Understanding Motor Awareness Through Normal and Pathological Behavior

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ABSTRACT—Data on patients with localized brain damage and on neurologically intact subjects show that normal motor control depends on the functionality of a chain of neurobiological events. These events, through the activation of internal representations of the desired, predicted, and actual condition of one’s body with respect to the external world, contribute to the construction of conscious knowledge of voluntary actions and to self-awareness.

KEYWORDS—consciousness; awareness; intention; motor system; action; anosognosia; brain damage; hemiplegia

Interaction with other individuals and with the environment more generally is mediated by motor actions through which people try to achieve their goals and purposes. Action is generated through a chain of neurobiological events that is often not available to consciousness, but people are usually aware of moving (or not moving) different parts of their bodies. Therefore, people experience motor awareness of actions performed (i.e., the conscious knowledge that, for instance, my hand is moving), as well as intentional attitudes, defined as the felt urge to make a movement that precedes the actual execution of a specific motor act. People also feel a strong sense of controlling their own actions (i.e., the belief that it is I who am moving my hand), designated as the sense of agency. The normal integration between these different aspects of conscious motor control seems to be crucial for the building up of one’s sense of self. When movement control is dramatically impaired, serious consequences for the construction of coherent self-knowledge can be observed. For instance, brain-damaged patients with contralesional hemiplegia (paralysis of the side of the body opposite to the damaged hemisphere) may deny their deficit, claiming that their paralyzed limbs can still move. This denial behavior, which almost always occurs after a right-hemisphere stroke (affecting, as a consequence, the left part of the body), is termed anosognosia (fragments from typical conversations with an anosognosic patient are shown in Box 1; Berti, Ladavas, Stracciari, Giannarelli, & Ossola, 1998). In the present article, we discuss how the description of anosognosic symptoms, integrated with data on normal subjects, can help in understanding the neural bases of motor awareness and self-monitoring.

MOTOR AWARENESS

Anosognosic patients are not aware of being unable to move. A question we can ask is whether tactile-proprioceptive feedback (i.e., the somatosensory information coming from joint position, muscle contraction, and skin stimulation) are, in these cases, so dramatically impaired as to prevent the construction of motor awareness. In fact, there are instances in brain-damaged patients of double dissociation between anosognosia and tactile-proprioceptive disorders (i.e., some patients are affected by denial of hemiplegia but have no sensory deficit, while some other patients present with the opposite combination of symptoms; Berti, Ladavas, & Della Corte, 1996), suggesting that somatosensory information is neither sufficient nor necessary for achieving a coherent view of our own motor behavior. Even in normal subjects, the sensations associated with the actual execution of movements can be unnecessary for the construction of movement awareness. Fournieret and Jeannerod (1998) demonstrated, in normal volunteers who were instructed to trace straight lines, that experimental events causing movement deviations were not consciously monitored by subjects.

A fascinating investigation, demonstrating that awareness of movement does not simply depend on sensory feedback, was carried out, in normal subjects, by Libet and coworkers (Libet, Gleason, Wright, & Pearl, 1983). The authors showed that, if
Subjects had to estimate the time at which they became aware of a voluntary movement ("M judgment"), they indicated a moment that preceded the actual initiation of the movement by 50 to 80 milliseconds. These results suggest that awareness emerges before any sensory input reaches the brain, thus showing that it is not linked in an absolute way to the feedback coming from the moving muscles and joints. Blakemore and Frith (2003) suggested that motor awareness is related to some signal that precedes the movement and that is formed prior to the processing of sensory feedback. They referred to a "forward model" of the motor systems (Haggard, 2005; Wolpert, Ghahramani, & Jordan, 1995), according to which, once there is a desired goal, appropriate motor commands are selected and sent to muscles (see Fig. 1).

Based on the signals (efference copy) sent to brain structures responsible for adjustments in perception and posture required by a programmed movement, a prediction (the forward model) of the sensory consequences of the movement is formed. This prediction is considered to be the basis for the construction of motor awareness (i.e., the one responsible for Libet’s M judgment) and it is subsequently compared to the actual feedback associated with sensory transmission (Blakemore, Wolpert, & Frith, 2002). The model implies that whenever we make sensory predictions about a certain programmed movement, we might construct the belief that this movement has actually been performed. A comparator checks for congruency between the awareness of the intended movement and the representation of the actual status of the system. When the motor act, actually performed, matches the representation of the intended movement, motor awareness is veridically constructed. When the peripheral event does not match the prediction, the comparator should detect the discrepancy. Hemiplegic patients without anosognosia—that is, who acknowledge their motor failure—are able to detect the mismatch between the prediction and the final sensory feedback.
sensorimotor condition and, therefore, they construct normal motor awareness. In contrast, hemiplegic-anosognosic patients, who may still be able to program movements and form predictions, might not be able to monitor the mismatch between the prediction and the actual execution, because of the failure of the comparator that checks for congruence between the two (see Fig. 1). This leads to the construction of an illusory motor awareness. The underlying brain mechanisms of the predictor and of the comparator are still a matter of debate.

In a recent study on the neural bases of anosognosia for hemiplegia (Berti et al., 2005), we found that denial of paralysis is related to damage mainly involving the frontal cortex, particularly premotor areas (Brodmann areas 6 and 44), situated in front of the primary motor area, that are known to be fundamental components of circuits related to the programming of motor acts (Rizzolatti, Luppino, & Matelli, 1998). Less frequently, other regions such as the insula (a brain area involved in sensorimotor control; Karnath et al., 2005) and a prefrontal area (Brodmann area 46) are affected (see Fig. 2).

This was also suggested by Haggard and Magno (1999) who gathered significant evidence that motor awareness arises somewhere between the primary motor and premotor cortex. Consequently, normal (non-illusional) motor awareness may be due to the integration of signals related to the prediction of the sensory consequences of a motor act and to the monitoring of the matching between this prediction and the actual performance.

In their seminal paper, Libet and colleagues (Libet et al., 1983) asked their subjects to signal not only when they became aware of the movement (the M judgment) but also when they first felt the urge to move (intention to move, the “W judgment”; note that in this context, intention refers to the urge to perform a specific movement within a chain of motor events and not to the subject’s design related to his or her beliefs and desires). They found that the conscious judgment about the intention to move precedes the actual movement by about 200 milliseconds. However, they also found that the W judgment follows (instead of preceding) the electrophysiological preparatory activity related to movement (called readiness potential), usually registered on the scalp over the supplementary motor area (part of the frontal lobe, situated close to the inner part of the cortical surface of the brain towards the body midline), by hundreds of milliseconds. These results strongly suggested that some kind of unconscious process precedes the conscious experience of intentionality. In a slightly (but crucially) different paradigm (Haggard & Eimer, 1999), subjects were asked on each trial to choose freely which hand to move and they evaluated the times of the intentional judgment. The authors found that awareness of intention to move was correlated with a brain potential (called lateralized readiness potential, LRP), considered to be an indicator of action selection and responsible for the specification of the characteristics of the movement (Fig. 1). LRP is subsequent to the very earliest neural preparation of action that may represent the initial decision to move (prior intention in Fig. 1; indicated by the potentials studied by Libet et al., 1983). These experiments seem to indicate that conscious intention to move is a consequence of brain activity related to the process of pro-
gramming and selecting the correct movements for action, instead of being the cause of that brain activity.

Recent studies have tried to identify the brain areas where intention for action arises. Using real-time visualization of brain activity, Lau and coworkers (Lau, Rogers, Haggard, & Passingham, 2004) asked normal subjects to perform voluntary movements. Subjects were instructed to report either the time of the conscious intention of starting the movement (W judgment) or the time of movement awareness itself (M judgment). The results showed that the judgment of conscious intention is related to greater activation in the presupplementary motor area (pre-SMA) and in the intraparietal sulcus (which divides the posterior part of the parietal lobe into superior and inferior sectors). Interestingly, the SMA and pre-SMA are usually spared in anosognosic patients (Berti et al., 2005), thus reinforcing the idea that the brain activity leading to the construction of a conscious intention of action is indeed available to an anosognosic patient.

Summarizing the data, in normal subjects conscious intentionality is constructed on the nonconscious activity arising in frontal and, possibly, parietal areas, prior to the execution of the movement. This process is so strongly coupled to the brain activity related to preparation of action that it seems to be present even in hemiplegic patients affected by anosognosia, when movement can be programmed and imagined but not performed (i.e., when there is a preparatory activity but no information about the successful accomplishment of the predicted movement). Interestingly, it has been demonstrated that even normal subjects without hemiplegia can have the feeling of intention (the urge to move) in the absence of any performed movement (Fried et al., 1991). Therefore, although intentionality may be partially due to a possible post-hoc reconstruction rooted in the successful effect of one’s own behavior, the data discussed above seem to suggest a major role of anticipation, based on the prediction model, in the construction of conscious intention.

Fig. 2. Brain areas frequently damaged in a group of patients affected by left hemiplegia and anosognosia (from Berti et al., 2005). The areas include frontal motor and premotor areas (Brodmann areas 4, 44, and, most frequently, the dorsolateral region of area 6), prefrontal area 46, and less frequently the insula. According to the theory suggested in the present article, these areas should be the neural bases of the comparator component of the forward model (movement predictor).
Conscious intention can be experienced without the actual execution of movements. Yet the sense of agency—the feeling that “I” am the one who is controlling the movements—is logically related to the presence of an ongoing action (Haggard, 2005). Pathological conditions in which the presence of actions is dissociated from both the sense of agency and conscious intention have, however, been described. There are, for instance, patients who, after localized damage on one side of the brain, show anachoric hand syndrome, in which the hand on the opposite side of the body produces coherent actions in response to environmental stimuli that nevertheless do not correspond to the patient’s conscious free will. In these cases, movements are present and possible, and the patients have intact motor awareness, but they feel that it is not their “self” that is in charge of the decision of moving (see Fig. 1). In contrast, hemiplegic-anosognosic patients not only believe that their left limbs can move, but they are usually convinced that they are the ones moving the arm. In other words, they never doubt about their will when they are programming a movement, despite the impossibility of performing it. Moreover, they seem to have intact, although decontextualised, motor intention—that is, they try to make movements with the paralyzed limbs, both spontaneously and under request. This picture suggests that, although the sense of agency can be present without any ongoing motor activity, it is tightly linked to the feeling of intention to move, even when that feeling is constructed on pathological beliefs.

CONCLUSIONS

In this article, we referred to the forward model of action generation, constructed on well-established knowledge of the motor system, as a theoretical framework for explaining the abnormalities of motor awareness and motor intention encountered in neurological patients. It is worth noting, however, that the model can be generalized to other psychological phenomena not directly related to brain damage, such as the phantom-limb experience reported by amputees. After amputation of a limb, many patients may still feel its presence. They may even report being able to move their “phantom” voluntarily. As discussed earlier, the conscious experience of movement is based on the predicted state formed after the motor command is formed. Blakemore and colleagues (Blakemore, Wolpert, & Frith, 2002) suggested that, even in the absence of the limb, the stream of motor commands leading to the construction of movement prediction can still be issued, giving rise to the nonveridical motor awareness related to the phantom sensation. We suggest that because there is no damage to the comparator, the mismatch between the movement and the no-movement condition is successfully detected and the patients know that the phantom movements are not real. This clearly demonstrates that, when the comparator functions normally, the difference between an action that is simply intended and the absence of that movement can be successfully detected, so false beliefs are not constructed. Future research should try to clarify the neural bases of, and the relation between, intentions and beliefs, using objective measures for mapping motor processes. This may be attained using activation studies for the identification of the brain areas involved in the mechanisms underlying the emergence of intention to act. Our prediction is that, when hemiplegic patients with anosognosia and false beliefs of movements try to perform a motor act with the affected limb, an activation of the brain areas related to the emergence of motor intention (SMA and pre-SMA) should be observed. Moreover, the presence of neurophysiological markers of action generation (readiness potentials) should be normally registered in anosognosic patients, despite the absence of any detectable movement of the hemiplegic side. Such evidence would disclose the strict relation between action generation and motor beliefs, and suggest that, in pathological cases, motor beliefs are the product of a nonveridical motor representation constructed within the operations of movement control, not a mere confabulation (a left-hemisphere story) with no relation to the actual status of the subject’s motor system.

Recommended Reading


Acknowledgments—This paper has been supported by a MIUR PRIN grant to AB and by a CNR Short Term Mobility Grant to LP.

REFERENCES


