SHORT REPORT

Modality specific neural correlates of auditory and somatic hallucinations

S S Shergill, L A Cameron, M J Brammer, S C R Williams, R M Murray, P K McGuire

Abstract

Somatic hallucinations occur in schizophrenia and other psychotic disorders, although auditory hallucinations are more common. Although the neural correlates of auditory hallucinations have been described in several neuroimaging studies, little is known of the pathophysiology of somatic hallucinations. Functional magnetic resonance imaging (fMRI) was used to compare the distribution of brain activity during somatic and auditory verbal hallucinations, occurring at different times in a 36 year old man with schizophrenia. Somatic hallucinations were associated with activation in the primary somatosensory and posterior parietal cortex, areas that normally mediate tactile perception. Auditory hallucinations were associated with activation in the middle and superior temporal cortex, areas involved in processing external speech. Hallucinations in a given modality seem to involve areas that normally process sensory information in that modality.

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A perception of being touched in the absence of a sensory stimulus is termed a somatic hallucination. These occur in schizophrenia and other psychotic disorders, although auditory hallucinations are more common. Although the neural correlates of auditory hallucinations have been described in several neuroimaging studies,¹⁻⁴ little is known of the pathophysiology of somatic hallucinations. An EEG study of a patient experiencing somatic hallucinations linked these with activity in the right parietal operculum, post central gyrus, and insula,⁵ although precise spatial localisation is difficult with this technique. The only previous neuroimaging study used single photon emission tomography to measure resting activity in chronic schizophrenic patients with somatic hallucinations. In this report activity was relatively reduced in the inferior temporal region and increased in the basal ganglia.⁶ In the present study, we examined the distribution of neural activity while a patient was actually

experiencing somatic hallucinations, and contrasted this with activity when he was experiencing auditory hallucinations or was hallucination free.

Case report**CLINICAL HISTORY**

We studied a 36 year old right handed man with a 6 year history of DSM-IV schizophrenia,⁷ who experienced both somatic and auditory hallucinations, often and intermittently. His somatic hallucinations involved an unpleasant perception of being "touched by spirits" predominantly in the perineum, back, and head. His auditory hallucinations involved hearing predominantly derogatory "voices" talking to him in the second and third person. He was being treated with olanzapine (10 mg daily) and provided informed consent to participate in the study.

METHODS

He was examined using a novel functional MRI (fMRI) acquisition method, which permits the measurement of spontaneous neural activity without requiring subjects to signal when hallucinations occur.¹ He lay in the scanner with his eyes closed. At randomly varied intervals of 30-60 seconds he heard the noise generated by the acquisition of a single volume of fMRI data (lasting 3 seconds). This served as an auditory cue for the patient to describe whatever he had been experiencing in the few seconds before the noise. Because there is a lag of 3-5 seconds between neural activity and the maximum BOLD signal⁸ (reflecting the local haemodynamic response to that activity), the resultant image depicts the activity that was occurring a few seconds before the onset of the cue. After providing a description, the subject returned to the resting state, during which he experienced intermittent auditory or somatic hallucinations.

IMAGE ACQUISITION AND ANALYSIS

Gradient echo echoplanar MR images were acquired using a 1.5 Tesla GE Signa system fitted with advanced NMR hardware and software. In each of 14 non-contiguous planes parallel to the intercommissural (AC-PC) plane, 40-100 T2* weighted MR images depicting BOLD contrast were acquired with TE=40 ms, TR=3000 ms, in plane resolution=3.1 mm, slice thickness=7 mm, slice=skip 0.7 mm.

Section of
Neuroimaging,
Division of
Psychological
Medicine, Institute of
Psychiatry, De
Crespigny Park,
Denmark Hill,
London, UK
S S Shergill
L A Cameron
R M Murray
P K McGuire

Brain Image Analysis
Unit, Institute of
Psychiatry, De
Crespigny Park,
Denmark Hill,
London, UK
M J Brammer

Department of
Neurology, Institute of
Psychiatry, De
Crespigny Park,
Denmark Hill,
London, UK
S C R Williams

Correspondence to:
Dr S S Shergill
s.shergill@iop.kcl.ac.uk.

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Table 1 Regions showing activation during auditory and somatic hallucinations (threshold $p < 0.001$)

Region	No of voxels	x	y	z
Activation during somatic hallucinations:				
Left middle frontal gyrus*	55	-35	36	20
Left postcentral gyrus	44	-29	-19	31
	13	-58	-22	15
Left insula*	41	-38	14	4
Left posterior cingulate gyrus	37	-14	-44	9
Right posterior cingulate gyrus*	31	3	-47	37
Right thalamus	29	23	-31	4
Left middle temporal gyrus	27	-55	-44	9
Left precentral gyrus	22	-46	6	9
Right precuneus	15	23	-72	26
Left superior temporal gyrus	12	-46	-47	15
Right inferior frontal gyrus*	10	52	19	26
Right insula*	7	35	22	4
Left inferior parietal lobule	4	-55	-39	31
Left thalamus	4	-3	-6	4
Activation during auditory hallucinations:				
Right superior temporal gyrus/insula*	64	32	-17	15
Right middle temporal gyrus	16	35	-58	26
Right parahippocampal gyrus	3	17	-25	-13

*Areas of significant activation in direct comparison of somatic versus auditory hallucinations.

After the minimisation of movement related artifacts by realignment and regression⁹ voxel-wise activation maps were constructed by computing the product moment correlation of the time series at each voxel¹⁰ with the reported occurrence of auditory hallucinations. Ten further maps were computed at each voxel after

randomly permuting the pattern of auditory hallucination reports. After mapping of observed and randomised correlation data into standard stereotactic space,¹¹ median observed and randomised maps were constructed. Foci of activation with a voxel-wise probability of type I error of < 0.0001 (at this level of significance there should be < 1 random error voxel per slice of data) were identified by determining the critical threshold from the distribution of correlation coefficients computed after random permutation.^{9, 12} Activation maps were overlaid on a template in standard stereotactic space.

Results

Twelve volumes were associated with reports of somatic hallucinations, 36 volumes with auditory hallucinations, and 12 with no hallucinations. Somatic hallucinations were reported as occurring on the back (three image volumes), the back of the head (one), left ear (one), right arm and back (one), right leg/foot (three) and perineum/genitals (three). The brain regions associated with the presence of somatic and auditory hallucinations are described in table 1 and shown in figure 1 A and B.

The main areas activated in association with somatic hallucinations (relative to non-hallucinating events) were the thalamus, insula,

Figure 1 Ascending transverse sections through the brain from left to right, relative to the intercommissural plane (mm) illustrating the brain areas associated with row (a) somatic hallucinations and row (b) auditory hallucinations. The right side of the brain is shown in the left side of each image. The main foci of activation are shown in red: (1) During somatic hallucinations these were in the left precentral gyrus (Talairach coordinates (x,y,z) A), the left posterior middle temporal gyrus (B), the posterior cingulate gyrus bilaterally (C), the left middle frontal gyrus (D), twin foci in the postcentral gyrus (E, H), the posterior superior temporal gyri (F), inferior parietal lobule (G), thalamus, insula bilaterally with rightsided inferior frontal gyrus, and precuneus. (2) Brain areas activated in association with auditory hallucinations were the right posterior insula/superior temporal gyrus (I).

and posterior cingulate gyrus bilaterally. Further activation was evident in the left middle frontal gyrus, the precentral gyrus, twin foci in the postcentral gyrus, inferior parietal lobule, the middle and superior temporal gyri with right sided inferior frontal gyrus, and precuneus (fig 1 A). By contrast, auditory hallucinations were associated with activation in a large region spanning the right superior temporal gyrus and posterior insula, the right middle temporal gyrus, and hippocampus/parahippocampal gyrus (fig 1 B). A direct comparison between the two hallucinating conditions demonstrated significant differences in activation within the bilateral insula, left middle frontal gyrus, right inferior frontal and posterior cingulate gyrus related to the somatic hallucinations and within the right superior temporal gyrus during auditory hallucinations.

Discussion

In this patient, somatic hallucinations were primarily associated with activation in the thalamus, the primary somatosensory cortex, and posterior parietal cortex, areas classically associated with tactile processing. In addition, the posterior portion of the superior temporal gyrus is also activated during normal tactile processing, and may correspond to secondary somatosensory cortex; attending to touch modulates activity in this region and in the insula bilaterally.¹³ Our neuroimaging findings are broadly consistent with those from an EEG study of somatic hallucinations, which associated these with activity in the postcentral gyrus, parietal operculum, insula, and the inferior parietal lobule.⁵ Involvement of the insula in the experience of tactile hallucinations has been shown in two cases of somatic and visceral hallucinations occurring during partial seizures caused by lesions of the insula¹⁴ and the finding that stimulation of the anterior insula in awake patients produces visceromotor and viscerosensitive responses.¹⁵

By contrast, auditory hallucinations in this patient were associated with activation in a distinct set of brain areas, particularly the right temporal cortex. Both middle and superior temporal gyri showed activation during auditory hallucinations in a group (n=6) analysis using the random sampling technique described in this paper.¹ The prominent involvement of the right temporal cortex may seem surprising given that the patients were perceiving speech, but is consistent with data from previous neuroimaging^{1 3 4} and EEG studies¹⁶ of auditory hallucinations, and with the greater right frontotemporal activation when subjects imagine another person's speech, as opposed to their own.¹⁷ Moreover, as auditory hallucinations in schizophrenia are typically derogatory and hostile in tone, the prominent engagement of right hemispheric areas might reflect processing of the prosody¹⁸ as well as an emotional response to its content.¹⁹

A methodological limitation of this study, common to all investigations using the cognitive subtraction method, is the lack of knowledge about the resting brain activity in patients

and whether it is different from resting activity in other non-hallucinating schizophrenic patients and from normal people. Similarly, although only limited conclusions can be drawn from single subject design, it is clearly advantageous to be able to map different modality hallucinations in the same subject, avoiding many of the issues in between group comparisons. A further limitation of the sampling approach is that it is less precise about the actual timing of the hallucinations, such as the duration of the preceding hallucinatory experience and reliant on the accuracy of self report.

Overall, the data from this patient suggest that hallucinations in schizophrenia are associated with activation in areas normally involved in sensory processing in that modality. This would be consistent with neuroimaging data, which suggest that visual hallucinations in patients with Charles Bonnet's syndrome are associated with activation in areas dedicated to visual processing.²⁰

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