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Interactive report

Explaining the symptoms of schizophrenia: Abnormalities in the awareness of action[1]

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Abstract

We propose that the primary cognitive deficit associated with delusions of control is a lack of awareness of certain aspects of motor control. This problem arises because of a failure in the mechanism by which the predicted consequences of an action are derived from a forward model based on the intended sequence of motor commands. This problem leads to a number of behavioural consequences, such as a lack of central error correction, many of which have been observed in patients with delusions of control and related symptoms. At the physiological level, delusions of control are associated with over-activity in parietal cortex. We suggest that this over-activity results from a failure to attenuate responses to sensations of limb movements even though these sensations can be anticipated on the basis of the movements intended. The lack of attenuation may arise from long range cortico-cortical disconnections which prevent inhibitory signals arising in the frontal areas which generate motor commands from reaching the appropriate sensory areas.

Keywords: Schizophrenia; Delusions of control; Motor system; Forward model

Contents

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1. Contrasting delusions of control and the anarchic hand sign

Rather than attempting to elucidate a biological basis for schizophrenia, our aim in this essay is to try and explain one symptom or class of symptoms. We shall concentrate on delusions of control. This is an example of a passivity experience in which a patient feels that his own actions are being created, not by himself, but by some outside force. The actions in question can be very trivial, such as picking up a cup or combing one's hair. Other examples of passivity include thoughts or emotions being made for the patient by outside forces (see Table 1). Schneider [29] believed that these symptoms were particularly characteristic of schizophrenia and included them among his 'first rank' symptoms.

It is informative to compare delusions of control with a neurological sign that, on the surface, has great similarity. The 'alien hand' sign (more properly referred to as the 'anarchic hand' [22]) is associated with damage to the supplementary motor area and/or the anterior corpus callosum. The hand contralateral to the lesion performs simple, goal-directed actions which are not intended by the patient. Such actions might include grabbing a doorknob or scribbling with a pencil. Sometimes the anarchic hand interferes with the actions the patient is trying to perform with his 'good' hand. Clearly the anarchic hand is not under the control of the patient. However, we want to emphasise the striking differences between the anarchic hand sign and delusions of control in the attitude of the patients towards their problem. The patient with an anarchic hand recognises that his hand is performing actions that he has not intended. Indeed he may try to prevent the hand from performing these actions by holding it with his good hand. But he does not conclude that his hand is being controlled by alien forces. In contrast, the patient with delusions of control carries out the actions he intends. For example, he correctly carries out the actions requested by an experimenter [31]. He recognises that these actions are successful and does not try to stop or correct them; and yet, at the same time, he experiences these actions as being made for him by alien forces. The patient with the anarchic hand sign has a problem with the control of his hand. The patient with delusions of control has a problem with awareness of the control of his hand. How do these problems arise?

2. Explaining symptoms in cognitive, physiological and experiential terms

In order to understand symptoms like delusions of control we require an explanation at least three levels. First, at the cognitive level, we must understand how the symptom arises in terms of a model of motor control that can be applied to normal and abnormal cases and which makes a distinction between those aspects of motor control which reach awareness and those which do not. Second, at the physiological level we need to consider how the cognitive components of the model relate to underlying brain function. Third, our explanation of the symptom should give us some insight into what it is like to have that symptom. We should gain some inkling of the experience that lies behind the patient's report.

3. Control of action and awareness of action

The motor system can be considered a control system in which the input is the motor command that produces a movement and the output is the sensory consequence of that movement (see Fig. 1). In order to produce a goal-directed movement the system must be able to estimate its current state (e.g. the current position of a limb) and must also represent its goal (e.g. the desired position of the limb). On the basis of these two representations the system can compute a sequence of motor commands that should generate the movement required to reach the goal (the inverse model [16,18]). It is not possible to compute a unique sequence of motor commands that will produce the required movement (the inverse problem). However, from a given sequence of motor commands the resulting movement and its sensory consequences can be computed exactly (the forward model [36]). Forward modelling makes it possible for the system to represent the predicted consequences of the movement (e.g. the predicted position of the limb).

Table 1
Examples of passivity experiences

Thought insertion	'Thoughts come into my mind from outer space.'
Thought withdrawal	'It doesn't allow me to think about what I want to hink about. It blocks my mind.'
Delusions of control	'My grandfather hypnotized me and now he moves my foot up and down.' 'They inserted a computer in my brain. It makes me turn to the left or right.' 'The force moved my lips. I began to speak. The words were made for me.' 'It's just as if I were being steered around, by whom or whatI don't know.'
Somatic passivity experiences	'I have tingling feelings in my legs caused by electric currents from an alternator.'
Made emotions	'It puts feelings into me: joy, happiness, embarrassment, depression. It just puts it in and I feel the glow spread over me'.

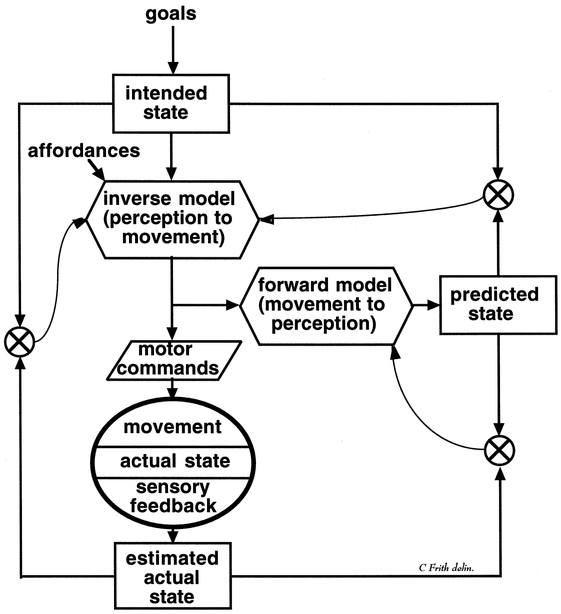

Fig. 1. The motor control system. In this simple model of the motor control system three states of the system are represented internally: the intended state, the predicted state, and the estimated current state. Appropriate movement commands are derived from an inverse model on the basis of the desired state and the current context. A forward model is used to predict the consequences of movement commands. Discrepancies between the states indicate errors and can be used to improve the functioning of the inverse and forward models. The only access the system has to the outside world is through actions performed in it and the sensory feedback the arises as a consequence of these actions.

Since inverse modelling may be less accurate than forward modelling it is possible for a discrepancy to be detected between the predicted and the desired consequences of the action before the action is actually generated. This is because the forward model may show that the movements based on the inverse model would not achieve precisely the goal required. In this case it is possible for the inverse model to be refined an the basis of the errors revealed by the forward model. A more appropriate sequence of commands can then be computed without any movements actually taking place [17]. There is much evidence that people can indeed benefit from such mental practice [6,10,39]. Both inverse and forward modelling can be improved on the basis of the errors revealed by comparing the state actually achieved by the movement with the desired and the predicted states [18]. The precise details of the motor commands are derived, not only on the basis of the desired goal, but also from the environment in which the movement takes place. Thus, the path of a reaching movement will be chosen to avoid obstacles and the grip will be adjusted to suit the size and shape of the target object [4].

Much of the operation of the motor system occurs outside our awareness. We are not aware of the computations underlying the forward and inverse models and are only intermittently aware of the representations of the current position of our limbs. Normal people can make rapid and accurate corrections to reaching and grasping movements in the absence of any awareness that these corrections are being made (see e.g. [3]). Patients with damage to early parts of the visual system (blind sight or form agnosia) can make appropriate reaching and grasping movements without being aware of the shape or location of the object they are grasping [26,35]. This observation implies that successful movements can be made without awareness of the desired or predicted limb positions. On the other hand there are many circumstances when we are aware and can report the current position of our limbs. In addition we can imagine making movements and there is evidence that motor imagery relates closely to motor preparation [15] suggesting that representations of the imagined position may correspond to representations of the desired or the predicted position of a limb during an actual movement. When asked to indicate the time at which a movement is initiated we systematically anticipate the actual time suggesting that we are reporting the predicted, rather than the actual current position of the limb [14,19]. We are also aware of discrepancies between the expected and actual outcome of a movement as when we pick up an object that is lighter than we anticipated [13].

4. The cognitive basis of the anarchic hand sign

In a patient with the anarchic hand sign the movements of the hand are no longer determined by the goals of the patient, but solely by the current context. The appearance of a door knob in the patient's line of vision is sufficient to elicit a reaching and grasping movement. Such movements are normally inhibited because they are incompatible with current goals. These inhibitory signals are no longer transmitted to the cortical regions controlling the movement of the hand because of damage to the supplementary motor cortex (SMA), or the corpus callosum. The rest of the motor system is functioning normally, however. Appropriate representations are formed and awareness of the components of the system is unaffected. In particular, the patient is aware that the movements of the hand are discrepant with his goals. He therefore corrects errors due to the action of the hand and tries to prevent the hand from making further unwanted movements.

5. The cognitive basis of delusions of control

In the patient with delusions of control something is wrong with that part of the motor system concerned with the generation of a forward model and the representation of the predicted state of the system. Since the rest of the system remains intact, the patient can represent the desired state, can calculate and carry out the motor commands

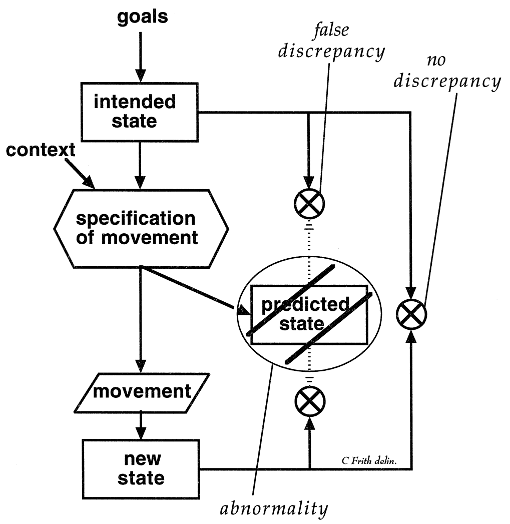

Fig. 2. The abnormality in the motor control system that leads to delusions of control. Delusions of control arise when no derivation of the predicted state of the system occurs prior to movement. This results in an abnormal experience of the movement. Nevertheless the movement is still correctly perfomed and there is no discrepancy between intended and achieved movement.

required to achieve the desired state, and can check that the desired state has been reached (see Fig. 2).

However, in the absence of an awareness of the predicted state his actions seem to move in one step from desire to execution with no intervening sense of volition, i.e. selecting and checking the action. Even though his actions are being correctly carried out the patient does not feel in control.

6. Behavioural evidence

The anarchic hand sign is directly observable. The behaviour of the anarchic hand can be studied, as can the strategies adopted by the patient to cope with this aberrant behaviour. This is not the case with delusions of control. There is nothing obviously abnormal about the patient's actions. It is only from the patient's report of his anomalous experiences that we know that there is something wrong with the motor system. A major advantage of specifying the disorder in cognitive terms is that we can predict that, in certain situations, the anomalies of the system will be manifest in abnormal behaviour as well as abnormal experience. Here are three such predictions. (1) As we have already discussed, the use of a forward model to predict the consequences of action makes it possible to improve performance of a task by mental practice. We can therefore predict that patients with delusions of control should not benefit from mental practice and may even be unable to carry out mental practice. (2) The possibility of predicting the outcome of an action before that action is performed makes it possible to correct errors very rapidly. These corrections are based on the realisation that the predicted outcome does not correspond to the desired outcome. In this circumstance the movement can be corrected before the actual outcome of the movement is known. Such rapid error corrections (sometimes called central error corrections) can be observed in normal people [25]. There is evidence that patients with schizophrenia, particularly those with delusions of control and related symptoms, tend not to make these rapid error corrections [11,21,33]. (3) Much sensory input derives, not as the consequence of the actions we perform, but from events in the outside world which can not be anticipated. There is no intrinsic difference between sensory signals arising from these two sources. However, for routine actions where the inverse and the forward models work reasonably well, if there is a discrepancy between the predicted and the actual outcome of an action, then it is likely that this is due to some event in the outside world. If patients with delusions of control and related symptoms cannot form representations of the predicted consequences of actions then they will have difficulty coping with unexpected sensory feedback and are likely to confuse the effects of they own actions with external events. This prediction can be examined in experiments in which sensory feedback is deliberately distorted. Cahill et al. [2] distorted auditory feedback so that patients heard their own voice at a different pitch. In this situation patients currently experiencing delusions reported that they heard someone else speaking whenever they spoke. They attributed the distorted sound of their own voice to an external source. This result has recently been replicated and extended by Johns and McGuire [40]. Daprati et al. [5] presented false visual feedback about hand movements so that patients sometimes saw someone else's hand rather than their own. In this experiment patients with delusions had greater difficulty than controls in identifying whether the hand they saw was their own or not.

7. The physiological under pinnings of motor control

At present we have only a very crude idea of how the motor control system illustrated in Fig. 1 can be mapped onto the central nervous system. Most of this knowledge comes from the study of neurological patients with circumscribed lesions. From such studies we know that prefrontal cortex has a major role in the formulation of goals and plans, see e.g. [20,30], and that medial premotor cortex (supplementary motor cortex, SMA) has a role in developing appropriate sequences of motor commands and initiating actions in the absence of external cues ([28], chapter 4). Superior parietal cortex seems to be the site of the mechanism by which reaching and grasping movements are refined by visual information about objects in the environment. Patients with damage in this area can show optic ataxia in which reaching and grasping movements are crude and inaccurate with the disposition of the hand not being modified to suit the shape of the object being grasped ([27], chapter 4). In contrast, a patient with damage to the SMA may have an anarchic hand which makes accurate, but inappropriate reaching and grasping movements. It is likely that representations of current and predicted limb positions might also be located in parietal lobe [7,37], but precise locations for the different representations have yet to be made. There are powerful arguments for thinking that inverse and forward modelling may be instantiated in the cerebellum [38], but little direct evidence as yet.

Self-generated tactile stimulation leads to minimal activation of somatosensory cortex and regions of parietal and anterior cingulate cortex in comparison to the same stimulation when this is externally generated [1]. This observation suggests that, if there is a match between sensation predicted (from the forward model) on the basis of the intended action and the sensation that actually results, then the physiological response to this stimulation is attenuated, in line with the reduction in the perceived intensity of the stimulation [34]. Similar results have been obtained in the auditory modality [23].

8. Physiological abnormalities associated with delusions of control

If patients with delusions of control fail to predict the sensory consequences of their actions, then, at the physiological level, we would expect to see over-activity in regions concerned with analysis of the relevant sensations. Spence et al. [31] scanned patients with delusions of control while they performed a simple motor task in which they were required to move a joy stick in one of four directions, chosen at random, in time with a pacing tone. In comparison to a control task involving routine joy stick movements this task activates prefrontal cortex and superior parietal cortex. The patients experienced their delusions in association with the performance of this task. They also showed over-activity in superior parietal cortex relative to normal controls and to patients who did not have delusions of control. Over-activity has also been observed in left superior temporal gyrus in schizophrenic patients performing auditory-verbal tasks [8,12], but we do not know if this phenomenon is related to specific symptoms.

We presume that the over-activity observed in these studies does not result from some abnormality intrinsic to the area in which the over-activity is observed. The over-activity arises through the lack of an inhibitory signal which normally attenuates activity associated with stimuli that can be predicted. The fundamental abnormality associated with the symptom is likely to be found in the system which generates this inhibitory signal. Before we can locate this abnormality it will probably be necessary to locate more precisely the brain regions concerned with developing the forward model and representing the predicted consequences of action. A possible clue comes from the observation in many studies of under-activity in the prefrontal cortex and/or anterior cingulate cortex of patients with schizophrenia (see Ref. [9] for a review). In the study of Spence et al. [32] under-activity of frontal cortex was observed in both groups of patients with schizophrenia, whether or not they had delusions of control. The patients were retested after an interval of several weeks when the delusions were not longer in evidence. At this time both the over-activity in parietal cortex and the under-activity of frontal cortex was no longer present and the overall pattern of brain activity was normal.

We might speculate that there is a causal link between the over-activity in parietal cortex and the under-activity in prefrontal cortex. A number of studies have found evidence for abnormal connectivity between frontal cortex and more posterior regions in patients with schizophrenia (see Ref. [24] for a review). In normal controls the interactions between these areas is reciprocal in the sense that high activity in the frontal region goes with reduced activity in the posterior regions. In patients with schizophrenia this relationship is not observed and activity in anterior and posterior regions is independent suggesting alack of connectivity. These observations are consistent with the notion that, normally, signals arising in prefrontal cortex where actions are initiated inhibit activity in posterior regions where the sensory consequences of actions are received. This might be the mechanism by which responses to new states are suppressed when that state has been correctly predicted on the basis of the forward model. This suppression seems not to be happening in patients with schizophrenia. We could also speculate that different symptoms arise as a result of slightly different disconnections. Failure to suppress activity in parietal cortex would lead to delusions of control, while failure to suppress activity in temporal cortex would lead to hallucinations or thought insertion. At present we do not know the precise route of these connections between frontal regions and sensory association cortex. It is likely that the basal ganglia and the cerebellum might form important stages.

9. Understanding delusions of control

At the cognitive level we suggest that delusions of control arise because of a failure to form a representation of the predicted consequences of an action. In addition to an abnormal experience of the control of movements this leads to measurable behavioural consequences in tasks involving mental practice, error correction and memory for actions.

At the physiological level we suggest that delusions of control arise because of a disconnection between frontal brain regions where actions are initiated and parietal regions where the current and predicted states of limbs are represented. The presence of delusions of control is associated with over-activity in these regions.

Do these explanations help us to understand what it is like to experience delusions of control? A useful analogy can be found by considering the artificial control systems with which we all interact. For example, the veteran conference goer knows that slide projectors will undoubtedly fail at the worst moment and in the most unexpected way. In one case the projector moves on to a new slide, not when you press the forward button, but at random moments or, perhaps, whenever there is a loud noise in the street outside. You know that the projector is not doing what you want and conclude that there is something wrong with it. This is what it is like to have an anarchic hand. Consider, in contrast, this very different case. You are speaking immediately after a rather old-fashioned Scandinavian lecturer who has studiously ignored the control box on the lectern and called out ‘next slide, please’ instead. You decide to operate the projector yourself, but each time you are about to press the forward button the projector moves on by itself. The projector is doing what you want, but it is not being controlled by you. What do you conclude? That someone in the projection box is anticipating your actions and advancing the projector for you. This is what it is like to have delusions of control.

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