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The self in action: Lessons from delusions of control

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Abstract

Patients with delusions of control are abnormally aware of the sensory consequences of their actions and have difficulty with on-line corrections of movement. As a result they do not feel in control of their movements. At the same time they are strongly aware of the action being intentional. This leads them to believe that their actions are being controlled by an external agent. In contrast, the normal mark of the self in action is that we have very little experience of it. Most of the time we are not aware of the sensory consequences of our actions or of the various subtle corrections that we make during the course of goal-directed actions. We know that we are agents and that we are successfully causing the world to change. But as actors we move through the world like shadows glimpsed only occasional from the corner of an eye.

Keywords: Self; Action; Schizophrenia

1. How do we understand disorders of the self in schizophrenia?

The diagnosis of schizophrenia is largely based on what patients report about their experiences and beliefs. These experiences and beliefs are typically labelled hallucinations and delusions and are considered to be abnormal because they are false. The experiences are false in the sense that they do not correspond to the sensory input. The beliefs are false in that they are not justified by the evidence. Since misperceptions and false beliefs in this sense are rather common in the general

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population a further requirement for the diagnosis of schizophrenia is that the false perceptions and false beliefs should be outside the normal range of experience and belief. An example of such a false perception associated with schizophrenia would be that the patient hears his thoughts spoken aloud just after he has thought them (thought echo). An example of a false belief would be the claim by the patient that other people can hear her thoughts just as well as if they were being spoken aloud (thought broadcasting).

This characterisation of the experiences and beliefs of patients as being outside the normal range immediately raises a problem when we try to understand these symptoms. However hard a patient tries to give a truthful and accurate account of her experiences, she will inevitably have difficulty in communicating them. The patient has somehow to relate her own bizarre experiences to the more normal experiences shared between her and her listener (Jack & Roepstorff, 2002). Thus, though my starting point for this consideration of the experience of the self in schizophrenia is based on self-reports from patients, I will place great emphasis on second-order inferences about experience derived from behavioural paradigms. I believe we need to use such inferences to get a better understanding of what it is that patients are trying to communicate through their reports. The same problem, although to a lesser extent, applies to any self-report concerning the experience of action. Henry Ey highlighted this problem with the normal experience of the body, "Except in the case of difficulty, pain, embarrassment..., the body seems transparent and silent in the field of perception" (Ey, 1973). If our bodies in action are indeed so transparent and silent then we may need information from experiments to help us understand even our own experience of action.

2. Disordered experiences of the self in schizophrenia

Hearing voices (auditory hallucinations) are a characteristic symptom of schizophrenia (Slade & Bentall, 1988). In some cases there is evidence that 'the voice' is overtly generated by the patient since the content of sub-vocal muttering can be shown to correspond to the content of 'the voice' reported by the patient (Gould, 1949; Green & Preston, 1981).

> The patient whispers, 'The only voice I hear is hers. She knows everything. She knows all about aviation.' At this point the patient states audibly, 'I heard them say I have a knowledge of aviation.'

This observation suggests that the immediate cause of the experience of 'the voice' is a failure to distinguish between the patient's own actions and the actions of other people. This formulation links auditory hallucinations with another class of symptoms known as passivity experiences or made experiences (Sometimes referred to as Schneiderian symptoms, Schneider, 1957). In these cases the patient reports that his actions, emotions or even thoughts are not his, but are made for him by some external force. These symptoms are labelled 'delusions of control,' 'made emotions,' and 'thought insertion,' respectively. In all these cases the problem can be formulated as a failure to recognise the self in action. This formulation leads to the question as to how we normally experience ourselves in action. In what follows I shall concentrate primarily on delusions of control and the experience of limb movements. Thoughts and emotion do not lend themselves so readily to experimental study.

Here are some examples of the kind of reports that are labeled delusions of control.

1. They inserted a computer in my brain. It makes me turn to the left or right.
2. It's just as if I were being steered around, by whom or what I don't know.

It is important to note that the patient with delusions of control has not actually lost control of his motor system. His problem resides in his awareness of his motor system.

3. The feeling of being in control

Hohwy and Frith (2004) have proposed that the feeling of being in control is a case where neuroscience has informed our understanding of one aspect of consciousness. We suggest that the feeling of being in control has two core components: a mechanism for prediction and attenuating sensations associated with movements, and a mechanism for the on-line adjustment of movements without awareness. Both mechanisms are necessary for our feeling of being in control of our actions. If one could make on-line adjustments to one's movements, but had to pay attention to them, then one would hardly feel in control in the way we normally do. Likewise, if we were fully aware of all the proprioceptive signals associated with our movements then we would not feel in control in the way we normally do. For patients with delusions of control both these mechanisms seem to be malfunctioning, so it is not surprising that they do not feel in control of their actions. But is this account sufficient to explain why they believe that their actions are being controlled by someone else? I shall first review the evidence supporting this account of the feeling of being in control before returning to the wider problem of agency.

3.1. Ownership and agency

An important distinction has been made between agency and ownership in action (Graham & Stephens, 1994). When I move my hand I recognise that it is my hand that is moving and also that I am the agent of the movement. After certain kinds of brain damage the sense of ownership of a limb can be lost. For example, a patient can report that his hand is 'alien' (somatoparaphrenia). This symptom is associated with damage to the parietal lobe and the hand in question is usually paralysed. The patient claims that the hand is not his and develops complex delusional accounts concerning who the hand does belong to (Halligan, Marshall, & Wade, 1995).

This sense of ownership can be disrupted in normal people by showing the volunteer a rubber arm that is seen to be stroked exactly in time with tactile stroking of the real arm. After a few minutes the volunteer 'feels' the touch sensation in the rubber arm (Botvinick & Cohen, 1998; Peled, Ritsner, Hirschmann, Geva, & Modai, 2000). Movements of the real arm become inaccurate because the volunteer assumes that the starting position is that of the rubber arm. We could speculate that the patient with an alien hand thinks that the hand he sees (or feels) cannot be his hand because it is in a different place from where he knows his hand to be.

In contrast, when a patient with schizophrenia reports a delusion of control it seems to be his sense of agency that is abnormal, not his sense of ownership. He feels he is not the agent of the movement, but he still recognises that it is his hand that is moving.[1] What is the basis of our sense of being the agents of our actions and how can this sense be impaired?

3.2. Self-monitoring

It has long been recognised that the acting self creates problems for the perceptual system (Helmholtz, 1866). Actions, such as moving the eyes, cause changes in sensation; the image moves across the retina. But there is nothing in the signal detected by the retina that can indicate whether this visual sensation is caused by the acting self or an independent event in the outside world. The problem can be solved by prediction. The brain can predict what changes will occur as a consequence of the intended movement. In this way the effects of actions can be labelled as self-generated and distinguished from external events. This process of monitoring intended actions is referred to as central monitoring or self-monitoring.

A failure of self-monitoring could explain why patients with delusions of control experience their own actions as being made by outside forces. The patient fails to monitor his intention to act (Frith, 1987). In other words the patient's intention to perform an action remains at an unconscious level. As a result he fails to anticipate that the action will occur. When this unexpected action does occur it is inevitable that he does not feel in control of this action. The advantage of this account is that it leads to predictions about behaviour that can be tested experimentally. A lack of self-monitoring will cause an inability to make the very rapid error corrections that depend upon being aware that the *intended* action is wrong rather than having to wait for the action to finish to observe its erroneous consequences.

These error corrections, sometimes called 'central error corrections,' can occur so rapidly that they cannot be based on sensory feedback (Megaw, 1972; Rabbitt, 1966; Rabbitt & Vyas, 1981). This ability to monitor intentions can lead the 'whoops' effect in which we realise that we are about to press the key that will wipe our hard disk, and that it is to late to stop this action. A number of studies have demonstrated a lack of central error correction in patients with delusions of control since they fail to correct errors in the absence of visual feedback (e.g., Frith & Done, 1989). A possible objection to these studies is that the problem might be a general one of attentional control rather than a specific problem with self-monitoring. However, Turken, Vuilleumier, Mathalon, Swick, and Ford (2003) have described a group of patients with schizophrenia who exhibited no significant dysfunction of attentional control during task performance, while their ability to correct errors without external feedback was markedly compromised.

The account of schizophrenia as a failure of self-monitoring suggests that the problem arises in the motor control system. It is important to remember, however, that this is not primarily a problem of motor control. An example of a problem with motor control would be seen in a neurological patient with optic ataxia (Perenin & Vighetto, 1988). In these patients the motor system is no longer properly guided by visual cues and they have difficulty reaching for and grasping objects. The reach does not get to quite the right place and the fingers do not form the appropriate shape for grasping the object. Patients with optic ataxia realise that they cannot control their movements

[1] Recently evidence has emerged suggesting that patients with schizophrenia might also have a weaker sense of ownership. Peled et al. (2000) found that the rubber hand illusion develops more strongly and more rapidly in patients with schizophrenia, particularly those currently experiencing hallucinations.

properly (although they incorrectly assume there is something wrong with their vision). This is not the sort of lack of control that patients with delusions of control complain about. Indeed, any problems that they have with motor control are subtle. For patients with schizophrenia the primary problem is not of control of the motor system, but of awareness of control of the motor system. By identifying the problem in schizophrenia more precisely we should also get clues about which aspects of motor control are available to consciousness which, in turn, will inform us about the sense of self in action.

In the first formulation of the self-monitoring deficit, I assumed that the patients are not aware of the intended state of their motor system. As a result, their actions, though goal-directed, are a surprise. Consideration of the phenomenology of schizophrenia shows that this idea is wrong. For example, the behaviour of patients with delusions of control is in marked contrast to patients with an anarchic hand (Marchetti & Della Salla, 1998). The Anarchic Hand is a neurological disorder (see chapter by Todd Feinberg in this volume) that sometimes occurs after lesions to the supplementary motor area (SMA) or the anterior corpus callosum. The contra-lesional hand makes movements, not intended by the patient, like grabbing doorknobs or scribbling with a pencil. The patient is aware that these movements are unintended and tries to stop them. However, such patients are more likely to complain that there is something wrong with their hand, rather than to say that alien forces are controlling their hand. These patients have a problem with the control of one of their hands, but their awareness of what is happening seems to be normal.

Patients with delusions of control do not behave in this way. This is revealed clearly in a study by Sean Spence in which such patients were asked to move a joystick in four different directions at random (Spence et al., 1997). The patients were able to perform this task normally. They made the movements at the correct time and the sequences of movements were as random as those of the controls. And yet the patients reported that their movements were being controlled by outside forces. These patients were making the movements they intended to make since they were successfully following the instructions of the experimenter. Furthermore they knew that the movements were intended since they did not try to stop the movements or correct them. Patients with delusions of control do not behave as if their actions were unintended. So why do they experience their movements as being under the control of alien forces and why cannot they make central error corrections?

3.3. The importance of prediction in the control of action

Since the idea of a self-monitoring failure in schizophrenia was first proposed, there have major developments in our understanding of the mechanisms of motor control. We now know that in normal, healthy people complex movements are often made without awareness (e.g. Castiello, Paulignan, & Jeannerod, 1991; Pisella et al., 2000) and that parietal cortex has a major role in this aspect of motor control. We also know that prediction (or forward modelling) is a key component of motor control systems (see for example Miall & Wolpert, 1996).

A simplified version of the motor control system would include representations of five different entities: (a) the estimated current state of the system (where the limbs are in relation to the rest of the body and the outside world. Note that this state cannot be known, only estimated). (b) The desired state of the system (where we want the limbs to be). (c) A specification of the motor commands needed to achieve the desired state (the inverse model). (d) A prediction of the effect of initiation of the motor commands in terms of (i) the resulting positions of the limbs (the forward dynamic model) and (ii) the sensory feedback (the forward output model). (e) The actual sensory feedback. The most important feature of this system is that the various representations are compared and the comparison errors used to improve control. If the intended state does not match the new state then the wrong movement has been made. More interesting are the consequences of comparing the intended state and the predicted state. If there is a mismatch then the intended movement is wrong. This is what permits central error correction and also improvements in performance after mental practice in which no movements are actually made (Feltz & Landers, 1983).

3.4. Prediction of proprioceptive feedback: The forward output model

We have remarkably little awareness of the proprioceptive feedback associated with movements or even of the corrections we make during goal directed movements (Pisella et al., 2000). For example, in the experiment of Fourneret and Jeannerod (1998) the subject uses a graphics tablet to control the movement of a cursor on a VDU, but his drawing hand is hidden from view. The subject is asked to make a movement straight forward that will make the cursor move straight forward on the screen. However, the experimenter produces distortions so that, to produce a straight forward movement of the cursor the drawing hand must deviate to the side. Subjects can easily make the appropriate correction to their movement, but are unaware that they are making this correction unless it is more than about 15°. This observation shows that they are unaware of the discrepancy between visual and proprioceptive feedback unless it is large. Even if asked to repeat the movement they have just made, but now in the absence of visual feedback they still make a straight forward movement rather than the deviant one they actually just made. This observation suggests that they remembered the movement they initially intended to make, but not the various corrective movements that were made along the way. Performance of this task has also been studied in GL, a patient who no longer receives any proprioceptive signals regarding the position of her limbs (Fourneret, Paillard, Lamarre, Cole, & Jeannerod, 2002). This patient can easily perform the task, modifying her hand movements on the basis of visual feedback, but is entirely unaware of any discrepancies between the visual feedback and the actual position of the hand, however, large they may be. This observation suggests that, in this task awareness of discrepancies is entirely based on proprioceptive feedback and not on efferent information.

I draw two conclusions from these observations. (1) We have rather little awareness of proprioceptive feedback during voluntary actions. This information only reaches awareness when it is very discrepant from expectations (and as a corollary when our limbs are moved passively since no precise expectations can be computed). This effect applies to physiological activity as well as awareness. Passive movements are associated with more activity in parietal cortex (particularly the secondary somatosensory cortex, SII) than active movements (Weiller et al., 1996). (2) Our awareness is restricted to discrete, high-level action units. We are not aware of subunits of action associated with on-line corrections (Castiello et al., 1991; Pisella et al., 2000). Given the first conclusion one possible indicator that I am performing a voluntary act could be a lack of proprioceptive experience.

3.4.1. Awareness of proprioceptive feedback is attenuated through prediction

I am assuming that proprioceptive feedback is attenuated during voluntary movements through forward modelling. We can predict the feedback we will receive on the basis of the motor commands we intend to issue. Any predictable signal has less impact on the nervous system (unless it has some special a priori value). Responses to sensory signals caused by voluntary actions are attenuated even when these signals are only indirectly caused by the movement. For example, the neural response to a sound caused by pressing a button is attenuated (Shafer & Marcus, 1973). The most extensively studied phenomenon of this kind is self-tickling in which movements of one hand cause tactile sensations in another part of the body. Such sensations are attenuated both phenomenologically (Weiskrantz, Elliott, & Darlington, 1971) and physiologically (Blakemore, Wolpert, & Frith, 1998).

This attenuation has at least two aspects. First, tactile and proprioceptive sensation associated with voluntary movements is non-specifically reduced (i.e., there is a change in base level or intercept). Sensation associated with a muscle twitch caused by a voluntary movement (via transcranial magnetic stimulation; TMS) is reduced by a constant amount whatever the strength of the twitch (Tsakiris & Haggard, 2003). However, the experience of a force directly applied by a finger (Shergill, Bays, Frith, & Wolpert, 2003) is attenuated by an amount proportional to the force applied (i.e., the force experienced is about 60% of the force applied). In the case of self-tickling there is a systematic increase in the sensation experienced as the discrepancy between the applied movement and the felt movement increases in time or space (Blakemore, Frith, & Wolpert, 1999). The increasing temporal discrepancy is associated with increased activity in the cerebellum (Blakemore, Frith, & Wolpert, 2001). These observations suggest that fairly precise predictions can be made about the timing and spatial location of sensations caused by movements. It is interesting to note that normal subjects are sometimes aware of the increase in sensation without being aware of the discrepancy between their movement and their sensation. They do not, however, report that their actions are being controlled by alien forces.

3.4.2. Abnormalities in the perception of proprioceptive feedback

A common procedure during the induction of hypnosis is to cause subjects to actively move their arm up and down while they believe the movements are passive. Note, however, that these subjects think that their arm is 'moving by itself' rather than being moved by alien forces. These illusory passive movements created under hypnosis are accompanied by greater activity in parietal cortex and cerebellum when contrasted with active movements that are correctly experienced as active (Blakemore, Oakley, & Frith, 2003). The pattern of activity seen during these illusory passive movements is similar to that seen during genuine passive movements. Does the instruction to perceive active movements as passive cause a reduction in the attenuation of proprioceptive feedback?

Schizophrenic patients currently experiencing delusions of control also show abnormally high activity in parietal cortex when making voluntary movements (Spence et al., 1997). This might reflect a failure to attenuate sensory feedback during voluntary movement. As yet, however, it still needs to be shown that the region of parietal cortex that is overactive when patients with delusions of control perform voluntary movements coincides with the region that is activated when the same movement is made passively. Assuming the same regions are involved then the implication of this result is that, when a patient with schizophrenia performs an active movement, it feels like a passive movement with the associated proprioceptive sensations. Is this the source of their belief that their movements are being controlled by alien forces? If my movement feels passive rather than active then presumably someone or something other than me is causing that movement to occur.

There is additional evidence that a lack of attenuation of sensory feedback during voluntary movement relates to delusions of control. Patients with passivity experiences do not show attenuation of sensory experience when tickling themselves (Blakemore, Smith, Steel, Johnstone, & Frith, 2000) and do not show the normal attenuation of self-applied force (Shergill, Sampson, Bays, & Wolpert, in press).

There is now good evidence that patients with passivity experiences are excessively aware of proprioceptive feedback and do not show the normal physiological attenuation of this feedback in parietal cortex. Presumably this reflects a defect related to the forward dynamic model. However, this defect is not sufficient to explain their experience. When we cause lack of attenuation of proprioceptive feedback in normal volunteers through hypnosis or direct distortion of the feedback, these volunteers do not experience delusions of control.

3.5. Prediction of movement outcome: The forward dynamic model

3.5.1. Imagining making movements

People can imagine making movements and performance of movements in the imagination can have effects on subsequent behaviour (Feltz & Landers, 1983). The time a movement takes in the imagination increases with the difficulty of the movement (i.e., there is a speed accuracy trade-off) just as when making a real movement. This observation suggests that people have explicit knowledge of the time movements will take. Patients with parietal lesions no longer show a speed accuracy trade-off when making movements in imagination (Danckert, Ferber, et al., 2002; Sirigu et al., 1996), even though they show the normal effect for the same actions performed in reality. The same observation has been made in patients with schizophrenia currently reporting passivity experiences (Maruff, Wilson, & Currie, 2003; see also Danckert, Rossetti, d'Amato, Dalery, & Saoud, 2002). Real movements show the normal pattern, but when performing the task in the imagination movement time does not increase with difficulty.

This problem could result from a failure to predict how long a specific action will take to perform. If these patients have a general problem with predicting what intended actions will be like this would also explain their failure to make central error correction. Without such predictions they cannot know in advance that the movement they have just initiated is going to end up in the wrong place. Predicting what a specific action will be like (i.e., how fast the limb will move and where it will be after a certain time) is the function of the forward dynamic model.

3.5.2. Anticipatory control of movements

There are many circumstances in which successful motor control depends upon anticipation. For example, if we move a heavy weight up and down we have to alter the grip force we apply to compensate for the changing gravitational forces; gripping harder as we move up and less hard when we move down. These force changes do not lag behind our movements as would be the case if we depended on detecting changes in sensory experience. The force changes are made exactly in phase with the movements. This means that the initiation of the appropriate muscle commands must be made in anticipation. Schizophrenic patients make normal anticipations in their change of grip when picking up objects or when waiting for something to collide with the object they are holding. However, grip change is delayed beyond normal when they initiate a collision by hitting something with the object they are holding (Delevoye-Turrell, Giersch, & Danion, 2003). This observation suggests that, when actions are responsive or largely automatic, the prediction system works normally in schizophrenia. But when novel actions are initiated appropriate predictive adjustments are not made. Perhaps the predictions made by the forward dynamic model are only available to low level control systems (i.e., they remain implicit). If patients with delusions of control have implicit, but not explicit knowledge of these predictions, then we might expect that such symptoms should be more likely to occur in conjunction with novel and deliberate movements rather than more automatic ones. I am not aware of any study that attempted to relate delusions of control to particular kinds of action.

3.5.3. Detecting distortions in visual feedback

Marc Jeannerod's group in Lyon have developed a clever system in which subjects apparently see their hand while in fact they are seeing an image on a VDU (Daprati et al., 1997). This is an electronic version of the technique originally described by Nielsen (1963). Subjects are asked to make simple movements like lifting a finger or moving a joystick forward. Using this set up visual feedback about movements can be presented in which the timing or the spatial orientation of the movement seen can be systematically distorted. In addition the image can be replaced by the same view of another person moving. The set up is similar to that used in the experiment by (Blakemore et al., 1999) in which tactile feedback was systematically distorted.

There is an obvious contrast between the experience of visual signals and tactile signals in this situation. We do not have the experience of the sight of our hand becoming more vivid when the feedback is distorted. This is because visual feedback provides information about the timing and location of the movement (i.e., matching the output of the forward dynamic model) rather than what the movement will feel like. When the visual feedback is actually someone else's hand performing the same action that we are performing then normal people can detect that this is not their hand on about 70% of occasions with such recognition being better for the dominant hand (Daprati & Sirigu, 2002). When the feedback is distorted people become aware of the distortion once it exceeds $\sim 15^{\circ}$ (in space) or is delayed more than 150 ms in time. These discrepancies are of the same order of magnitude as those found for tactile feedback. Associated with the increasing spatial distortion of the visual feedback was increasing activity in the right parietal lobe (Farrer, Franck, Georgieff, et al., 2003), while associated with increasing temporal distortion was increasing activity in posterior STS (Leube et al., 2003). The later study used event related fMRI and it was therefore possible to identify activity associated with conscious detection of the visual discrepancy that was independent of the size of the discrepancy. This was found, not in STS, but in the cerebellar vermis.

What is the visual feedback being compared with to detect these discrepancies? There are two sources of evidence; proprioceptive feedback and efferent information (i.e., prediction). In the paradigm used by Daprati et al. (1997) the respective roles of proprioceptive feedback and efferent information cannot be distinguished. In an ingenious variation on the paradigm, Tsakiris and colleagues separated out these two sources of information (Tsakiris, Haggard, Franck, Mainy, & Sirigu, 2005). In every condition a movement of the subject's right hand occurred. At the same time the subject saw a moving right hand on a computer screen, which could either be her own or that of the experimenter. The right hand movement was always passive. In one condition the movement was caused by the subject's left hand so efferent and proprioceptive information was available. In another condition the movement was caused by the experimenter so that only proprioceptive information was available. It is clear from previous studies of passive movements that subjects are aware of discrepancies between proprioception and vision (Farrer, Franck, Paillard, & Jeannerod, 2003). However, the results of the study by Tsakiris et al. showed that self-recognition was significantly better when efferent information was also available. This result shows that we can make use of efferent signals (i.e., prediction) when making explicit judgments about the self in action.

I suggested earlier on the basis of studies using the Fourneret paradigm that we have rather little awareness of proprioceptive feedback during voluntary actions. Is this compatible with the evidence that we can use these signals to detect feedback discrepancies in the Daprati paradigm? This paradigm differs from the Fourneret paradigm in one important aspect. In the Fourneret paradigm the subject has the goal of drawing a line on the screen. Because of this explicit goal on-line corrections can be made during the movement. In other words the movement is *operant* in the sense of producing an external consequence. It is this consequence (a straight line of the screen) that is of primary importance rather than the movement. In the Daprati paradigm the task is to make simple ballistic movements (e.g., lift a finger) with no external consequences beyond the movement itself. It is the movement itself that is of primary importance.[2] In a task concerned with the awareness of the initiation of an action (see below) Wohlschläger, Engbert, Haggard, Clark, and Kalogeras (2003) found that the presence of an external consequence for an action (i.e., pressing a button caused a tone) weakened the effect of proprioception on the awareness of action in comparison with an action with minimal external consequences (i.e., pressing the button had no effect).[3] On the basis of this observation we might expect there to be less awareness of proprioception in the Fourneret paradigm compared to the Daprati paradigm.

3.5.4. Abnormalities in the recognition of visual feedback

Patients with schizophrenia are less able to detect distorted visual feedback. Discrepancies need to be ~30° or 300 ms before they are detected (i.e., twice as large as for normal controls, Daprati et al., 1997). This difficulty is slightly more pronounced in patients with Passivity experiences. Patients with parietal lesions have a similar problem (Sirigu, Daprati, Pradat-Diehl, Franck, & Jeannerod, 1999). In these studies the problem could lie either with failure to use proprioceptive feedback or with failure to use efferent information (i.e., prediction). By using passive movements it would be possible to study the role of proprioceptive feedback, but I am not aware of any such studies.

However, different results have been obtained when the Fourneret paradigm was used with schizophrenic patients. In this task schizophrenic patients with Passivity experiences were better able to learn to compensate for the visual distortion than other patients (Fourneret, Franck, Slachevsky, & Jeannerod, 2001). Given the evidence that the effects of prioprioception are normally weakened in this task, this observation could relate to the abnormal lack of suppression of proprioceptive feedback in these patients that has been observed in other tasks (e.g., Blakemore et al.,

[2] A similar distinction has emerged in studies of imitation. When asked to imitate an action with a clear goal (e.g., picking up an object) a child will achieve the goal with which ever hand is most convenient rather than imitating the movement exactly. When there is no external goal then the movement is imitated Bekkering, Wohlschlager, and Gattis (2000).

[3] Presumably proprioceptive feedback would have its greatest effect when subjects simply moved their finger rather than pressing a button.

2000). This hyper-awareness of proprioceptive information might help these patients to learn the compensation needed to perform the task.

4. Awareness of action initiation

So far I have discussed how prediction modifies our experience during the course of an action; what the movement will feel like and its course and timing. However, we are also aware of the moment of initiating an action. The well-known paradigm developed by Libet (Libet, Gleason, Wright, & Pearl, 1983) reveals two aspects of actions that we are aware of before any sensory feedback occurs. The first is the time at which we first have the 'urge' to perform an act and the second is the time at which we initiate that act. Presumably this knowledge is derived from aspects of the forward model. When subjects are asked to attend to this urge to perform an act, increased activity is detected in preSMA and a number of other regions including parietal cortex (Lau, Rogers, Ramnani, & Passingham, 2004). Haggard and Eimer (1999) have shown that the time at which we have the urge to act correlates with the time at which the lateralised component of the EEG readiness potential first emerges. This is presumably the time at which the intended act is completely specified (i.e., I am going to lift my left index finger rather slowly) and might therefore require the development of the forward dynamic model. Patients with parietal lesions can report when they start moving, but cannot report when they first become aware of their urge to move (Sirigu et al., 2004). Such a study has not yet been done with patients with Passivity experiences.

4.1. Awareness of initiating a movement

Libet et al. (1983) also measured the time at which people report initiating an act. Rather than indicating the time at which they first felt the 'urge' to lift their finger, subjects were asked to indicate the time at which their finger first began to move. This time is reliably in advance of the actual start of the movement by ~80 ms. Haggard and Magno (1999) have used TMS to show that this awareness is not affected by stimulation of motor cortex (although this delays the actual initiation of the act). However, stimulation of more anterior regions (probably SMA) delays awareness and initiation. Since this awareness also precedes the action it cannot be based on sensory feedback resulting from the initiation of the act. But, whatever the source of this awareness, it must be different from that which creates the awareness of the urge to act since the urge occurs about 200 msec earlier.

It is well established that when we imagine making a movement brain activity is seen in many of the regions that are activated when we actually make a movement (Jeannerod, 1994). Clearly there has to be some inhibitory mechanism that stops us making movements when all we want to do is imagine them. Preparing to make a movement also activates these regions. In this case the inhibitory process may also be employed to prevent the movement happening before the appropriate time. In some circumstances this inhibitory mechanism can be over-ridden as, for example, when we remove our hand from a hot plate. However, it is also possible to deliberately turn off the inhibitory mechanism. This happens in simple reaction time tasks where there is only one stimulus and one response. Response times in such tasks are faster than would be expected by extrapolation from the gain achieved when the number of responses is reduced successively from 8 to 4 to 2

(Frith & Done, 1986). By deliberately suppressing the control available from the inhibitory process faster response times can be achieved. But this is at the expense of errors. Frith and Allen (1983) asked subjects to *prepare* to press a button whenever the word 'READY' appeared on the screen and to *press* it when the word changed to 'PRESS.' Unbeknown to the subjects irrelevant tones also occurred during this experiment. On the first occasion that a tone occurred when the subjects were preparing to press the button because READY was on the screen, the majority of them pressed to the tone before the word PRESS appeared on the screen. They only made this mistake once.

I think this kind of mistake is another example of the 'whoops' effect (Megaw, 1972; Rabbitt & Vyas, 1981) in which we are not aware of initiating the response until too late. When we are aware of the time of initiating an act (as opposed to being aware of the time of the stimulus which elicited the act) then I think that what we are aware of is the releasing of the inhibitory mechanism. This inhibitory process seems to be intact in schizophrenia, but I know of no studies on their awareness of response initiation time in the Libet task (but see below in my discussion on awareness of agency).

From the evidence discussed so far I can develop an account of delusions of control that categorises the problem as one of experiencing the self in action (i.e., an abnormality in the feeling of being in control of one's actions). Patients with delusions of control are abnormally aware of the sensory consequences of their movements and cannot accurately predict the consequences of their movements. But is the account sufficient to explain why they believe that their actions are being controlled by someone else? Patients with parietal lesions have many similar problems with control, but do not report delusions of control. Furthermore, we can induce abnormal feelings of control in normal volunteers by distorting sensory feedback (Blakemore et al., 1999; Daprati et al., 1997) or hypnosis (Blakemore, Oakley, et al., 2003), but these feelings do not lead our subjects to say that their movements are being controlled by someone else. To explain this paradox we need to consider experiments on the experience of agency.

5. The feeling of agency

Agency is all about causality. There are two aspects of agency in action. At the lower level there is the perception that my act has caused some effect. For example, by pressing this button I have caused a sound to occur. At a more abstract level there is the perception that my intention to press the button has caused my act of pressing the button.

Where does our feeling of agency come from? Wegner and Wheatley (1999) have shown that simple contingency can be sufficient. If the intention to act (e.g., thinking of moving a cursor to point to a particular object on the VDU) is followed within a short time by the consequences of the intended act (the cursor moves to that object), then subjects believe that they have caused the movement of the cursor even when this is not the case. Prediction seems to have a key role in this illusory sense of agency since descriptions of the movements about to be performed enhance the feeling that we are controlling these movements (Wegner, Sparrow, & Winerman, 2004). We can also have the false sense that we are not the agents of our own actions. Wegner, Fuller, and Sparrow (2003) have shown that subjects can attribute responses to others, which they have in fact given themselves. In these examples, subjects have a strong sense that there is an agent causing an action, but can be manipulated by the circumstances into making errors about who the agent is. Perhaps this is an unavoidable consequence of the 'transparency and silence' of our perception of our body in action. Through a small change in our perceptual criteria we can perceived that we made an action when we have not and vice versa. What is the role of the perception of action in our sense of agency?

5.1. Action and consequence

Haggard, Clark, and Kalogeras (2002) have shown that there is a phenomenon of temporal binding associated with the sense of agency. When a voluntary act (a button press) causes an effect (a tone) then the perceived time of initiating the act is closer to the perceived time of the effect. The time at which the act is initiated is perceived later and the time at which the effect occurs is perceived as earlier than is actually the case. In contrast when the button press is involuntary, having been caused by TMS, then the times of the button press and the tone are perceived as occurring further apart than is actually the case. Haggard has called this effect 'intentional binding' and suggests that it may be an important component in the perception of agency. Intentional binding probably derives from the predictive mechanisms of motor control that I have already discussed. Intentional binding depends upon efferent signals since it does not occur with passive movements. In addition, intentional binding causes anticipatory awareness of action effects, a shift in direction that suggests prediction (Haggard et al., 2002). Haggard and Clark (2003) tested the hypothesis that binding depends upon prediction by using TMS to insert occasional involuntary movements into the standard task in which a button press with the right index finger causes a tone. On some trials the TMS pulse caused the movement of the right index finger at a time when the subject was intending to press the button, but had not yet done so. This involuntary movement also caused the tone. In both conditions the intention to act was followed by a tone, but the shifts in temporal awareness that constitute intentional binding only occurred when the button press was voluntary. These results show that the efferent signal involved in pressing the button has a critical role in intentional binding. An intention followed by the appropriate effect (the tone) is not sufficient. Haggard and Clark conclude that predictive models have a critical role in constructing the conscious experience of an action; regulating sensory suppression, determining the perceived time of an action and binding an action to its effect.

6. Awareness of agency in others

This binding effect (and the associated perception of agency) also occurs when we observe other peoples' actions. If we watch someone else doing the button pressing task, then the time at which the button is pressed and the time at which the tone occurs appear to be closer together than they really are. However, this intentional binding does not occur when the button is pressed by a mechanical device (Wohlschläger, Haggard, Gesierich, & Prinz, 2003). At first sight the intentional binding that occurs when watching other people is very surprising. Efferent signals and proprioceptive feedback are privileged forms of information that are only available for our own actions. We would expect our experience of other peoples' actions to be very different from our experience of our own actions. The key seems to lie in the difference I have already discussed between the experience of actions where the primary aim is to achieve an external goal (operant actions) and actions where the primary aim is to make a movement. Our experience of agency in actions directed at an external goal does not seem to be so dependent on information to which we have privileged access.

Wohlschläger, Engbert, et al. (2003) have shown that the time at which we perceive an action to be initiated depends upon the task being performed. If the act has an external goal (a button press causing a tone), then perception of initiation time is effected by whether the act was intentional (active self or other) or not (passive self or machine). There is no effect of proprioception. However, if the act does not cause an effect (no tone) then the perception of initiation time is not affected by intention, but is affected by the presence of proprioception (active self or passive self) or not (other or machine). With this version of the task there is no effect of intentionality. This is a very important observation. It suggests that perception of the initiation of movements (with no goals) does indeed depend upon signals to which the self has privileged access. However, perception of the initiation of acts (movements with goals) does not depend upon these privileged signals and can therefore be applied to others as well as to the self. In this case the perception is based neither on the proprioceptive feedback that follows the movement nor on the efferent signals (muscle commands) that precede the movement. However, predictive models would be available for the self, based on the intended action. Such models could also be applied to others by a form of simulation (e.g. Wolpert, Doya, & Kawato, 2003) that does not require access to privileged information.

This result suggests that the experience of agency (i.e., intentionality) is distinct from the experience of being in control of an action. Further, while the feeling of being in control relates to the self, the experience of agency is not linked to a particular person, but applies to self or other. If these two aspects of experience are independent then it is possible for one to be impaired while the other remains intact, or even that the two experiences might be impaired in different ways. For example, a patient might experience a strong sense that there was an agent causing an action that he had just performed, while at the same time feeling that he was not in control of that action. Might this be the basis of his conviction that some one else is controlling his actions? The patient is experiencing spontaneously what Wegner and his colleagues generate in the laboratory in their studies of facilitated communication (Wegner et al., 2003).

On this account we might expect that patients with Passivity experiences would have a normal or even an exaggerated sense of agency. Haggard, Martin, Taylor-Clarke, Jeannerod, and Franck (2003) measured intentional binding in a group of patients with schizophrenia. These patients showed unusually strong binding with temporal intervals between actions and their consequence being shorter than for controls. However, this effect was not linked to particular symptoms.

An exaggerated sense of agency of a somewhat different form has also been observed in patients with delusions of persecution (Blakemore, Sarfati, Bazin, & Decety, 2003). When observing simple animation sequences, these patients attributed intentional behaviour to moving shapes in conditions where other patients (and controls) reported seeing no intentionality.

7. Conclusions

Since the original proposal that delusions of control in schizophrenia might be explained by a defect in self-monitoring there has been a dramatic increase in studies of the awareness of action in normal volunteers and in various patient groups. In the normal case the experience of action is indeed transparent. Our perception of the sensations caused by our actions is attenuated and we are not aware of the minor corrections made on the course of goal directed movements. These effects derive from our ability to predict the consequences of our movements. In contrast patients with delusions of control are abnormally aware of the sensory consequences of an action and cannot accurately predict the consequences of their movements. This leads to a feeling of not being fully in control of their actions. Their experience reflects a failure of forward modelling in the motor control system.

There are two problems with this account. First, the failure of forward modelling must only be partial. A complete failure would lead to a much greater problem with motor control. Furthermore patients can use forward modelling to make predictive alterations of grip force in routine situations (Delevoye-Turrell et al., 2003). The problem seems to lie in the ability to make explicit (i.e., conscious) use of forward models, as when imagining a movement (e.g., Maruff et al., 2003). Knoblich, Stottmeister, and Kircher (2004) have shown that patients with schizophrenia are normal in their ability to use forward modelling to automatically adjust their hand movements to overcome discrepancies between these movements and their visual consequences, while at the same time being impaired in their ability to report the discrepancies. Once again this result emphasises that, for these patients, the problem is not with motor control, but with awareness of motor control. The existence of people with an impairment that is restricted to awareness raises interesting possibilities for addressing the question of what awareness is good for.

The second problem with this account is that similar failures of forward modelling also occur in patients with parietal lobe damage (e.g., Sirigu et al., 1996), but these patients do not report delusions of control. In terms of underlying physiology patients with delusions of control show overactivity in parietal cortex (Spence et al., 1997). This observation suggests that their problem might lie higher in the hierarchy of control. The problem is not in parietal cortex, but results from some abnormality in the signals that modulate activity in parietal cortex during self-generated actions. These signals might well arise in prefrontal cortex; the source of willed action (Spence, Hirsch, Brooks, & Grasby, 1998).

It remains to be seen whether this hypothetical failure of long-range cortico-cortical modulation can also explain the other experiential abnormality reported by patients with delusions of control; the feeling that the actions they are performing are intentional, but the intention is not theirs. There is preliminary evidence that patients with schizophrenia perceive agency where others see none (Blakemore, Sarfati et al., 2003). Perhaps it is this over-active tendency to perceive agency that gives the delusion of control its special flavour.

The tendency to perceive agency where there is none may be a more general feature of schizophrenia. In patients with auditory hallucinations this tendency is coupled with a failure to predict the sensory consequences of speech (Ford & Mathalon, 2004). In patients with persecutory delusions the over-active tendency to perceive agency exists in isolation. Key questions concern the neural basis of our perception of agency and its relationship with the forward modelling system.

I have deliberately avoided discussing those passivity experiences that involve thoughts and emotions. It would be pleasing if a similar account could be given for the experience of not being in control of one's thoughts and emotions (e.g. Feinberg, 1978), but there are many problems to be resolved, especially if I continue to demand supporting evidence from behavioural experiments. I find the distinction between agency and ownership is more difficult to conceive in the case of emotions and thoughts. The patient experiencing made emotions reports that it is him having the emotion, but that it is being forced upon him (''It puts feelings into me: joy, happiness, embarrassment, depression. It just puts it in and I feel the glow spread over me.''). But in what sense do we ever feel that we are the *agents* of the emotions that we feel? The situation is even worse for thoughts (''Thoughts are put into my mind like 'Kill God.' It's just like my mind working, but it isn't. They come from this chap, Chris. They're his thoughts.''). It is even more difficult to separate ownership from agency in the case of thoughts (but see Stephens & Graham, 2000).

What do the studies I have reviewed here tell us about our normal experience of the self in action? Paradoxically it seems as if the mark of the self in action is that we have very little experience of it. Most of the time we are not aware of the sensory consequences of our actions or of the various subtle corrections that we make during the course of goal-directed actions. We know that we are agents and that we are successfully causing the world to change. But as actors we move through the world like shadows glimpsed only occasional from the corner of an eye. Neuroscience is beginning to cast some light on these shadows.

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