Conversion hystérique, hypnose et imagerie cérébrale

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Motor inhibition in hysterical conversion paralysis

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ABSTRACT

Brain mechanisms underlying hysterical conversion symptoms are still poorly known. Recent hypotheses suggested that activation of motor pathways might be suppressed by inhibitory signals based on particular emotional situations. To assess motor and inhibitory brain circuits during conversion paralysis, we designed a go–nogo task while a patient underwent functional magnetic resonance imaging (fMRI). Preparatory activation arose in right motor cortex despite left paralysis, indicating preserved motor intentions, but with concomitant increases in vmPFC regions that normally mediate motivational and affective processing. Failure to execute movement on go trials with the affected left hand was associated with activations in precuneus and ventrolateral frontal gyrus. However, right frontal areas normally subserving inhibition were activated by nogo trials for the right (normal) hand, but not during go trials for the left hand (affected by conversion paralysis). By contrast, a group of healthy controls who were asked to feign paralysis showed similar activation on nogo trials and left-go trials with simulated weakness, suggesting that distinct inhibitory mechanisms are implicated in simulation and conversion paralysis. In the patient, right motor cortex also showed enhanced functional connectivity with the posterior cingulate cortex, precuneus, and vmPFC. These results suggest that conversion symptoms do not act through cognitive inhibitory circuits, but involve selective activations in midline brain regions associated with self-related representations and emotion regulation.

Introduction

Conversion disorders have been observed in medical practice for many centuries but the exact cognitive and emotional processes as well as the underlying neurophysiological substrates remain poorly known (Kozlowska, 2005; Vuilleumier, 2005, 2009). Formerly called "hysteria" in classic psychiatry terminology, conversion is defined by the presence of neurological symptoms (such as paralysis, anesthesia, blindness and so forth) that cannot be attributed to organic brain injury but appear to be triggered by particular emotional stressors or conflicts. Importantly, these symptoms are not consciously feigned by the patient in order to obtain help or gain, but rather thought to result from some distortion of bodily functions in self-awareness. The notion of "conversion" was inspired by the influential work of Freud and Breuer (1895), who proposed that physical symptoms might reflect psychological motives or affective motive (often related sexual issues) that are unconsciously repressed and then transformed into bodily complaints with some symbolic meaning. This view was partly derived from the earlier work of Charcot (1892) and Janet (1894) who insisted on the role of a dissociation between conscious and unconscious processes, with the latter overtaking the former for the control of mental or sensorimotor functions.

Although the Freudian account of hysterical conversion did not make reference to any specific cerebral mechanisms underlying the production of physical symptoms, Charcot and several other theorists after him have speculated on the possible neural pathways by which emotional states might affect the mind and behavior of these patients. Charcot himself considered that the functioning of the nervous system could be altered without any visible pathology under the influence of powerful ideas, suggestions, or psychological states, in a manner similar to the effect of hypnosis (Charcot, 1892), while his student Babinski added that such factors could produce conversion in specific individuals based on the personal meaning of emotional triggers and idiosyncratic predispositions (Babinski and Dagnan-Bouveret, 1912). Others have proposed that conversion might represent a pathological exaggeration of some primitive forms of reflexive behavior in response to psychological or physical stressors (Kretschmer, 1948; Whitlock, 1967). An early account for these phenomena in terms of specific neural mechanisms was proposed by Pavlov (1941) who speculated that an over-excitation of "subcortical centers" due to strong emotions might lead to a response of cortical inhibitory processes (tentatively located in frontal lobe) whose regulatory action could then overflow to other systems and somehow

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"switch off" sensorimotor functions. Similarly, several subsequent theorists suggested that the pseudo-neurological deficits in hysterical conversion (such as paralysis, anesthesia, or blindness) might result from a selective "blockade" or "gating" of sensorimotor inputs, either at the level the thalamus (Ludwig, 1972; Sackeim et al., 1979) or through the action of attentional mechanisms mediated by anterior cingulate or parietal cortex (Marshall et al., 1997; Sierra and Berrios, 1999; Spiegel, 1991). Other more recent accounts suggested a disconnection between ongoing sensory or motor representation and self-awareness processes mediated by central executive systems in prefrontal cortex (Oakley, 1999), or a by distortion of sensory or motor representation due to emotional states or past experiences (Brown, 2004; Damasio, 2003).

However, until recently, very few studies have used direct neurophysiological measures such as EEG, MEG, or functional brain imaging to provide direct support for these theoretical accounts of conversion (Vuilleumier, 2005, 2009). A pioneer study used SPECT in a single female patient with left arm anesthesia (Tiihonen et al., 1995) and reported abnormal hemispheric asymmetries with decreased activity in right parietal areas and increases in right frontal areas during left sensory stimulation, but these results did not suggested specific causal mechanisms for such changes. A subsequent influential study was conducted by Marshall et al. (1997) in another single patient who suffered from chronic leg weakness since a few years, and was asked to attempt to move one of the other leg on command during PET imaging. Results showed that unlike a normal left motor activation for executed movements with the right leg, attempts of movements with the left/paralyzed leg did not only produce no activation in right motor cortex but activated orbitofrontal and anterior cingulate areas instead, a finding that was taken to suggest that voluntary actions were prevented due to an active inhibition of motor pathways by ventromedial prefrontal areas. Subsequently, several other studies using fMRI have also reported decreases activations in motor (Burgmer et al., 2006; Kanaan et al., 2007; Stone et al., 2007), sensory (Ghaffar et al., 2006; Mailis-Gagnon et al., 2003), or visual regions (Werring et al., 2004) in conversion patients with paralysis, anesthesia, or blindness, respectively, often together with concomitant increases in medial or dorsolateral prefrontal areas. Another study reported reduced activation of thalamus and basal ganglia contralateral to the limbs affected by motor and sensory conversion symptoms during passive vibratory stimulation (Vuilleumier et al., 2001), which returned to normal symmetric levels after remission of the symptoms. Network connectivity analyses in these patients further revealed that subcortical decreases were functionally coupled with changes in ventral prefrontal areas (BA 11/BA 45), suggesting that the latter brain regions might provide a source for modulatory influences on the basal ganglia-thalamic loops controlling voluntary movement (Haber, 2003; Vuilleumier et al., 2001).

While these studies generally converge to demonstrate that conversion symptoms may lead to functional changes in brain areas concerned with the affected sensorimotor domain, it still remains unclear which areas within prefrontal cortex are most specifically implicated, and whether their activity corresponds to inhibitory processes or to other attentional or motivational functions (see Ballmaier and Schmidt, 2005; Sierra and Berrios, 1999; Vuilleumier, 2009). Thus, changes in anterior and cingulate medial prefrontal areas in conversion have also been related to increased self-monitoring and ferror processing (de Lange et al., 2007; Roelofs et al., 2006; Vuilleumier et al., 2001). Another study comparing patients with conversion and feigned paralysis during a motor task found reduced activation in left dorsolateral prefrontal cortex in the former case, but in right dorsolateral prefrontal cortex in the latter case (Spence et al., 2000b), and these changes were attributed to disturbances in mechanisms underlying conscious will and the internal generation of motor intentions (Spence, 1999). Such disturbances might potentially accord with impairments in covert planning of motor actions during mental imagery (de Lange et al., 2008; Maruff and Velakoulis, 2000) or action observation (Burgmer et al., 2006) in some conversion patients. Nevertheless, because conversion symptoms remit with sedation and distraction, their production might be consistent with a role of active inhibition or monitoring processes mediated by prefrontal executive systems (Oakley, 1999; Spiegel, 1991). Hence, taken altogether, current imaging data have not fully determined the exact neural networks involved in conversion and the exact functional role of changes in prefrontal regions.

Here we used fMRI in a patient with unilateral conversion paralysis to directly test whether her motor deficit involved inhibitory processes subtended by anterior and medial prefrontal areas, and whether these were similar or not to those responsible for conscious inhibition in normal conditions (and/or to those recruited during simulation). We designed a new go–nogo paradigm that allowed us to probe for different aspects of motor preparation, execution, and inhibition within a single task, for both the intact and affected hand. Go–nogo paradigms have been extensively used to study motor inhibition and are known to recruit selective brain regions, particularly the right inferior frontal gyrus (Aron et al., 2004; Garavan et al., 1999). In our study, by comparing performance in a go–nogo task in normal conditions and during motor conversion affecting one hand, we could determine whether voluntary inhibition of an action (e.g. nogo condition for a "normal" hand) and conversion paralysis (e.g. go condition for a "paralyzed" hand) would share similar neural mechanisms (i.e., activation of right IFG). In addition, by combining go–nogo responses with a motor preparation phase, during which participants must prepare a hand movement prior to the imperative Go or NoGo cue, we could also test whether conversion paralysis involved a suppression of motor intention, i.e., a selective loss of volition for the affected limb. If the internal generation of motor actions is impaired (Spence et al., 2000b), then the preparation phase should evoke no motor activation for the paralyzed hand (and no subsequent inhibition). Alternatively, if conversion paralysis results from active inhibition of willed movement (Marshall et al., 1997), then activation of motor and premotor areas should arise normally during preparation, while inhibitory activity should arise at the time of execution (e.g. left-go trials should actually correspond to the nogo conditions). Finally, if conversion involves a functional dissociation between discrete brain networks supporting executive and sensorimotor functions (Oakley, 1999), then the connectivity patterns of motor regions should differ between conversion and normal conditions, or between the affected and normal hand side. Importantly, to determine effects specific to conversion, we also investigated a control group of healthy subjects who were instructed to simulate a unilateral hand paralysis.

Methods

Participants

The patient was a 36-year-old right-handed woman, divorced with two young children and with several recent stressful life events, including a new relationship break-up. She had a degree in psychology but was not currently working. She was initially admitted to the hospital for acute and transient gastro-abdominal symptoms (diarrhea and vomiting) of probable viral origin. She had no psychiatric or neurological history, except a minor post-traumatic neck pain several years ago that recovered after a few days, and she remembered no motor or sensory symptoms during this event. At the time of her current admission, she also described a left arm weakness involving the hand and wrist, which was reported to have started already several days prior to admission. She described an impossibility to grasp and hold objects, and on demands could only execute small amplitude movements of the fingers, without neither full extension nor full flexion, and with clear giveaway weakness against resistance. She subjectively felt that she had no control over her right hand, with a lack of "reactivity" or sense of "blockade" when she attempted to make a

movement. A complete neurological examination was performed by a qualified physician (independent of the study) and found to be normal. When asked to move her right hand, she executed only small, irregular movements, with a mild extension and spreading of the fingers, but marked weakness during grasping or against resistance. No dystonic posturing, tremor, or muscular co-contraction was observed. Sensation and motor reflexes were intact. A brain MRI scan showed no structural abnormality. Routine blood exams showed no inflammatory or systemic disorder. The motor deficit in the left arm persisted for the next 10 days but with no other neurological signs. The final neurological diagnosis was a psychogenic upper arm paresis, without sensory deficit, attributed to the recent psychological stress associated with her personal life events and the transient gastric disease.

The patient was referred to us for further neuroradiological investigation of brain function. She was informed about the research goals and gave her written consent according to the rules of Geneva Hospital University Ethics Committee. Our fMRI study was performed five days after her admission, while the motor deficit was still present. Her gastro-abdominal disorder has fully recovered. She was not under any medication at the time of fMRI.

Results in the go–nogo task for the patient were compared to a normal control group of thirty healthy subjects. These were volunteers who participated in the study after informed consent, and were recruited for separate work on motor function and inhibition. They had no past neurological or psychiatric disease, were right-handed, and had normal or corrected-to-normal vision. A group of 24 participants performed the same task as the patient in a normal condition (for two fMRI blocks), while another group of six participants performed this task with the instruction to simulate a left hand paralysis (also for two blocks). The latter subjects were told that they served as controls for a study of stroke patient with hemiplegia, and asked to act "as if" they were suffering from motor weakness and unable to move their fingers.

Stimuli

Visual stimuli included three iso-luminant pictures of hands (one grayscale, one green, and one red), which depicted either a right or left (mirrored) hand as seen from a dorsal view (palm down). All images were projected on a screen and reflected on a mirror mounted on the MRI head coil, with a size of ~6×6° visual angle.

Procedure

All participants performed a modified go–nogo task using both hands (see Fig. 1). Each trial began with a fixation cross of 500 ms, followed by a preparation cue (PREP condition) represented by a grayscale picture of a hand (right or left), indicating on which side to prepare the upcoming movement. After a varying interval (1 to 5 s), the hand picture could turn to either green or red (for 750 ms). When green, participants had to respond as quickly as possible by pressing a button with the corresponding hand (GO condition, 75% of trials); but when red, the prepared movement had to be withheld (NOGO condition, 25% of trials). Thus, NOGO trials were relatively rare relative to GO trials (1:4) but not unexpected. A visual feedback was given on all trials after a random interval of 100 to 800 ms (signaling correct, incorrect, or no response detected). All conditions were presented in blocks of 100 trials (in pseudo-randomized order), separated by 30-second rest periods after each block (see below).

The upper face and hands of participants were continuously monitored by an infrared eye-tracker (ASL LRO 450) and an MRI-compatible video-camera (Philips Medical Systems), respectively.

Prior to fMRI, all participants performed the task for a short training block of 20–30 trials.

fMRI acquisition and analysis

MRI data were acquired on a 1.5 T whole-body INTERA system (Philips Medical Systems), using the standard head coil configuration. For each participant, structural images were acquired with a 3D-GRE T1-weighted sequence (FOV = 250 mm, TR/TE/Flip = 15 ms/5.0 ms/30°, matrix = 256×256, slice-thickness = 1.25 mm); and functional images with a GRE EPI sequence (TR/TE/Flip = 2500 ms/40 ms/80°, FOV = 250 mm, matrix = 128×128). Each functional image comprised 32 contiguous 3.4 mm axial slices (TR = 2.5s) oriented parallel to the inferior edge of the occipital and temporal lobes. For each of the four experimental blocks, a total of 266 functional images were acquired continuously.

Functional images were analyzed using the general linear model (Friston et al., 1998) for event-related designs in SPM2 (Wellcome Dept. of Imaging Neuroscience, London, UK; http://www.fil.ion.ucl.ac.uk/spm). All images were realigned, corrected for slice timing, normalized to an EPI-template (re-sampled voxel-size of 3 mm), spatially smoothed (8 mm FWHM Gaussian kernel), and high-pass filtered (cutoff 120 s).

Statistical analyses were performed on a voxelwise basis across the whole-brain. Individual events were modeled by a standard synthetic hemodynamic response function (HRF). To account for residual movement artifacts after realignment, movement parameters derived from realignment corrections (3 translations, 3 rotations) were entered as covariates of no interest. The general linear model was then used to generate parameter estimates of activity at each voxel, for each experimental condition (PREP, GO, and NOGO, for both hands). Trials with errors were included as supplementary regressors in the

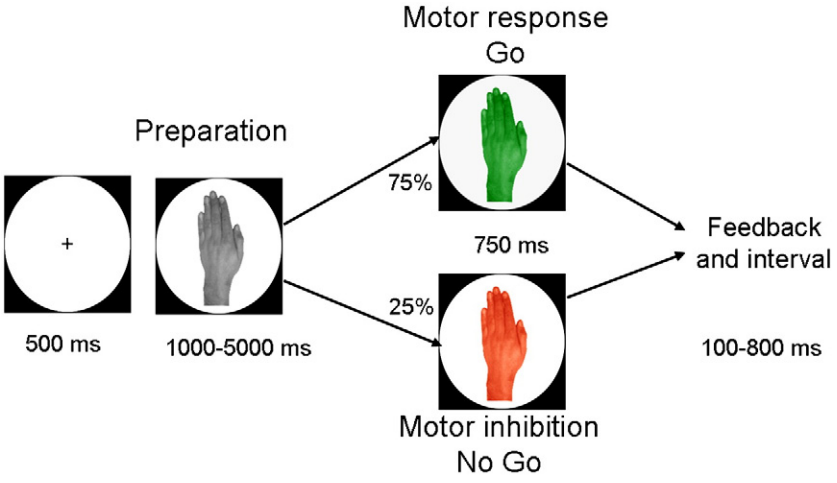

Fig. 1. Illustration of the paradigm. Pictures could display either a right or left hand (half of the trials each).

analysis of fMRI data resulting in six regressors for each run (L-PREP, R-PREP, L-GO, R-GO, L-NOGO, R-NOGO) plus possibly four additional regressors (L-GO_error, R-GO_error, L-NOGO_error, R-NOGO_error) in each participant. Statistical parametric maps were generated from linear contrasts between the HRF parameter estimates for the different conditions.

A random-effect group analysis was conducted on contrast images from the individual analyses, using one-sample *t*-tests across the whole-brain (Friston et al., 1998). For the group of normal subjects, focal activations were considered as significant at a voxel level of $p<0.001$ (uncorrected) with a cluster threshold of more than 10 voxels, unless reported otherwise. For the simulators, we used a threshold of $p<0.005$ due the smaller number of subjects. For the patient, we report only those clusters with peak values of $p<0.001$ and that showed significant or marginally significant probabilities at the cluster size level ($p<0.05$ or $p<0.10$, respectively; corresponding to cluster size >30 voxels). In addition, post-hoc analyses were performed on selected regions of interest (i.e. to compare two conditions for a cluster identified in a main contrast pooling across these conditions) by using *t*-test contrasts on the peak of activation defined by a previous contrast and searching for the *z*-score maxima within a 10-mm sphere in SPM. ANOVAs and *t*-tests were also performed on average parameter estimates of activity (betas) extracted from selected regions of interest (previously defined in SPM), using standard statistics in SPSS 15.0 (SPSS Inc., Chicago, Illinois, USA).

For functional connectivity analysis, we first selected the peak of activity in right and left motor cortex (M1, seed regions) based on the results found for GO trials in the normal group, and a corresponding region in the patient and simulators that overlapped with activation on the PREP conditions (see Results). We then used a new GLM model with the average signal from a 6 mm sphere centered on the peak of motor activity for each side as two additional regressors. Thus, this new design matrix included 2 runs that each contained 6 regressors for the 6 experimental conditions (see above), plus two regressors for the time-series of rM1 and lM1 activity (non-convolved with the HRF), as well as 6 regressors for the movement realignment parameters, and one regressor for the constant session effect in each run. We then contrasted the rM1 regressors to the lM1 regressors, using a paired *t*-test across the whole-brain for each subject. Again, a random-effect group analysis was conducted on these individual contrast images for the normal control and simulator groups.

Behavioral data were analyzed with Microsoft Excel and SPSS.

Results

Behavioral performance

In the normal condition, healthy participants correctly responded with both hands for GO (97.4%) as well as NOGO conditions (96.9%). During simulation, performance was also highly accurate with the right hand for GO (95.8%) and NOGO trials (96.4% respectively), whereas no movement was made with left hand, indicating successful compliance with our instruction in the simulator group. Likewise, RTs on correct GO trials with the right hand were similar in both control groups (normal condition and simulation). ANOVAs and paired *t*-tests showed no significant difference between hands in the normal condition and between the two control groups for the right hand (all pairwise comparisons, $t<1$, for both RTs and error rates).

By contrast, the patient was less accurate than controls in the normal condition and than simulators. Overall, with the right hand, she was 65% correct for GO trials and only 35% correct for inhibition on the rare NOGO trials. With the left hand, she made no response at all on GO trials, and no commission error on NOGO trials, consistent with her left hand paralysis. However, poor accuracy was particularly observed during the first block and attributable to precipitate responding, because the patient appeared to understand the task instructions correctly during practice trials prior to scanning, and she then improved during the subsequent blocks. When excluding the first block, accuracy was 85% for GO condition, with the probability of a key-press being significantly higher on GO trial than on NOGO ($\chi^2=4.01$, $p=0.045$). Moreover, consistent with a tradeoff for precipitated responses against accuracy, her RTs for right hand GO were among the fastest (average 404 ms) and below the 95% distribution interval of healthy controls (432–475 ms), although they were still within the normal range (min 382 ms–max 599 ms). This suggests that the patient tended to make hasty responses and thus also made more errors than controls. In the subsequent fMRI analysis, we therefore used only data from correct trials for the right hand, and all no response trials for the left hand. Nonetheless, the same fMRI results were found when analyses were repeated without the first block.

fMRI data

For clarity, we will first describe results in normal controls and then report those from the conversion patient, for each of the three task conditions separately.

Movement preparation

To test whether conversion affected motor intentions with the left hand, we examined brain activity during the preparation phase for each hand. We first contrasted responses evoked by the PREP cues for one or the other side (R-PREP>L-PREP, and conversely). In the normal

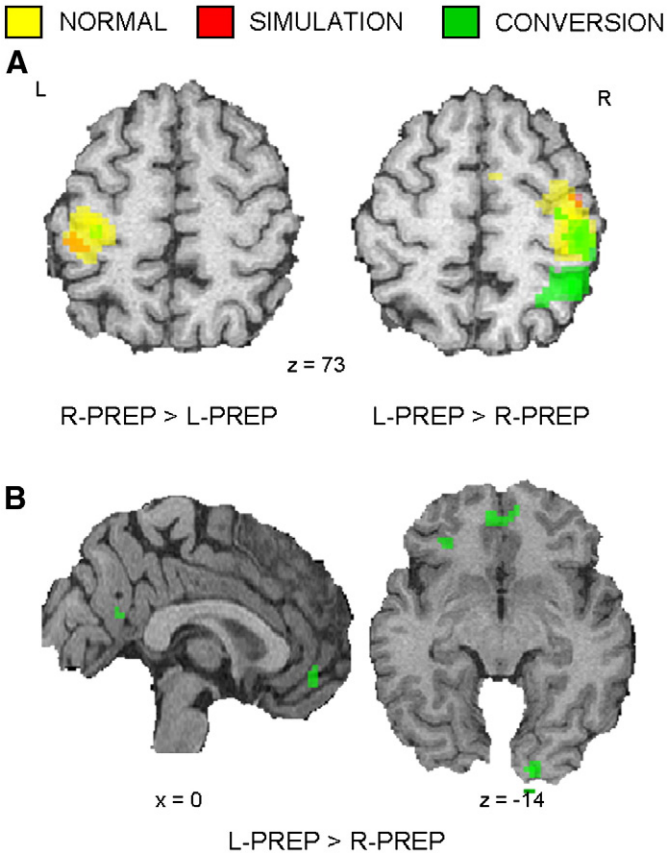

Fig. 2. Activation during the preparation phase. (A) Increases are shown in the PREP condition for the right>left/paralyzed hand (left part of figure) and for the left/paralyzed>-right hand (right part of figure) in normal controls (yellow), conversion patient (green, $p<0.001$ uncorrected, $k=10$ voxels), and simulation controls (red, $p<0.005$ uncorrected, $k=10$ voxels). Bilateral and symmetric activations were seen in primary motor cortex in all cases. (B) In the conversion patients, additional increases were found in right posterior cingulate cortex (PCC) and ventromedial prefrontal cortex (vmPFC) as well as left orbitofrontal cortex (OFC) and right occipital cortex, for the left/paralyzed hand selectively.

Table 1
SPM results for the preparation phase.

	Hemisphere	Brain region	*x*	*y*	*z*	*Z* value	*p*-cluster corrected
A.							
NO: L-PREP>R-PREP	R	Motor cortex	42	−18	57	5.43	
	R	Fusiform gyrus	9	−87	−12	4.23	
	R	Putamen	21	9	0	4.12	
	R	Supplementary motor area	9	−3	54	3.95	
	R	Superior parietal lobe	27	−54	69	3.91	
	L	Fusiform gyrus	−36	−90	−12	3.77	
NO: R-PREP>L-PREP	L	Motor cortex	−42	−30	51	4.78	
	R	Fusiform gyrus	36	−87	−3	3.81	
	L	Supplementary motor area	−3	−15	51	3.75	
B.							
CONV:L-PREP>R-PREP	R	Motor cortex	42	−30	69	4.99	<0.001**
	R	Postcentral gyrus	42	−48	60	5.77	<0.001**
	R	Fusiform gyrus	18	−93	−12	5.82	<0.002**
	L/R	ventromedial prefrontal cortex	0	48	−12	4.27	0.006**
	L	lateral Orbitofrontal cortex	−27	33	−15	3.97	0.062*
CONV:R-PREP>L-PREP	L	Fusiform gyrus	−15	−84	−12	Inf	<0.001**
	L	Motor cortex	−42	−21	42	4.77	0.016**
	R	Inferior parietal lobule	54	−48	39	4.43	0.001**
	L	Middle frontal gyrus	−33	36	24	4.31	0.069*
	R	Fusiform gyrus	12	−69	−15	3.84	0.036**
C.							
SIM: L-PREP>R-PREP	R	Motor cortex	45	−12	60	3.08*	
	R	Inferior parietal lobule	45	−45	54	4.21	
SIM: R-PREP>L-PREP	L	Motor cortex	−45	−30	54	3.03	
	R	Middle frontal gyrus	39	33	−3	4.34	
	L	Middle temporal gyrus	−54	−63	12	3.78	
	L	Posterior insula	−39	−21	15	3.73	
	L	Superior temporal gyrus	−57	−39	15	3.62	
	R	Ventral premotor cortex	57	−6	18	3.34	

NO= normal state; SIM= left simulated paralysis; CONV = patient with conversion, ** $p<0.05$; * $p<0.1$.

condition, there was a reliable activation of motor cortex in precentral gyrus (primary motor area, M1), contralateral to the hand being prepared (Fig. 2, Table 1). The same pattern was found for the patient and during simulation (Table 1). For simulation relative to normal condition, a 2 (hand side) × 2 (group) ANOVA showed a main effect of hand ($F_{(1,28)}=19.91$, $p<0.001$), but no interaction ($F_{(1,28)}=0.60$, n.s.) for the left motor area; and similarly there was a main effect of hand ($F_{(1,28)}=56.41$, $p<0.001$) but no interaction ($F_{(1,28)}=1.55$, n.s.) for the right motor area. Thus, despite conversion or simulation, participants still normally activated their right motor cortex during the preparation of a left hand movement, indicating that they could still generate covert motor plans and correctly followed task instructions (Toni et al., 1999). Moreover, activation in the contralateral fusiform gyrus was also found for both the normal controls and the patient (Table 1).

However, in the conversion patient, the same contrast (L-PREP>R-PREP) showed additional increases in the ventromedial prefrontal cortex (vmPFC) and left orbitofrontal cortex (OFC) for movement preparation with the left/paralyzed hand (Fig. 2B, Table 1). By contrast, in the normal condition and simulation condition, activity in these two regions was generally low and similar for both hands. Inspection of ROIs centered on the same peaks showed no difference for vmPFC (L-PREP vs R-PREP in normal condition: *z*-score = 0.01, n.s.; simulation: *z*-score = 0.64, n.s.), for posterior cingulate cortex (PCC; L-PREP vs R-PREP in normal condition: *z*-score = 0.83, n.s.; simulation: *z*-score = 0.26, n.s.), or for OFC (L-PREP vs R-PREP in normal condition: *z*-score = 0.04, n.s.; simulation: *z*-score = −0.24, n.s.). This differential activity across hands and conditions for the patient suggests a specific involvement of the vmPFC, the PCC and left OFC during motor conversion concerning the left hand (see Fig. 2).

Motor execution

Next, we identified activations produced by motor execution (in normal conditions) or attempted movements (during simulation and conversion). To this aim, we compared brain responses to GO stimuli with one hand relative to GO stimuli with the other hand (i.e. L-GO>R-GO, Table 2A). As expected, these analyses showed that left motor networks (including left primary motor cortex and right cerebellum) were significantly recruited by right hand movements (R-GO>L-GO), with a similar response in all conditions (normal, simulation, or conversion; Fig. 3, Table 2A).

By contrast, left motor execution (L-GO>R-GO) activated motor areas (including the contralateral right primary motor cortex and left cerebellum) in the normal condition only (Fig. 3, Table 2B). The same comparison showed such motor increases neither in the conversion patient (*z*-score = −0.28, n.s., for the right motor cortex peak) nor in the simulation group (*z*-score = 0.54, n.s.). This lack of motor activation is consistent with the lack of executed movement on L-GO in these two cases (see Table 3).

Importantly, in the conversion patient, the critical attempts of left movement (L-GO>R-GO) showed additional activations in the right ventrolateral prefrontal areas (*xyz* = 51, 36, −3, *z*-score = 3.33, $p<0.001$), as well as left superior frontal gyrus (*xyz* = −27, 42, 48, *z*-score = 4.07, $p<0.001$) and bilateral precuneus (*xyz* = 0, −60, 51, *z*-score = 3.68, $p<0.001$), but these were all different from activations observed during motor inhibition on NOGO trials in the normal controls or during feigned paralysis on GO trials in simulators (as further described in more details in the next section).

Motor inhibition

To identify brain regions specifically activated by motor inhibition, we compared NOGO vs GO trials for healthy controls in the normal condition. This contrast revealed a bilateral but right predominant network involving the inferior frontal gyrus (IFG), posterior middle frontal gyrus (post MFG) gyrus, and inferior parietal lobule (IPL) (see Fig. 4 and Table 4A for details), consistent with previous work on motor or cognitive inhibition (Chambers et al., 2007; Chikazoe et al.,

Table 2
SPM results for the execution phase.

	Hemisphere	Brain region	x	y	z	Z value	
A.							
NO: R-GO>L-GO	L	Motor cortex	−33	−27	72	4.38	
	L	Fusiform gyrus	−12	−96	0	4.37	
	R	Cerebellum	18	−54	−27	4.28	
NO: L-GO>R-GO	L	Cerebellum	−12	−57	−18	5.69	
	R	Motor cortex	42	−21	63	5.21	
	R	Fusiform gyrus	27	−78	−15	4.13	
	L/R	Cingulate cortex	0	−27	30	4.03	
B.							
CONV: R-GO>L-GO	L	Motor cortex	−36	−30	66	Inf	<0.001**
	R	Cerebellum	21	−57	−18	6.52	<0.001**
	L	Middle temporal gyrus	−54	−72	12	4.67	0.032**
	L	Superior temporal gyrus	−42	−27	15	4.25	0.016**
	R	Precuneus	6	−69	63	4.25	0.023**
	R	Postcentral gyrus	36	−48	60	3.87	0.069*
C.							
SIM: R-GO>L-GO	L	Motor cortex	−39	−18	63	3.47	
	R	Precuneus	15	−48	42	4.15	

NO= normal state; SIM= left simulated paralysis; CONV = patient with conversion.
** $p<0.05$; * $p<0.1$.

Table 3
SPM results for inhibition.

	Hemisphere	Brain region	x	y	z	Z value	
A.							
NO: NOGO> GO	R	Inferior parietal lobule	57	−54	39	5.48	
	R	Inferior frontal gyrus	57	27	18	5.42	
	L	Middle temporal gyrus	−48	−30	−6	5.03	
	L	Inferior frontal gyrus	−45	45	−12	4.87	
	R	Medial frontal gyrus	42	3	54	4.87	
	L	Inferior frontal gyrus	−45	15	30	4.54	
	R	Inferior frontal gyrus	48	42	−9	4.51	
	L	Inferior parietal lobule	−48	−54	36	4.3	
B.							
CONV:L-NOGO> R-NOGO	L	Superior frontal gyrus	−21	15	63	4.84	<0.001**
	R	Precuneus	3	−45	57	4.57	0.097*

NO= normal state; SIM= left simulated paralysis; CONV = patient with conversion.
** $p<0.05$; * $p<0.1$.

2008; Garavan et al., 1999; Menon et al., 2001). Notably, simulation showed a similar activation of the right IFG during normal inhibition (right and left NOGO trials) and during feigned paralysis of left hand movement (i.e. voluntary inhibition on L-GO trials; see above and Fig. 4). This was verified by pairwise contrasts relative to the "normal" R-GO condition during simulation (using a 10 mm ROI centered on the peak of the main effect R-NOGO + L-NOGO>R-GO in this group, $xyz = 54, 30, 24$): L-GO, z-score = 2.98, $p = 0.001$; L-NOGO, z-score = 2.82, $p = 0.002$; R-NOGO, z-score = 2.53, $p = 0.006$; but L-NOGO vs L-GO, z-score = 2.18, $p = 0.014$). Moreover, during conversion, similar increases were also in the right IFG for NOGO vs GO trials, overlapping with a ROI centered on the peak of the right IFG activation in the normal condition (Fig. 4).

There was no significant difference when comparing L-NOGO and R-NOGO trials in the normal condition (whole-brain contrast), suggesting that there was no selective hemispheric lateralization contralateral to the to-be-inhibited hand in the normal condition. Conversely, in the conversion patient, we observed a difference between these two conditions in the ventrolateral frontal cortex, at a more inferior and more anterior location than the main effect of NOGO trials (Fig. 4B and Table 4B), but this region also activated to L-GO trials (i.e. attempted movements) suggesting a more general involvement in left hand control (see Fig. 4B).

Importantly, if motor conversion was produced by an active inhibition of motor outputs (Marshall et al., 1997), a key prediction would be that GO trials should elicit a distinct pattern of inhibitory activation for the left/paralyzed hand so as to stop the motor commands that were still normally prepared in motor cortex (see above). According to this hypothesis, a comparison between a left/inhibited movement and a right/executed movement (L-GO>R-GO) should identify any activity specific to attempted movements with the left/paralyzed hand with conversion, and therefore potentially reveal increases similar to the NOGO trials. However, in our patient, the L-GO trials (compared to R-GO) showed no activation of brain regions typically associated with cognitive or motor inhibition, such as the right IFG (Aron and Poldrack, 2006; Garavan et al., 1999; Kawashima et al., 1996; Konishi et al., 1999) or ACC (Halligan et al., 2000; Marshall et al., 1997). As described in the previous section, in the patient, this contrast (L-GO>R-GO) showed selective increases in precuneus ($xyz = 0, -60, 51$, z-score = 3.68, $p<0.001$) and ventrolateral prefrontal areas ($xyz = 51, 36, -3$, z-score = 3.33, $p<0.001$), which were not observed in normal controls (precuneus: $xyz = 0, -60, 51$, z-score = 0.14, n.s. and ventrolateral prefrontal areas: $xyz = 51, 36, -3$, z-score = 0.82, n.s.).

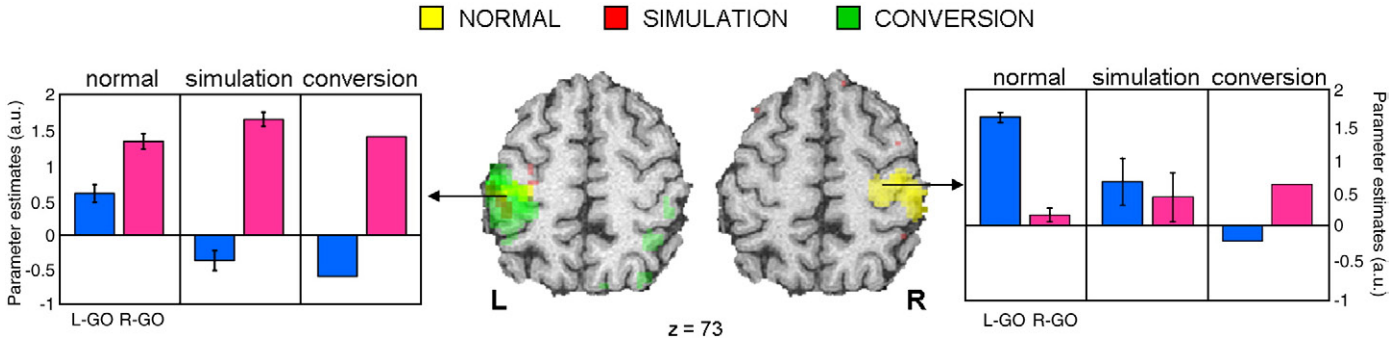

Fig. 3. Activation of the primary motor cortex during motor execution. Increase are shown for L-GO>R-GO trials (right part of figure) and the reverse contrast of R-GO>L-GO (left part of figure) in the normal controls (yellow), conversion patient (green, $p<0.001$ uncorrected, $k = 10$ voxels) and simulation controls (red, $p<0.005$ uncorrected, $k = 10$ voxels). Plots represent the parameter estimates (betas) for L-GO and R-GO (yellow) trials, respectively in the normal, simulation, and conversion conditions. Consistent with paralysis (or simulation of a paralysis) of the left hand, no right motor activation was observed during conversion and simulation for L-GO conditions, whereas the left primary motor cortex was activated for R-GO in all three conditions.

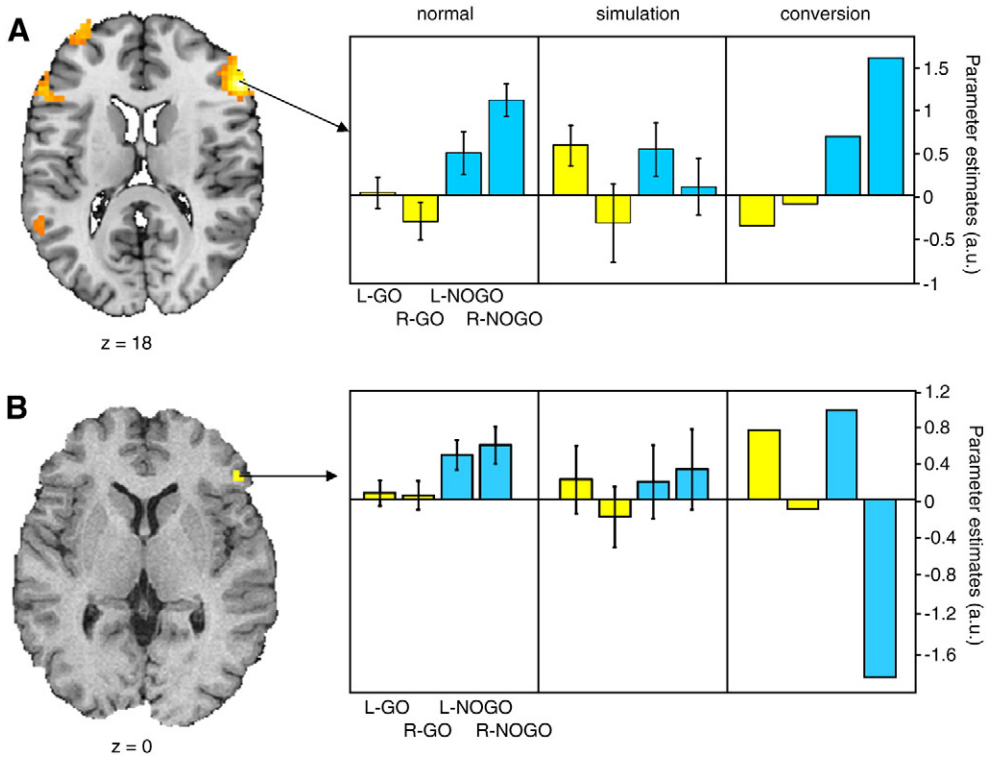

Fig. 4. Activation of inhibitory networks. (A) Contrast between NOGO>GO trials in normal controls (irrespective of hand side) revealed increased activity in a bilateral but predominantly right hemisphere network including inferior frontal gyrus (IFG) and inferior parietal lobule (IPL); threshold $p<0.001$ uncorrected, $k=10$ voxels. Plots represent the parameter estimates (betas) in right IFG for L-GO and R-GO (yellow), plus L-NOGO and R-NOGO (blue) trials, respectively in the normal, simulation, and conversion conditions. Simulation produced similar increases during normal inhibition (NOGO trials) and feigned left hand paralysis (left GO trials), whereas conversion produced a similar pattern to normal condition. (B) Contrast between L-GO>R-GO during conversion revealed a more ventral cluster in anterior lateral prefrontal cortex ($p<0.001$ uncorrected, $k=10$ voxels), distinct from right IFG activated by NOGO trials in normal controls. Plots represent the parameter estimates (betas) in the ventrolateral PFC for L-GO and R-GO (yellow), plus L-NOGO and R-NOGO (blue) trials, respectively in the normal, simulation, and conversion conditions. A left vs right pattern can be observed for this region. Activity in the same regions for the normal and simulation conditions tended to show the same pattern as in the upper IFG cluster, although these differences were not significant.

By contrast, in participants who feigned a paralysis, the left GO condition (compared to R-GO) activated a distinct network of regions including the right IFG (peak $xyz=54, 18, 18$, z-score$=3.39$, $p<0.001$), the right IPL (peak $xyz=63, -51, 36$, z-score$=3.18$, $p=0.001$), the left MTG (peak $xyz=-57, -33, -9$, z-score$=3.14$, $p=0.001$), the left IFG (peak $xyz=-45, 45, -15$, z-score$=2.87$, $p=0.002$), the right MFG (peak $xyz=42, 3, 54$, z-score$=2.79$, $p=0.003$), the left IFG (peak $xyz=-42, -18, 33$, z-

Table 4
SPM results for the main effect of the hand.

	Hemisphere	Brain region	*x*	*y*	*z*	*Z* value	
A.							
NO: all_L>all_R	R	Motor cortex	45	−24	60	5.95	
	L	Cerebellum	−21	−51	−27	4.95	
	R	Postcentral gyrus	51	−18	15	4.89	
	R	Fusiform gyrus	18	−87	−18	4.34	
B.							
CONV: all_L>all_R	L	Superior frontal gyrus	−21	15	63	5.83	<0.001**
	L	Precuneus	−3	−60	54	4.93	0.008**
	L/R	ventromedial Prefrontal Cortex	0	60	−9	4.19	0.014**
C.							
SIM: all_L>all_R	L	Angular gyrus	−36	−66	30	4.07	
	R	Superior temporal gyrus	48	6	−3	3.95	
	L	Inferior frontal gyrus	−51	21	−9	3.91	
	L	Inferior frontal gyrus	−45	39	−12	3.81	
	L	Superior frontal gyrus	−12	15	60	3.79	
	L	Inferior parietal lobule	−51	−48	39	3.73	
	L	Middle frontal gyrus	−39	9	42	3.63	
	R	Middle frontal gyrus	45	15	45	3.5	
	R	Supplementary motor area	9	0	66	3.45	

NO= normal state; SIM= left simulated paralysis; CONV = patient with conversion.
* indicates p-cluster<0.1 and ** indicates p-cluster<0.05.

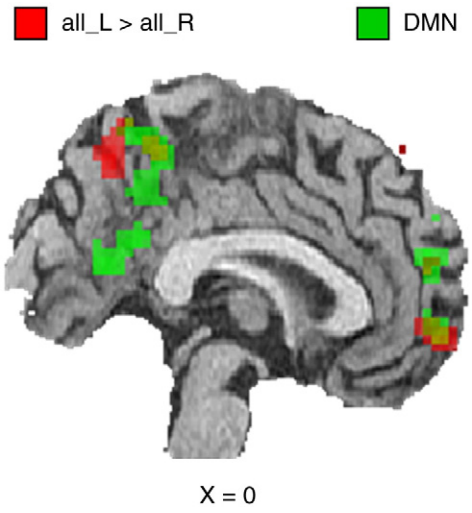

Fig. 5. Main effect for the left/paralyzed hand during conversion. A contrast between all trial types with the left hand (L-PREP, GO, and NOGO) and all those with the right hand during conversion showed selective increases in precuneus and vmPFC (depicted in red, threshold $p<0.001$ uncorrected, $k=10$ voxels). These areas overlapped only partly with brain regions showing "default mode" activity, as estimated by relative deactivation of all trial types (R and L hand) relative to baseline (threshold $p<0.001$ uncorrected, $k=10$ voxels).

score = 2.81, $p=0.002$) and the left TPJ (peak $xyz=-45, -51, 42$, z-score = 3.90, $p<0.001$) overlapping with activations during normal voluntary inhibition (see Table 2).

Main effect of left hand paralysis in conversion

For completeness, we also tested for any general change in brain activity associated with actions involving the left/paralyzed hand as compared to the right/normal hand during conversion, irrespective of the motor task conditions. Whereas this contrast (all L hand trials > all R-hand trials) showed right motor activation in normal controls (Table 5A), the same analysis revealed selective increases in the vmPFC and precuneus in the patient (Table 4B), but bilateral IFG and parietal increases in simulators (Table 4C). Conversely, the opposite contrast (all R-hand > all L hand trials) in the patient showed a normal pattern with extensive activations in left motor regions including left M1 and left SMA ($xyz=-3, -9, 48$, z-score = 6.83, $p<0.001$) as well as left lateral thalamus ($xyz=-12, -18, 6$, z-score = 3.71, $p<0.001$), and left putamen ($xyz=-21, -9, -3$, z-score = 2.64, $p<0.005$).

Because both the vmPFC and precuneus are known to be involved in "default mode" activity (Raichle et al., 2001), we also determined brain regions that were more activated during baseline relative to all trial types (with either hand) in the patient. This analysis showed that regions with default mode activity were partly (but not entirely) overlapping with the main effect of left hand paralysis (Fig. 5), suggesting that these regions remained with a relatively constant level of activity during baseline and left hand conditions. Note however that left hand conditions did not correspond to simple resting state (with a lack of any differential activation), because specific patterns of task-related responses were clearly observed in the different left hand conditions in the patient even in the absence of overt movement (including not only L-PREP but also L-GO and L-NOGO conditions, see preceding sections above).

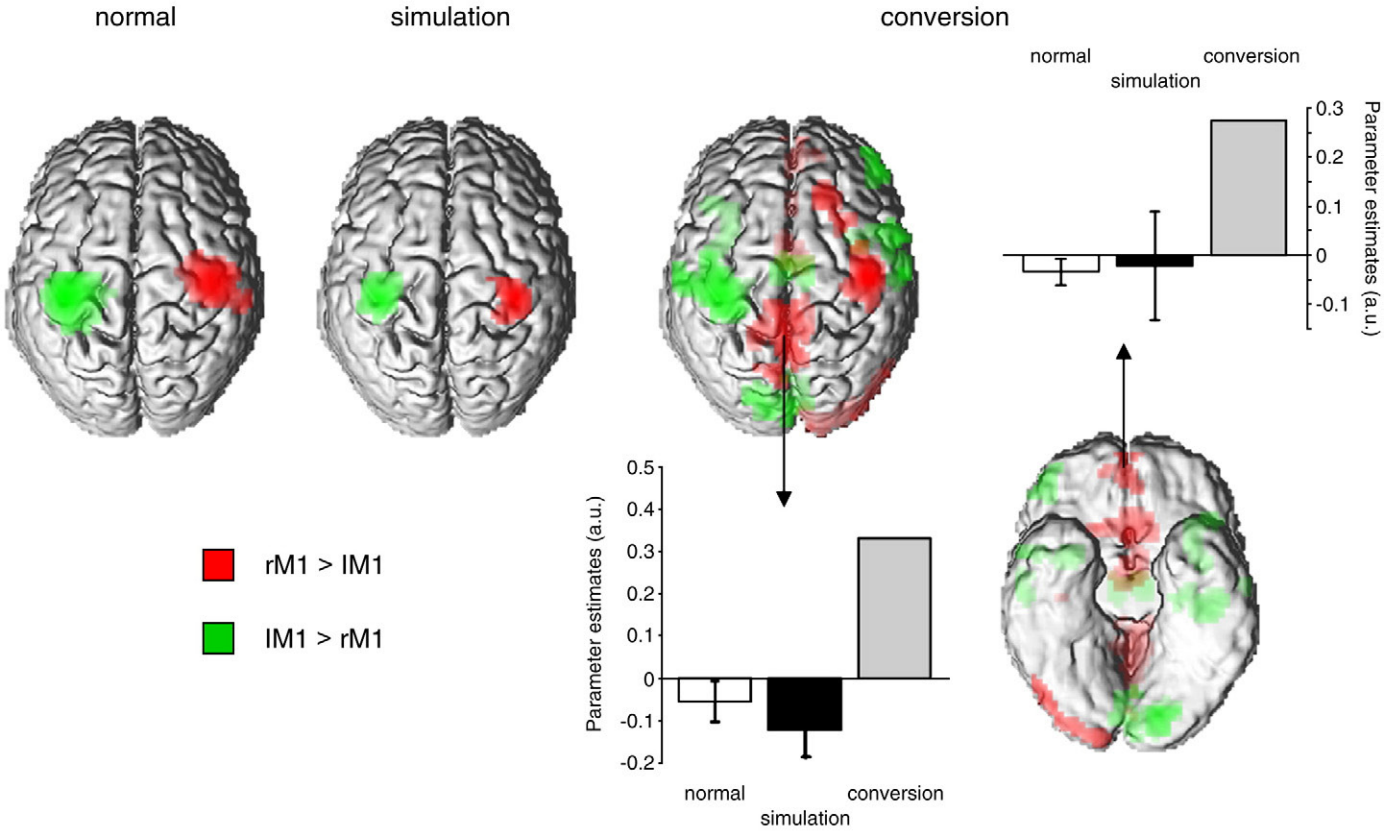

Fig. 6. Functional connectivity of primary motor cortices. Regions showing an increase in correlated activity with the right primary motor cortex (M1) compared to the left M1 (depicted in red) and conversely (left M1 > right M1, depicted in green) in the normal controls, simulation condition, and conversion patient (threshold $p<0.001$ uncorrected, $k=10$ voxels). Motor connectivity was symmetrical and restricted to sensorimotor areas in normal and simulation conditions; but in the conversion patient, selective increases were found for right M1 connectivity with the precuneus and vmPFC, as well as with the right superior gyrus. Plots represent the parameter estimates (betas) for the rM1 > lM1 connectivity in the normal, simulation, and conversion conditions for precuneus (6 mm sphere centered on $xyz=-3, -48, 63$) and vmPFC (6 mm sphere centered on $xyz=3, 48, -12$).

Functional connectivity of motor cortex

Finally, to test whether conversion might induce a disconnection or "decoupling" between motor pathways and other brain regions mediating motor will or awareness (Hilgard, 1974; Woody and Farvolden, 1998), we also investigated changes in the functional connectivity of the primary motor area as a function of condition. Since conversion produced a lack of left movement and suppressed activation of the right primary motor cortex (see above), we hypothesized that the latter region might be selectively disconnected from regions normally involved in voluntary motor control. We first selected the peak of activity in motor cortices (based on results for PREP and GO trials, see above), and then compared the functional connectivity of this region during conversion, simulation, and normal condition by whole-brain contrasts (see Methods).

Our results showed significant asymmetries in the connectivity of right motor cortex (rM1) compared to left motor cortex (lM1) during conversion whereas such changes were not observed for normal condition and simulation (Fig. 5). Right motor cortex was particularly more connected to the precuneus and vmPFC, overlapping with brain areas that were differentially activated by left hand during conversion (e.g. see L-PREP or L-GO trials). By contrast, in normal condition and simulation, a differential coupling of right vs left M1 concerned only the ipsilateral sensorimotor regions (Fig. 6).

Discussion

By systematically comparing different aspects of motor control (preparation, execution, inhibition) during a go–nogo task, we were able to test for several hypotheses concerning the neural mechanisms of unilateral hand paralysis in a patient with conversion. Our results reveal that conversion does not involve an active inhibition of motor outputs by inhibitory control systems subserved by anterior or medial prefrontal regions such as IFG or ACC. Rather, conversion produced selective changes in midline brain areas (PCC, precuneus and vmPFC) that were not recruited by inhibition in normal conditions, and were differentially modulated in our patient in terms of both task-related activation and functional connectivity. Changes in connectivity included an increased coupling of the rM1 with precuneus and vmPFC, which both were also selectively activated by instructions involving the left hand (L-PREP or L-GO).

As expected, activation of the right motor cortex was suppressed for the patient as well as during simulated paralysis. However, despite the left hand paralysis, the right motor cortex was still normally activated during instructions to prepare a left hand movement, just as in the normal state (Fig. 2). On the one hand, this finding reveals that conversion paralysis did not produce a complete suppression of activity in motor pathways and did not totally eliminate the internal representation of motor intentions, as postulated by some account of conversion (Liepert et al., 2008; Maruff and Velakoulis, 2000; Roelofs et al., 2002b; Spence et al., 2000a), or for some related neurological conditions such as motor neglect (Fiorelli et al., 1991; Laplane and Degos, 1983) or motor anosognosia (Gold et al., 1994). Thus, despite her complaints of left hand paresis, the patient still performed the task according to our instructions to prepare a left hand movement on PREP cues, and could still normally recruit the right motor cortex in this condition. This finding suggests that some form of motor imagery was preserved despite motor conversion (de Lange et al., 2007), with the actual movement initiation being "blocked" only at the execution stage but not at the planning stage. Altogether, these results might be consistent with the patient's subjective experience of a preserved intention but paralyzed action.

On the other hand, a distinct pattern of activation was found in the patient during the preparation of movement with the left hand, as compared with the right hand, involving selective increases in the left orbitofrontal cortex (OFC), ventromedial prefrontal cortex (vmPFC), and posterior cingulate cortex (PCC, see Fig. 2). These areas were not recruited in the same condition by normal controls or by subjects who simulated a left hand paralysis. The latter results converge with previous findings from other studies of motor conversion that reported increased activity in medial prefrontal areas in one patient while trying to move her paralyzed limb (Marshall et al., 1997) and in a group of 8 patients while imagining a movement with the affected hand (de Lange et al., 2007). But here, additionally, we also observed greater activity in PCC during the preparation phase concerning the left/paralyzed hand. Furthermore, similar increases were found in vmPFC and precuneus in response to the critical L-GO trials in the patient.

Remarkably, the vmPFC and the PCC are part of the "intrinsic" or "default mode" network (Raichle and Mintun, 2006), showing decreased metabolic activity during performance of sensorimotor and cognitive tasks (Gusnard et al., 2001; Raichle et al., 2001), and possibly reflecting internally-oriented self-related awareness during resting state periods Gusnard et al., 2001; Schneider et al., 2008). Hence, our results could potentially be interpreted as a relative lack of suppression of activity in these regions during task performance, perhaps remaining in a "default" or "resting" state due to the lack of movement with the left/paralyzed hand. However, a direct contrast of baseline activity against task-related responses showed that the default mode network involved several additional areas in medial prefrontal and parietal areas, and this network was partly dissociated depending on the experimental conditions: vmPFC and PCC were activated by the preparation phase (L-PREP>R-PREP), whereas vmPFC and precuneus were activated by imperatives cues (GO and NOGO). Moreover, note that we found a preserved activation in right motor cortex during preparation for the left hand, similar to the left motor cortex for preparation with the right/normal hand. A specific pattern of increases was also observed for L-GO and L-NOGO conditions. Taken together, these data clearly demonstrate that the patient did not simply rest during left hand trials, but followed our task instructions and still generated a covert representation of motor action for the paralyzed hand, despite a lack of overt movement.

Our results therefore suggest that vmPFC and posterior medial parietal areas may not only exhibit a relative lack of deactivation by left hand trials during conversion, but could also have a more direct role in the modulation of motor activity in this condition. This observation would be compatible with previous accounts of conversion paralysis that proposed that vmPFC activity might reflect an active inhibitory control of the motor system during the generation of movements with the affected (Halligan et al., 2000; Marshall et al., 1997) or increased self-monitoring processes (Roelofs et al., 2006; Vuilleumier, 2005). However, here we found no increases in vmPFC during NOGO trials for either hand in controls, nor for the right hand in the patient and simulators, suggesting that vmPFC may not be directly responsible for motor inhibition or task monitoring when left movement must be withheld. Further, vmPFC was not activated by inhibition on NOGO trials in the normal controls. Instead, activations in the medial prefrontal and parietal cortex in conversion may indicate a recruitment of self-referential processes during the preparation of a movement involving the affected hand, which might also persist during the baseline rest periods when no motor plans and no inhibition are required.

Our study specifically tested for the role of active inhibition of motor outputs during conversion, by comparing GO and NOGO trials in the same task. Thus, we were able to determine whether left hand paralysis due to conversion (i.e. on L-GO trials) was, at least in part, functionally equivalent to voluntary inhibition of left hand movements in a normal condition (i.e. L-NOGO). Convergent evidence from neuroimaging (Aron and Poldrack, 2006; Bunge et al., 2002; de Zubicaray et al., 2000; Garavan et al., 1999; Kawashima et al., 1996; Konishi et al., 1999; Leung and Cai, 2007; Liddle et al., 2001; Menon et al., 2001; Rubia et al., 2001) and neuropsychology studies (Chambers

et al., 2006; Mostofsky and Simmonds, 2008; Watanabe et al., 2002) has demonstrated that a right-sided fronto-parietal network is critically involved in the suppression of prepotent motor responses, and typically activated in conditions requiring an inhibition of ongoing motor programs (Brass et al., 2005; McNab et al., 2008) including no-go or stop tasks (Aron et al., 2003; Garavan et al., 1999; Konishi et al., 1998; Rubia et al., 2003). In particular, it is thought that the right IFG is a key component of this 'braking circuit' (Aron et al., 2004; Corbetta and Shulman, 2002). Consistent with these studies, our results showed that inhibitory processes mediated by the right IFG were activated during NOGO trials (for both hands) in normal controls. Remarkably, feigned paralysis also produced selective increases in right IFG on GO trials for the left/paralyzed hand, similarly to NOGO trials for either hand (right or left), indicating that simulation of paralysis on GO trials involved inhibitory activity in IFG equivalent to the NOGO trials. However, in clear contrast, no such increase in IFG was found for the patient on L-GO trials, despite preserved motor activation during the preparation phase, suggesting that the absence of movement during motor conversion was different from voluntary inhibition as seen in no-go conditions. This pattern therefore clearly testifies that conversion and simulation induced functionally distinct changes in brain activity.

Note that although the right IFG, responsible for motor inhibition in the normal condition and simulation, did not activate on GO trials for the left paralyzed hand during conversion, we found greater activity in a more ventral part of the right prefrontal cortex (see Fig. 4) that arose on L-GO trials in the patient only. However, this region was also differentially activated by L-NOGO trials, whereas it was not recruited during either GO or NOGO trials with the intact right/normal hand (see Fig. 4B). This pattern cannot be explained by an exclusive role in response inhibition, but rather by more general involvement for controlling left hand actions. This ventral sector of prefrontal cortex receives dense inputs from limbic areas critically involved in emotional processing such as OFC and vmPFC (Cavada et al., 2000), and might therefore provide a critical node through which affective information can be integrated with task-related representations held in lateral prefrontal regions, and thus influence voluntary motor control. Consistent with this possibility, a recent study in healthy participants found that a similar ventrolateral prefrontal area was specifically involved in the modulation of motor inhibition by emotional stimuli (Schwartz et al., 2006). An increased emotional influence on motor control for the left/paralyzed hand would accord with the notion that conversion symptoms emerge subsequent to emotional and stressful events, with affectively charged representations somehow overrunning normal voluntary motor control (Damasio, 2003; Kozlowska, 2005; Vuilleumier, 2005, 2009).

Importantly, our functional connectivity analysis revealed striking changes in functional coupling of the right motor cortex (M1) during left conversion paralysis, as compared with the normal condition and simulation (Fig. 5). These changes in the connectivity of rM1 involved both vmPFC and posterior medial parietal areas in precuneus. Both regions are known to be activated by self-related processing (D'Argembeau et al., 2005; Gusnard et al., 2001; Schneider et al., 2008), including during judgments of personal traits for self vs others (D'Argembeau et al., 2007; Jenkins et al., 2008), and during access to personal information from either past or prospective memory (Schacter et al., 2007; Szpunar et al., 2007). In particular, the vmPFC is not only recruited during tasks that require participants to introspect about their own mental experience or feelings (Johnson et al., 2002; Kelley et al., 2002; Macrae et al., 2004; Zysset et al., 2002), but also associated with emotion regulation (Lane, 2008; Ochsner and Gross, 2005; Simpson et al., 2000). On the other hand, the precuneus is critically involved in mental imagery and autobiographical memory, particularly in relation to representations of self-relevant events (den Ouden et al., 2005; Lou et al., 2004) and introspective self-oriented processes (Boly et al., 2007; Cavanna and Trimble, 2006).

Our results therefore suggest that left motor conversion symptoms might imply some increases in self-monitoring processes that could control right motor activity, and hence left hand action, based on internal representations and memories related to the self. This pattern would be consistent with the present findings of selective activations of midline brain areas for trials involving the left/paralyzed hand, and provide new support to theoretical accounts suggesting that the normal experience of conscious will of conversion patients might be overrun by self-relevant and emotionally-significant signals possibly retrieved from past history or previous traumatic experiences (see Brown 2004; Vuilleumier, 2005, 2009). Moreover, functional neuroimaging studies of dissociative disorders have also highlighted a change in medial prefrontal areas in relation to personalization symptoms that may distort perception of the self and conscious control in stressful situations (Lanius et al., 2003; Reinders et al., 2003).

Incidentally, our study also replicated previous findings of reduced activation in thalamus and basal ganglia (putamen) contralateral to the paralyzed hand (Vuilleumier et al., 2001), but using a different task. In the latter study, this reduction was observed when comparing passive stimulation of the affected hand during motor conversion and after recovery. Here we found increases in left thalamus and left putamen for the main effect of right hand actions, but no similar increases were found in the right hemisphere for the left hand. It is likely that such changes in subcortical motor pathways are downstream effects due to the influences of modulatory signals from "limbic" emotional systems in medial prefrontal cortical regions that project to the basal ganglia-thalamic loops (Yeterian and Pandya, 1991).

The present results demonstrate selective changes in functional connectivity of motor cortex with precuneus and vmPFC during conversion paralysis, but preserved motor intention and motor imagery, but it should be acknowledged that conversion might include heterogeneous disorders across patients, with different psychological and neural changes leading to the same symptoms. It is possible that different subjective symptoms or motor phenomena (such as flaccid weakness or dystonic features) might entail distinct neural correlates and explain some discrepancies between imaging studies (Stone et al. 2007; Vuilleumier chapter 2009). Hence, it remains to be seen how our results in a single patients may generalize to other cases. It is still unclear if acute conversion, lasting only a few days, and more chronic conversion with paralysis for several months show comparable functional changes. More research across larger sample is needed to fully understand conversion paralysis and conversion in general, a challenge that brain imaging techniques will certainly help take up in the future.

Finally, we note that our present findings in conversion paralysis showed some similarities but also clear differences relative to the neural correlates of left paralysis induced by hypnosis (Cojan et al., in press). Because hypnotic suggestion can also induce striking changes in motor or perceptual behavior unrelated to any organic brain anomalies, many influential theories since the time of Charcot and others in the 19th century have proposed that conversion may resemble the "dissociation states" induced by hypnosis (Halligan et al., 2000; Roelofs et al., 2002a). However, both types of phenomena have rarely been directly compared. In a recent study, we used fMRI to investigate the same go–no-go task in volunteers who performed either in a normal state or during a suggestion of left hand paralysis hypnosis (Cojan et al., in press). Results showed that preparatory activation arose in contralateral right motor cortex despite left hypnotic paralysis, together with concomitant increases in the precuneus. The latter region also showed enhanced functional connectivity with right motor cortex. In addition, right inferior frontal areas subserving inhibition during no-go trials in the normal state and during feigned paralysis in simulators, showed global increases for all conditions during hypnosis, irrespective of motor

blockade or execution. These results were interpreted to suggest that hypnosis may enhance self-monitoring processes, allowing internal representations generated by the suggestion and mental imagery to guide motor behavior, but did not act through direct motor inhibition.

Here, most notably, we found that changes in the activity of the precuneus and its connectivity with motor cortex were associated with motor conversion, similar to the unilateral paralysis under hypnosis (Cojan et al., in press), suggesting some similarity between both phenomena that might relate to the recruitment of mental imagery processes. On the other hand, two clear differences were found: first, for the vmPFC, which was not differentially activated during hypnosis; and second, for the right IFG, whose activity was generally increased across both NOGO and GO conditions during hypnosis. The latter two changes suggest a modulation of attentional and executive monitoring functions (Egner and Raz, 2007; Oakley, 1999) that is specific to the hypnotic state, and distinct from the conversion state.

In sum, our findings provide new insights into the possible neural mechanisms of conversion, by showing that unilateral paralysis was associated not only with a suppressed activation of motor cortex during attempted movements but also with changes in its functional connectivity, including greater recruitment of precuneus and vmPFC regions that are critical for accessing self-related representations and memories. We found no evidence that brain regions normally implicated in conscious motor inhibition (such as IFG) were responsible for the paralysis, unlike during voluntary simulation. Moreover, motor preparation still produced residual activation of the motor cortex during conversion, without any overt movement, a finding that may accord with the subjective report of patients suggesting that intentions are preserved, but execution “blocked” by modulatory influences outside conscious will. Taken together, our results may thus help better understand the brain pathways by which self-awareness become distorted in these patients and how the mind may take control over the body during conversion.

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