ARTICLE IN PRESS

+ MODEL

Available online at www.sciencedirect.com

SCIENCE DIRECT

Schizophrenia Research xx (2006) xxx – xxx

SCHIZOPHRENIA RESEARCH

www.elsevier.com/locate/schres

Left superior temporal gyrus activation during sentence perception negatively correlates with auditory hallucination severity in schizophrenia patients

Marion Plaze [a], David Bartrés-Faz [a,b], Jean-Luc Martinot [a,*], Dominique Januel [c], Franck Bellivier [f], Renaud De Beaurepaire [e], Sandra Chanraud [a], Jamila Andoh [a], Jean-Pascal Lefaucheur [f], Eric Artiges [a], Christophe Pallier [g], Marie-Laure Paillère-Martinot [a,d]

[a] *Inserm U.797, CEA-INSERM Research Unit "Neuroimaging and Psychiatry"; Institute for Health and Medical Research (INSERM) and Atomic Energy Commission (CEA) Hospital Department Frédéric Joliot, IFR49, Paris-Sud 11 and Paris-5 Universities; 4 place Gl. Leclerc 91401, Orsay, France*

[b] *Department of Psychiatry and Clinical Psychobiology, Barcelona University, and Institute of Biomedical Research August Pi i Sunyer (IDIBAPS), Spain*

[c] *Romain Roland Hospital, Department 3 (area 93G03)-CHS Ville-Evrard, Saint-Denis, France*

[d] *AP-HP, Department of Adolescent Medicine, Cochin Hospital, Paris, France*

[e] *Paul Guiraud Hospital, Department 4 (area 94G11), Villejuif, France*

[f] *AP-HP, Psychiatry department and Neurophysiology department, H. Mondor and A. Chenevier hospitals, Créteil, France*

[g] *INSERM-CEA U562 "Cognitive Neuroimaging Research Unit", IFR49, Orsay, France*

Received 3 March 2006; received in revised form 4 May 2006; accepted 4 May 2006

Abstract

The left superior temporal cortex, which supports linguistic functions, has consistently been reported to activate during auditory–verbal hallucinations in schizophrenia patients. It has been suggested that auditory hallucinations and the processing of normal external speech compete for common neurophysiological resources. We tested the hypothesis of a negative relationship between the clinical severity of hallucinations and local brain activity in posterior linguistic regions while patients were listening to external speech. Fifteen right-handed patients with schizophrenia and daily auditory hallucinations for at least 3 months were studied with event-related fMRI while listening to sentences in French or to silence. Severity of hallucinations, assessed using the auditory hallucination subscales of the Psychotic Symptom Rating Scales (PSYRATS) and of the Scale for the Assessment of Positive Symptoms (SAPS-AH), negatively correlated with activation in the left temporal superior region in the French minus silence condition. This finding supports the hypothesis

* Corresponding author. Tel.: +33 1 6986 7757; fax : 33 1 6986 7810.
E-mail address: jlmartinot@cea.fr (J.-L. Martinot).

0920-9964/$ - see front matter
doi:10.1016/j.schres.2006.05.005

that auditory hallucinations compete with normal external speech for processing sites within the temporal cortex in schizophrenia.

Keywords: Schizophrenia; Superior temporal gyrus; Auditory hallucination; Magnetic resonance imaging; Language

1. Introduction

Auditory verbal hallucinations, or perceptions of external speech in the absence of any stimulus (i.e., "hearing voices" often conversing with or commenting on the patient) are the most common symptoms of schizophrenia, being reported by about 70% of patients (Sartorius et al., 1986). Brain imaging studies have revealed that the main areas activated during the experience of auditory hallucinations are language-related—for instance, the superior temporal cortex, particularly in the left hemisphere. The superior temporal cortex includes Wernicke's area and has been classically implicated in language perception. Activations accompanying the hallucination phenomenon have been less consistently reported in other regions, such as Broca's area (McGuire et al., 1993; Shergill et al., 2000, 2004), anterior cingulate cortex (Copolov et al., 2003; Shergill et al., 2000), basal ganglia (Silbersweig et al., 1995), and medial or anterior temporal regions (Shergill et al., 2000; Silbersweig et al., 1995). One limitation of these investigations is that most patients do not have sufficient insight into their hallucinatory symptoms and their self-reports of hallucinations during scanning may be unreliable.

An alternative approach is to investigate cortical activation during language perception in patients with chronic auditory hallucinations. These 'cognitive interference' studies have attempted to identify the cortical regions and corresponding cognitive processes associated with auditory hallucinations by demonstrating dysfunction in established neurocognitive networks of language. Lower temporal activation in response to periodic exogenous auditory stimulation has been highlighted by functional magnetic resonance imaging (fMRI) in patients with schizophrenia scanned during auditory hallucination and during a non-hallucinating period. These findings suggest that auditory hallucinations and the processing of external speech compete for common neurophysiological resources (David et al., 1996, Woodruff et al., 1997).

The present study investigated this hypothesis by searching for a relation between auditory hallucination severity and cerebral activation in functional MR images in response to a language perception task. We predicted that the more severe the auditory hallucinations, the lower the activation of language-related areas, particularly in the left superior temporal cortex.

2. Methods

2.1. Subjects

Fifteen subjects (9 women) fulfilling DSM-IV-R criteria for schizophrenia with daily auditory hallucinations for at least 3 months despite well-conducted pharmacological treatment were studied. Other inclusion criteria were French as maternal language and right-handedness according to the Annett scale (Annett, 1970). Exclusion criteria included substance abuse or dependence, affective disorder or any other DSM-IV-R axis I diagnosis, severe head injury, neurological disorders, and contraindications for MRI scanning (including metal implants or claustrophobia). The patients were assessed by interviews of the patients and their psychiatrists and examination of the medical records. Their mean ± S.D. age was 34 ± 10 years (range, 22–49 years), and the mean duration of illness was 12 ± 10 years (range, 3–28).

Symptomatology was assessed immediately after the scan session by two independent senior psychiatrists (JLM, MP; interrater reliability $R = 0.76$). Severity of auditory hallucinations was assessed using the auditory hallucination subscale of the Psychotic Symptom Rating Scales (PSYRATS, Haddock et al., 1999) and the auditory hallucination items of the Scale for the Assessment of Positive Symptoms (SAPS, Andreasen, 1983). The auditory hallucination subscale of the PSYRATS has 11 items which tap general symptom indices of frequency, duration, severity and intensity of distress and also symptom-specific dimensions of hallucination controllability, loudness, location, negative content, degree of negative content, beliefs about origin of voices and disruption. A five-point ordinal scale is used to rate symptom scores (0–4). Items were rated after a semi-structured interview assessing the severity items retrospectively in a 2-week period.

The patients' mean±S.D. PSYRATS score was 30±6 (range 18–39).

The second measure for severity of hallucinations was derived from the SAPS (Andreasen, 1983). We pooled the three SAPS items "auditory hallucinations," "voices commenting" and "voices conversing" (each ranging from 0 to 5) to create a single score for each patient (SAPS-AH, Gaser et al., 2004). The patients' mean SAPS-AH score was 10±3 (range 4–15). Severity of clinical symptoms was also assessed using the SAPS mean total score±S.D. (35±19), and the Scale for the Assessment of Negative Symptoms (SANS, Andreasen, 1984) mean total score (34±31).

All patients were treated with usual or atypical antipsychotic drugs (mean±S.D.=425±604 mg chlorpromazine equivalent/day; Woods, 2003).

Participants were fully informed of the requirements of the behavioral task and all demonstrated that they understood the aims and demands of the experiment. Ethical approval was obtained from the Paris-Pitié-Salpétrière ethics committee. All subjects gave written informed consent.

2.2. fMRI design

Event-related fMRI was performed while the participants listened to 32 sentences in French, or to 32 silence periods (modified from Pallier et al., 2003), randomly presented through headphones and a PC. Sentences were selected from recordings by three female speakers. All recordings had been made in the same sound-proof room (sampling rate 64 kHz; low-pass 20 kHz; 4× undersampling). The sentences, read with natural intonation, were 16–21 syllables long and did not contain any emotional content. All lasted approximately the same time. The mean energies (rms) of the stimuli were also equated. To ensure that the subjects paid attention to the sentences, they were required to perform a fragment detection task. Following each 3 s sentence and after a 500 ms delay, a 500 ms fragment was played. Subjects had to indicate whether or not this fragment had appeared in the sentence by pressing one of two response buttons: pressing the right button with the right thumb if the fragment was 'present', and pressing the left button with the left thumb if it was 'absent'. The inter-trial interval was 5000 ms. The first four trials were excluded from the analyses to allow for stability in magnetization. Before scanning, subjects performed a training run of 12 trials on this task. The fragment detection performance (i.e., response accuracy) was registered with the PC for each patient.

2.3. Image acquisition

Auditory event presentation was randomized and synchronized with functional MR image volume acquisitions. During presentation of auditory stimuli, a gradient-echo echo-planar imaging sequence sensitive to brain oxygen level dependent (BOLD) contrast was used (18 contiguous axial slices, 6 mm thickness, TR/TE=2000/60 ms, FOV 24 cm, 64×64 matrix, voxel size 3.75×3.75×6 mm^3) on a 1.5-T whole-body system (Signa, General Electrics).

The stimuli were administered in two 10-min blocks, each including 64 events. The sentences and silence periods were presented in a different randomized order for each subject. A total of 280×2 functional images were acquired for each subject.

High-resolution T1 anatomical images were also acquired with a SPGR sequence providing high contrast between gray and white matter (3-D gradient-echo inversion-recovery sequence, Ti=2200 ms, TR=2000 ms, flip angle 10°, FOV=24, 124 slices of 1.2 mm thickness, acquisition time 6 min).

2.4. Image processing

fMRI data and anatomical images were processed using SPM99 software (Statistical Parametric Mapping, Wellcome Department of Cognitive Neurology, University College London, UK) running on Matlab 6.1 (Kiebel et al., 1999). For fMRI analyses the following steps were performed: slice timing, spatial normalization and smoothing with a 5 mm Gaussian kernel.

2.5. Statistical analysis

The Spearman rank order correlation statistic was used to search for correlations between clinical variables. Correlations were computed between the PSYRATS and the SAPS-AH scores. Correlations were also sought between the auditory hallucination severity score on the PSYRATS and demographic or psychopathological variables (including age, duration of illness, SAPS, SANS, and Annett total scores) in order to determine whether auditory hallucinations could be isolated from patients' other clinical dimensions. In addition, a correlation between the PSYRATS score and the fragment detection performance was calculated.

For the fMRI statistical analyses, a linear model was generated defining two categories of events: French and Silence. These categories were crossed with indicator variables for the two conditions, yielding 4 onset vectors, which were convolved by an ideal hemodynamic impulse response and its derivative (included to model small temporal shifts).

Two voxel-based statistical analyses were performed on the whole-brain fMRI images, completed by a volume-of-interest confirmatory approach.

First, activation maps were obtained for individuals, which identified a network of areas responsive to French minus silence. Group activation was examined using a random-effect procedure.

Second, the "simple regression (correlation)" SPM99 analysis was performed on the whole brain between the PSYRATS scores and the individual activation maps obtained for French minus silence. Both analyses were examined at a voxelwise threshold of $p<0.001$ (uncorrected) and a threshold $p<0.05$ for the extent of clusters.

A confirmatory "Small Volume Correction" procedure (SVC) implemented in SPM99 was applied at a $p<0.05$ threshold corrected for multiple comparisons, for the regression between the SAPS-AH scores and the group activation maps for French versus silence. A 5-mm radius sphere was defined on the coordinates of the peak voxel detected in the regression with PSYRATS.

3. Results

The auditory hallucination scores on the PSYRATS and on the SAPS-AH correlated significantly ($R=0.68$, $p=0.01$). No association was found between the PSYRATS score and age ($R=0.17$, $p=0.54$), duration of illness ($R=0.02$, $p=0.91$), SANS ($R=0.05$, $p=0.86$) or SAPS total ($R=0.39$, $p=0.14$), or Annett laterality scores ($R=0.13$, $p=0.64$).

No significant correlation was found between performance on the detection task during fMRI and the PSYRATS scores ($R=0.01$, $p<0.95$). The mean performance during the fragment detection task was 85% correct responses, suggesting that most patients maintained their attention during the task. No significant correlation was found between the medication in mg chlorpromazine equivalent and the PSYRATS scores ($R=0.015$, $p=0.96$).

Whole-brain random-effect analysis showed increased activity in several cortical regions during active listening to French compared to silence. Two clusters of voxels were centered bilaterally on the superior temporal sulcus [Talairach's coordinates of left cluster voxel-maximum at (−48, −28, 12), $Z=4.98$ ($p<0.001$), extent: 774 voxels, extending to the inferior frontal gyrus (Broca's area); right voxel-maximum at (52, −12, −4), $Z=5.51$ ($p<0.001$), extent: 564 voxels]. The motor cortex was activated bilaterally as the subjects had to press response buttons after listening to sentences in French [voxel maximum at (8, 8, 36) and (−4, 0, 40), $Z=4.90$ ($p<0.001$), extent: 245 voxels]. These results replicate data previously reported in healthy subjects (Pallier et al., 2003).

The subsequent covariation analyses detected a relationship between French minus silence activation maps and the hallucination scores, with either voxel-based (SPM) or region-of-interest (SVC) approaches. The SPM regression analysis on whole-brain fMRI images showed that only the posterior part of the left superior temporal gyrus (Brodmann Area 22) covaried

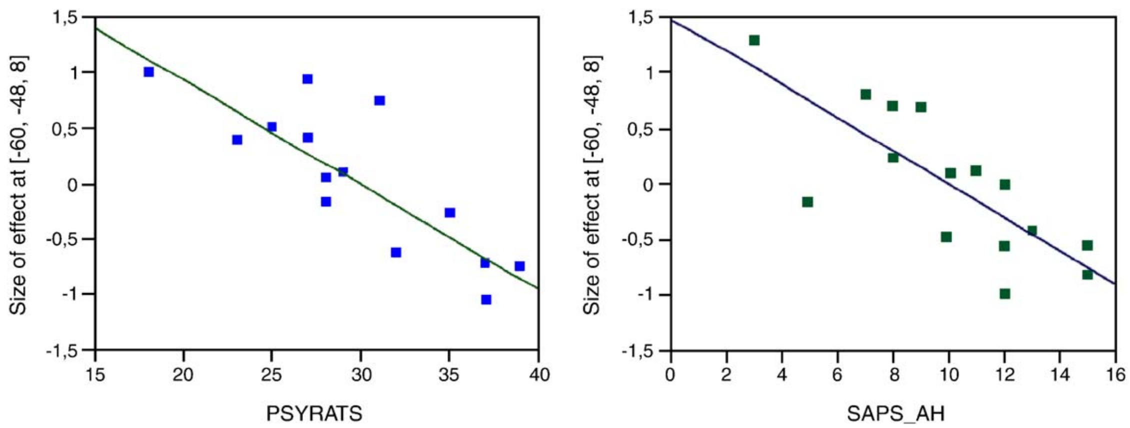

Fig. 1. Left: bivariate fit at voxel [−60, −48, 8; Talairach's coordinates] between PSYRATS hallucination score (abscissa), and BOLD adjusted activity value for exogenous sentence perception compared to silence ($R=0.82$, $F_{1,14}=27$, $p=0.0002$). Right: bivariate fit at voxel [−60, −44, 8] between SAPS-AH hallucination score (abscissa) and BOLD adjusted activity ($R=0.77$, $F_{1,14}=19$, $p=0.0007$), using the SPM99 Small Volume Correction procedure.

negatively with the auditory hallucination PSYRATS scores [Talairach's coordinates of voxel maximum at (−60, −48, 8), $Z=3.75$ ($p<0.001$), extent: 10 voxels, voxel size: 4×4×4 mm; Fig. 1]. No other cluster was detected. In addition, a negative covariation between the SAPS-AH scores and French minus silence activation maps was detected within a 5-mm radius sphere centred on the voxel of maximum covariation with the PSYRATS (Talairach's coordinates −60, −48, 8), using the SVC. This covariation was significant using corrected statistics (voxel maximum $Z=3.38$ ($p=0.009$), extent: $p=0.008$).

Finally, we checked that no correlation between gray matter density and the PSYRATS scores was found with optimised Voxel Based Morphometry analysis (Good et al., 2001), either at an uncorrected threshold of $p<0.001$, or at a less stringent threshold ($p<0.01$).

4. Discussion

We used an event-related fMRI speech perception task to assess temporal cortex activation in schizophrenic patients with chronic auditory hallucinations. A negative correlation between the cortical response to external speech and the severity of chronic auditory hallucinations was found in the posterior part of the left superior temporal gyrus; no other clusters were detected.

Our findings in the left superior temporal gyrus are consistent with previous reports linking this region with auditory hallucinations (Shergill et al., 2000, 2004; Copolov et al., 2003; Bentaleb et al., 2002; Lennox et al., 2000; Stephane et al., 2000; Silbersweig et al., 1995; Suzuki et al., 1993; DeLisi et al., 1989). They should be seen in the context of the putative dysfunction of a larger network involved in the neural correlates of hallucinations, including Broca's area (McGuire et al., 1993; Shergill et al., 2000, 2004) and anterior cingulate cortex (Copolov et al., 2003; Shergill et al., 2000). This network may underlie the mechanism that predicts the outcome of intended actions (the "forward model"; Frith, 2005). Such prediction requires integration of information about intended actions generated in frontal cortex (for example, inner speech in Broca's area) with language processing in posterior regions of the brain (e.g., Wernicke's area); also, the activation of the anterior cingulate cortex differs according to whether the stimuli are self- or non-self-referent (Northoff and Bermpohl, 2004). Measures of functional (Lawrie et al., 2002) and anatomical (Hubl et al., 2004) connectivity suggest that long-range interactions between frontal and posterior language-related areas are abnormal in patients with auditory hallucinations. The impairment in this network may result in abnormal activation of temporal regions processing external speech.

Auditory hallucinations in this clinically homogeneous sample were rated with the PSYRATS, a subscale specifically designed for their assessment (Haddock et al., 1999). This scale correlated with a composite score pooling the three items of the SAPS related to auditory hallucinations (SAPS-AH, Gaser et al., 2004). Therefore, the correlation analyses within the present sample suggest that the more severe the chronic auditory hallucinations, the lower the response of the left temporal cortex to external speech. This region corresponds to Wernicke's area, which is related to speech perception and comprehension (Wernicke, 1874; Hickok and Poeppel, 2000). These results support the hypothesis that auditory hallucinations compete with normal external speech for processing sites within the temporal cortex in schizophrenia (David et al., 1996; Woodruff et al., 1997).

The objective of the study was not to specifically examine the putative covariation between fMRI BOLD-EPI signal and the current presence of hallucinations. Rather, we searched for a link between brain activity during external speech processing and auditory symptoms scores assessed globally by external raters, in patients with chronic auditory verbal hallucinations, independently of whether they were experiencing hallucinations at the time of the fMRI. We chose this approach for practical reasons. Indeed, deciding whether auditory hallucinations are present solely on the basis of the fMRI activation maps probably lacks sensitivity and specificity (Lennox et al., 2000; Van de Ven et al., 2005). Furthermore, it may be inappropriate to rely on the patient's response (e.g., pressing a button) to designate the presence of hallucinations, since in many patients psychotic phenomena may be accompanied by anosognosia.

Alternatively, our results might be attributed to the attention engaged in speech perception. Attention has been shown to modulate neuronal activation in response to speech perception, since the temporal lobe presents more activation during active listening than during passive listening (Hugdahl et al., 2003). As the co-occurrence of auditory hallucinations may compete for attention resources during cognitive tasks, we sought to determine whether patients maintained their attention to stimuli. We measured this indirectly, by adding, within each fMRI-event, a fragment of each sentence which the patient had to detect. Patients' response accuracy did not correlate with the hallucination scores, and their number of errors was low, suggesting that they performed the task correctly.

In conclusion, our language-related fMRI results support the hypothesis that the posterior area of the left superior temporal gyrus forms part of the brain network associated with the perception of auditory hallucinations in patients with schizophrenia. Specifically, our findings indicate that activity in this cortical region may be related to hallucination severity.

Acknowledgments

Marion Plaze was supported by the Fondation pour la Recherche Médicale and by a research fellow grant from the Commissariat à l'Energie Atomique and Assistance Publique Hôpitaux de Paris (CEA and APHP). Dr. David Bartrés-Faz by the INSERM and the Spanish Ministry of Science and Technology (Ramón y Cajal Program).

References

Andreasen, N., 1983. The Scale for the Assessment of Negative Symptoms (SANS). The University of Iowa, Iowa City.

Andreasen, N., 1984. The Scale for the Assessment of Positive Symptoms (SAPS). The University of Iowa, Iowa City.

Annett, M., 1970. A classification of hand preference by association analysis. Br. J. Psychol. 61, 303–321.

Bentaleb, L.A., Beauregard, M., Liddle, P., Stip, E., 2002. Cerebral activity associated with auditory verbal hallucinations: a functional magnetic resonance imaging case study. J. Psychiatry Neurosci. 27, 110–115.

Copolov, D.L., Seal, M.L., Maruff, P., Ulusoy, R., Wong, M.T., Tochon-Danguy, H.J., Egan, G.F., 2003. Cortical activation associated with the experience of auditory hallucinations and perception of human speech in schizophrenia: a PET correlation study. Psychiatry Res. 122, 139–152.

David, A.S., Woodruff, P.W., Howard, R., Mellers, J.D., Brammer, M., Bullmore, E., Wright, I., Andrew, C., Williams, S.C., 1996. Auditory hallucinations inhibit exogenous activation of auditory association cortex. NeuroReport 7, 932–936.

DeLisi, L.E., Buchsbaum, M.S., Holcomb, H.H, Langston, K.C., King, A.C., Kessler, R., Pickar, D., Carpenter III, W.T., Morihisa, J.M., Margolin, R., 1989. Increased temporal lobe glucose use in chronic schizophrenic patients. Biol. Psychiatry 25, 835–851.

Frith, C., 2005. The neural basis of hallucinations and delusions. CR Biol. 328 (2), 169–175.

Gaser, C., Nenadic, I.S., Volz, H.P., Buchel, C., Sauer, H., 2004. Neuroanatomy of "hearing voices": a frontotemporal brain structural abnormality associated with auditory hallucinations in schizophrenia. Cereb. Cortex 14 (1), 91–96.

Good, C.D., Johnsrude, I.S., Ashburner, J., Henson, R.N., Friston, K.J., Frackowiak, R.S., 2001. A voxel-based morphometric study of ageing in 465 normal adult human brains. NeuroImage 4, 21–36.

Haddock, G., McCarron, J., Tarrier, N., Faragher, E.B., 1999. Scales to measure dimensions of hallucinations and delusions: the psychotic symptom rating scales (PSYRATS). Psychol. Med. 29, 879–889.

Hickok, G., Poeppel, D., 2000. Towards a functional neuroanatomy of speech perception. Trends Cogn. Sci. 4, 131–138.

Hubl, D., Koenig, T., Strik, W., Federspiel, A., Kreis, R., Boesch, C., Maier, S.E., Schroth, G., Lovblad, K., Dierks, T., 2004. Pathways that make voices: white matter changes in auditory hallucinations. Arch. Gen. Psychiatry 61 (7), 658–668.

Hugdahl, K., Thomsen, T., Ersland, L., Morten Rimol, L., Niemi, J., 2003. The effects of attention on speech perception: an fMRI study. Brain Lang. 85, 37–48.

Kiebel, S.J., Poline, J.B., Friston, K.J., Holmes, A.P., Worsley, K.J., 1999. Robust smoothness estimation in statistical parametric maps using standardized residuals from the general linear model. NeuroImage 10, 756–766.

Lawrie, S.M., Buechel, C., Whalley, H.C., Frith, C.D., Friston, K.J., Johnstone, E.C., 2002. Reduced frontotemporal functional connectivity in schizophrenia associated with auditory hallucinations. Biol. Psychiatry 51 (12), 1008–1011.

Lennox, B.R., Park, S.B., Medley, I., Morris, P.G., Jones, P.B., 2000. The functional anatomy of auditory hallucinations in schizophrenia. Psychiatry Res. 100, 13–20.

McGuire, P.K., Shah, G.M., Murray, R.M., 1993. Increased blood flow in Broca's area during auditory hallucinations in schizophrenia. Lancet 342, 703–706.

Northoff, G., Bermpohl, F., 2004. Cortical midline structures and the self. Trends Cogn. Sci. 8 (3), 102–107.

Pallier, C., Dehaene, S., Poline, J.B., LeBihan, D., Argenti, A.M., Dupoux, E., Mehler, J., 2003. Brain imaging of language plasticity in adopted adults: can a second language replace the first? Cereb. Cortex 13, 155–161.

Sartorius, N., Jablensky, A., Korten, A., Ernberg, G., Anker, M., Cooper, J.E., Day, R., 1986. Early manifestations and first-contact incidence of schizophrenia in different cultures. A preliminary report on the initial evaluation phase of the WHO Collaborative Study on determinants of outcome of severe mental disorders. Psychol. Med. 16, 909–928.

Shergill, S.S., Brammer, M.J., Williams, S.C., Murray, R.M., McGuire, P.K., 2000. Mapping auditory hallucinations in schizophrenia using functional magnetic resonance imaging. Arch. Gen. Psychiatry 57, 1033–1038.

Shergill, S.S., Brammer, M.J., Amaro, E., Williams, S.C., Murray, R. M., McGuire, P.K., 2004. Temporal course of auditory hallucinations. Br. J. Psychiatry 185, 516–517.

Silbersweig, D.A., Stern, E., Frith, C., Cahill, C., Holmes, A., Grootoonk, S., Seaward, J., McKenna, P., Chua, S.E., Schnorr, L., 1995. A functional neuroanatomy of hallucinations in schizophrenia. Nature 378, 176–179.

Stephane, M., Folstein, M., Matthew, E., Hill, T.C., 2000. Imaging auditory verbal hallucinations during their occurrence. J. Neuropsychiatry Clin. Neurosci. 12, 286–287.

Suzuki, M., Yuasa, S., Minabe, Y., Murata, M., Kurachi, M., 1993. Left superior temporal blood flow increases in schizophrenic and schizophreniform patients with auditory hallucination: a longitudinal case study using 123I-IMP SPECT. Eur. Arch. Psychiatry Clin. Neurosci. 245, 257–261.

Wernicke, C., 1874/1977. Der aphasische Symptomcomplex: eine psychologische Studie auf anatomischer basis. In: Eggert, G.H. (Ed.), Wernicke's Works on Aphasia: A Sourcebook and Review, pp. 91–145.

Van de Ven, V.G., Formisano, E., Röder, C.H., Prvulovic, D., Bittner, R.A., Dietz, M.G., Hubl, D., Dierks, T., Federspiel, A., Esposito, F., Di Salle, F., Jansma, B., Linde, R., 2005. The spatiotemporal pattern of auditory cortical responses during verbal hallucinations.

NeuroImage (article in press, corrected proof available on the journal website).

Woodruff, P.W., Wright, I.C., Bullmore, E.T., Brammer, M., Howard, R.J., Williams, S.C., Shapleske, J., Rossell, S., David, A.S., McGuire, P.K., Murray, R.M., 1997. Auditory hallucinations and the temporal cortical response to speech in schizophrenia: a functional magnetic resonance imaging study. Am. J. Psychiatry 154, 1676–1682.

Woods, S.W., 2003. Chlorpromazine equivalent doses for the newer atypical antipsychotics. J. Clin. Psychiatry 64, 663–667.