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Brain mechanisms for loss of awareness of thought and movement

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Abstract

Loss or reduction of awareness is common in neuropsychiatric disorders and culturally influenced dissociative phenomena but the underlying brain mechanisms are poorly understood. fMRI was combined with suggestions for automatic writing in 18 healthy highly hypnotically suggestible individuals in a within-subjects design to determine whether clinical alterations in awareness of thought and movement can be experimentally modelled and studied independently of illness. Subjective ratings of control, ownership, and awareness of thought and movement, and fMRI data were collected following suggestions for thought insertion and alien control of writing movement, with and without loss of awareness. Subjective ratings confirmed that suggestions were effective. At the neural level, our main findings indicated that loss of awareness for both thought and movement during automatic writing was associated with reduced activation in a predominantly left-sided posterior cortical network including BA 7 (superior parietal lobule and precuneus), and posterior cingulate cortex, involved in self-related processing and awareness of the body in space. Reduced activity in posterior parietal cortices may underlie specific clinical and cultural alterations in awareness of thought and movement. Clinically, these findings may assist development of imaging assessments for loss of awareness of psychological origin, and interventions such as neurofeedback.

Key words: dissociation; non-epileptic seizures; automatic writing; cultural neuroscience; fMRI; hypnosis

Introduction

The everyday sense of being aware of our thoughts and movements and exercising control over them can be altered or lost, as occurs in a range of common neuropsychiatric disorders, e.g. psychogenic non-epileptic seizures, defined as 'episodes of altered movement, sensation, or experiences resembling epileptic seizures which have a psychological origin;' (Lesser, 1996). Awareness is partially or fully lost in up to 50% of these patients (Brown et al., 2011). Alien control of thought or movement associated with loss of awareness is also described in culturally

influenced dissociative phenomena associated with spirit possession, mediumship and shamanism (Crapanzano and Garrison, 1977; Rouget, 1985).

'Automatic writing' represents one cross-culturally prominent form of altered experience and behaviour involving attributions of alien control frequently accompanied by loss of awareness (Ellenberger, 1970; Shaw, 2011). The experience of handwriting integrates both thought (thinking what to write) and movement (the motor act of writing). Phenomenological accounts indicate that during automatic writing, our sense of

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control, ownership and awareness of these two handwriting components can be selectively altered. For example, historical accounts describe how thoughts ‘surged . . . apparently from nowhere into the mind’ (thought insertion), or of how an ‘arm was lifted into the air’ (alien control of movement) during automatic writing (Koutstaal, 1992). Automatic writing can involve either full or reduced awareness (Taves, 2006). Previously, we combined suggestion and fMRI to investigate reduced awareness for alien control of a simple joystick movement (Deeley et al., 2013). Reduced awareness was associated with inactivity in parietal cortex (BA 7, BA 40) and insula, providing a potential basis for the attenuation of bodily and self-awareness reported in pathological and culturally influenced dissociative phenomena (Deeley et al., 2013). Nevertheless, the brain processes underpinning both psychopathological and culturally influenced changes in awareness of *thought* and *complex movement* remain poorly understood.

We therefore combined fMRI and suggestions for automatic writing in hypnotically suggestible individuals to create an experimental model whereby awareness, control and ownership of thought and complex movement are altered. Our behavioural study modeled experiences of thought insertion and alien control during automatic writing with and without awareness (Walsh et al., 2014). The task design separated thought (thinking of a sentence ending) from writing movement (writing the sentence down). Previously we reported the neural correlates of thought insertion and alien control of movement as separate suggestions validating the automatic writing fMRI paradigm (Walsh et al., 2015). Here, we focus on the neural correlates of reduced awareness for thought and movement during our writing task. This allows us to model loss of awareness of involuntary mental content or movement as occurs in some forms of culturally influenced dissociation such as mediumship, possession, or inspired writing, and dissociative psychopathology, e.g. non-epileptic seizures. Based on our earlier study modelling loss of awareness for simple joystick movement (Deeley et al., 2013), we predicted that loss of awareness for both thought insertion and alien control of complex movement (writing) would involve reduced activity in networks including parietal cortex (Brodmann Area BA 7, BA 40) and insula as regions mediating the loss of bodily and self-awareness reported in pathological and culturally influenced dissociative phenomena (Deeley et al., 2013).

Materials and methods

Participants

Eighteen right-handed (Oldfield, 1971) highly hypnotically suggestible (mean Harvard Group Scale; Shor et al. (1962); score = 9.7; SD = 1.4) native English-speaking participants (13 female), mean age 26.2 (SD = 8.3) years were recruited. All participants were tested in a mock training scanner for compatibility prior to participating in the fMRI study. This research was approved by the Research Ethics Committee at King’s College London.

Procedure

Throughout each session, participants were provided with both ear-plugs and headphones to protect their hearing from MRI scanner noise (Hattori et al., 2007). Participants listened to instructions/suggestions via headphones and could communicate with the control room via a microphone. Earlier studies have demonstrated that hypnotic depth and response to suggestion

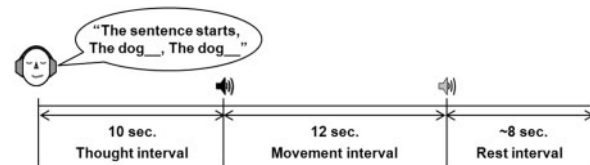


Fig. 1. Trial design. Each trial consisted of a thought and a movement interval. Participants were presented with a sentence stem, which was repeated once, via headphones. Two different tones marked the onset and offset of the movement interval. The duration of the rest interval (approximately 8 seconds) was randomly jittered by up to 500 ms on each trial.

are not discernibly affected by the fMRI environment (Oakley et al., 2007; Pyka et al., 2011; Walsh et al., 2015).

Prior to each experimental block (10 trials), the participant received a set of instructions/suggestions via the headphones. The number of trials was kept constant for each subject and in each condition to ensure good model estimation of the neuroimaging data. The VOL condition involved voluntary self-controlled writing while ‘hypnotised’ and in the absence of any suggestion for altered subjective experience or behaviour. Participants listened to the sentence stem and wrote down a suitable ending when they heard the appropriate tone (see Figure 1; Walsh et al., 2014, 2015). All three blocks were presented in random order after a hypnotic induction procedure.

Hypnotic induction and reversal

The hypnosis induction procedure was carried out with the participant lying in the scanner and fixating their eyes on a white crosshair target projected onto a black background. An experimenter administered suggestions (Supplementary Box S1). Continued fixation on the target was accompanied by suggestions of involuntary eye closure (“your eyes will begin to close all by themselves”) which the participant was asked to confirm with “yes” when this had happened (Deeley et al., 2012; Oakley et al., 2007). The eye closure suggestions were combined with suggestions of muscle relaxation, commencing with the face, and then progressing systematically throughout the body to the feet. Then, a counting procedure (1 to 20) was used to further deepen the experience of relaxation, and the ability to carry out all tasks they would be asked to do without it disturbing the state they had achieved at the end of the count. Participants’ eyes remained closed throughout hypnosis. Ratings for subjective ‘depth of hypnosis’ were taken (where ‘0’ = ‘not at all hypnotized’ to ‘10’ = ‘as hypnotized as I’ve ever been’) and the experimental blocks were not commenced until participants reported a depth of hypnosis rating of 7 or higher. All participants had at least one prior experience of hypnosis (i.e. during participant screening for hypnotic suggestibility) on which to base their response. At the end of the experiment and before exiting the scanner, reversal of hypnosis was achieved by a reversed counting procedure (20 to 1) and an eventual suggestion that the participant’s eyes would open and that they would be wide awake and fully alert at the end of the count. The participant was asked to say ‘yes’ when this had happened.

For the experimental conditions, hypnotic suggestion was used to model automatic writing by creating combined experiences of alien control for thought and movement during a sentence completion task (Table 1) both with and without awareness, in order to model automatic writing (Janet and Prince, 1907) and analogous dissociative and passivity phenomena. During scanning, participants were presented with 10 sentence stems in each experimental block and were instructed to

Table 1. Experimental conditions. The three experimental conditions and the focus of the suggestion/instruction for each condition. All conditions took place after a standard hypnotic induction procedure comprising visual fixation and progressive relaxation suggestions (Oakley et al., 2007). Scripts for the automatic writing conditions (Numbers 2 and 3) differed only in terms of whether the experience of awareness was removed or not (see Supplementary Material for full scripts for automatic writing suggestions)

Condition	Suggestion/Instruction
1. Voluntary (VOL) (after induction of hypnosis)	“When you hear the sentence stem, <i>your job is to quickly think of a short simple suitable ending</i> and then hold it in your mind and wait for the 1st tone. When you hear this tone, write down the <i>short simple ending to the sentence</i> that you held in your mind. Once you hear the 2nd tone – stop writing immediately.”
2. Automatic writing (TI + ACM)	“When you hear the sentence stem, you will have the experience that an Engineer has composed and then inserted a <i>short simple suitable ending to the sentence</i> into your mind. This happens immediately after the sentence stem, and before the 1st tone is heard. . . When you hear the 1st tone, you will have the experience of the movements of your right hand being initiated and controlled by an Engineer; these movements cause the marker to write down the sentence ending which you kept in mind, each time. Just hold the marker, the rest will happen by itself”.
3. Automatic writing with reduced awareness (TI + ACM + rA)	[Note: the suggestion for this condition was the same as for the “Automatic writing” (Nr.2) condition above, but with an additional suggestion to reduce awareness for both thought and movement components of writing]: “As the Engineer controls both your thoughts and your hand movements, (s)he also blocks your awareness. The Engineer prevents you from being aware of the thoughts (s)he is inserting into your mind. (S)he also prevents you from being aware of any hand movements during writing. The Engineer does not want you to be aware of the end of the sentences or of anything that might be written.”

Notes: The gender of the “Engineer” always matched that of the participant.

TI + ACM = ‘Thought insertion’ plus ‘alien control of movement’.

TI + ACM + rA = ‘Thought insertion’ plus ‘alien control of movement plus reduced awareness’.

think of a short simple suitable ending to the sentence and write it down upon hearing a tone. Each trial had an interval for generation of a sentence ending (‘thought interval’) and an interval for writing it down (‘movement interval’; see Walsh et al., 2014, 2015). At the start of the thought interval, participants were presented with a sentence stem, which was repeated once, via headphones. A tone marked the start of the movement interval while a separate tone signalled the end of the trial. Each trial was succeeded by an 8 s rest interval (see Figure 1). Trial interval durations were jittered by up to 500 ms from trial to trial to facilitate characterisation of hemodynamic responses. A video camera monitored the participants’ right (writing) hand throughout.

The first automatic writing condition (TI + ACM; ‘thought insertion’ plus ‘alien control of movement’) combined suggestions for TI and ACM within a single condition (Walsh et al., 2014). It was suggested that an ‘engineer’ was ‘inserting the sentence endings into your mind’ in the thought interval, and also ‘controlling your hand movements during writing’ in the movement interval. The second condition was identical to the first but also contained an additional suggestion for reduced awareness for both thought and movement components of writing (“*The Engineer prevents you from being aware of the thoughts (s)he is inserting into your mind. (S)he also prevents you from being aware of any hand movements during writing*”); (see Supplementary Information and Table 1; TI + ACM + rA; ‘thought insertion’ plus ‘alien control of movement’ plus reduced awareness).

Participants verbally rated (‘0’–‘10’) their subjective experience for the thought and movement intervals of each condition immediately following each scanning block with respect to: (i) awareness (from ‘0’ = ‘no awareness’ to ‘10’ = ‘full awareness’) (ii) control (from ‘0’ = ‘no control’ to ‘10’ = ‘full control’); and (iii) ownership (from ‘0’ = ‘no ownership’ to ‘10’ = ‘full ownership’). Additionally, ratings were taken for subjective ‘depth of

hypnosis,’ ‘0’–‘10’ (where 10 = ‘as hypnotized as I’ve ever been’). The two ‘automatic writing’ conditions differed only in terms of whether suggestions for awareness or reduced awareness were given (see Table 1). Four additional conditions are reported elsewhere (Walsh et al., 2014; Walsh et al., 2015). All conditions were randomized and took place after a standard hypnotic induction procedure comprising visual fixation and progressive relaxation suggestions (see above; Oakley et al., 2007).

Image acquisition parameters

Imaging data were acquired at 3T using a GE Signa HDx MRI scanner at the Centre for Neuroimaging Sciences, King’s College London, UK. Functional MRI examinations were conducted using gradient echo, echoplanar imaging (EPI) with the following scanner parameters: repetition time = 2000 ms; echo time = 30 ms; RF flip angle = 80°; Slice orientation = near-axial, aligned to the anterior-posterior commissure; number of slices = 38, interleaved acquisition; slice thickness = 3.3 mm; slice gap = 0.3 mm; acquisition matrix size = 64 × 64. For each block, 150 functional images were acquired continuously.

Neuroimaging data analysis

Functional images were processed and analyzed in SPM8 (<http://www.fil.ion.ucl.ac.uk/spm>). All images were initially realigned to first image and then coregistered to their mean image. The mean image was spatially normalized to the SPM8 EPI template with a 2 × 2 × 2 mm voxel size and spatially smoothed (8 mm FWHM Gaussian kernel), and high-pass filtered (128 s). Standard assessment of movement parameters and correction was conducted as part of the preprocessing of the imaging data (using SPM8) and no excessive movement was recorded. For the single subject first level analysis, the sentence

cue onsets and durations, movement onsets and durations and head motion parameters were entered as regressors. The group ANOVA second level analysis included all experimental conditions for all participants. All images were corrected for multiple comparisons at the cluster level ($P < 0.05$) with voxel threshold $P < 0.001$.

Results

Behavioural results

Depth of hypnosis. For the three conditions VOL, TI+ACM and TI+ACM+rA, the mean self-rated depths of hypnosis were 7.7 (SD = 1.3), 7.8 (1.8) and 7.8 (1.3), respectively. There was no significant difference in depth of hypnosis between the three conditions; $F(2, 34) = 0.057$; $P = 0.945$, confirming that depth of hypnosis was successfully established and then maintained throughout. A 3 (conditions: VOL, TI+ACM, TI+ACM+rA) \times 2 (cognitive component of writing: thought vs. movement) repeated measures ANOVA was performed on the subjective self-ratings for awareness, control and ownership. There was a main effect of condition, i.e. ratings for awareness, control and ownership of thought and movement components of writing differed significantly across conditions (all $F > 34.0$). There was no main effect of cognitive component (all $F < 2.1$) nor did the interactions reach significance (all $F < 0.33$).

Follow-up 2 (conditions: TI+ACM, TI+ACM+rA) \times 2 (cognitive component of writing: thought vs. movement) ANOVAs were performed to investigate changes in subjective experience during both automatic writing conditions. For the awareness ratings there was a significant main effect of condition $F(1, 17) = 25.369$; $P < 0.0001$; $\eta^2_p = 0.599$. A modest but significant reduction (difference in awareness ratings between conditions = 1.4) in awareness ratings was observed between VOL and TI+ACM $t(17) = 3.160$; $P = 0.006$; Cohen's $d = 0.873$, (Figure 2, left panel). This occurred in the absence of any suggestion for a loss of awareness during this condition. Consequently, targeted suggestions for loss of control of thought and movement also reduce awareness ratings. However, a significantly greater reduction in awareness ratings ($\eta^2_p = 0.599$) was observed following the additional suggestion specifically targeted to reduce awareness for both the thought ("The Engineer prevents you from being aware of the thoughts (s)he is inserting into your mind") and motor ("The Engineer also prevents you from being aware of any hand movements during writing") components of writing in the TI+ACM+rA condition (see Figure 2). The control ratings showed a similar pattern with the main effect of condition reaching significance $F(1, 17) = 4.541$; $P = 0.048$; $\eta^2_p = 0.211$. Also note that there was an incidental reduction in control ratings associated with the combined automatic writing conditions and in the absence of any specific suggestion for additional reduction in control over writing (Figure 2, middle panel). The main effect of condition for the ownership ratings just failed to reach significance; $F(1, 17) = 3.747$; $P = 0.070$; $\eta^2_p = 0.181$ (Figure 2). The awareness, control and ownership ratings data were also further examined with a separate mixed 3 \times 2 ANOVA for each rating and with experimental condition (VOL, TI+ACM; and TI+ACM+rA) and trial interval (thought; movement) as within subject factors and with order of condition as between subject factor. No evidence of order effects was found for any of the ratings for the 3 experimental conditions which were randomized (all $p > 0.281$).

The number of words (Table 2) and characters written per sentence-ending differed across experimental condition ($F_s >$

5.4). There was no significant difference between the number of words or characters written between the VOL and TI+ACM conditions; $t(17) = 0.852$; $P = 0.406$; Cohen's $d = 0.284$. However, during suggestions for reduced awareness (TI+ACM+rA), people wrote less than in both the VOL and TI+ACM conditions (all P 's < 0.021). The effects of suggestion on the content of written output (written word frequency, imageability and form of writing) are described in the Supplementary Materials. There was no difference in onset latency between the two automatic writing conditions; $t(15) = 0.987$; $P = 0.341$; $d = 0.345$. The duration of writing across the three experimental conditions did not significantly differ. Participants were asked immediately after the experiment how well they could recall each block of the experiment. Recall during suggestions of automatic writing with reduced awareness (TI+ACM+rA) was significantly lower than during voluntary writing; $t(17) = 2.600$; $P = 0.019$; $d = 0.867$ (Supplementary Materials).

Behavioural correlates and functional anatomy of loss of awareness

To identify brain regions associated with the experience of reduced awareness during thought insertion and alien control of movement, we compared activity in the 'automatic writing' (TI+ACM) and 'automatic writing with reduced awareness' (TI+ACM+rA) conditions. During the thought interval condition, participants generally did not move as confirmed by video recordings of their right hand ($< 2\%$ of trials excluded from the analysis). Videos were inspected offline by a reviewer blind to the experimental conditions using VideoPad Video Editor (NCH software, VideoPad v2.22) and at a resolution of 10 ms. Videos were reviewed frame by frame in order to pinpoint writing onset and offset. Writing onset was defined as the unique frame showing the initial segment of the first alphanumeric character and writing offset was defined as the unique frame showing the final segment of the final alphanumeric character written for each sentence. A random selection (15%) of videos was reviewed by a second independent reviewer (inter-rater correlation Pearson's $r = 0.84$) confirming the validity of the review.

Effects of suggestion on onset latencies and duration of written output

The video data from two participants were not available for technical reasons. For the remaining participants onset latency between the three conditions was significant; $F(2,28) = 4.261$; $P = 0.037$; $\eta^2_p = 0.233$. Writing produced in TI+ACM (mean = 1726; SD = 523 ms) and TI+ACM+rA (mean = 1817; SD = 652 ms) had a longer onset latency than voluntary writing (mean = 1458; SD = 556 ms); $t(15) = 1.348$; $P = 0.198$; Cohen's $d = 0.471$ and $t(15) = 2.823$; $P = 0.014$; Cohen's $d = 0.987$, respectively. There was no difference in onset latency between the two automatic writing conditions; $t(15) = 0.987$; $P = 0.341$; Cohen's $d = 0.345$. The duration of writing for each of the three conditions – voluntary (mean = 6091; SD = 1286), automatic writing (mean = 6217; SD = 1488), and automatic writing with reduced awareness (mean = 5816; SD = 1542) – did not differ; $F(2,30) = 0.987$; $P = 0.377$; $\eta^2_p = 0.062$.

During the thought interval, the suggestion for reduced awareness was associated with a decrease in activity in left-lateralized fronto-parietal networks. During the movement interval, activity decreased in superior temporal gyrus bilaterally, left mid cingulum and right superior parietal lobule and Heschl's gyrus (see Table 3; Figure 3). There was no statistical

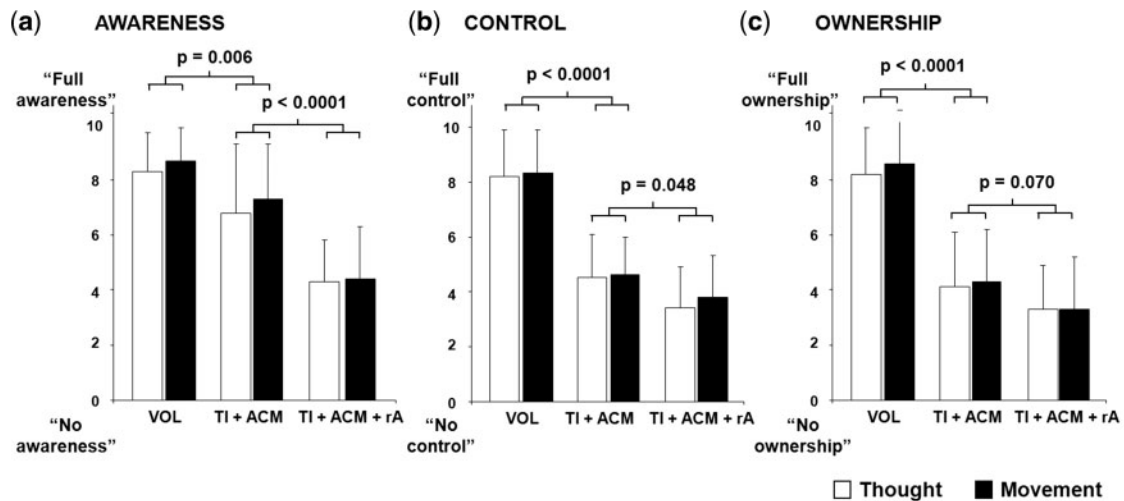


Fig. 2. Mean (A) awareness, (B) control and (C) ownership ratings during the thought (white bars) and movement (black bars) intervals of a trial for the voluntary writing (VOL), automatic writing (TI + ACM) and automatic writing with reduced awareness (TI + ACM + rA) conditions. Standard deviations are shown as error bars.

Table 2. The mean number (N) of words and characters written per sentence ending, written frequency (CELEX-W; Baayen et al., 1995) and imageability of written words for the three experimental conditions. Standard deviation of group mean is given in brackets

Condition	N words	N characters	Frequency (Celex-W)	Imageability
Voluntary writing (VOL)	2.8 (0.8)	11.7 (3.9)	7427 (3419)	308 (18)
Automatic writing (TI + ACM)	2.9 (0.9)	11.8 (4.0)	8969 (4426)	318 (31)
Automatic writing with reduced awareness (TI + ACM + rA)	2.5 (0.8)	10.4 (4.0)	6270 (3636)	325 (23)
Overall mean (SD)	2.7 (0.8)	11.3 (4.0)	7555 (3827)	317 (24)

difference in head movement between the different conditions. However, it could be argued that minor differences in participants' total head movement between the TI + ACM condition and the TI + ACM + rA condition when awareness was reduced, might have contributed to the neuroimaging results. Therefore, we repeated the analysis with the inclusion of a regressor describing total head movement-related (translation and rotation in 3D) effects in the design matrix of our General Linear Model (GLM). Importantly, the neuroimaging findings were unchanged (results not shown) with the inclusion of the regressor, indicating that the observed changes in neural activity are not attributable to head movement artefacts. We present an 'overlap map' of brain regions involved in both loss of awareness of thought and movement in their respective contrasts (Figure 3). Statistically significant overlapping areas were found in left posterior cortices, marking these regions as critical nodes in loss of awareness of involuntary thought and movement (Table 4).

Larger cluster sizes can cross multiple anatomical boundaries, making them difficult to interpret. Therefore to further explore larger clusters (Table 3), we repeated our main neuroimaging analysis at a more stringent threshold ($P = 0.0001$). The main results were still present for both intervals. In the thought interval, the left superior parietal peak and the left superior temporal peak (Table 3) were still present, and a peak emerged in the superior occipital gyrus (coordinates: $-6, 14, 66$). In the movement interval, the superior temporal peak (Table 3; coordinates: $-34, -36, 14$) fractionated into two smaller clusters peaking in superior temporal cortex (coordinates: $-60, -42, 18$) and in the mid-cingulum (coordinates: $-6, -32, 50$). A new mid-temporal peak emerged (coordinates: $-48, -68, 20$). Therefore

tightening the cluster forming threshold did not change the significant regions involved, but separated the clusters into more discrete anatomical locales.

Imaging data for the contrasts between the automatic writing conditions (i.e. TI + ACM and TI + ACM + rA) and the control voluntary writing (VOL) condition are given in the Supplementary Materials.

Discussion

Using fMRI and suggestions for automatic writing in highly hypnotically suggestible individuals, we created an experimental model of conditions of altered awareness of thought and movement. The main finding was that posterior parietal cortical regions were identified as critical nodes in loss of awareness of both involuntary thought and movement. Other areas were more selectively involved in loss of awareness of thought and movement separately.

Subjective effects of suggestions for automatic writing

At a phenomenological level, relative reductions in ratings of control, ownership, and awareness of thought and movement were in line with the suggestions (Table 1). This demonstrated effective modelling of automatic writing with reduced or absent awareness of the production of messages attributed to an external agent, as well as dissociative psychopathology with reduced awareness of involuntary mental content and movements. This extends previous studies which have shown how suggestions in hypnosis can model involuntary loss or production of movement rather than loss of awareness of movement *per se*

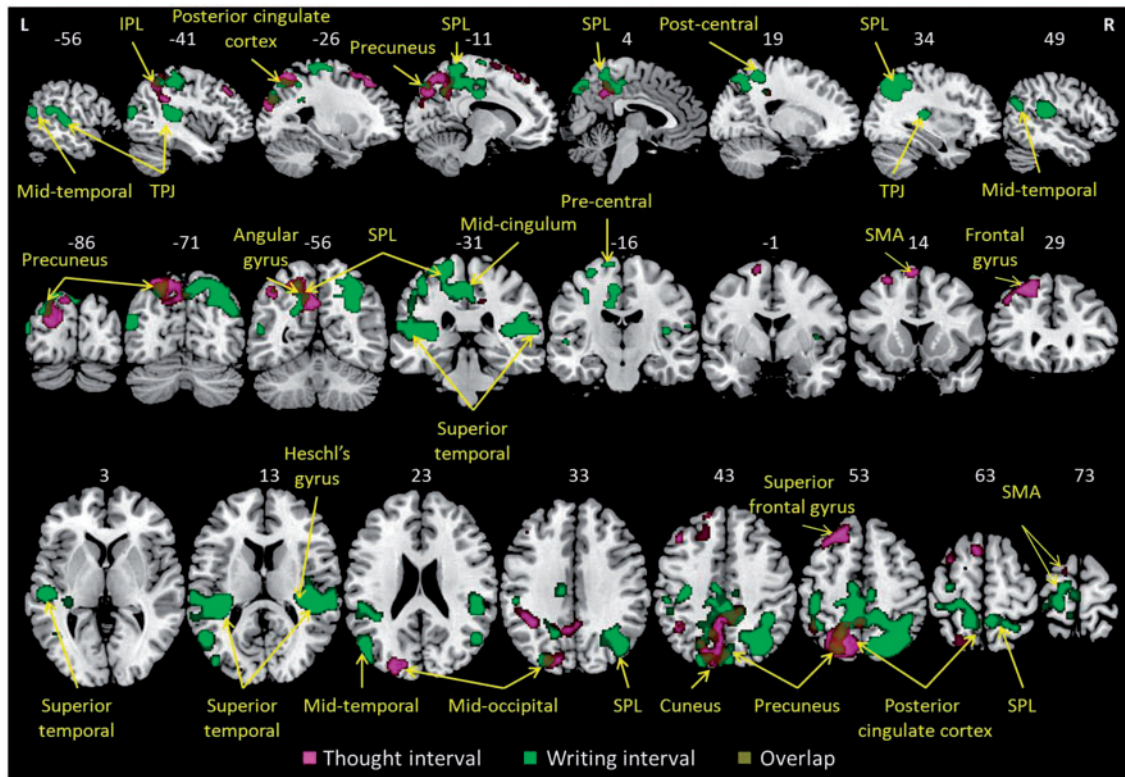


Fig. 3. Brain regions showing lower activity following suggestions for reduced awareness during automatic writing ('TI + ACM + rA' < 'TI + ACM') for the thought (magenta) and movement (green) intervals of a trial (see Figure 1). Areas of overlap are indicated by olive colour (see also Tables 3 and 4). No significant changes in activation were observed for the reverse contrast. Images are significant clusters overlaid on the single subject T1-weighted image provided with MRIcron with slice number relating to the MNI template shown above each slice. For the coronal (middle row) and axial (bottom row) views the left side of the brain is on the left.

Table 3. Brain regions showing lower activity following suggestions for reduced awareness for the thought and movement intervals during automatic writing. No brain regions showed increased activation during automatic writing following suggestions for reduced awareness (TI + ACM + rA)

Hemisphere	Anatomical Region	MNI coordinates	BA	Cluster size	Z value	Cluster-level p corrected
	'TI + ACM + rA' < 'TI + ACM'					
L	<i>Thought interval</i>					
L	Superior parietal	-22, -68, 54	7	2828	5.42	0.000
L	Precuneus	-6, -58, 40	-		4.89	
L	Cuneus	-10, -78, 40	19		4.39	
L	Superior Frontal	-22, 34, 52	9	806	4.92	0.001
L	SMA	-6, 14, 66	6		4.17	
L	Mid-frontal	-42, 28, 42	46		3.77	
	'TI + ACM + rA' < 'TI + ACM'					
	<i>Movement interval</i>					
L	Superior temporal	-34, -36, 14	48	9258	5.21	0.000
L	Mid-Cingulum	-6, -32, 50	4		5.15	
R	Superior parietal	20, -48, 56	2		4.86	
R	Superior temporal	48, -36, 16	41	1087	4.46	0.000
R	Heschl's Gyrus	34, -28, 14	48		4.37	

Notes: Reverse contrasts: Thought interval TI + ACM + rA > TI + ACM; all p > 0.541; Movement interval 'TI + ACM + rA' > 'TI + ACM'; all p > 0.690. BA = Brodmann Area.

Table 4. Brain regions showing the areas of overlap following suggestions for reduced awareness between the thought and movement intervals (see Table 3) during automatic writing

Hemisphere	Anatomical Region	MNI coordinates	BA	Cluster size	Z value	Cluster-level p corrected
L	Mid-occipital	-28, -82, 32	19	1247	4.31	0.000
L	Precuneus	-14, -48, 58	5		4.29	
L	Superior parietal	-18, -58, 54	5, 7		4.25	

Note: BA = Brodmann area.

(Blakemore, 2003; Ward et al., 2003; Haggard et al., 2004; Cojan et al., 2009; Burgmer et al., 2013; Deeley et al., 2013).

Neural correlates of loss of awareness during automatic writing

To identify brain regions involved in reduced awareness, we examined the conjunction (Figure 3; Table 4) of changes in brain activity during the thought and movement intervals. Compared to automatic writing with awareness, reduced awareness during both the thought and movement intervals of automatic writing was associated with reduced activation in a predominantly left-sided posterior cortical network including superior parietal lobule, precuneus and posterior cingulate cortex. This is consistent with the established role of these regions in bodily and spatial awareness (Northoff et al., 2006; Guterstam et al., 2015). Regions in the superior parietal lobule (BA 7) and its medial extension in the precuneus are involved in representing the sense of body in space and body movements, and in conscious awareness (Cavanna, 2007; Xie et al., 2011). Also, lateral posterior parietal cortices (including BA 7) are involved in awareness of intention to move (Desmurget et al., 2009). Previously we demonstrated reduced left posterior parietal (BA 7) activation during reduced awareness for involuntary simple hand movements, suggesting a common role for posterior parietal regions in mediating awareness of both simple and complex hand movements, and thought (Hyvärinen and Poranen, 1974; Kjaer et al., 2002; Farrer et al., 2008; Deeley et al., 2013). Posterior cingulate cortex has been shown to be involved in processing self-related stimuli in a variety of tasks (Northoff and Bermpohl, 2004; Johnson et al., 2006; Guterstam et al., 2015).

Reduced awareness of thought and movement was also associated with reduced activity in left angular gyrus, a region with an established role in writing movement (Gerstmann, 1942; Rusconi et al., 2009). Our previous study of automatic writing with preserved awareness showed *increased* activity of left angular gyrus during the movement interval but not during thought insertion (Walsh et al., 2015; see also Supplementary Material, Figure S1). The decreased activity of the angular gyrus during reduced awareness of thought as well as writing in the present study suggests a wider role for this brain region in awareness. Understanding whether reduced activity of angular gyrus during loss of awareness is specific to writing would require studies utilizing different, i.e. non-writing, tasks. To the best of our knowledge, the current study is the first to demonstrate brain regions involved in reduced awareness of thought insertion, which are also involved in reduced awareness of involuntary complex movements.

Neural correlates for loss of awareness during thought insertion

The degree of suggested loss of awareness did not differ with task component (thought; movement; Figure 2) but distinct neural changes accompanied loss of awareness for each component. Non-overlapping regions of SMA showed reduced activation in both the thought and movement intervals. This may relate to the relatively greater reduction in self-rated control and ownership in the reduced awareness condition (Walsh et al., 2014, 2015). In addition, other areas not previously associated with control and ownership showed decreased activation during reduced awareness of thought insertion relative to thought insertion with preserved awareness. Specifically, a left-lateralized network including angular gyrus and superior frontal

gyrus showed reduced activation during the thought interval with loss of awareness. This network includes areas commonly associated with language (Price, 2010).

Neural correlates for loss of awareness during alien control of writing movements

In addition to reduced activity in the posterior cortical regions, reduced awareness for the motor act of writing was associated with reduced activity in bilateral temporo-parietal junction (TPJ), in keeping with the established role of the TPJ in bodily self-awareness (Blanke, 2012). There was also a decrease in activity of superior temporal gyrus bilaterally, left mid-cingulum, right superior parietal lobule (BA 2), and Heschl's gyrus (Table 3; Figure 3). These regions are not associated with awareness based on previous studies. Similar to the angular gyrus and superior frontal gyrus during the thought interval, these regions may be involved in reduced awareness in a process- or task-specific manner. Superior temporal gyri are involved in auditory processing (Howard et al., 2000). It is therefore possible that reduced activity in these regions may reflect reduced response to the auditory tone following suggestions for reduced awareness. However, we consider this unlikely because a similar reduction in superior temporal gyri was not seen during the thought interval, which included complex auditory stimuli.

Together these results suggest a role for posterior parietal cortical regions in mediating reduced awareness, acting in conjunction with additional changes in brain activity specific to the type of cognition or behaviour for which awareness is lost (i.e. thought and movement). Our findings cannot however reveal whether the reduced activity in parietal regions is sufficient for reduced awareness of thought and movement. While TMS of the parietal lobe does indeed reduce awareness of hand movements (MacDonald and Paus, 2003), it is not known how stimulation might influence awareness of thoughts. Future studies using TMS can test whether posterior parietal cortex is involved in awareness of both thought and movement processes.

Modelling pathological and culturally influenced experiences of alien control

The relevance of this experimental model to understanding pathological and culturally influenced experiences involving reduced awareness and control of thought and movement depends on the presence of analogous features of the respective cultural and clinical phenomena. In the case of culturally influenced automatic writing such as occurs in inspired writing or mediumship (Prince, 1929; Ellenberger, 1970; Shaw, 2011), implicit suggestive processes based on social modelling and implicit learning may produce similar changes in experience and brain function to the present experiment (Walsh et al., 2014). Similarly, narrowing or reduced awareness is reported to occur in half of patients with non-epileptic seizures and occurs in dissociative states such as fugue and dissociative identity disorder (Brown et al., 2011). Some patients with dissociative symptoms report reduced awareness in the absence of excessive movement, potentially allowing measurement of brain activity with fMRI to test the hypothesis that dissociative reductions in awareness are associated with reduced posterior parietal cortical activity.

In post experimental debriefing, participants reported significantly reduced recollection of the experience of reduced awareness of automatic writing compared to voluntary writing. Reduced awareness may contribute to the amnesia reported for

some cases of automatic writing and other culturally influenced possession states (Crapanzano and Garrison, 1977) through reduced encoding of information (Allen et al., 1999). Alternatively, amnesia may result from inhibition of memory retrieval (Markowitsch, 2003; Kopelman, 2010), as has been reported in cases of dissociative and post-hypnotic amnesia (Bell et al., 2011). Future studies of 'suggested amnesia' could inform understanding of mechanisms of dissociative memory loss.

In conclusion, we have identified neural correlates for the experience of loss of awareness of thought insertion and alien control of movement. Our findings suggest the involvement of a general network in loss of awareness for thought and movement, including predominantly left-sided posterior cortical regions involved in self-related processing and spatial bodily awareness. Employing suggestion to model reduced awareness for involuntary mental content or movement during automatic writing therefore reveals mechanisms for functional loss of awareness. From a cultural neuroscientific perspective, this provides insights into potential cognitive and brain processes mediating reduced awareness in practices such as shamanism and mediumship. Clinically, our findings may inform the development of imaging assessments for conditions where there is loss of awareness with unknown aetiology, and provide candidate targets for interventions such as neurofeedback.

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Conflict of interest. None declared.

Supplementary data

Supplementary data are available at SCAN online.

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