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After amputation, individuals often have vivid experiences of their absent limb (i.e., a *phantom limb*). Therefore, one’s conscious image of one’s body cannot depend on peripheral input only (Ramachandran & Hirstein, 1998). However, the origin of phantom sensations is hotly debated. Reports of vivid phantoms in the case of congenital absence of the limb show that memory of former body state is not necessary (Brugger et al., 2000). According to one view, phantoms may reflect innate organization of sensorimotor cortices (Melzack, 1990). Alternatively, phantoms could reflect generalization from viewing other people’s bodies (Brugger et al., 2000), a sensorimotor example of the classic theory that understanding oneself follows from understanding the “generalized other” (Mead, 1934, p. 154). Because phantom limbs cannot be stimulated, sensory testing cannot directly compare visual and somatosensory influences on representations of phantom limbs. Consequently, empirical investigation of phantoms is limited.

We recently developed a novel method for constructing maps of body representations (Longo & Haggard, 2010), and that method may clarify the sensory origins of phantoms. The hand is occluded, and participants indicate the perceived locations of fingertips and knuckles. The configuration of perceived locations generates a perceptual hand map. We found that these maps are systematically distorted: The hand is represented as shorter and wider than it actually is. Similar distortions characterize early somatosensory processing (see Longo & Haggard, 2010). Although phantom limbs lack physical substance, they have shape and spatial location, which can be measured using our paradigm. Thus, our method provides a unique way to “image” phantom limbs. In the study reported here, we used this method to study the form of a phantom limb in a case of congenital limb absence.

**Method**

C. L. is a 38-year-old woman born without a left arm. She has periodic but distinctive experiences of a stable left phantom hand. We compared maps of her phantom left hand with maps of her intact right hand and with the true shape of her right hand. Initially, C. L.’s phantom hand was mapped using the method we described in previous work (Longo & Haggard, 2010). C. L. used a baton in her right hand to indicate the perceived location of the fingertip and knuckles of each finger on the phantom hand. An overhead camera took photographs of these judged locations. Ten maps (each including one judgment of each landmark in random order) were collected. C. L. reported clear sensations of location of her phantom left hand during the task, which she did not find difficult.

Because C. L. cannot use her left hand to point to landmarks on her intact right hand, we asked her to verbally instruct an experimenter who was naive to the purpose of our study to position the baton, so that we could collect five maps of her intact right hand. Before and after we collected each map, the camera took photographs without the occluder so that we could assess the size and shape of the actual right hand. Finally, so that we could compare right-hand and left-hand maps created using the same response modality, we collected five additional maps of the phantom hand by asking C. L. to verbally report the locations to an experimenter who positioned the baton accordingly. The maps of the phantom left hand that were created by C. L.’s pointing and verbal report were highly similar, so we averaged them for the analyses reported here.

From photographs, pixel coordinates of judged locations were coded off-line. A ruler that was included in the photographs taken without the occluder allowed conversion from pixels to centimeters. Finger length (distance between knuckle and fingertip) and distance between knuckle pairs were measured for each map. For the intact right hand, we calculated the percentage of overestimation of these distances relative to the actual proportions of the hand. For the phantom left hand, we calculated the percentage of overestimation relative to a hypothetical left hand with proportions identical to those of the right hand.

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Results and Discussion

The top row of Figure 1 shows C. L.’s percentage overestimation of finger length (left panel) and spacing between pairs of knuckles (right panel). The bottom row of the figure shows perceptual maps of C. L.’s intact right hand and of her phantom left hand in Procrustes superposition with the actual shape of her right hand. C. L. showed the pattern of distortions that we found in previous studies (Longo & Haggard, 2010, 2012), both for her intact right hand and for her phantom left hand. First, there was overall underestimation of finger length—phantom left hand: 31.8% underestimation, \( t(14) = -8.99, p < .0001 \); right hand: 36.7% underestimation, \( t(4) = -16.01, p < .0001 \). Second, there was clear overestimation of hand width as measured by the distance between the index- and little-finger knuckles—phantom left hand: 29.0% overestimation,
of embodiment arises not only from interactions with the organizing principles of the somatosensory system. The feeling either visual or somatosensory input. Such representations suggest that representation of body structure can exist without overridden by vision (Botvinick & Cohen, 1998). Our resultstributes to bodily awareness (Lackner, 1988), yet is readily limbs, but instead reflect enduring sensorimotor structures in we showed that phantoms are not merely simulacra of actual ing the form and structure of a phantom limb for the first time, for experiencing a phantom (Brugger et al., 2000). By measur-ing the form and structure of a phantom limb for the first time, we showed that phantoms are not merely simulacra of actual limbs, but instead reflect enduring sensorimotor structures in the brain.

Bodily illusions show that somatosensory afference contributes to bodily awareness (Lackner, 1988), yet is readily overridden by vision (Botvinick & Cohen, 1998). Our results suggest that representation of body structure can exist without either visual or somatosensory input. Such representations nevertheless have a characteristic structure aligned with organizing principles of the somatosensory system. The feeling of embodiment arises not only from interactions with the environment, but also from a basic, and possibly innate, organization of the “body in the brain.”

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