LETTER TO THE EDITOR

Persistent hand movement representations in the brains of amputees

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Reilly et al. (2006) report that each type of voluntary movement of a phantom hand evokes a distinct pattern of activity of stump muscles in patients with longstanding upper extremity amputations, even when the amputations are above-elbow and the stump muscles are not those ordinarily used in hand movement. This variety of patterns in stump muscle activity was absent in one shoulder-level amputee who reported that he could not move his phantom limb voluntarily. When pressure palsy of the nerves of the stump was induced in three below-elbow amputees by an inflated cuff spanning the elbow, the stump muscle activity decreased, and the patients reported reduced amplitude or loss of voluntary phantom movement. The authors conclude that reorganization of motor cortex following amputation ‘reflects the fact that preserved hand movement representations retarget stump muscles to express themselves’.

This interpretation requires clarification. First, we need to know what is meant by ‘hand movement representation’ in the reorganized cortex. We generally use that term to denote the set of neurons in motor cortex that gives rise to a hand movement when activated either voluntarily or electrically. But in the reorganized cortex of these amputees there are no longer any such neurons. Second, the authors’ view that retargeting of stump muscle motor neurons by corticospinal neurons of the hand area facilitates voluntary phantom movement is inconsistent with the temporal evolution of such movements. Voluntary movements of a phantom hand are most varied and vivid immediately after amputation and tend to decrease in variety and range with the passage of time, as was the case in the authors’ subjects in this study. In contrast, cortical reorganization develops progressively after amputation. Thus cortical reorganization to target stump muscles is not required for voluntary movement of a phantom hand.

I suggest the following interpretation. After amputation the spinal motor neurons of the distal upper extremity either undergo retrograde degeneration or find new targets. In turn the corticospinal neurons synapsing with the degenerated motor neurons must find new motor neuron targets, and those that remain connected with motor neurons that have changed muscle targets will also have altered the set of muscles they can influence. Despite this major peripheral retargeting there is apparently no such reorganization with regard to the central connections of the corticospinal neurons to other parts of the brain. To the rest of the brain these are still corticospinal hand neurons. For example, when the amputee attempts to follow a command to make a fist, the activity in language cortex excites the same corticospinal neurons as before the amputation, but these now activate the retargeted stump muscles. In addition there is reorganization in the sensory system. Stimulation of the stump now activates the territory in somatosensory cortex formerly excited by stimulating the missing limb. In the amputee attempting to make a fist the stump muscles that contract sendafferent feedback to the same somatosensory cortical area that was formerly activated by the muscles that moved the hand. The more central projections of the cortical neurons in this area to other parts of the brain apparently undergo less or no reorganization, so that the activity in these somatosensory cortical neurons is interpreted by the rest of the brain as resulting from excitation of afferents in muscles moving the hand. Reilly et al.’s finding that ‘hand movement representation’ is preserved can thus be taken as evidence for little or no reorganization of the central connectivities of the neurons in the hand areas of motor and sensory cortex despite major restructuring of their peripheral connections.

How is it that a moveable phantom limb can be present immediately after amputation? I have suggested (Levine,
the following mechanism. Under circumstances calling for a hand movement the patient activates the appropriate corticospinal neurons in the hand area of motor cortex. In the absence of sensory feedback from the missing limb there is no information that the limb has not moved. Furthermore, the information that is available is often consistent with a hand movement. This information includes contraction of muscles at the stump that formerly moved the hand and the contraction of more proximal muscles that might have served to fixate the more proximal joints or to move them as part of a multi-joint movement such as reaching. This information, combined with the patient’s expectations based on a lifetime of having a mobile limb before the amputation, is opposed by other information that the limb is missing. This includes the visual feedback of an amputated limb and the patient’s knowledge of the recent amputation. Under some circumstances the information supporting the presence of the limb will prevail, and the patient will experience a mobile phantom limb.

The authors argue against such a mechanism by pointing out that attempted movement of a limb paralysed by curare does not evoke a sense of movement. They fail to note that the limb paralysed by curare has an intact somatosensory system that signals the brain that no movement has occurred. When the motor cortex is activated but the sensory feedback indicates that no movement has occurred, the patient experiences paralysis. In contrast, the amputee has no somatosensory feedback from the missing limb and thus has no immediate knowledge that a movement has or has not occurred.

We can now understand the effects of inflating the cuff in Reilly et al.’s below-elbow amputees. During the inflation there is progressive reduction in motor power of the stump muscles and progressive reduction in somatosensory feedback. The patient activates the hand area of the motor cortex as he attempts to follow the request to move the phantom hand. In turn, as a result of the peripheral reorganization, the stump muscles contract, but progressively more weakly as a result of the cuff compression. As the inflation continues the remaining feedback from the stump muscles becomes increasingly more discrepant with that of the intended movement. This residual feedback informs the reorganized somatosensory hand area that the changes in muscle length and tension are more consistent with a hand at rest or with a hand that has moved feebly rather than with one that has moved as intended, and the patient reports paralysis or weakness of the phantom.

References