. None had any other neurological abnormalities except for Horner syndrome in the left eye of patient 4. None of the patients was aware of the purpose of our experiments.

We requested that an assistant place her hand on a table in front of patient 1 so that it was close (eg, 30.48 to 45.72 cm) to the phantom hand of the patient but not actually on top of it. The hand of the assistant could either be parallel to the phantom hand or orthogonal to it (at a 90° angle) or pointing in the opposite direction (ie, toward the patient). We then repeatedly stroked and rubbed the hand of the assistant as the patient watched. Each "stroke" was over a length of 5.08 cm on the skin of the assistant and was delivered quickly (a one-half second duration) 10 times with an inter-stroke interval of a half second (roughly 10 seconds total); we randomly varied the location or direction after every couple of strokes (to avoid habituation, if any). The patient was asked to report whether he felt anything on any part of his body, including the phantom limb. If he reported a sensation, he was asked to say (or point to) where it was felt.

Each cluster of strokes, which lasted 10 seconds total, was repeated 8 times, again with a movement to randomly chosen locations on the hand of the student during different trials. The 8 clusters were separated from each other by 20-second intervals so that the entire session lasted roughly 3 minutes. Since the patients claimed, without prompting (see the "Results" section), that sensations were felt vividly by the phantom hand, the patients were asked explicitly whether they felt anything in their intact hand. They reported that this never happened.

We then applied the touch stimuli to the brow of the assistant while the patients watched; we asked whether the patients felt the touch on their brow or their phantom limb. This stimulus-and-questioning sequence was repeated 6 times per patient (the stimulus and intertrial durations were identical to those of the previous experiment and replicated in all subsequent experiments). Lastly, we asked the patient to watch the assistant while we rubbed a piece of ice on her hand. He was asked if he ever felt the cold (or any sensation) anywhere on the body, including the phantom limb. This was repeated 6 times for each patient. The cold trials were done independently, ie, not interspersed with the touch sessions.

For patients 1, 2, and 3, the experiment was repeated 2 weeks later by means of identical procedures and an identical number (8) of trials for each patient. The entire experiment was repeated for patient 4, by means of the same experimental protocol except that the 2 testing sessions were separated by 2 months. For patient 4, special attention was paid to topography; ie, to see if the location of referral to sensation depended on the specific part of the hand of the assistant that was touched (eg, thumb, index finger, palm, etc). We also repeated the ice experiment with him.

Finally, 16 control individuals with no amputations were recruited. The protocol used was similar (but since no referral was given by any control individual, the procedure was not repeated a week later). The instructions given were identical.

RESULTS

Patients 1 through 4 experienced vivid and consistent referral on almost all trials (61 out of 64). The 3 trials in which patient 2 experienced hesitation or doubt were counted as "no referral."

The subjective accounts of the patients were interesting. All stated they were surprised by the experience, especially during the first few trials (comments included, "It's spooky, sir" and "Well, I learn something new about my phantom every day"). All of them claimed to experience a latency of about 5 seconds during the first 3 or 4 trials (and a latency of 1 or 2 seconds on subsequent trials) before the referral occurred and asked us why this was the case. Patient 4 commented that this latency may have been the reason he had not noticed the effect himself before this experiment ("Sensations sometimes come and go, and I probably wasn't paying attention—nor do I often continuously watch people stroke themselves in the manner you just did").

The topography was also nearly always stable and consistent for patient 4. The stroking of the thumb of the assistant elicited sensations of being stroked on the phantom thumb, pinky to pinky and palm to palm. The third and fourth digits were not delineated; on many trials there was a "diffuse" sensation that spread across and beyond those digits in the phantom hand when either of those fingers of the assistant was touched. It was our impression that there was topography in the other 3 patients as well, but because they were the first patients to be tested, we did not have the opportunity to specifically study this aspect of their referral.

In patients 1 through 3, there was no referral of cold. They each reported spontaneously that they felt the rubbing but not the cold. This was true no matter how long they watched ("Well, I expect the cold in my phantom, but I can't feel it: no wetness, no cold, just the touch"). This is an important distinction, as it reduces the likelihood that these effects are confabulatory; why would touch be referred and not cold? Patient 4, however, reported a vivid experience of cold on every single trial: he seemed amused and surprised by the sensation. He noted that touch was referred first, followed a few seconds later by the arrival of cold. This was true on all trials.

All 4 patients also noted, 3 without our having questioned them, that on some occasions when the assistant wiggled her hand slightly, the phantom limb felt like it was wiggling. The referral of touch was enhanced, if initially "primed," by the wiggle (perhaps by sensory or attentional enhancement of the phantom limb itself). The reason for this finding is obscure.

No referral was seen for any trial with any patient (to either his brow or his phantom limb) when the brow of the assistant was touched. Of the 16 control individuals, 15 felt no referral to their own arm(s) on either touch or cold on any trial. One control individual reported occasional tingling (in 3 out of 8 trials) in the hand but said the tingling was very feeble.

COMMENT

The results clearly show that when a person who has had a limb amputated watches the corresponding intact limb of another person being touched, the former person experiences it in his or her phantom limb. The referral was organized topographically, especially with Patient 4, although with poor resolution between the third and fourth digits. The other 3 patients also demonstrated topography but were not tested systematically for this purpose. Stroking along the length of the index finger, however, produced a sensation of being stroked on the phantom index finger in all 4 patients.

We interpret these results in terms of the known properties of the mirror neuron system (MNS), which is activated both when one is touched and when one watches someone being touched. The reason one does not literally experience touch when someone else is touched is because, we suggest, the "null" signal from an intact hand prevents activity in the MNS from reaching the threshold for conscious awareness. The amputation removes this null signal, thereby causing the patient to literally feel touch administered to another. It is a sobering thought that the only barrier that stops one from experiencing the sensations of someone else is the skin; remove it and the epistemic barrier between oneself and "other minds" is also removed.

The lack of referral to cold in patients 1 through 3 is noteworthy and may reflect the fact that most individuals do not have "temperature mirror neurons" or perhaps have few of them. The manner in which mirror neurons are constructed is unknown but if it is, at least in part, based on Hebbian associative learning rather than being hard-wired ("I feel touch whenever I see someone touch my hand, etc"), then it is possible that these learned associations are more prominent for touch than cold. These lifelong associations may depend on previous experience with ice, which would produce individual differences; this factor would account for the experience of patient 4.

We considered the possibility that these effects are confabulatory in origin. This is unlikely for 5 reasons. (1) None of the patients knew (nor were they told) what to expect. (2) The patients were genuinely surprised and intrigued by these observations. Patient 1 even added that after we had demonstrated this, he had gone home and asked his wife to massage her own hand while he watched, and watching her do so seemed to relieve his phantom pain. (3) In patients 1 through 3, there was referral of touch but not cold. If these patients were confabulating, why would they each independently report this finding? Each patient reported being surprised by this uncoupling. (4) In all patients there was a latency of a second or two before referral was felt, which would be a curious thing to confabulate. (5) No referral was ever reported to have been felt in the intact hand.

Additional informal observations deserve mention. We tried stroking a crushed piece of tissue paper while patient 4 watched. He responded with a slightly amused chuckle, "No, I don't feel the paper texture or anything, just a diffuse touch." Tactile "texture-detecting" cells (probably in the secondary somatosensory cortex) may not be adequately wired to the MNS; the other 3 subjects had not been tested in an experiment that used crushed tissue paper. Nor was there any referral of pain when the assistant was observed being poked with a needle. This finding, too, argues against confabulation. patient 4 said he could feel the indentation on the skin but no pain. For practical reasons, this experiment could not be carried out with the other patients.

It is important that 15 of 16 control individuals experienced no referral to their intact hands. It is unclear why the 16th control individual experienced some vague "tingling" during 3 trials, but perhaps there is incomplete vetoing of the MNS in this individual, which causes some "leakage" of MNS activity into consciousness (ie, the distinction between actual sensation and empathy was muddled). No biological system is perfect. This observation of "leakage" in control individuals is not unprecedented. In what may have been the earliest observation of the MNS in action, Charles Darwin[11] commented, "Thus persons cutting anything with a pair of scissors may be seen to move their jaws simultaneously with the blades of the scissors."[11] What is new in our present study is the demonstration that the removal of real sensory input can, by itself, increase the MNS activation so that it emerges into consciousness.

The sensations one experiences consciously in daily life do not depend only (or even mainly) on a direct "hotline" from sensory channels to sensory brain areas, but on interactions within complex multimodal networks, of which the MNS is an important part. By changing parts of this network, one can literally feel the sensations of others. Indeed, it may not be too radical to suggest that the brain is in a state of dynamic equilibrium not just with regard to sensory input, but also with other brains, in the earliest stages of neural processing. Thus, the "privacy" of qualia, to which philosophers give so much importance, is an illusion.

An important observation by Blakemore and colleagues[12] is also relevant to this discussion. They observed a new form of synesthesia: an otherwise healthy individual who experienced touch when simply watching others being touched. They suggest that this may result from a congenital hyperconnectivity within the MNS system itself.

Aside from the theoretical implications, our observation may also be of clinical interest. Recall that patient 1 observed that if he simply watched his wife massage her own hand, it seemed to partially relieve his phantom pain. Obviously, the information is merely anecdotal at this point but it raises therapeutic possibilities. Similarly, the efficacy of mirror visual feedback in the treatment of stroke and phantom pain[10,13] may partially rely on the reactivation of portions of the MNS that are repressed or rendered dormant as a result of disease. One also wonders whether even a "real" pain (as in complex regional pain syndrome) would be reduced if the patient were merely to watch the corresponding location on the arm of another person be massaged. The time course of the effect also deserves study and can be investigated by seeing if referral occurs immediately after a brachial block instead of merely after amputation.

In addition to their inherent theoretical and clinical interest, these findings also set the stage for future brain imaging studies in order to, at the very least, obtain pretty pictures. Would primary somatosensory cortex activity be seen to correspond to the amputated arm when a patient merely watches the intact arm of another being touched?

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