CHAPTER

26 On the origin of intentions

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Abstract

This chapter proposes an alternative approach for understanding how intentions are induced. This approach is based on the assumption that generating intentions in a third person relies on similar mechanisms to those involved in generating first-person intentions. The chapter examines cognitive and cerebral operations supporting the generation of communicative actions and suggests that motor intentions are retrodictive with respect to the neurophysiological mechanisms that generate a given action, while being predictive with respect to the potential intention attribution evoked by a given action in other agents.

Keywords: intentions, cognitive operations, cerebral operations, communicative action, neurophysiological mechanisms, intention attribution

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Any model of motor control or sensorimotor transformations starts from an intention to trigger a cascade of neural computations, yet how intentions themselves are generated remains a mystery. Part of the difficulty in dealing with this mystery might be related to the received wisdom of studying sensorimotor processes and intentions in individual agents. Here we explore the use of an alternative approach, focused on understanding how we induce intentions in other people. Under the assumption that generating intentions in a third person relies on similar mechanisms to those involved in generating first-person intentions, this alternative approach might shed light on the origin of our own intentions. Therefore, we focus on the cognitive and cerebral operations supporting the generation of communicative actions, i.e. actions designed (by a Sender) to trigger (in a Receiver) the recognition of a given communicative intention. We present empirical findings indicating that communication requires the Sender to select his behavior on the basis of a prediction of how the Receiver will interpret this behavior; and that there is spatial overlap between the neural structures supporting the generation of communicative actions and the generation of first-person intentions. These results support the hypothesis that the generation of intentions might be a particular instance of our ability to induce and attribute mental states to an agent. We suggest that motor intentions are retrodictive with respect to the neurophysiological mechanisms that generate a given action, while being predictive with respect to the potential intention attribution evoked by a given action in other agents.

Introduction

Models of motor control or sensorimotor transformations presuppose the existence of an intention that is responsible for triggering a cascade of neural computations (Haggard, 2005; Wolpert and Ghahramani, 2000), yet it remains a mystery how or why motor intentions are generated. The concept of intention is somehow slippery, varying from a cognitive prediction of the immediate consequences of an action [i.e. 'intentions in action': Searle, 1983; 'proximal intentions': Bratman, 1987; 'motor intentions': Jeannerod, 2006] to a neurophysiological description of early preparatory processes (Snyder *et al.*, 1997; Calton *et al.*, 2002; Thoenissen *et al.*, 2002; Lau *et al.*, 2004)—see also Pacherie (2006) for a recent taxonomy of intention. Furthermore, the private nature of this ↳ phenomenon makes it difficult to investigate
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empirically, and several studies on motor intentions have followed the introspective approach of Libet *et al.* (1983). In this setting, subjects are asked to perform 'freely capricious' finger flexions, and the onset of their urge to move (W-judgments) is quantified by means of a cross-modal timing method. This seminal study reported that we become aware of our motor intentions ~200 ms before actually starting a movement, and ~150 ms before we think we have started to move (Libet *et al.*, 1983). Given that W-judgments occur much later than the first electrophysiological signs of movement preparation (Bereitschaftpotential: Kornhuber and Deecke, 1965), Libet's finding was the first empirical demonstration that, on a trial-by-trial basis, awareness of motor intentions cannot be causally related to action generation. Later studies have shown that W-judgments are related to a specific movement (Haggard and Eimer, 1999), and that parietal patients (but not cerebellar patients) are impaired in providing such judgments (Sirigu *et al.*, 2004), pointing to the possibility that W-judgments might be related to a perception of the motor preparatory process (Haggard, 2005). Accordingly, recent data have shown that the Libet's task is more appropriate to assess the effects of paying attention to the urge to move than to study motor intentions *per se* (Keller and Heckhausen, 1990; Lau *et al.*, 2006, in press). In particular Lau *et al.* (in press) have provided strong evidence in favor of the postdictive nature of W-judgments, by showing that the perceived onset of a motor intention can be shifted backward in time by applying transcranial magnetic stimulation at the level of the pre-supplementary motor area (SMA) up to 200 ms after the movement was executed. These results fit with the general thesis that motor intentions might represent confabulatory and postdictive phenomena (Wegner, 2002). However, the causal irrelevance of motor intentions for the performance of a movement raises the issue of their functional role. Why would natural selection preserve the use of neural resources for this confabulatory process?

In this chapter we argue that part of the difficulty that arises when dealing with motor intentions might be related to the received wisdom of studying sensorimotor and cognitive processes in individual agents. We suggest temporarily suspending the initial query concerning the origin of first-person intentions, and focusing first on the problem of how we induce intentions in other people. The rationale of this approach is to try to tackle the issue of third-person intentions, and then to use this knowledge to understand better how first-person intentions are generated.

At first glance, this approach sounds counter-intuitive, since it suggests that intention, a prototypically private phenomenon, might actually be better understood in a social context. Yet this approach simply relies on the assumption that generating intentions in a third person uses mechanisms that are similar to those involved in generating first-person intentions. This assumption is just a particular instance of the suggestion that understanding our own mental states might be related to our ability to understand the mental states of others (Frith and Frith, 2006b; Prinz, 2006), or more generally that apparently private cognitive phenomena might be better understood in a social perspective (Roepstorff and Frith, 2004; Smith and Semin, 2004; Knoblich and Sebanz, 2006).

p. 603 In this social perspective, the issue of the origin of intentions can be re-phrased and operationalized as follows: How does an agent generate intentions in another person? Obviously, in order to alter the mental state of another person (we will call this person a 'Receiver'), the agent (a 'Sender') needs to generate an observable behavior (or refrain from generating it when the behavior is expected). The behavior of the Sender might then lead to the generation of intentions in the Receiver. With this approach, intentions have a clear starting point, defined by the behavior used to generate the intention. Furthermore, recognizing the intentions of a Sender from his overt behavior is one of the cornerstones of human-human communication: *communication is achieved when a recipient recognizes the intention with which a communicative act is produced* (Grice, 1957; Levinson, 1995; Sperber and Wilson, 2001). Therefore, the issue that we need to address first, before dealing with first-person intentions, is the issue of communication.

The generation of communicative intentions: encoding/decoding approaches

One might argue that communication is even less tractable than intention generation. However, the former issue enjoys the advantage of having been conceptualized in a few explanatory frameworks. For instance, several scholars take as a starting point the influential 'mathematical theory of communication' (Shannon, 1948). This theory identified the main elements of a communicative system, consisting of a Sender and a Receiver, using encoding and decoding mechanisms, respectively, to transfer a signal through a physical medium. We loosely use these elements in the analyses that follow, but this does not imply that we rely on the encoding/decoding framework of Shannon's theory. This theory was formulated to solve an engineering problem, namely to minimize the effect of noise on signal transfer, rather than a cognitive problem like the generation of communicative intentions. Even in a noiseless medium, a Sender would be left with the hard problem of selecting a particular behavior from his motor repertoire in order to evoke a specific intention in a Receiver.

Other authors have used Shannon's scheme and focused their analysis of human communication on the parity problem (Liberman and Mattingly, 1985). This is the problem of having a common code that counts for both Sender and Receiver, without any prior agreement. Liberman raised this issue in a phonetic context, trying to explain how the same phonetic unit can remain perceptually invariant despite dramatic changes in its acoustic properties as a function of the phonological context in which it was embedded. The solution he put forward, the 'motor theory of speech perception', consists in *the unique but lawful relationship between the gestures and the acoustic patterns* (Liberman and Mattingly, 1985). Recently, this theory has experienced renewed interest (Fadiga *et al.*, 2002; Pulvermuller *et al.*, 2006). However, it is not immediately obvious how the sensorimotor coupling between phonetic percepts and motor codes, postulated by this theory, could be applied to language, let alone communication in general. One is drawn to
p. 604 the suspicion that these approaches to the parity problem (Rizzolatti and Arbib, 1998) rely on ↳ a conceptual confusion between modality-specific sensorimotor regularities (phonetics), modality-independent linguistic constraints (language), and modality-independent inferential processes that depend on nonlinguistic information (communication).

This issue brings us to a more recent elaboration of the 'motor theory of speech perception' (Rizzolatti and Arbib, 1998; Arbib, 2005). The claim put forward in this elaboration is that sensorimotor couplings (motor resonance: Rizzolatti *et al.*, 1999) somehow allow for solving a semantic parity problem, not just the phonetic parity problem addressed by Liberman. The suggestion here is that Sender and Receiver can establish common ground by exploiting the dominant statistical regularities occurring in the interaction of their bodies with the environment: *actions done by other individuals become messages that are understood by an observer without any cognitive mediation* (Rizzolatti and Craighero, 2004). There is an obvious appeal in this perspective, given its simplicity and the potential for a solid neurobiological link between Sender and Receiver in the form of the mirror neuron system (Arbib, 2005). This position is further strengthened by the widespread use in animal communication systems of one-to-one mapping systems between physical and semantic properties of various behaviors, that is, mapping systems that in principle could be supported by the mirror neuron system. There are several examples, from the alarm calls of vervet monkeys (Cheney and Seyfarth, 1990), to bees' dances (Dyer, 2002), and cephalopod skin displays (Mather, 2004). These mapping systems work well for messages that need to be broadcast, rather than individually tailored, and in which the change in the environment generated by the Sender is unambiguously associated with a particular communicative effect. By the same token, this strength becomes a weakness when motor resonance mechanisms are invoked for solving the parity problem in nonconventional messages, i.e. messages in which there is not an *unequivocal* mapping between a sign and the signified. This is not a marginal problem. Studies on the pragmatics of language have shown that daily-life utterances are pervasively ambiguous: *as a rule, there is no 1:1 mapping between a communicative signal (gesture, speech, etc.) and its communicative intention* (Levinson, 1983). There are other important issues that are not immediately tackled by a motor resonance mechanism. For instance, it remains unclear how direct sensorimotor couplings between Sender and Receiver could float free from sensory or motor events that occur in the environment. This is crucial, since symbols used in communicative exchanges are different from perceptual or sensorimotor representations, insofar as symbols refer to mental representations of the Receiver (Hurford, 2004; Tomasello *et al.*, 2005). Finally, there is a third challenge for accounts of communicative abilities based on the mirror neuron system. Although mirror neurons are responsive to patently nonintentional

communicative acts, like a monkey watching another grasping a fruit (Jacob and Jeannerod, 2005), it remains unclear whether and how motor resonance mechanisms can provide a comprehensive account of how Senders manage to generate communicative acts that can be understood by a recipient, acts whose communicative intention is *designed* to be interpretable for a specific Receiver. This particular selection process occurring in the Sender has been called *recipient design* (Sacks and Schegloff, 1979) or *audience design* (Clark and Carlson, 1982).

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The generation of communicative intentions: inferential approaches

When the issue of the recognition of the intentions of a Sender is seen from the perspective of recipient design, the problem of parity requirement becomes subsumed in a larger and more fundamental problem. This is the problem of generating actions designed by taking into account that they will need to be interpreted by a specific Recipient. Therefore, the Sender generates a given behavior under the assumption that the Receiver will manage to infer the Sender's private intentions on the basis of his public behavior. From a formal computational viewpoint, the problem faced by the Receiver is intractable (Levinson, 1995; Sperber and Wilson, 2001). Therefore, its solution needs to rely on some heuristics that constrain a potentially infinite search-space. The nature of these heuristics constitutes the battleground between different current accounts of the distinctive human ability to interpret the behavior of conspecifics in terms of its underlying intentions. These accounts are 'theory theory' (Carruthers, 1996), 'theory of mind' (Leslie, 2000), and 'simulation theory' (Goldman, 1992; Heal, 1998). In a nutshell, we could think of constraining the search-space of the Sender by using a pre-existing database of psychological laws ('theory theory') or people's mental states ('theory of mind'). This would allow one to predict and retrodict the relationships between people's actions and people's intentions. Conversely, simulation theory suggests that we infer the intentions underlying people's behavior by generating a simulation of the observed behavior, taking our own conceptual and sensorimotor machinery offline, and then reading the intentions generated by the simulation (Gallese and Goldman, 1998). Without going into the details of this ongoing debate (Gordon, 2005; Goldman and Sebanz, 2005; Saxe, 2005), it is evident that, in the context of communication, the Sender is facing an even more complex problem (i.e. a larger search-space) than the Receiver (empirical support for this claim can be found in J. P. De Ruiter *et al.*, unpublished data). Some authors have denied the existence of such a problem, arguing that the Sender does not normally engage in recipient design, but rather refines his communicative actions on the basis of corrective feedback from the Receiver in the course of multiple communicative exchanges (Keysar *et al.*, 2000). Yet this does not explain how a Sender could select a particular action (among an infinite set of possible actions) appropriate to communicate a particular intention to the Receiver. It might be argued that the communicative problem faced by Sender and Receiver can be solved by means of Bayesian inferential processes (Wolpert *et al.*, 2003), exploiting the commonalities of the priors instantiated in two agents sharing the same environment. However, this solution does not account for communicative actions selected against their dominant statistical priors (to express irony, for instance), and for the single-trial successful interpretation of signal-to-meaning mappings that a Receiver has never encountered before (as during fast learning of novel mappings).

Here, we advance the hypothesis that the heuristics used by the Sender to select a particular action to communicate his intentions is based on a prediction of the process of intention recognition that the Receiver could perform on such an action. The prediction exploits the intention recognition system of the Sender, and it is based on a conceptual ↳ model of the Receiver. This suggestion is an elaboration on previous theoretical suggestions that emphasized the inferential nature of communication (Grice, 1957; Levinson, 1983, 2000; Clark, 1985; Levelt, 1989; Sperber and Wilson, 2001). In the following sections, we will present the details of a novel experimental setting we have developed to test this hypothesis.

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The tacit communication game (TCG)

In this game, there are two subjects (a Sender and a Receiver—for ease of exposition, we will consider a male Sender and a female Receiver). Sender and Receiver are seated behind separate screens, controlled by a single computer, displaying a 3 × 3 grid (the 'board': Figure 26.1) and two geometrical shapes (rectangles, circles, or triangles: in brief, the 'tokens'). The Sender can move (translate and rotate) the token below the board, the Receiver can move the other token. Translations and rotations were controlled by a handheld controller, with four face buttons that moved the token to the left, right, up and down; two shoulder buttons rotated the token clockwise and counter-clockwise; a third shoulder button was used as a start button (see below). There were two more (target) tokens inside the game board (Figure 26.1). These target tokens indicated the position and orientation that Sender's and Receiver's (playing) tokens should have at the end of the trial. A trial was correct when the tokens of both Sender and Receiver were in the position and orientation indicated by their respective target tokens (goal configuration). On each trial of the game, Sender and Receiver are asked to overlay their tokens with the goal configuration. Crucially, in the 'communicative' trials, only the Sender has knowledge of the goal configuration. Therefore, in these trials, a Sender/Receiver pair can solve the game only if the Sender manages to convey his knowledge of the goal configuration ↳ to the Receiver. The only way this could happen is by the Sender moving around his token on the board. Furthermore, participants (starting with the Sender) have unlimited time to prepare their movements and to signal their readiness to move by means of a button press. At this point, the token of the participant is automatically positioned at the centre of the board and the participant has 5 s to move around the board. Consider the problem illustrated in Figure 26.1. During communicative trials, the Sender has to decide not only how to move his token (the circle) to his goal location (down to the right), but also to communicate to the Receiver where *she* should place her token (the rectangle), and in which orientation. It is important to emphasize that the only way the Sender can convey this information to the Receiver is by translating and rotating his token in the board. Figure 26.2 provides a representative example of how the problem illustrated in Figure 26.1 was solved by our participants. Further details on the experimental set-up and on a validation of the TCG are provided by J. P. de Ruiter *et al.* (unpublished data).

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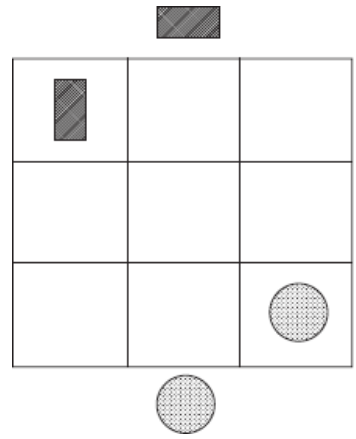
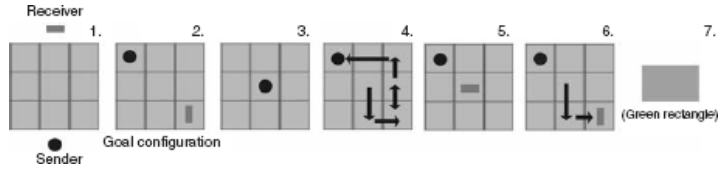
Figure 26.1



Example of workspace in the Tacit communication game, with the Sender's token (circle outside the grid) and his goal (circle within the grid), the Receiver's token (rectangle outside the grid) and her goal (rectangle within the grid).

Figure 26.2



Sequence of events in a Communicative trial of the tacit communication game.

1. Sender and Receiver view their tokens (1.5 s)
2. The Sender, but not the Receiver, sees the goal configuration (unlimited time for inspection and planning).
3. The Sender signals his readiness to move by pressing the start button—his shape moves to the center of the board, and the goal configuration disappears.
4. The Sender moves his token on the game board by means of a multi-button controller (max. 5 s). The movements of the Sender's token are visible to the Receiver. The double arrow indicates that the Sender moved back and forth between those two positions.
5. The Receiver signals her readiness to move by pressing the start button—her shape moves to the center of the board.
6. The Receiver moves her token on the game board (max. 5 s). The movements of the Receiver's token are visible to the Sender.
7. Sender and Receiver receive feedback indicating whether they were correct (green box) or incorrect (red box) in matching their token to the goal configuration.

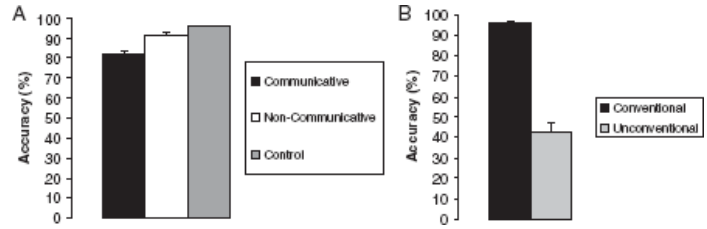
There were two further types of trials, in which both Sender and Receiver could see the goal configuration. Therefore, in these trials, the Sender *did not* need to signal to the Receiver the position and orientation that her token should have taken by the end of the trial. In the 'control' trials, the Sender could move directly to his goal configuration, and the Receiver followed suit. In the 'noncommunicative' trials, the Sender was p. 608 instructed first to overlay his token to the goal configuration of the Receiver, and then move to his ↳ goal configuration. The rationale of using these noncommunicative trials was to have trials that were matched to the communicative trials in terms of motor output, but without the need to engage in a communicative exchange (since both Sender and Receiver knew the goal configuration).

Within the communicative trials, the Sender was faced with a variety of communicative problems. The most difficult problems were related to the communication of orientation. If both the Sender and the Receiver had the same shape, or if the shape of the Receiver was not rotated, then the communicative task of the Sender was straightforward. In these trials, the Sender could apply a simple rule to solve the task (go first to the Receivers' goal, then to the Sender's goal). Accordingly, we called these 'conventional communicative' trials. In contrast, if the Sender and the Receiver had different shapes, or if the shape of the Receiver was rotated in such a way that its orientation could not be matched by the shape of the Sender, then the communicative task of the Sender was problematic. In these trials, the Sender could not apply a simple rule to solve the task. Accordingly, we called these 'unconventional communicative' trials.

Behavioral performance

We tested 24 Sender/Receiver pairs (aged 18–26 years, 24 male Senders, 24 female Receivers). Each Sender-Receiver pair performed 80 trials (40 control trials) in two sessions. The same stimuli (including shapes and goal configurations) were used in the communicative and the noncommunicative sessions. The Senders were successful in communicating the goal configuration to the Receivers (Figure 26.3A). In addition, the success rate of Senders and Receivers was much lower on these unconventional trials than on the conventional trials, but still well above chance levels (Figure 26.3B).

Figure 26.3



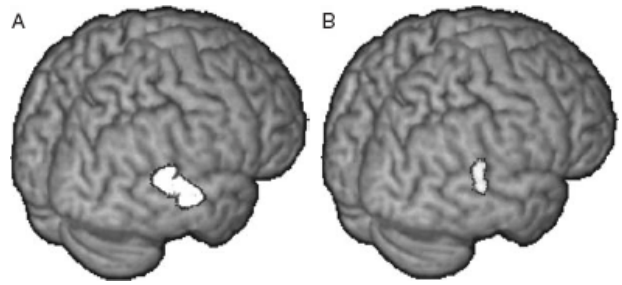
Tacit communication game performance. (A) Mean accuracy scores for Communicative, Noncommunicative and Control trials. Error bars indicate standard errors. (B) Mean accuracy scores for Conventional and Unconventional Communicative trials.

Cerebral activity

In the previous sections we have suggested that the communicative problem faced by the Sender might be solved by means of a prediction of intention recognition. Here, we test this hypothesis. If the generation of
p. 609 communicative actions (in the Sender) exploits his ↳ intention recognition system, then there should be a functional overlap between the intention recognition processes of Sender and Receiver. This functional overlap should give rise to a correspondingly cerebral overlap in the brain activity supporting these cognitive processes in the Sender and in the Receiver. Therefore, during performance of the TCG, we used functional magnetic resonance imaging (fMRI) to measure cerebral activity in Senders and Receivers. Given that during the TCG the Sender has an extremely limited time to move around the board (Figure 26.2), it is reasonable to assume that the bulk of simulation of intention recognition takes place after the Sender is presented with the goal configuration, and before he starts to move. Accordingly, the experimental design was organized to disambiguate cerebral activity evoked in the Senders during the planning phase (phase 3 in Figure 26.2) from the other trial events, and to compare the planning phase fMRI signal across the three experimental conditions ($\text{Communicative}_{\text{Sender}}$, $\text{Non-communicative}_{\text{Sender}}$, and $\text{Control}_{\text{Sender}}$ trials). It also appears reasonable to assume that, during the TCG, the Receivers need to engage in intention recognition mainly during the observation of the Senders' movements. Accordingly, we distinguished cerebral activity evoked in the Receivers during the observation of the Senders' movements ($\text{Communicative}_{\text{Receiver}}$) from the other trial events, and we compared this observation phase fMRI signal with the signal measured in a matched control condition. In this latter condition ($\text{Control}_{\text{Receiver}}$), the Receivers were asked to move their token to the last position on the board in which the Sender moved his token twice. Therefore, the $\text{Communicative}_{\text{Receiver}}$ and $\text{Control}_{\text{Receiver}}$ conditions were matched in terms of attentional load, movement planning, and movement execution, but differed with respect to the presence of intention recognition.

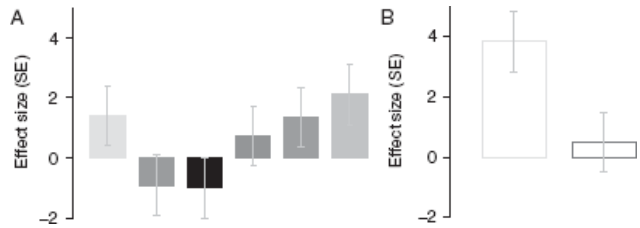
The results were clear-cut. In the Receivers, there was a cluster of significant activity along the posterior part of the superior temporal sulcus, in the right hemisphere (Figure 26.4A). This result confirms previous
p. 610 studies reporting activity in this region during intention ↳ recognition (Castelli *et al.*, 2000; Saxe *et al.*, 2004; Zacks *et al.*, 2006), extending these inferences to the domain of human communication. Accordingly, the inferential process operating in Receivers (i.e. the recognition of communicative intentions) might rely on the posterior part of the superior temporal sulcus (pSTS) capacity to infer perceptual and/or conceptual scenarios different from those currently experienced by an observer, using learned priors to generate temporal predictions on different sensory materials (Frith and Frith, 2006a; Zilbovicius *et al.*, 2006). Crucially, we found that the same region, in the same hemisphere, was active in the Senders during the planning phase of the TCG (Figure 26.4B). We would like to emphasize that during this phase of the game there was no task-related change in sensory input or motor output (see phase 3 in Figure 26.2). Therefore the activity we measured in this region in the Senders cannot be related to visual motion or hand movements *per se*. This is further confirmed by a *post hoc* analysis of the activity of this region, in which it can be seen that the fMRI signal evoked in the Senders during the *performance* of the communicative movements (phase 4 in Figure 26.2) is not different from zero (Figure 26.5A, black bar).

Figure 26.4



(A) Cerebral activity evoked in the Receivers during observation of the Senders' movements in the context of successful performance of the TCG. The cluster of differential activity covers the posterior part of the superior temporal sulcus. (B) Cerebral activity evoked in the Senders during planning of the Senders' movements in the context of successful performance of the TCG. This cluster of differential activity falls within the cluster described in panel A.

Figure 26.5



(A) Cerebral activity evoked in the right posterior superior temporal sulcus (MNI coordinates: 50, 42, −14, corresponding to the local maximum of the clusters described in Figure 4). The histograms represent the effect size (i.e. parameter estimates of a multiple regression analysis in standard error units) of different trial components. In yellow, activity evoked in the Sender during the planning phase of COMMUNICATIVE trials (corresponding to phase 2 of the TCG as described in Figure 2). In orange, activity evoked in the Sender during the planning phase of NON-COMMUNICATIVE trials. In black, activity evoked in the Sender during the execution phase of the TCG (phase 3 and 4, Figure 2). In grey, activity evoked in the Sender during the planning phase of communicative trials that was related to the number of moves performed in that trial. In cyan, activity evoked in the Receiver during the observation of the Sender's movements (phase 4, Figure 2). In pink, activity evoked in the Sender during the observation of the Receiver's movements (phase 6, Figure 2). (B) Differential cerebral activity (at 50, −42, 14) evoked in the Sender during the planning phase of communicative trials with either "unconventional" problems (yellow empty histogram) or "conventional" problems (magenta empty histogram).

We performed further controls. For instance, it could be argued that the differential activity we found in the Senders is related to differences in the complexity of the planned movements between Communicative and Noncommunicative trials. Therefore, we considered whether the number of moves performed in the
p. 611 subsequent trial phase ↳ (phase 4 in Figure 26.2) could explain the effect we observed—but this was not the case (Figure 26.5A, grey bar). Next, we explored whether this region was responsive during the observation of the Receiver's movements, a further indication that simulation of intention recognition and intention recognition share the same cerebral territory. It can be seen that there was a robust response during this phase (Figure 26.5A, cyan bar). Finally, we explored whether this region was differently engaged when the Sender needed to solve either conventional or nonconventional communicative problems (see behavioral experiment). It can be seen that this region is completely driven by the latter type of communicative problems (Figure 26.5B), an indication that simulation of intention recognition might be used parsimoniously, when it is not possible to solve a communicative problem by means of rule-based behavior.

Given that the processes involved in solving the TCG fall into the general category of making inferences about unobservable psychological states of other agents, we also explored whether we could isolate cerebral activity within the brain networks supporting the two main neurocognitive accounts of 'mind reading', i.e. theory of mind (ToM; Frith and Frith, 2005) and 'simulation theory' (as implemented in the mirror neuron system, MNS; Iacoboni, 2005). This enquiry was made possible by the fact that the cerebral structures supporting ToM and MNS have been mapped into relatively well-defined and largely segregated brain networks (Saxe, 2005; Frith and Frith, 2006b). Despite the increased sensitivity associated with using a-priori search regions (Friston, 1997), we did not find any statistically significant effect in either the ToM or the MNS networks.[1] Taken together, our findings support the hypothesis that Senders, in order to select an action that can convey their communicative intention, engage in a prediction of intention recognition. This prediction appears to be based on a conceptual model of the Receiver, since the intention recognition

activity was independent of sensory inputs and motor outputs (Figure 26.5). This finding fits with the neurophysiology of the pSTS. This region is not a primary sensory or motor area, and it is not directly connected to sensory or motor areas (Boussaoud *et al.*, 1990). In this respect, our results fall in the category of conceptual simulation mechanisms (as suggested by Nichols and Stich, 2003), and not in the domain of offline simulation mechanisms with the same inputs as those involved in motor control (as suggested by Gallese and Goldman, 1998 and Rizzolatti and Craighero, 2004). On a more neurobiological note, it can be noticed that the cerebral site involved in intention recognition and simulation of intention recognition (Figure 26.4) falls in a region that has been consistently implicated in the perception of biological motion (Allison *et al.*, 2000; Pelphrey *et al.*, 2005). Given the tight link between impairments in ↳ communicative abilities and perception of biological motion (Blake *et al.*, 2003; Dakin and Frith, 2005), it is conceivable that these two inferential processes might share a similar neuroanatomical and computational basis. Namely, this temporal region might be involved in evaluating the plausibility of current perceptual evidence given a series of biological priors (for instance: How likely is it that this collection of moving dots describes a person walking? How likely is it that 'can you tell me the time' is a question about my abilities?). One way to test this possibility is to assess whether inter-subjects variation in thresholds of biological motion detection predicts variation in communicative abilities.

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On the origin of intentions

What does this tell us about the origin of intentions? In the Introduction, we asked the reader to suspend temporarily the initial query concerning the origin of first-person intentions, and to focus first on the problem of how we induce intentions in other people. We have argued that, in order to effectively induce intentions in other people, we need to select a particular behavior on the basis of a prediction of the intention that a Receiver will attribute to our behavior. In other words, when we are in a social context and we want to influence other people's mental states, we select our behavior on the basis of a preview of the effects of our actions on other people's mental states (Wolpert *et al.*, 2003; see Levelt, 1989 for a similar mechanism in the domain of speech production). This observation might be relevant for understanding the origin of our own intentions insofar as one could envisage that this social predictive mechanism is the same mechanism that generates our own intentions, even when we are in a private rather than in a social setting. The hypothesis we put forward is that what we perceive to be our own intentions are in fact predictions of the *potential* attribution of intentions triggered by our actions in others. In this perspective, the rules that govern the attribution process of first-person intentions might be the same rules that govern the induction of mental states in other agents for communicative purposes (the generation of communicative actions).

This hypothesis fits with the general notion that understanding our own mental states might be related to the ability to understand other people (Frith and Frith, 2006a); and that attributing causal intentions to our own independent minds appears to be a (modern) possibility among a series of historical trajectories, in which other agents (social and religious entities, for instance) were considered the source of intentionality supporting a given behavior (Prinz, 2006). However, it might be argued that our hypothesis is at odds with current models that link intention generation with awareness of the motor preparatory process (Haggard, 2005). These models are supported by empirical evidence pointing to a premotor region, the pre-SMA, as the region crucially involved in generating both actions and awareness of motor intentions (Fried *et al.*, 1991; Haggard and Magno, 1999; Lau *et al.*, 2004). In particular, Fried *et al.* (1991) directly stimulated the mesial frontal cortex of several patients with intractable seizures, evoking both the urge to move and, at higher stimulation currents, actual movements. Crucially, Fried *et al.* (1991) noted that the evoked movements were not necessarily the same movement for ↳ which an urge has been reported, and that movements were not invariably evoked when the stimulation current was raised. Therefore, Fried *et al.* (1991) actually provide strong evidence on the lack of a robust relationship, in the pre-SMA, between awareness of motor intentions (operationalized as an introspective 'urge to move') and actual movements. Accordingly, it is conceivable that activity found in the pre-SMA during performance of Libet's task might be related to paying attention to the motor preparatory process, rather than to the generation of motor intentions *per se* (Lau *et al.*, 2004, 2006, in press). By the same token, the hypothesis put forward in this paper predicts that other brain regions (like the pSTS), by virtue of their role in intention attribution, might in fact be responsible for intention generation. While this hypothesis remains to be tested, the available evidence already suggests that the same right pSTS region involved in the generation of third-person intentions might also be involved in the generation of first-person intentions (Toni *et al.*, 2001).

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The hypothesis articulated in this paper might appear in conflict with previous suggestions that emphasize the reconstructive character of motor intentions (Wegner, 2002; Lau *et al.*, in press). In fact, it builds on those suggestions. Wegner (2002, 2004) suggested that conscious volitional experiences represent the 'emotion of authorship', a somatic marker important for building a sense of self, and possibly for tagging actions as open to future regulation. In this perspective, a currently experienced intention does not directly influence a currently selected action, but it might leave a cerebral trace that influences future instances of the same action. However, if motor intentions are *post hoc* narratives tuned to influence a future action, why would their phenomenological experience need to be shifted backward in time with respect to an ongoing action? Lau *et al.* (in press) have suggested that this backward shift might be a consequence of a general mechanism based on optimal Bayesian cue integration, in which the weight given to different sources of information is scaled on the variance of their estimate (Ma *et al.*, 2006). Our hypothesis is compatible with these considerations. Motor intentions can be retrodictive with respect to the neurophysiological mechanisms that generate a given action, while being predictive with respect to the potential intention attribution evoked by a given action in other agents.

Conclusions

This chapter has argued that intentions might not constitute a prototypical private phenomenon, as the intuitions of introspection would lead us to believe. Rather, intentions might be related to a need to account for the social consequences of our actions. Humans invariably try to account for the behavior of other agents in terms of underlying mental states. It is conceivable that this attitude might entail the attribution of a mental state to the very agent that generates this attribution. When it comes to intentions, we might interpret our own actions by using the same mechanisms devoted to evaluate other's actions.

This does not need to be a voluntary mechanism, as intention attribution appears to be a quite automatic
p. 614 phenomenon (Heider and Simmel, 1944; Michotte, 1954). On the ↳ other hand, a person usually does not elaborate on the intentions of each and every behavior produced, so we are not claiming that this mechanism is continually and necessarily at work. I can reflexively scratch my ear, computing all the necessary sensorimotor transformations necessary for bringing my fingernail to my earlobe without generating or recognizing an intention in this movement. But I can scratch my ear having the intention of doing so, and in this case we suggest that generating this intention relies on the same procedures that allow us to generate communicative actions.

There is some preliminary empirical support for this hypothesis. First, it appears that the generation of communicative actions is based on a prediction of the intention recognition of the Receiver. Second, there appears to be cerebral overlap between the structures supporting intention recognition, prediction of intention recognition, and first-person intention generation. These results point to the possibility of a cognitive overlap between the generation of communicative actions and the origin of first-person intentions, i.e. we hypothesize that the generation of our own intentions is essentially the same process as generating intentions in others. This hypothesis can be further tested, for instance by assessing whether alterations in the ability to generate communicative actions are associated with altered experiences of first-person intentions.

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Notes

1 We used spherical volumes of interest, with radius = 10 mm, centered on the following stereotactical (MNI) coordinates: (a) ToM network: −48–69 21; 54–54 24; 0 60 12; 3 −60 24 (Saxe *et al*., 2004); MNS network: −50, 12, 14; 37, −44, 60; 59, −26, 33 (Iacoboni *et al*., 1999). We did not include the pSTS in the MNS network since pSTS neurons lack mirror properties, i.e. they respond during the observation of goal-directed actions, but not during the execution of similar actions (Perrett *et al*., 1989; Jellema *et al*., 2000; Iacoboni, 2005).