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Research report

Modelling psychiatric and cultural possession phenomena with suggestion and fMRI

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ABSTRACT

Involuntary movements occur in a variety of neuropsychiatric disorders and culturally influenced dissociative states (e.g., delusions of alien control and attributions of spirit possession). However, the underlying brain processes are poorly understood. We combined suggestion and fMRI in 15 highly hypnotically susceptible volunteers to investigate changes in brain activity accompanying different experiences of loss of self-control of movement. Suggestions of *external personal control* and *internal personal control* over involuntary movements modelled delusions of control and spirit possession respectively. A suggestion of *impersonal control* by a malfunctioning machine modelled technical delusions of control, where involuntary movements are attributed to the influence of machines. We found that (i) brain activity and/or connectivity significantly varied with different experiences and attributions of loss of agency; (ii) compared to the impersonal control condition, both external and internal personal alien control were associated with increased connectivity between primary motor cortex (M1) and brain regions involved in *attribution of mental states* and *representing the self in relation to others*; (iii) compared to both personal alien control conditions, impersonal control of movement was associated with increased activity in brain regions involved in *error detection* and *object imagery*; (iv) there were no significant differences in brain activity, and minor differences in M1 connectivity, between the external and internal personal alien control conditions. Brain networks supporting error detection and object imagery, together with representation of self and others, are differentially recruited to support experiences of impersonal and personal control of involuntary movements. However, similar brain systems underpin attributions and experiences of external and internal alien control of movement. Loss of self-agency for movement can

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therefore accompany different kinds of experience of alien control supported by distinct brain mechanisms. These findings caution against generalization about single cognitive processes or brain systems underpinning different experiences of loss of self-control of movement.

1. Introduction

Involuntary movements occur in a variety of neuropsychiatric disorders and culturally influenced dissociative states (e.g., delusions of alien control in schizophrenia and attributions of spirit possession respectively). While involuntary movements constitute an altered sense of agency in which the everyday sense of the subject initiating and controlling movement is reduced or lost, the associated causal attributions and phenomenological changes vary with the type of symptom or alteration in experience.

In the case of ‘anarchic’ or ‘alien’ hand following medial frontal or corpus callosal lesions, the experience of loss of control for apparently purposive hand movements may not be accompanied by an attribution that some other agent is responsible for the movements (Spence, 2002). However, other experiences of loss of control of movement are linked to specific types of causal attribution. In the case of psychosis, delusions of control or passivity phenomena entail that movements (as well as other mental contents such as thoughts, feelings, and sensations), are made or remotely influenced by a force or entity other than the self (Oyebode, 2008). Delusions of control typically involve attributions of *external personal alien control* by a persecuting agent (e.g., the CIA, or a malevolent supernatural being such as a spirit, god, or demon).

However, delusions of control by machines (‘technical’ delusions) include attributions of *external impersonal (non-agentive) control*, in which movement is under the immediate control of a machine (Hirjak & Fuchs, 2010). The earliest description of a technical delusion of control is from Haslam’s 1810 case study of James Tilly Matthews who experienced his thoughts, feelings, and movements as under the remote control of an ‘air loom’ (Haslam, 1810). Bleuler reported that delusions could involve beliefs that “the most devilish, modern, technical apparatus ever invented has been put up and is used to speak from a distance, to project pictures, to electrocute” (p114) (Bleuler, 1950). Victor Tausk’s paper *On the Origin of the “Influencing Machine” in Schizophrenia* (Tausk, 1933) described the phenomenology of alien technical control delusions including experiences of induced sensations, thoughts and motor phenomena. More recent examples have been described where the ’influencing machines’ include contemporary technology (Hirjak & Fuchs, 2010), but a common theme in all such accounts is that while machines are identified as an impersonal or non-agentive means of loss of control of movement (or some other mental content such as thought, sensation, or feeling), maleficent agents are commonly also identified as using the machines to persecute the subject of the passivity phenomena. Nevertheless, technical delusions of control also raise the question of what cognitive and neural processes might be involved in the formation of a delusion of technical (impersonal) alien control *per se,* to the extent that representations of impersonal alien control may dominate aspects or phases of the experience of involuntary movement in a person suffering a technical delusion of control.

In contrast to the external attributions of personal and impersonal (technical) delusions of control, cultural accounts of spirit possession posit *internal personal alien control* whereby a possessing supernatural agent assumes control of the person from within. The attribution of spirit possession may sometimes be used as a local explanatory model to account for mental disturbance or disreputable behaviour that would be differently interpreted in psychiatric terms (Littlewood, 2002). However, in many cases of spirit possession the experience and behaviour of the possessed individual closely conforms to local expectations of possession and in many cases is culturally sanctioned or normative (Crapanzano & Garrison, 1977; Rouget, 1985; Seligman & Kirmayer, 2008; Vitebsky, 2001). Culturally influenced possession of this kind that occurs outside or as an unwanted prolongation of normative possession states is classified as ‘possession – form dissociative identity disorder’ in DSM-V and ‘possession disorder’ (F44.3) in the ICD-10 diagnostic manuals respectively (American Psychiatric Association, 2013; World Health Organization, 1993). While some cases are associated with amnesia for the experience of possession, subjects who recall the experience often report awareness of an alien identity coupled with loss of the sense of control of movement and functions such as speech (Boddy, 2002, pp. 398–418; Crapanzano & Garrison, 1977; Deeley, 1999).

However, the cognitive and neural processes underpinning these varieties of altered experience of agency are poorly understood. Specifically, there is limited understanding of the brain systems involved in producing the experience of involuntary movement associated with attributions of impersonal causation (e.g., by a machine), and personal causation (e.g., by an external agent, such as is commonly found in delusions of control; and an alternate ‘internal’ agent, as posited in cases of spirit possession where awareness of a possessing agent is reported).

It has long been established that motor automatisms can be produced by suggestion (Hilgard, 1977; Spitz, 1997; Wegner, 2002). We therefore extended the approach of prior experiments combining fMRI and suggestion in highly hypnotically responsive individuals to model different causal attributions and experiences of the loss of control of movement whilst measuring brain activity (Deeley et al., 2013). The overall aim of this ‘instrumental’ application of hypnosis was to identify differences in brain activity involved in these diverse ways in which loss of the sense of self-control of movement could be experienced and interpreted. Consequently, key contrasts focused on conditions where involuntary movement had been established by suggestion, rather than the contrast between voluntary and involuntary movement (separately reported (Deeley et al., 2013)). Experimental conditions and the phenomena they modelled included:

1) *external personal alien control*, with the suggestion that an Engineer was remotely controlling right hand movements of a joystick via a machine (delusion of control);
2) *external impersonal (non-agentive control)*, in which it was suggested that the machine was malfunctioning and purposelessly causing the hand to move remotely (the ‘machine’ aspect of a technical delusion of control); and
3) *internal personal alien control*, involving the suggestion that the Engineer had found a way to conduct experiments by entering the subject and controlling movement from within, with the experimental subject aware of the thoughts and motives of this possessing agent but unable to control the hand movements produced by it (spirit possession).

We tested the hypotheses that: (i) compared to the personal control conditions, impersonal control would be associated with increased activity in brain regions involved in producing mental imagery of objects, and that these regions would show greater functional connectivity with motor implementation systems; (ii) compared to impersonal control, personal alien control conditions would be associated with increased activity in networks supporting representations of agentive intentionality (‘mentalising’ or ‘theory of mind’ networks), and that these networks would show greater functional connectivity with M1 (a key motor implementation region); and (iii) compared to external agentive alien control, the internal personal alien control condition would be accompanied by increased activity in brain regions involved in self-related processing (Northoff & Bermpohl, 2004; Northoff et al., 2006).

2. Methods

2.1. Assessment of suggestibility

As an experimental strategy, we selected participants for high levels of suggestibility using the Harvard Group Scale of Hypnotic Susceptibility: Form A (HGSHS:A) (Shor & Orne, 1962), which is preceded by a hypnotic induction procedure. Scores on this scale (range 0–12) derive from the participant’s responsiveness to a series of formal suggestions, and serve as a measure of ‘hypnotic suggestibility’. Importantly, the scores obtained in this way correlate strongly with an individual’s score obtained using the same scale administered without hypnosis (Braffman & Kirsch, 1999). This indicates that the same form of suggestibility is involved in both these conditions and that the underlying cognitive mechanisms are an important component of an individual’s general responsiveness to suggestion. It is important to note, however, that ‘suggestibility’ does not seem to be a unitary trait. Other forms of suggestibility, such as placebo (Evans, 1976) and interrogative suggestibility (Register & Kihlstrom, 1988) and some forms of social influence, such as conformity (Moore, 1964), do not correlate with HGSHS:A scores (Kihlstrom, 2008). As we wished to maximise the responsiveness of our participants to suggestion we chose to use the HGSHS:A with a hypnotic induction as this produces an increase in the strength of the suggested effect in terms of both subjective and brain activation measures (Derbyshire, Whalley, & Oakley, 2009; McGeown et al., 2012).

2.2. Participants

Databases of volunteers previously tested at University College London (UCL) or the Institute of Psychiatry (IoP) on the Harvard Group Scale of Hypnotic Susceptibility: Form A (HGSHS:A) (Shor & Orne, 1962) were used to recruit potential participants for this study. Thirty-three highly hypnotically suggestible individuals (14 male/19 female) with HGSHS scores ranging from 8 to 12 (Mean score 10.06; SD 1.06) were identified (UCL, $N = 16$; IoP, $N = 17$) and were screened using the same protocol as that used in the neuroimaging study described below. An exception was that whereas the participants held an actual joystick in their right hand in the scanner and moved it from side to side, no joystick was present during the screening session, but participants were instructed to make similar right hand movements. During screening carried out at either UCL ($N = 31$) or IoP ($N = 2$), participants were seated comfortably in a small experimental room with normal levels of illumination. Eighteen of this group were excluded from the study at this stage for a variety of reasons: 7 did not report experiencing a reliable change in sense of ‘agency’ in response to suggestion; 4 were not suitable for scanning [metal in body, grommets, above upper weight limit for scanner, recent subdural haemorrhage]; 3 were no longer available; 2 were left handed; and 2 failed to produce sufficiently large hand movements. The remaining fifteen of the potential participants (10 female; 5 male) were tested in the scanner. The mean HGSHS score was 9.8 (SD 1.08: range 8–12) and mean age was 33.67 (SD 11.91: Range 20–61 years). Eight were undergraduate or postgraduate students and the remainder were from a variety of professions. Four of this final group were not included in the final data analysis for technical reasons (three because of excessive drop-out of frontal MRI signal and one due to an error during scanner data acquisition). The experimental data from the eleven remaining participants (7 female) are reported below. Their mean HGSHS score was 9.91 ($SD = 1.04$, Range 9–12) and their mean age was 29.27 ($SD = 8.40$, Range 20–47) years.

2.3. Hypnotic induction, movement instructions and agency suggestions

The hypnotic induction procedure consisted of muscle relaxation with suggested eye-closure and a counting procedure. Hypnosis was terminated by a reversed version of the induction. Full details of these procedures have been reported previously (Deeley et al., 2013; Oakley, Deeley, & Halligan, 2007). The motor task involved moving a joystick from side to side

(MOVE) or simply doing nothing (REST). The relevant task instructions relating to joystick movement are also described in an earlier study (Deeley et al., 2013). Following the induction procedure and prior to experimental testing the participants were told that 'though your arm may feel relaxed you will retain your grip and your hand will remain in contact with the joystick at all times', and 'in all movement tests your hand will not move during the instruction to "Rest" – but will make the required movement when the instruction to "Move" is given – though your experience of that movement will vary.'

Two baseline conditions where participants carried out the motor task in the absence of movement related suggestions were included in the scanning session. One involved normal voluntary movement with eyes closed before the hypnotic induction procedure [NOHYP VOLUNTARY]. The other also involved normal voluntary movement and was carried out in hypnosis i.e., with eyes closed after the hypnotic induction procedure before the experimental conditions [HYP VOLUNTARY]. In both these conditions the instruction given for REST was the same as for the experimental conditions, described below. For MOVE the instruction was:- 'The word 'MOVE' means move the joystick to the right and then the left once with your right hand each time.' See Table 1 for a summary of the baseline and experimental conditions.

All three experimental conditions were also performed during hypnosis, with the participant's eyes closed, in randomised order. In each of the three experimental conditions the instruction given for REST was – 'When you hear the word 'REST' do not attempt to use or prepare to move your right hand – just relax'.

For MOVE, in the 'External impersonal (technical) alien control' [IMPERSONAL] condition the following suggestions were given: When you hear the word 'MOVE' you will have the experience of your right hand being remotely controlled by a machine ... resulting in the joystick being moved to the right and then to the left once each time. The remote control machine is however malfunctioning due to an error and the Engineer who created the machine left no instructions on how to correct this error. The machine error causes your hand to move every time there is an instruction to move – there is no apparent purpose to these movements which you have no control over, they are simply the product of machine error. You will have no control over when your right hand is going to move, this is controlled by the machine, but you will be clearly aware of the movement of your hand and of the joystick when it occurs.' At the end of this condition the suggestions were removed as follows: 'The machine has been disconnected from its power supply and can no longer control the movements of your right hand – your right hand is back to normal again.'

Table 1 – The abbreviated name and a précis of the suggestion for the two baseline and the three experimental conditions.

Condition	Abbreviation	Suggestion
Baseline conditions		
1 Voluntary movement before hypnosis	NOHYP VOLUNTARY	None
2 Voluntary movement during hypnosis	HYP VOLUNTARY	None
Experimental conditions		
1 External impersonal alien control	IMPERSONAL	Hand movement controlled by a machine
2 External personal alien control	EXTERNAL PERSONAL	Hand movement controlled by a machine operated by an Engineer
3 Internal personal alien control	INTERNAL PERSONAL	Hand movement controlled by an Engineer who has taken over your mind from within

For the 'External personal alien control' [EXTERNAL PERSONAL] condition, the suggestion were: 'When you hear the word 'MOVE' you will have the experience of your right hand being remotely controlled by a fully functional machine operated by its Engineer and the joystick will be moved to the right and then to the left once each time. The Engineer is fascinated by limb movement, and is using the machine to remotely control your hand movements. He/she causes your hand to move every time there is an instruction to move – he/she is doing this because he/she is researching limb movement. You are aware of your hand movement when he/she causes it to move in response to the instructions to move, but you have no control or influence over the hand movements yourself. Apart from these movements of your hand by someone else, you feel your normal self. You feel calm and relaxed throughout.' These suggestions were removed as follows – 'The Engineer has completed his/her research task. The machine has been switched off and he/she is no longer in control of the movements of your right hand – your right hand is back to normal again.'

In the 'Internal Personal alien control' condition [INTERNAL PERSONAL] the suggestion were: 'When you hear the word 'MOVE' you will have the experience of your right hand being controlled by an Engineer, and the joystick will be moved to the right and then to the left once each time. The Engineer has developed a way of taking over parts of your body and mind to control your right hand movements from within you. He/she does this because he/she is fascinated by limb movement, and wants to employ the most direct method of limb control. He/she causes your hand to move every time there is an instruction to move – he/she is doing this to advance his/her research into limb movement. When he/she assumes control of your hand movements, you lose your normal sense of who you are, and all the associations of your normal life fade away. Instead of your usual thoughts and feelings, you find yourself aware of the thoughts and feelings of the Engineer – his/her interest in the research, his/her desire for the experiment to succeed, his/her thoughts of how impressed his/her colleagues will be by his/her research. You can no longer tell any difference between yourself and the Engineer, so that you share all of his/her thoughts and feelings, and also his/her sense of controlling the movements of your hand. There is a feeling of being calm and relaxed throughout.' The suggestions were removed as follows: 'Just focus your attention back to your body and as you do so you begin to regain your awareness of your normal self, your body

Table 2 – Mean subjective ratings (0–10 scale) for 'awareness', 'control', and 'ownership' for the three experimental conditions (standard deviation in brackets) and the voluntary movement condition in hypnosis.

	HYP VOLUNTARY	IMPERSONAL	EXTERNAL PERSONAL	INTERNAL PERSONAL
Awareness	8.1 (1.2)	7.0 (2.4)	7.2 (1.2)	7.5 (1.6)
Control	9.2 (.8)	3.9 (2.5)	3.9 (2.1)	3.9 (2.3)
Ownership	9.0 (1.2)	5.2 (2.5)	5.7 (1.8)	5.4 (2.7)

and your surroundings – you become aware of the positions of your arms and your legs – aware of your hands and your fingers – aware of your own actions and any movements you might make. Once again you are aware of, and in touch with your own internal thoughts and ideas, and are reconnected with your body and your surroundings. The Engineer is no longer inhabiting your body and awareness and is no longer in control of the movements of your right hand – your right hand is back to normal again.'

At the end of each condition, following the suggestion removal procedure and before moving on to the next experimental stage, the participant was asked to indicate by saying 'Yes' when the suggested effects had completely gone and normal feelings had returned. In the EXTERNAL PERSONAL and INTERNAL PERSONAL conditions the script was edited so that the gender of the Engineer was presented as being the same as that of the participant.

2.4. *Motor tasks and induction of agency phenomena*

Presentation of motor epochs, and concurrent acquisition of fMRI data followed a blocked design, involving alternation between non-movement ('REST') and activation ('MOVE') epochs (see Deeley et al., 2013). Each epoch lasted 30 sec and five repeats of each epoch were presented. The position of the joystick was recorded throughout each condition during scanning and the standard deviation of the position was used to index joystick displacement amplitude for the MOVE trials.

At the end of each experimental block, for both of the baseline conditions and the three experimental conditions participants verbally rated their subjective experience of the movement of their right hand and their depth of hypnosis. The experience of movement was rated on 0–10 scales with respect to i) awareness (0 = 'you had no awareness of your hand and its movement'; 10 – 'you had full normal awareness of the movements of your hand'); ii) control (0 = 'you had no part in initiating or controlling the movement of your hand'; 10 = 'you alone initiated and controlled the movement in response to the instructions'); and iii) ownership (0 = 'you did not experience the moving hand as being your hand – it does not feel like your hand'; 10 = 'you have the normal sense of the moving hand being your own hand'). For subjective depth of hypnosis (see (Oakley et al., 2007) participants rated their

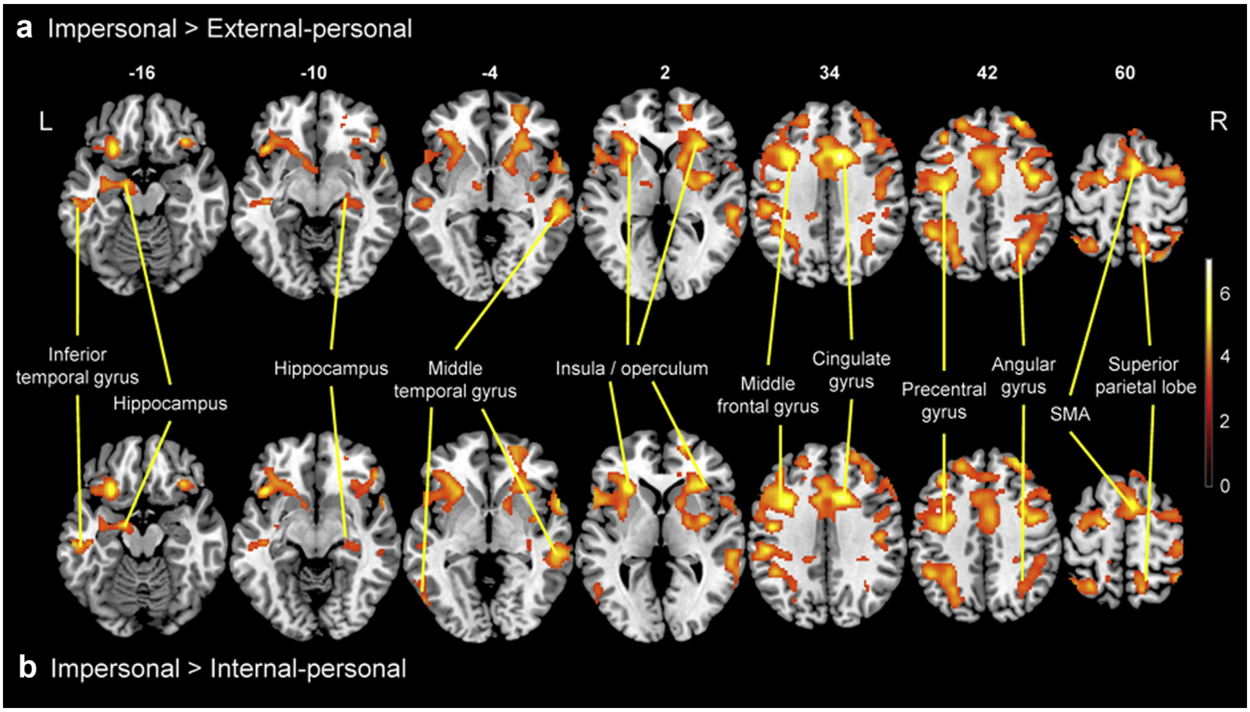

Fig. 1 – Comparison of significant brain activation ($p < .05$ cluster corrected) during a) IMPERSONAL > EXTERNAL PERSONAL alien control and b) IMPERSONAL > INTERNAL PERSONAL alien control overlaid on the high resolution T1-weighted image provided with MRIcron. Representative slices are chosen to illustrate the peaks and main subpeaks of the clusters from Tables 1 and 2.

Table 3 – Increases in activation for IMPERSONAL compared to INTERNAL PERSONAL alien control.

Anatomical region	Hemisphere	MNI coordinates	Cluster size	Z value	Cluster-level p corrected	BA
a)						
Precentral gyrus	L	−36, −10, 46	20,058	6.03	.000	6
Cingulate gyrus	R	10, 14, 34		5.90		24/32
Precentral gyrus	L	−34, 10, 32		5.52		44
SMA	R	8, 8, 58		5.11		6
b)						
Temporal pole	R	56, 14, −8	198	4.88	.053#	38
Frontal operculum/insula	R	50, 12, 6		3.53	.053	48
c)						
Middle temporal gyrus	R	58, −32, 0	668	4.76	.000	21
Hippocampus	R	32, −22, −6		4.41		20
Middle temporal gyrus	R	46, −36, −4		3.95		21
d)						
Hippocampus	L	−14, −8, −18	388	4.53	.003	35
Hippocampus	L	−30, −8, −16		3.95		20
e)						
Angular gyrus	R	32, −60, 42	2599	4.51	.000	7
Superior parietal lobe	R	14, −60, 60		4.51		5
Superior parietal lobe	R	28, −70, 60		4.15		7
f)						
Inferior temporal gyrus	L	−44, −22, −18	315	4.40	.009	20
Middle temporal gyrus	L	−54, −22, −4		4.29		21
g)						
Cerebellum	L	−24, −70, −22	351	4.39	.005	–
Cerebellum	L	−42, −68, −24		4.00		–
Fusiform gyrus	L	−46, −62, −20		3.45		37

Peak changes within each cluster together with co-ordinates in MNI space. Subpeaks within a cluster are shown in italics.

current experience with reference to their previous experiences of hypnosis during HGSHS:A testing and the screening session on 0–10 scales (0 = 'not at all hypnotised'; 10 = 'at least as deep as you have been before').

2.5. *Image acquisition parameters*

Imaging data were acquired at 3 Tesla (3 T) using a GE Signa HDx MRI scanner at the Centre for Neuroimaging Sciences, Kings College London UK. Functional MRI examinations used gradient echo, echoplanar imaging (EPI; TR = 2000 msec; TE = 30 msec; RF flip angle = 80°; slice thickness = 3 mm; slice gap = .3 mm; interleaved acquisition). For each experimental block/condition, 150 functional images were acquired continuously.

2.6. *Neuroimaging data analysis*

Functional images were processed and analysed in SPM5 (Wellcome Trust Centre for Neuroimaging, London, UK; http://www.fil.ion.ucl.ac.uk/spm). Single-subject models were constructed with conditions of the motor task as one regressor (MOVE onsets and durations), and the six movement parameters as covariates of no interest. A flexible-factorial ANOVA group analysis was conducted on contrast images for movement versus rest from the single-subject analyses. Group brain activation maps were calculated for 'movement' versus 'rest' to confirm significant engagement of the motor network for each condition and contrasts between conditions were generated to test the effects of hypnosis and targeted suggestions (Deeley et al., 2013).

2.7. *Functional connectivity analysis*

In order to establish the nature of interactions between different brain areas that mediate joystick movements under the three experimental conditions, we performed a psychophysiologic interaction (PPI) analysis using an M1 (−30, −30, 62) seed (Deeley et al., 2013). The seed was defined as a sphere with the centre as the peak of activity in M1 for all 11 subjects in left motor cortex (M1, seed region −30, −30, 62 from the group activation map) and with a standard 6 mm radius. Participants for whom the Euclidian distance between the peak activation voxel per condition closest to the seed coordinates for M1 exceeded 6 mm were excluded. The PPI analysis included 10 participants (one excluded). A voxel-wise threshold of $p < .01$, with statistical inference based on a cluster statistics threshold of $p < .05$ corrected for multiple comparisons was used.

3. Results

3.1. *Self-ratings*

Self-ratings for the depth of hypnosis accompanying voluntary movement in the hypnotised state (HYP VOLUNTARY mean = 7.8; SD = 1.5) were significantly higher compared to those accompanying voluntary movement in the non-hypnotised state (NOHYP VOLUNTARY mean = 1.7; SD = 2.1); $t(10) = 9.13$; $p < .0001$. This confirmed the effectiveness of the induction procedure in the scanner.

As expected, depth ratings also increased for all three involuntary conditions compared to NOHYP VOLUNTARY:

IMPERSONAL $t(10) = 8.95$; $p < .001$; EXTERNAL PERSONAL $t(10) = 9.48$; $p < .001$; INTERNAL PERSONAL $t(10) = 7.56$; $p < .001$. There were no differences in self-ratings of depth of hypnosis for the three experimental conditions IMPERSONAL (mean = 7.8; SD = 1.6), EXTERNAL PERSONAL (mean = 7.6; SD = 1.1) and INTERNAL PERSONAL (mean = 7.9; SD = 1.4); $F(2, 20) = .54$; $p = .59$.

The three involuntary conditions were associated with significant reductions in perceived control compared to the voluntary movement condition in hypnosis (HYP VOLUNTARY) [$F(3, 30) = 35.39$; $p < .001$]. Perceived ownership was also reduced for involuntary conditions compared to the voluntary condition [$F(3, 30) = 13.23$; $p < .001$]; see Table 2.

Perceived control did not differ between the three involuntary conditions [control: $F(2, 20) = .005$; $p = .992$]. However, there were differences for perceived ownership between all four conditions [$F(3, 30) = 13.220$; $p < .001$], due to perceived ownership being higher in the HYP VOLUNTARY condition relative to the three involuntary conditions. For awareness there was no overall difference between all four conditions [$F(3, 30) = 1.76$; $p = .20$].

3.2. *The effects of specific suggestions on joystick displacement*

Previously we described a main effect of hypnosis on reducing movement amplitude by ~14% (Deeley et al., 2013). Here we were interested in the differences between the targeted suggestion conditions. Paired *t*-tests confirmed that there were no significant differences in movement amplitude between the IMPERSONAL (mean = 14.7; SD = 9.7), EXTERNAL PERSONAL (mean = 15.4; SD = 7.5) and INTERNAL PERSONAL (mean = 17.0; SD = 7.1) conditions; all $t < 1.19$.

3.3. *Functional MRI data*

3.3.1. *General linear model analyses*

The contrast of ‘MOVE’ versus ‘REST’ instructions in the non-hypnotised condition (NON-HYP VOLUNTARY) was, as expected, associated with increased activation in the motor system (including left M1, left SMA, and right cerebellum). This indicated that our paradigm elicited task-related activation in relevant components of the motor system (Deeley et al., 2013).

Next we tested for any changes in brain activity during joystick movement between the three experimental conditions. The contrast of brain activity during impersonal compared with internal personal alien control (IMPERSONAL > INTERNAL PERSONAL) revealed increased activation in left cerebellum and precentral areas, right mid-cingulum and parietal areas during impersonal alien control (see Fig. 1a, Table 3). Activity was also significantly greater in mid-temporal and hippocampal areas bilaterally. A very similar network of regional differences in brain activity was seen when impersonal alien control was contrasted with external personal alien control (IMPERSONAL > EXTERNAL

Table 4 – Increases in activation for IMPERSONAL compared to EXTERNAL PERSONAL alien control.

Anatomical region	Hemisphere	MNI coordinates	Cluster size	Z value	Cluster-level *p* corrected	BA
a)						
Precentral gyrus	L	−34, 10, 32	20,876	5.71	.000	44
Precentral gyrus	L	−36, −10, 46		5.69		6
Cingulate gyrus	R	12, 16, 34		5.55		32
Insula	L	−28, 24, 2		5.06		48
SMA	R	6, 12, 58		4.98		6
b)						
Middle temporal gyrus	R	60, −32, 0	685	4.66	.000	21
Hippocampus	R	34, −26, −6		4.48		20
Middle temporal gyrus	R	64, −46, 2		4.00		21
c)						
Hippocampus	L	−14, −8, −18	264	4.48	.018	35
Brainstem	–	0, −20, −24		4.05		–
Hippocampus	L	−32, −8, −14		3.67		20
d)						
Inferior temporal gyrus	L	−56, −24, −16	245	4.45	.025	20
Inferior temporal gyrus	L	−44, −22, −18		4.15		20
Middle temporal gyrus	L	−54, −22, −4		3.72		21
e)						
Superior parietal lobe	R	14, −60, 60	952	4.22	.000	5
Postcentral gyrus	R	44, −26, 60		4.02		3
Postcentral gyrus	R	10, −38, 70		3.90		4
f)						
Fusiform gyrus	L	−42, −50, −24	390	4.18	.003	37
Cerebellum	L	−26, −70, −28		4.12		–
Cerebellum	L	−40, −66, −26		4.07		–
g)						
Inferior occipital gyrus	L	−54, −70, −4	199	3.98	.053	37
Middle temporal gyrus	L	−52, −64, 6		3.66		37
Inferior temporal gyrus	L	−60, −54, −6		3.34		37

Peak changes within each cluster together with co-ordinates in MNI space. Subpeaks within a cluster are shown in italics.

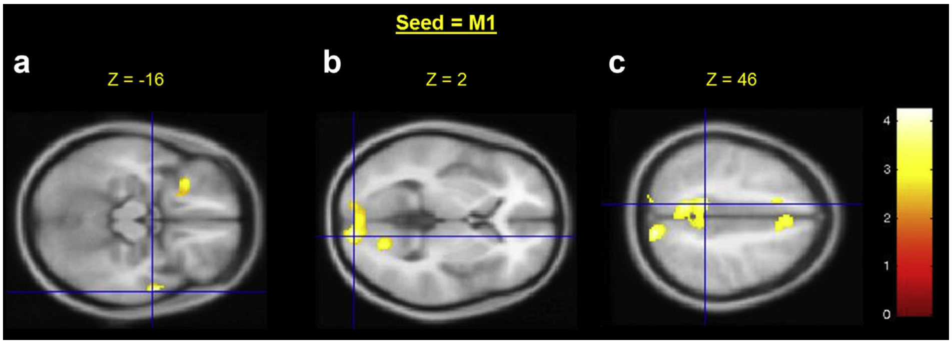

Fig. 2 – Psychophysiological interaction (PPI) analysis. M1 seed: a) INTERNAL PERSONAL > IMPERSONAL; b) EXTERNAL PERSONAL > INTERNAL PERSONAL and c) EXTERNAL PERSONAL > IMPERSONAL.

PERSONAL) (Table 4). For example, increased activity was again shown in left cerebellum and precentral areas, right parietal areas, and bilaterally in temporal and hippocampal areas. However, activity in right post-central and left fusiform gyrus was also increased for this contrast (Fig. 1b). There were no brain regions which showed greater activation to the INTERNAL PERSONAL or EXTERNAL PERSONAL conditions relative to IMPERSONAL, nor were there significant differences between the EXTERNAL- compared to INTERNAL PERSONAL conditions. Overall these findings indicate that a specific network of regions is associated with IMPERSONAL alien control.

3.3.2. *Functional connectivity (psychophysiological interaction) fMRI data analysis*

Psychophysiological interaction (PPI) connectivity analysis showed increased connectivity between left M1 and other brain regions for internal personal relative to impersonal alien control of movement (INTERNAL PERSONAL > IMPERSONAL) (Fig. 2a) (Table 5). Increased connectivity was largely confined to the right hemisphere including temporal and frontal regions as well as the anterior cingulum and the cuneus. Increased connectivity in the left hemisphere was restricted to the caudate and precuneus. In the EXTERNAL PERSONAL > IMPERSONAL contrast increased connectivity was observed in a similar set of regions including the left precuneus, and right cuneus and superior and orbital frontal areas as well as bilaterally in anterior cingulum and superior medial frontal areas (Fig. 2c, Table 5). Increased connectivity between the M1 seed for the EXTERNAL PERSONAL > INTERNAL PERSONAL contrast was confined to posterior right regions including the calcarine sulcus and the lingual gyrus (Fig. 2b, Table 6).

4. Discussion

We combined suggestion and fMRI to investigate changes in brain activity associated with different types of causal

Table 5 – Psychophysiological interaction analysis showing increased connectivity between M1 and other brain regions for PERSONAL relative to IMPERSONAL alien control.

Anatomical region	Hemisphere	MNI coordinates	Cluster size	Z value	Cluster-level *p* corrected	BA
INTERNAL PERSONAL > IMPERSONAL						
Middle temporal gyrus	R	60, −4, −16	1219	4.19	.004	21
Superior temporal gyrus	R	66, −16, 8		3.77		22
Superior temporal gyrus	R	56, −6, −8		3.69		22
Medial orbitofrontal	R	16, 48, −4	3533	4.00	.000	10/11
Anterior cingulate gyrus	R	8, 28, 30		3.89		32
Caudate/putamen	L	−14, 18, −8		3.66		11
Posterior Cingulate gyrus/cuneus	R	20, −64, 26	1079	3.51	.008	23
Posterior cingulate	R	2, −50, 34		3.37		23
Precuneus	L	−10, −56, 48		3.02		7
EXTERNAL PERSONAL > IMPERSONAL						
Precuneus	L	−10, −40, 46	2011	3.58	.000	7
Cuneus	R	16, −70, 34		3.54		18
Cuneus	R	16, −82, 46		3.48		19
Superior medial frontal	L	−6, 54, 6	983	3.52	.013	10
Superior frontal	R	16, 56, 2		3.22		10
Medial orbital frontal	R	16, 50, −6		3.03		11
Superior medial frontal	R	2, 28, 40	863	3.51	.025	32
Anterior cingulate gyrus	R	10, 30, 28		3.51		32
Anterior cingulate gyrus	L	−2, 28, 26		3.21		24

Peak changes within each cluster together with co-ordinates in MNI space. Subpeaks within a cluster are shown in italics.

Table 6 – Psychophysiological interaction analysis showing increased connectivity between M1 and other brain regions for EXTERNAL PERSONAL relative to INTERNAL PERSONAL alien control.

Anatomical region	Hemisphere	MNI coordinates	Cluster size	Z value	Cluster-level p corrected	BA
Calcarine gyrus	R	14, −94, 2	909	3.97	.019	18
Lingual gyrus	*R*	*12, −86, −2*		*3.75*		*17*
Lingual gyrus	*R*	*22, −70, 2*		*3.22*		*19*

Peak changes within each cluster together with co-ordinates in MNI space. Subpeaks within a cluster are shown in italics.

attribution and experience of the loss of the sense of agentive self-control of movement. Targeted suggestions produced vivid subjective experiences of external and internal personal control by an “Engineer”, modelling delusions of control and spirit possession respectively. Also, a suggestion of impersonal control by a malfunctioning machine modelled the ‘machine’ aspect of technical delusions of control.

The main findings were that (i) brain activity and/or connectivity significantly varied with different experiences and attributions of loss of agency; (ii) this was despite the absence of significant differences in self-rated depth of hypnosis, control, or awareness of movement, or differences in amplitude of joystick movement during conditions in which agency was lost; there was a small but significant reduction in ownership of movement in the IMPERSONAL relative to PERSONAL conditions, which may be relevant to differences in brain activity (see below); (iii) compared to the impersonal control condition, both external and internal personal alien control conditions were associated with increased connectivity between M1 (a key movement implementation region) and brain regions involved in attribution of mental states (e.g., BA 10) and representing the self in relation to others (cortical midline structures including BA 10 and left precuneus); (iv) compared to both personal alien control conditions, impersonal control of movement was associated with increased activity in a brain network including regions involved in error detection (anterior cingulate cortex, BA 32) and object imagery (left middle temporal gyrus); (v) there were no significant differences in brain activity, and minor differences in M1 connectivity, between the external and internal personal alien control conditions.

4.1. *Experience and behaviour during alien control of movement*

At a behavioural level, there were no significant differences in movement amplitude of the joystick across the three experimental alien control conditions. Also, the hypnosis induction procedure was associated with a significant increase in self-rated depth of hypnosis compared to the non-hypnotised state, which did not differ across the alien control conditions following induction. This indicates that any differences in self-reported experience or brain activity across conditions cannot be attributed to differences in movement or depth of hypnosis.

Compared to hand movement following induction of hypnosis but before suggestions of involuntary movement, the alien control conditions were all associated with significant reductions in perceived control and ownership of limb movement, but no differences in awareness. The suggestions therefore succeeded in establishing loss of a sense of control of the right hand during movement of a joystick. Also, the comparable decrease in perceived control of hand movement across conditions indicates that loss of perceived self-control of movement can be embedded in a range of complex experiences and attributions of loss of agency that differ in important respects (e.g., such as whether the loss of agency is attributed to a personal or impersonal cause). The parallel loss of perceived ownership of the right hand across conditions – despite the absence of explicit suggestions of loss of hand ownership – is consistent with proposals that the experiences of limb control and ownership are closely integrated (de Haan & de Bruin, 2010).

Semi-structured qualitative interviews conducted after scanning revealed that the suggestions of different types of alien control of movement elicited subjectively realistic experiences accompanying the sense of loss of control of hand movement. In keeping with the content of suggestions, suggestions of external impersonal control [IMPERSONAL] were associated with vivid multisensory imagery of malfunctioning machinery in which human agency was absent. Participant descriptions of the resultant movements included words such as ‘robotic’, ‘jerky’, and ‘mechanical’. For example: “Robot with red eyes controlled two-button remote control, movement delayed because of robot pressing remote, then movement started, movement more jerky because of the delay”; “I felt as if my hand had been made of metal and movement was mechanical. I can’t say why I couldn’t move my hand properly, I mean the capacity to move the hand was limited.” By contrast, both external and internal personal alien control conditions were accompanied by imagery and mental state representations of an agent (the Engineer), acting on the experimental subject on the basis of thoughts, intentions, feelings, and motivations (“More fluid movement, less control. No feelings about it just let Engineer get on with it.” [EXTERNAL PERSONAL]; “Felt Engineer’s excitement and anticipation of hand movements, movements also felt more purposeful” [INTERNAL PERSONAL]). Machine imagery was also present in both personal alien control conditions in keeping with the content of suggestions, although not exclusively so given the presence of mental state representations of an agent (“I imagined the same glove grip and wires connected it to the engineer who was probably on the right. She had a smaller joystick where she used her fingers to control my hand” [EXTERNAL PERSONAL]; “2 steps. 1) Engineer put sticks through my stomach up to my left and right brain and make [sic] my hand move. 2) After that the engineer took over ‘me’”.

4.2. *Brain activity during alien control of movement*

Between condition contrasts revealed that brain activity and/or connectivity significantly varied with different experiences and attributions of loss of agency. Compared to the impersonal control condition, both external and internal personal alien control conditions were associated with increased connectivity between M1 (a key movement implementation region) and a network of brain regions (Table 5). While these brain regions are associated with a variety of processes, in the context of the present task we focus on processes relating to attribution of mental states, representing the self in relation to others, and representation of the body in space and visuomotor integration. For example, compared to impersonal control, the external personal control condition was associated with increased connectivity between M1 and superior, medial, and orbito-medial prefrontal regions (BA 10 and 11); left precuneus, and right extrastriate cortices (BA 18/19). Both BA 10 and precuneus are involved in mental state attribution (Frith & Frith, 2003; Vogeley et al., 2004); reflexive awareness (Frith & Frith, 2003; Lou et al., 2004); and determining the self-relevance of stimuli (Fossati et al., 2003; Kelley et al., 2002; Kjaer, Nowak, & Lou, 2002; Lou et al., 2004; Zysset, Huber, Ferstl, & von Cramon, 2002). The precuneus also supports spatial representation and visuomotor co-ordination (Wenderoth, Debaere, Sunaert, & Swinnen, 2005). Anterior cingulate cortex forms part of a cortical midline network involved in self-related processing in addition to visuomotor co-ordination (Northoff & Bermpohl, 2004), while extrastriate cortices represent imagery and knowledge of objects and people (Schultz, 2005). The PPI contrast of the internal personal control relative to the impersonal control condition revealed increased M1 connectivity in an overlapping network of brain regions (Table 5). Additional regions showing increased M1 connectivity were right posterior cingulate cortex (BA 23), known to be involved in self-related processing (Johnson et al., 2002), and right middle and superior temporal gyri (BA 21/22), which may reflect differences in the processing of auditory perception and imagery between conditions (Bunzeck, Wuestenberg, Lutz, Heinze, & Jancke, 2005).

A number of brain regions differed between IMPERSONAL alien control and the PERSONAL conditions suggesting these regions are involved in supporting the experience of impersonal alien control. The precise role of these regions in impersonal alien control cannot be fully determined from this study alone. However, based on their known roles, content of suggestions and qualitative reports of participants, we propose that the present findings are in keeping with a hypothesis of the retrieval of object imagery from memory. For example, compared to external personal alien control, activity during impersonal control was significantly increased in brain regions involved in retrieval of imagery from memory, including left precentral cortex (BA 6, BA 44); left cerebellum; bilateral hippocampus (BA 21) and inferior and mid-temporal lobes (BA 20/21) (Dennis, Bowman, & Vandekar, 2012) (Table 4). Also, activity increased in right superior parietal lobule structures of BA 5 and 7, brain regions involved in the representation of object location in relation to the body in space and visuomotor integration (Iacoboni, 2006); and left BA 19 and 37, brain regions involved in representing object identity (Kanwisher, McDermott, & Chun, 1997) (Table 4). Activity in anterior cingulate cortex (ACC, BA 32) was also greater in impersonal relative to external personal alien control. This may relate to greater involvement of ACC in error detection, given the perceived randomness of purposeless movements caused by a malfunctioning machine in contrast to the purposive (if alien) movements of the Engineer. Similarly, increased activity in right anterior insula may reflect heightened interoceptive monitoring of purposeless relative to purposeful movements (Craig, 2009). Overall, the significant reduction in perceived limb ownership during impersonal relative to personal conditions may indicate greater unpredictability and salience of these movements relative to the personal control conditions.

We recognise that alternative processes have been associated with all of these regions, but present an explanatory account that links the task and the activation of all these regions. The contrast of impersonal to internal personal control showed increased activation in a largely overlapping network of regions (Table 3). There were no regions which were more active during the personal alien control conditions compared to impersonal alien control. Hence, while experiences of both impersonal and personal control involved the construction of vivid imagery, the present findings suggest that generating non-social (technical) imagery compared to agentive imagery is achieved through relatively greater engagement of brain systems involved in identifying and locating objects in space. Also, activation of parietal cortices may not only be involved in representing the spatial location of the machine in relation to the self, but also the causal influence of the machine on movement given the role of BA 7 in visuomotor integration (Nishitani, Uutela, Shibasaki, & Hari, 1999).

Whilst we did find the predicted increase in connectivity between M1 and mentalising and self-related processing networks in the personal compared to impersonal conditions, GLM analysis did not reveal increases in activity in these brain regions. While this may reflect a Type II error due to a final sample size of 11 (noting that 300 subjects were screened to recruit 15 subjects for scanning), we do not consider this the most likely explanation given that the reverse contrast (impersonal > personal conditions) revealed widespread increases in brain activity in relevant brain regions. An alternative explanation relates to the fact that the regions involved in mentalising and self-related processing include midline cortical regions that are already ‘active’ during resting and control conditions (i.e., the ‘default mode network’) (Deeley et al., 2012). Consequently, engagement of these networks in representing an agent influencing movement may be achieved through increased functional integration of social cognition and motor networks, rather than a change in the relative magnitude of activity. This interpretation would also imply that the increased activity in brain regions in the impersonal relative to personal conditions occurred because constructing vivid non-social object imagery is a more resource-intensive departure from ‘default mode’ cognition and brain function than imagining agents influencing the self. A neurocognitive bias towards representing and detecting agentive rather than impersonal influence on the self may help explain why patient reports indicate that delusions of influencing machines tend to be connected with maleficent agency, rather than exist as ‘pure’ technical delusions which exclusively posit impersonal causation of passivity phenomena.

There were no significant differences in the GLM contrast between internal and external personal control, while the differences in connectivity with M1 were limited (greater M1 connectivity with right extrastriate visual processing regions in external relative to internal personal control conditions). This implies that similar brain regions are enlisted to construct vivid experiences of personal agentive control, whether the experienced locus of agentive control is internal or external.

4.3. *Modelling possession phenomena with suggestion and fMRI*

The method and findings described have potential implications for understanding neuropsychiatric and culturally influenced possession phenomena. Firstly, suggestions can be used to experimentally model different kinds of loss of agency, amongst other symptoms and alterations in experience (Bell, Oakley, Halligan, & Deeley, 2011; Deeley et al., 2012; Oakley & Halligan, 2009). Changes in brain activity and/or connectivity associated with suggested alterations in agency are likely to contribute to the respective experiences, and by analogy to the neuropsychiatric and/or culturally influenced phenomena they model (Bell et al., 2011; Deeley et al., 2012; Oakley & Halligan, 2009).

However, suggestive-dissociative processes may not only represent a way of modelling possession phenomena, but crucially also contribute to their production. For example, it has been proposed that spirit possession, and dissociative phenomena including dissociative identity disorder (DID) result from suggestions or autosuggestions of the type measured by hypnotic suggestibility scales (Deeley, 2003, 2013; Oakley, 1999). Nevertheless, suggestive processes can take a range of forms – for example, while internally or externally generated verbal processes predominate in hetero- and self-hypnosis procedures (Kirsch & Lynn, 1998), non-verbal external or internal cues are also present and are particularly likely to contribute to clinically and culturally relevant dissociative processes (Bell et al., 2011; Deeley, 2013). This implies that the beliefs, expectancies, and attributions through which suggestive processes exercise their effects on cognition and brain function can be mobilized or accessed in a variety of ways (Edwards, Adams, Brown, Pareés, & Friston, 2012). Verbal and non-verbal mechanisms of suggestion and dissociation are relevant topics for further research, in particular to improve understanding of how suggestive processes may contribute to neuropsychiatric and culturally influenced possession phenomena. Future research should also investigate how social, cognitive, and neural processes involved in the acquisition and maintenance of beliefs influence responses to suggestive processes (Deeley, 2003, 2004).

The present findings also raise the question of the extent to which beliefs and expectancies influence the formation of delusions of control in psychosis. While loss of the normal sense of agency of movement may result from structural, functional, and neuromodulatory disruptions of action control systems (Fornito, Zalesky, Pantelis, & Bullmore, 2012), the attributions made to interpret these primary disturbances of agency may enlist beliefs and expectancies that are similar in their effects to suggestions or autosuggestions. Elucidating the contribution of beliefs and expectancies to delusions of control and other psychotic phenomena merits further research, given that it may lead to improved understanding of cross-cultural and historical variations in psychotic symptomatology, as well as novel or adapted therapeutic interventions and assessments of therapeutic efficacy considering that, for example, beliefs about the power and identity of hallucinated voices are a significant mediator of the distress they cause.

The experimental condition of *internal personal alien control*, involving the suggestion that the Engineer entered the subject and controlled movement from within, was developed to model cases of spirit possession in which the experimental subject is aware of the thoughts and motives of the possessing agent but unable to control movement. However, the suggested alteration in experience may also serve to model the ‘alter’ of DID, in which two or more distinct personality or identity states recurrently take control of the person’s behaviour (DSM-V). Similarities between the phenomenology of and influence of social context on spirit possession and DID have been previously noted, raising the possibility that the respective phenomena may share underlying cognitive and neural mechanisms (Deeley, 2003; Littlewood, 2002). Indeed, the fifth edition of the Diagnostic and Statistical Manual of the American Psychiatric Association distinguishes unwanted, prolonged ‘possession-form’ and ‘non-possession form’ dissociative identity changes, but classifies both as subtypes of a single overarching category of DID (American Psychiatric Association, 2013). The current experiment would be most relevant to model non-possession form cases of DID where the normal self is aware of but unable to influence the thoughts and actions of the ‘alter’.

Our study has a number of limitations. We conducted our experimental protocol on 33 highly hypnotically responsive individuals outside the scanner, of whom 15 were suitable for and/or consented to participate in the fMRI experiment. 11 of these 15 individuals were included in the imaging analysis, and 7 in the PPI analysis (see Methods and Results). While these exclusions may have increased the risk of Type II errors, we believed it was more important to implement robust data quality procedures to minimise the risk of false positive results or inflated variability in the data. Further, as noted above we believe the extensive and consistent between condition differences in the GLM and PPI analyses of impersonal and personal control conditions suggests that our findings were not subject to major Type II errors. We also note that because only 10% of the population is highly hypnotically suggestible, we had to screen more than 300 individuals to recruit those who participated in fMRI scanning (Oakley et al., 2007). While this illustrates a practical challenge of this experimental approach, the database established will facilitate future studies with larger sample sizes. Also, there may be other cognitive differences between conditions other than those we have considered in our hypotheses and interpretation of the findings. However, the wording was virtually identical between conditions, with the only exception being the elements regarding causal or agentive attributions. Similarly, the movements did not differ between ‘involuntary’ conditions, which were randomised in their order of presentation.

Further, we did not include a feigning or simulation condition, but note that the experimental conditions were associated with distinctive changes in brain activity and/or connectivity that were consistent with predicted changes in cognitive and neural functioning. We suggest that simulation strategies would be less likely to be associated with such distinctive differential modulation of brain activity and connectivity. Also, whenever simulation (Cojan et al., 2009; Ward, Oakley, Frackowiak, & Halligan, 2003) or imagination (Derbyshire, Whalley, Stenger, & Oakley, 2004; Szechtman, Woody, Bowers, & Nahmias, 1998) conditions have been employed in studies combining hypnosis and neuroimaging, the neural correlates of the suggested and simulated/imagination conditions have differed. However, future studies could employ a simulation condition to provide further evidence that the suggested effects reported by participants are not attributable to simulation.

4.4. *Conclusions*

We combined suggestion and fMRI to investigate changes in brain activity associated with different types of causal attribution and experience of the loss of the sense of agentive self-control of movement. Compared to the impersonal control condition, both external and internal personal alien control conditions were associated with increased connectivity between M1 (a key movement implementation region) and brain regions involved in attribution of mental states (e.g., BA 10) and representing the self in relation to others (e.g., cortical midline structures including BA 10 and left precuneus). Further, there were no significant differences in brain activity, and minor differences in M1 connectivity, between the external and internal personal alien control conditions. By contrast, compared to both personal alien control conditions, impersonal control of movement was associated with increased activity in brain regions supporting error detection (anterior cingulate cortex) and the retrieval and maintenance of mental imagery of objects (e.g., left middle temporal gyrus). These findings suggest that brain networks supporting object imagery and representation of self and others are differentially recruited to support experiences of impersonal and personal control of involuntary movements. Also, similar brain systems underpin attributions and experiences of external and internal alien control of movement. Loss of self-agency for movement can therefore be associated with different kinds of causal attribution and experience of alien control supported by distinct brain mechanisms. Collectively these findings illustrate how cognition, brain function, and experience can be influenced by the imagery, concepts, and expectancies engaged by suggestive processes, and caution against generalization about single cognitive processes or brain systems underpinning complex symptomatology and alterations in experience.

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