Delusions of alien control in the normal brain

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Abstract

Delusions of alien control, or passivity experiences, are symptoms associated with schizophrenia in which patients misattribute self-generated actions to an external source. In this study hypnosis was used to induce a similar misattribution of self-generated movement in normal, healthy individuals. Positron Emission Tomography (PET) was employed to investigate the neural correlates of active movements correctly attributed to the self, compared with identical active movements misattributed to an external source. Active movements attributed to an external source resulted in significantly higher activations in the parietal cortex and cerebellum than identical active movements correctly attributed to the self. We suggest that, as a result of hypnotic suggestion, the functioning of this cerebellar-parietal network is altered so that self-produced actions are experienced as being external. These results have implications for the brain mechanisms underlying delusions of control, which may be associated with overactivation of the cerebellar–parietal network.
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1. Introduction

Delusions of alien control are symptoms associated with schizophrenia in which patients misattribute self-generated actions to an external source [40]. The actions in question can be trivial, such as picking up a cup or combing one's hair. Patients describe their thoughts, speech and actions as having been influenced or replaced by those of external agents rather than being produced by themselves: "My fingers pick up the pen, but I don't control them. What they do is nothing to do with me" [29].

Normally, humans can readily detect whether a movement is self-generated or externally caused. It has been proposed that an internal predictor, or forward model, uses information about intentions to enable this distinction [31,47,49]. Forward models use an 'efference copy' of the motor command [24] to make a prediction of the consequences of the motor act. A *forward dynamic model* makes predictions about the next state of the system and compares this with the desired state. A *forward output model* makes predictions about the sensory consequences of the movement, and this prediction is compared with the actual sensory consequences

of a movement (see Fig. 1). This comparison can be used to cancel the sensory effect of the motor act, attenuating it perceptually compared with identical stimulation that is externally produced [4,46]. This predictive system is useful because it filters incoming sensory signals, picking out sensory information caused externally, such as touch produced by an external object or agent, and distinguishes it from sensory stimulation that occurs as a necessary consequence of self-produced motion. An impairment in such a predictive system could cause a lack of attenuation of the sensory consequences of self-produced actions, which would therefore be indistinguishable from externally generated sensations [19,20]. This would result in the interpretation of one's own movements as being externally caused—a delusion of alien control.

How does the brain distinguish between self and externally produced sensory stimulation? The cerebellum is believed to be involved in predicting the sensory consequences of movement [30,48]. Forward models are proposed to be stored in the lateral cerebellar cortex [25]. The same region of the cerebellum is differentially activated according to the specific consequences of movement [2] and its activity increases as the actual feedback from movement deviates from the predicted sensory consequences [5]. There is accumulating evidence that the parietal cortex is also involved in the distinction between self-produced actions and actions generated by others. Activity in the parietal operculum (secondary

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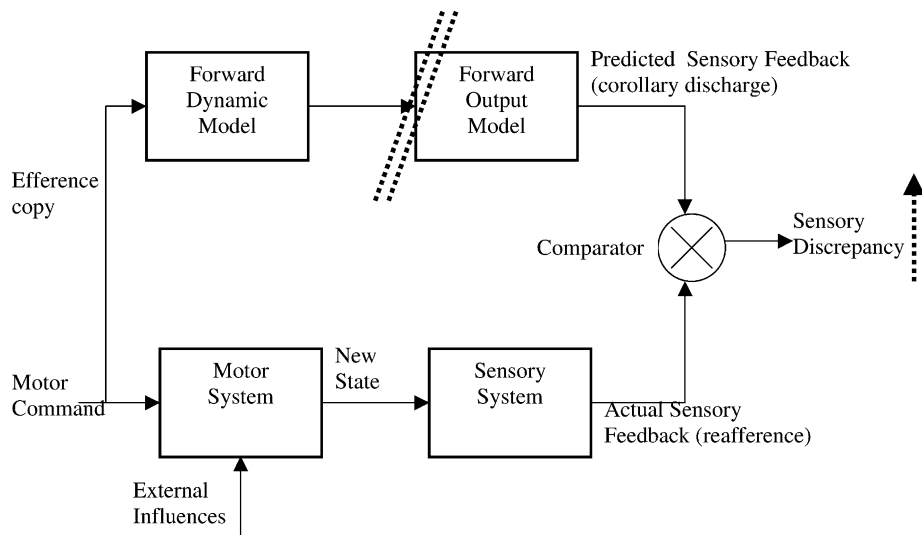 *E-mail address:* s.blakemore@ucl.ac.uk (S.-J. Blakemore).

Fig. 1. The forward model of motor control, as proposed by Miall et al. [30]. A forward dynamic model predicts the consequences of motor commands and these are compared with the desired state. The forward output model makes a prediction of the sensory consequences of motor commands, which is compared with the actual consequences of movement (reafference). Discrepancies resulting from this comparison can be used to cancel reafferent inputs and to distinguish self-produced and externally produced signals. The dashed lines indicate the proposed underlying disorder leading to delusions of control, and a possible mechanism by which hypnotic suggestion can alter the experience of a self-produced movement. In both delusions of control and hypnotic suggestion the subject can formulate the action appropriate to his intention and the action is successfully performed. The forward output model is dysfunctional such that it cannot make an accurate prediction of the sensory consequences of the movement based on the efference copy. This might be because the efference copy signals do not reach the forward output model, or that the forward output model cannot make accurate predictions based on the efference copy it receives. This results in a high level of sensory discrepancy (indicated by the dashed arrow) and no cancellation of the reafference, so that the (self-produced) movement feels externally produced.

somatosensory cortex) is attenuated during self-initiated movements and self-produced sensory stimulation compared with passive movements and external sensory stimulation [2,45]. Patients with left parietal lesions tend to confuse the ownership of hand movements when they are shown someone else's hand making movements similar to those they are making themselves [43]. The right inferior parietal cortex is activated when subjects simulate actions from someone else's perspective but not from their own [40], and when subjects observe their own actions being imitated by someone else compared with when they imitate someone else's action [12,15]. Furthermore, overactivity of the parietal cortex appears to contribute to the feeling that active movements are externally controlled in delusions of alien control [44].

The current study was designed to test the hypothesis that the cerebellum and parietal cortex are involved in generating the feeling that a movement is externally produced. Hypnosis was used as a cognitive tool to create delusions of alien control in normal, healthy subjects. 'Ideomotor movement' is a frequently demonstrated hypnotic phenomenon in which self-produced actions are attributed to an external source [23,33,38]. A typical example involves suggesting to the hypnotised subject that their arm is being raised upwards passively by an external device, such as a helium balloon attached to their wrist. This suggestion causes highly hypnotisable subjects to produce an appropriate movement. Despite generating the movement themselves, such sub-

jects describe the raising and lowering of their arm as being involuntary and typically claim that it was caused by the helium balloon. Here, Positron Emission Tomography (PET) was used to scan highly hypnotisable subjects during three movement conditions. In the Active Movement (AM) condition subjects were instructed to move their left arm up and down. In the Real Passive Movement (RP) condition, the left arm was moved up and down passively by a pulley system. In the Deluded Passive Movement (DP) condition, subjects were told that their left arm would be moved up and down by the pulley, but in fact the pulley did not move and resulting arm movements were self-generated. Movements in all conditions were performed while subjects were hypnotised. Thus, movements in the Active Movement and Deluded Passive Movement conditions were identical— subjects made the same self-generated arm movements in both conditions. The only difference between these two conditions was the source to which the movement was attributed.

Using this paradigm we were able to compare brain activation during active movements that are correctly attributed to the self (Active Movement condition) with identical active movements that are misattributed to an external source (Deluded Passive Movement condition) (see Section 2). Our results demonstrate that active movements attributed to an external source resulted in significantly higher activations in the parietal cortex and cerebellum than identical active movements correctly attributed to the self.

2. Methods

2.1. Subjects

Six healthy, male volunteers (age range 19–23 years) took part in this experiment. Each subject was pre-screened using the Harvard Group Scale of Hypnotic Susceptibility [41] to ensure that they were highly hypnotisable (indicated by a score of 9 or above on the Harvard scale out of a maximum of 12) and were able to produce the desired hypnotic arm levitation in response to suggestion. This stage of the study was approved by the UCL/UCH Joint Ethics Committee. Permission to administer radioactive substances was obtained from the Administration of Radioactive Substances Advisory Committee (ARSAC), UK. The PET study was approved by the National Hospital for Neurology and Neurosurgery Ethics Committee.

2.2. Data acquisition

All subjects underwent both PET and MRI scanning. A Siemens VISION (Siemens, Erlangen) operating at 2.0 T was used to acquire axial T1 weighted structural images for anatomical co-registration. PET scans were performed with an ECAT EXACT HR+ scanning system (CTI Siemens, Knoxville, TN) in 3D mode with septa retracted. The axial field of view was 155 mm providing whole brain coverage including cerebellum. A cannula to administer the tracer was inserted in a vein of the right arm. Approximately 350 MBq of $H_2^{15}O$ in 3 ml of normal saline were loaded into intravenous tubing and flushed into subjects over 20 s at a rate of 10 ml/min by an automatic pump. After a delay of approximately 35 s, a rise in counts could be detected in the head that peaked 30–40 s later. The interval between successive administrations was 8 min. The data were acquired in one 90 s frame, beginning 5 s before the rising phase of the head curve. Correction for tissue and helmet attenuation was made using a transmission scan from 68Ga/68Ge sources at the start of the scanning session. Images were reconstructed by filtered back projection (Hanning filter, cut-off frequency 0.5 cycles per pixel) into 63 transverse image planes (separation 2.4 mm) and into a 128×128 pixel image matrix, with a resulting pixel size of 2.4 mm × 2.1 mm × 2.1 mm, and a resolution of 6 mm at full-width half maximum.

2.3. Procedure

Throughout the experiment subjects lay supine in the PET scanner. Before scanning, subjects underwent a hypnotic induction procedure conducted by the first experimenter (DAO) commencing with voluntary eye closure, accompanied by suggestions of regular diaphragmatic breathing and muscle relaxation. This was followed by deepening involving descent imagery, and finally a 'special place' procedure involving a location of each subject's own choice [23]. Throughout scanning the subject's left forearm was fixed in an arm mould that was attached to a pulley system. This pulley system consisted of a cord that passed around a wheel positioned above the scanner bed. Movements of the free end of the cord caused vertical passive movements of the subject's forearm, flexing at the elbow. The pulley system was completely silent. The pulley system was controlled by the second experimenter (SJB) in the one condition in which passive movements of the subject's arm were required. In the other three conditions the pulley was not used, but remained attached to the subject's arm.

Before scanning took place, each subject was trained, under hypnosis, to perform voluntary vertical movement of their left forearm from its horizontal resting position to approximately 30 cm elevation and back down to the horizontal, so that each whole up and down movement took 2 s. When subjects were adept at performing this movement, they were told that in some of the ensuing conditions they would be instructed to move their arm in this way for approximately 90 s, and in other conditions the pulley system would move their arm at the same rate.

2.4. Experimental design

Subjects remained hypnotised throughout the duration of the experiment and the continuation of the hypnotic experience in the form of the 'special place' was confirmed before each scan. There were four conditions.

2.4.1. Active Movement (AM)

The subject was instructed by the first experimenter to move his left hand and forearm up and down smoothly, at a rate of approximately once every 2 s, with his elbow remaining stationary. The subject was told when to stop moving his arm by the second experimenter.

2.4.2. Real Passive Movement (RP)

The subject was informed by the first experimenter that the pulley was about to be used to move his left arm. Simultaneously with this information the second experimenter started to move the pulley system so that the subject's arm was passively moved up and down, again at the rate of approximately once every 2 s. Because the pulley system started moving the subject's arm as the information was being given, the subject felt his arm being moved by the pulley at the same time and so did not start moving his arm by himself. The absence of active movement was confirmed by the second experimenter feeling the weight of the subject's arm resting on the arm mould as the pulley was used to raise and lower it. The subject was told by the second experimenter when the pulley system was about to stop moving his arm.

2.4.3. Deluded Passive Movement (DP)

The subject was informed by the first experimenter that the pulley was about to be used to move his left forearm up and down at the same rate as before. In fact the pulley system was not used and thus the subject's arm was not moved

by it. However, within a few seconds of the suggestion that the pulley was being used to move the arm up and down, the subject began to move his arm in the manner suggested. The first exposure to this condition always occurred after the AM and RP conditions so that the subject knew what it would feel like to have his arm moved up and down by the pulley. This helped to ensure that while the arm was not moved actively in the RP condition the subject would start to move his arm in the DP condition. The scan was not started until the subject was moving his arm in the required manner. When the second experimenter told the subject that the pulley system was about to stop the arm movement ceased.

2.4.4. Rest

In this baseline condition, the subject was told by the first experimenter that no movement was needed and that he was to remain still and rest his arm.

Prior to the PET scan, each subject underwent extensive behavioural testing to ensure that arm movements were of the same frequency and amplitude in the Active Movement and the Deluded Passive Movement conditions. During this stage each subject was asked to rate the 'voluntariness' of the movement on a scale from 0 (voluntary) to 100 (involuntary). Experiencing their arm movements in the Deluded Passive Movement condition as caused by the pulley was one of the inclusion criteria for the experiment.

Each participant underwent 12 PET scans, corresponding to three replications of the four conditions. Each scan lasted 90 s with an 8-min interval between the start time of each scan. Each scan was started when the subject (or the pulley) produced appropriate movements of the specified rate and magnitude in the three movement conditions. Neither experimenter talked to the subject during the scan. The order of conditions was pseudorandom (the first DP condition always occurred after an AM and RP condition) and counterbalanced. Scanning took place in a darkened room and subjects kept their eyes closed during the experiment.

2.5. Post-experiment debriefing

To verify the source attribution of the movement in each condition, subjects were asked to indicate how voluntary the movement felt on a scale from 1 to 7 (1 indicating that it felt completely voluntary and self-generated and 7 indicating that it felt completely involuntary and externally generated). Subjects were asked to give one average rating to indicate how voluntary the movement felt in the active conditions and another average rating to indicate how voluntary the movement felt in the passive conditions (subjects believed there was only one type of passive movement condition). Since asking the subjects to make these ratings during scanning may have disturbed the subject's hypnotic state, the ratings were made after the scanning session. A paired *t*-test was used to test whether there was a significant difference between the ratings in the active and passive conditions.

2.6. Statistical analysis

Functional imaging analysis used the technique of statistical parametric mapping, implemented in SPM99 (http://www.fil.ion.ucl.ac.uk/spm). For each subject, a set of 12 PET scans was automatically realigned and then stereotactically normalised [16] into the standard space defined by the Montreal National Institute template. The scans were then smoothed with a Gaussian kernel of 12 mm full-width half maximum. The analysis of functional imaging data entails the creation of statistical parametric maps that represent a statistical assessment of condition-specific effects [17]. The effects of global changes in blood flow between conditions were modelled as a confound using a subject-specific ANCOVA [18]. Areas of significant change in brain activity were specified by appropriately weighted linear contrasts of the condition-specific effects and determined using the *t*-statistic on a voxel to voxel basis. The statistical contrasts were used to create an SPM$\{t\}$, which was transformed into an SPM$\{Z\}$. Resultant areas of activation were characterised in terms of their peak heights.

Statistical analysis was performed to examine the effects of the three movement conditions (AM, DP and RP) compared with the Rest condition, and in addition to make a direct comparison between the three movement conditions. We report regions that survive correction for multiple comparisons at $P < 0.05$ plus those regions surviving an uncorrected threshold of $P < 0.001$ for which we had an a priori hypothesis. Based on previous findings showing that the parietal cortex and the cerebellar cortex are key brain regions for the distinction between self-produced and externally produced events, we predicted that these regions would be differentially activated by active movements attributed to the self and active movements misattributed to the pulley. Specifically, previous research suggests that activity in the parietal cortex and cerebellum contributes to the feeling that a sensory event or movement is external.

3. Results

3.1. Behavioural ratings

Prior to the PET scanning, each subject underwent extensive behavioural testing to ensure that they experienced their arm movements in the Deluded Passive Movement condition as caused by the pulley. Subjects were asked to rate the voluntariness of their movement on a scale from 0 (voluntary) to 100 (involuntary). Each subject experienced his arm movement as highly involuntary in the Deluded Passive Movement condition: the average rating was 85.6 ($\pm$4.63) in this condition. In addition, to verify the source attribution of the movement in each condition, we asked subjects after the experiment to indicate how voluntary the movement felt in the active and passive movement conditions (see

Section 2). Subjects rated the Active Movement condition as significantly more 'voluntary' than the passive movement conditions (mean rating for 'Passive' = 6.50 ± 0.55 (S.D.); mean rating for 'Active' = 2.67 ± 1.63 (S.D.); d.f. = 5; $t = 7.06$; $P < 0.005$) even though half of these 'passive' conditions were really active. When asked, none of the subjects felt that the movement in any of the passive movement conditions was voluntary or self-generated, confirming that although movement in the Deluded Passive Movement condition was entirely self-generated, it was always attributed to an external source. The subjective involuntariness of ideomotor responses produced in a similar way to the arm movements in the present Deluded Passive Movement condition has been demonstrated in another study both in terms of the subjective estimated time of the movement and also by direct ratings of voluntariness taken separately from those for the equivalent voluntary and truly passive conditions [22].

3.2. Functional neuroimaging data

The functional neuroimaging results show that the two conditions in which subjects made active movements (Active Movement and Deluded Passive Movement conditions compared with Rest) were associated with significant activation of the right sensorimotor cortex, premotor cortex, supplementary motor area and insula, bilateral basal ganglia and parietal operculum and left cerebellum. These brain regions are known to be associated with movement production [13,45]. In addition to these regions, the insula and cerebellum bilaterally were significantly activated by the Deluded Passive Movement condition compared with Rest. The parietal opercular cortex and cerebellum bilaterally and right sensorimotor cortex and insula were significantly activated by the Real Passive Movement condition compared with Rest. These results are consistent with previous studies that have examined the neural correlates of passive movement [32,45].

There were several significant differences between brain activations associated with the different movement con-

Table 2
Brain regions that were activated significantly more by the Deluded Passive Movement than by the Active Movement condition (DP–AM)

Region	Coordinates (MNI)	Z-value
Right cerebellum	50, −37, −36	3.72
Left cerebellum	−26, −56, −30	3.47
Left inferior parietal cortex	−48, −46, 44	2.95
Right parietal operculum	30, −24, 20	2.96
Left putamen, extending to insula	−18, 4, 6	3.76

ditions, as shown in Tables 1 and 2. Cerebellar cortex ipsilateral to the moving arm was activated by the Active Movement condition, consistent with the notion that the ipsilateral cerebellum is involved in movement control [13,27]. The Real Passive Movement condition activated the cerebellum on both sides, but particularly on the left. This activity was located in the anterior and posterior regions that are associated with sensory processing [10,34]. This is likely to reflect the afferent sensory feedback from the pulley and the truly passive nature of the movement that was specific to this condition. The Deluded Passive Movement condition was associated with widespread activation in both cerebellar hemispheres, which was significantly greater than in the Active Movement condition, as shown in Table 2 and Fig. 2. Again, the left cerebellar hemisphere was particularly activated in this condition.

The parietal operculum bilaterally was activated to a greater extent in the Deluded Passive Movement condition than in the Active Movement condition (Table 1, Fig. 3). When a direct statistical comparison between these two conditions was made, the parietal cortex in the region of the parietal operculum on the right and the inferior parietal cortex on the left were significantly more active in the Deluded Passive Movement condition than in the Active Movement condition (Table 2).

The left prefrontal cortex (−50, 28, 24) was activated more in the Deluded Passive Movement condition than in both the Active Movement and Real Passive Movement conditions ($Z = 3.70$).

Table 1
Regions of activation in the three movement conditions compared with Rest

Condition region	AM–Rest			DP–Rest			RP–Rest		
	Coordinates	Cluster size	Z-value	Coordinates	Cluster size	Z-value	Coordinates	Cluster size	Z-value
Right sensorimotor	32, −22, 68	1986	5.71	26, −20, 68	901	5.27	28, −20, 68	1937	5.92
Right insular	34, −2, 0	334	4.22	34, 0, 2	447	5.12	34, 4, 4	766	5.85
Right parietal operculum	46, −32, 26	93	3.67	58, −32, 24	286	4.38	60, −32, 32	1517	6.53
Left parietal operculum	−46, −36, 20	76	3.70	−38, −44, 28	369	4.24	−46, −36, 20	1283	5.96
Right cerebellum	–	–	–	38, −58, −26	272	4.14	48, −46, −44	153	4.81
Left cerebellum	−42, −60, −30	47	3.61	−26, −54, −30	1662	5.39	−14, −48, −22	1301	5.43
Right basal ganglia	12, −6, −6	119	4.47	12, −8, −6	149	4.82	12, −4, −4	86	3.94
Left basal ganglia	−14, −2, −2	111	3.89	−18, 4, 2	551	5.11	−16, −2, −4	381	4.36

AM: Active Movement; DP: Deluded Passive Movement; RP: Real Passive Movement. The activation differences between the Active Movement and Deluded Passive Movement conditions must be due to the different source attribution associated with these two conditions, since the movements they produced were identical in every other way.
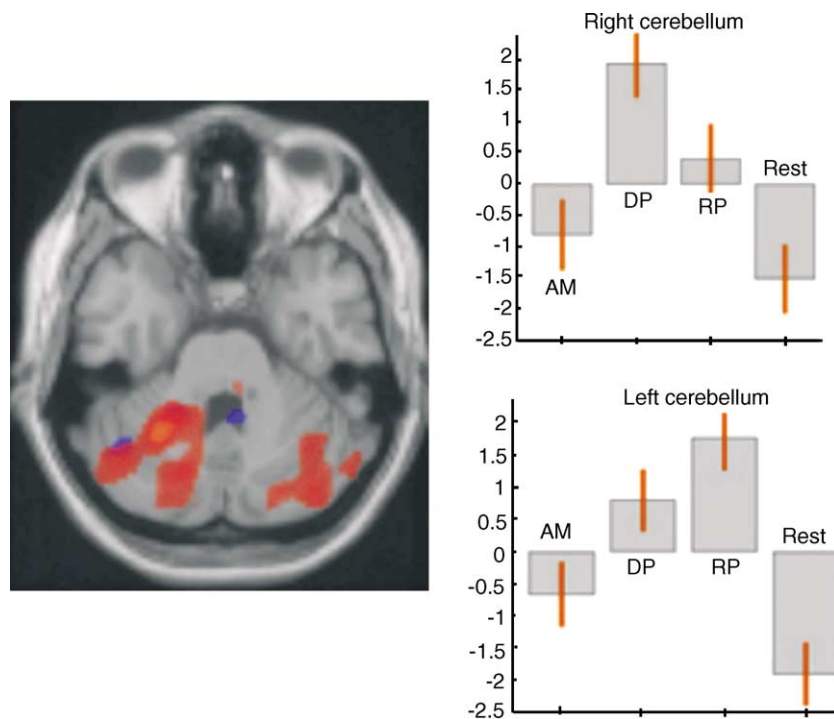
Fig. 2. Cerebellar activations in the Active Movement (blue) and Deluded Passive Movement (red) conditions superimposed on a TI image, at $Z = -30$. Activations in the cerebellum were more widespread in the Deluded Passive Movement condition (1662- and 272-voxel clusters on the left and right, respectively) compared with the Active Movement condition (47-voxel cluster on the left). There was a significant difference between the amplitude of activation in the cerebellum in the Active Movement and Deluded Passive Movement conditions. Condition-specific parameter estimates, which reflect the adjusted blood flow in each condition relative to the fitted mean and expressed as a percentage of whole brain mean blood flow, are shown for the right ($38, -58, -26$) and left ($-22, -54, -36$) cerebellum. The labelling of the conditions corresponds to: AM, Active Movement; DP, Deluded Passive Movement; RP, Real Passive Movement.

4. Discussion

Our results demonstrate that identical active movements are processed differently in the brain depending on whether they are attributed to the self or to an external source. The parietal cortex and cerebellum showed differential activity depending on whether an active movement was experienced as truly active or as passive. Parietal opercular activity is suppressed during active compared with passive movements and during self-produced sensory stimulation compared with external stimulation [2,8,9,45]. The results of the current study demonstrate that movements do not have to be passive, nor is tactile stimulation necessary, for these somatosensory areas to be activated. Activation of parietal opercular cortex during the Deluded Passive Movement condition indicates that this activity is associated with the attribution of a movement to an external source, whether the movement is actually active or passive.

How can one explain the misattribution of self-generated movement in the Deluded Passive Movement condition? In terms of the forward model [31,47,49], which is thought to be stored in the cerebellum [25,30], we propose that the abnormality in the Deluded Passive Movement condition may lie in the forward output model, and not the forward dynamic

model (Fig. 1). The forward dynamic model compares the estimated state with the desired state, and the results of this comparison are used to adjust motor commands in order to optimise motor control and learning. Subjects produced the same smooth arm movements in the Deluded Passive Movement and Active Movement conditions. Therefore, the motor system appears to be functioning normally in terms of motor control in the Deluded Passive Movement condition. In contrast, the forward output model compares the predicted consequences of motor commands with the actual consequences of movement (reafference), and discrepancies resulting from this comparison can be used to cancel reafferent inputs and to distinguish self-produced and externally produced sensory signals [20,31]. Rainville et al. [36] noted that introducing specific suggestions to hypnotised subjects was accompanied by widespread increased in rCBF in frontal cortical areas, mainly on the left. We propose that hypnotic suggestion in the Deluded Passive Movement condition, possibly mediated by top-down signals from the left prefrontal cortex, which was activated only in this condition, prevents the motor intentions from reaching the forward output model. In this case the forward output model would no longer be able to make an accurate prediction of the sensory consequences of the movement. This would
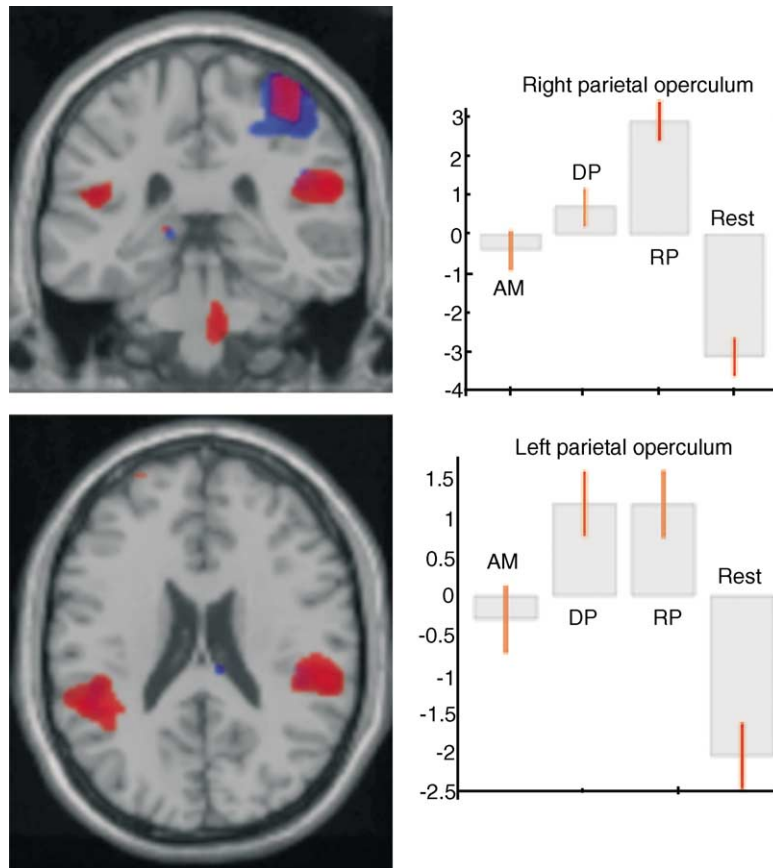
Fig. 3. Parietal activations in the Active Movement (blue) and Deluded Passive Movement (red) conditions superimposed on TI images, at $Y = -33$ and $Z = 24$. Parietal opercular activations were more widespread in the Deluded Passive Movement condition (286- and 369-voxel clusters on the left and right, respectively) compared with the Active Movement condition (76- and 93-voxel clusters on the left and right, respectively). The amplitude of response in the parietal cortex was significantly higher in the Deluded Passive Movement than in the Active Movement condition. Condition-specific parameter estimates, which reflect the adjusted blood flow in each condition relative to the fitted mean and expressed as a percentage of whole brain mean blood flow, are shown for the right (58, −32, 24) and left (−38, −44, 28) parietal operculum. The labelling of the conditions corresponds to: AM, Active Movement; DP, Deluded Passive Movement; RP, Real Passive Movement.

lead to a discrepancy between predicted and actual sensory feedback, which would result in no attenuation of the sensory feedback, making the (self-produced) movement feel externally produced. The cerebellum is thought to signal sensory discrepancies between predicted sensory feedback of movements and their actual sensory consequences [1,5], and so increased cerebellar activation would be expected in the Deluded Passive Movement condition [2,5,25, 30,48].

The left cerebellum was activated to a greater extent than the right hemisphere in each condition, as can be seen in Table 1. This is presumably because of the predominantly ipsilateral receptive fields in the cerebellum, which respond both to movement and to tactile stimulation. There was significant activation in the right cerebellum during the Deluded and Real Passive Movement conditions, but not during the Active Movement condition, suggesting that this activation was due to tactile stimulation associated with the operation of the pulley, whether real or not, experienced by subjects in those conditions.

Why should there be greater activity in parietal cortex when active movements are misinterpreted as being externally produced? Damage to the parietal lobe can cause impairments in the distinction between self and other [7,45]. A recent case-study reported a patient with a right hemisphere lesion in which the white matter underlying cortex including the parietal operculum had been damaged. This patient suffered from the delusional belief that her left limb belonged to her niece [6]. The parietal cortex, in particular the inferior parietal lobe and the intraparietal sulcus, has been consistently implicated in the attribution of actions to external agents. For example, greater activity is observed in these regions when subjects mentally simulate actions from someone else's perspective compared with from their own perspective [39] and when subjects attribute actions to someone else compared with when they attribute actions to themselves [12,15].

We propose that activity in the parietal cortex is required for an arm movement to feel as if it is externally generated. The inferior parietal lobe is the direct target of output from

the cerebellum [11] and parietal opercular cortex activity can be influenced by cerebellar activity [3]. Higher levels of activation occur in the cerebellum and parietal operculum when tactile stimulation is external compared with when it is self-produced [2]. In the Deluded Passive Movement condition, if the cerebellum signals a discrepancy between predicted and actual sensory feedback, then no parietal opercular attenuation would occur, which is what normally occurs during externally produced sensory stimulation. The parietal operculum, which has bilateral receptive fields, was activated in both hemispheres to a greater spatial extent in the Deluded Passive Movement than in the Active Movement condition (see Table 1). In the direct comparison between these two conditions, significant differences were found in the parietal lobe in the region of the secondary somatosensory cortex on the right and the inferior parietal cortex on the left (Table 2). That the left inferior parietal cortex was activated to a greater extent by the deluded passive movements than by the active movements is in line with the finding that damage to this region causes a confusion between self-produced and external actions [42].

There is an alternative—or additional—explanation for the parietal activity in the Deluded Passive Movement condition. It is well established that attention to a particular sensory modality or feature increases activity in the brain region that processes that feature even in the absence of a sensory signal [14]. It has also been suggested that hypnotic suggestion, by focussing attention, can produce increased activity in specific brain areas, which causes a modulation of sensory experience [35]. For example, Rainville and colleagues have shown that the hypnotic suggestion to increase or decrease the affective components of constantly applied experimental pain are accompanied by a modulation of activity in anterior cingulate cortex, an area previously shown to be involved in the experience of pain [35]. Activity in this region increased as the experience of pain increased in response to suggestion even though the painful stimulus itself did not change. They also showed that suggestions to alter the subjective intensity (but not painfulness) of the same stimulus selectively altered levels of activity in somatosensory cortex [37]. Similarly, suggestions given in hypnosis to fade the colour out of colourful test stimuli or to introduce the experience of colour to grey-scale stimuli are accompanied by corresponding changes in activation in colour processing regions in the fusiform gyrus [28]. Here, we suggest that subjects' attention is more highly focussed on the sensations associated with passive movement in the Deluded Passive Movement condition than in the Active Movement condition. This increased attention produces activation in brain regions that process such sensations (the parietal cortex). It is the activation in these regions, we suggest, that causes the movement to feel external.

A similar mechanism may underlie the disorder leading to delusions of control in schizophrenia and other clinical conditions. In particular, it has been proposed that delusions

of control are caused by an impairment in the forward model system that predicts the sensory consequences of one's own actions ([20] and Fig. 1). This could cause a lack of attenuation of the sensory consequences of self-produced actions, which would therefore be indistinguishable from externally generated sensations, hence causing a confusion between the self and the other [19,20]. A similar theory that attempts to account for delusions of control posits that these symptoms reflect a disruption of the cognitive processes that normally produce a sense of agency or volitional control [26]. Jeannerod has suggested that conscious judgement about a movement requires a different form of representation from that needed for unconscious comparisons of predictions and outcomes within the motor system [26]. Specifically, he suggests that conscious judgements about movements require 'third-person' information while control of movement depends upon private 'first-person' information. On this basis, Jeannerod proposes that patients with delusions of control fail to monitor the third-person signals that enable them to make judgements about their own actions. Spence [43], on the other hand, has suggested that the problem underlying delusions of control has to do with the timing of awareness. The awareness of the actual outcome of the movement precedes the awareness of the predicted outcome, which is contrary to the normal experience of our own agency.

There is one crucial difference between delusions of control in clinical populations and the misattribution of movement in the hypnotised subjects in this study. The patient with delusions of control has an intention to move and misattributes her movement to someone or something else, whereas the hypnotised person is not aware of the intention to move and experiences his movement as passive ([22]; see Section 3). We suggest that the patient with delusions of control is aware of her intention, makes a movement based on this intention, but no cancellation of the consequences of the movement occurs, so the movement, even though it matches the intention, feels like an externally caused movement. The hypnotised subject, on the other hand, is not aware of any intention to move, moves due to the hypnotic suggestion to move, but no sensory cancellation occurs, and his movement is experienced as passive.

The ability to distinguish between active and passive movements is an important part of a 'who' system, which allows one to link an action with its cause [21]. Our results suggest that overactivation of a cerebellar–parietal network during self-generated actions is associated with the misattribution of those actions to an external source. Overactivity of the parietal cortex and cerebellum occurs during self-generated movements in patients with delusions of alien control, and subsides when the same patients are in remission [44]. It is possible that malfunctioning in this network leading to overactivity produces the feeling of 'otherness' associated with self-produced movements in delusions of alien control. The precise nature and cause of this malfunction remains to be determined.

Acknowledgements

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