Schizophrenia Research 150 (2013) 380–385

Contents lists available at ScienceDirect

Schizophrenia Research

journal homepage: www.elsevier.com/locate/schres

Auditory processing and hallucinations in schizophrenia

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ARTICLE INFO

Article history:
Received 20 December 2012
Received in revised form 27 August 2013
Accepted 27 August 2013
Available online 17 September 2013

Keywords:
Schizophrenia
Auditory hallucination
Auditory deficit
Speech prosody

ABSTRACT

The aim of this study was to investigate whether deficits in auditory processing are associated with auditory hallucinations in patients with schizophrenia. It was hypothesised that individuals with a diagnosis of schizophrenia would demonstrate deficits in processing the spectral and temporal aspects of sound and that such deficits would be more pronounced in patients with a history of auditory hallucinations (hallucinators) than those without such a history (non-hallucinators). A community sample meeting clinical criteria for schizophrenia or schizoaffective disorder (19 hallucinators, 15 non-hallucinators) and a matched healthy control group ($n = 17$) completed a broad range of auditory processing tasks involving pitch discrimination of modulated (temporal) and unmodulated (spectral) pure tones, auditory streaming and affective prosodic identification, as well as measures assessing current psychiatric symptoms. In all experimental tasks patients were impaired compared to controls. Specifically hallucinators performed worse than non-hallucinators and controls for pitch discrimination of unmodulated tones and auditory streaming, and both hallucinators and non-hallucinators performed significantly worse than controls for discrimination of modulated tones and affective prosody. These findings suggest that impaired temporal processing may contribute to general difficulties identifying affective speech prosody in patients with schizophrenia, while spectral processing deficits may specifically compromise melodic streaming in hallucinators, which combined with deficits in temporal processing, contribute to the experience of auditory hallucinations.

1. Introduction

Research on factors contributing to the development of auditory hallucinations in schizophrenia has primarily focused on top–down mechanisms such as externalising response bias, deficits in verbal self-monitoring, impaired memory for one's own speech, and a misattribution of inner speech (Seal et al., 2004). However, more recent research has investigated the possibility that low-level auditory processes might be implicated in auditory hallucinations in patients with schizophrenia because difficulties, such process, which include pitch perception, may give rise to higher order perceptual deficits (i.e. McKay et al., 2000).

In keeping with this idea, Nielzén and Olsson (1997) found that patients with schizophrenia were impaired in their ability to stream melodies. Melodic streaming involves the segregation of a sequence of pitches into different perceptual categories, or 'streams' (Bregman, 1990). The closer the pitch of successive tones, the more likely they are to be perceptually subsumed into one melodic stream. In patients with schizophrenia errors in streaming may give rise to auditory streams with no physical correlate, possibly leading to auditory hallucinations (although not specifically examined by these authors).

The relationship between auditory processing and auditory hallucinations may be examined by focusing on individuals with a significant history of hallucinations (hallucinators). For instance, Lindstrom et al. (1987) noted a preponderance of auditory brain-stem pathology in patients with schizophrenia who experienced auditory hallucinations compared to those who did not (non-hallucinators). However, McKay et al. (2000) did not replicate this finding. Rather, they established hallucinators only performed worse than non-hallucinators when recognizing filtered speech presented to the left ear. Since the right temporal lobe shows specialisation for spectral and sequential pitch processing (Zatorre and Belin, 2001), this task may have been sensitive to greater deficits in these functions in hallucinators.

Leitman et al. (2005) found a large correlation between performance on a pitch-matching task and the ability to hear emotional expression in speech ("affective prosody" discrimination). They theorised that difficulties in pitch perception may give rise to impairments in prosodic processing in patients with schizophrenia. Consistent with this, Rossell and Boundy (2005) showed impaired affect judgements for spoken, non-lexical stimuli (such as happy sighs, shrieks and grunts) in hallucinators compared to non-hallucinators, while Shea et al. (2007) found hallucinators were worse at classifying the affective prosody of semantically neutral sentences. Since identification of affective speech prosody requires pitch discrimination in the presence of rapidly fluctuating pitch and amplitude, impaired affective prosody in hallucinators may also

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http://dx.doi.org/10.1016/j.schres.2013.08.039

reflect poor temporal processing. Consistent with this, Davalos et al. (2003) showed poorer auditory discrimination of short temporal durations (between 300 and 500 ms) in patients with schizophrenia compared to controls, while Matsumoto et al. (2006) found that patients with schizophrenia were less accurate than controls in discriminating verbal (spoken) as well as non-verbal (musical) pairs of stimuli.

To further explore the relationships between spectral and temporal processing and higher auditory functions, such as streaming and prosodic classification, in schizophrenia, the present study employed four pitch-based tasks in one sample of patients with and without auditory hallucinations, and compared them to a group of healthy participants controlling for age, sex, IQ, substance use, and music training. The experimental tasks included discrimination of differences between the pitch of pure tones at varying rates of frequency modulation, melodic streaming, and the classification of affective prosody. We hypothesised that (1) patients with schizophrenia would demonstrate poorer performance of all experimental tasks compared to healthy controls, (2) discrimination of unmodulated pure tones (spectral condition) would be worse in hallucinators than non-hallucinators, and that this would be reflected in poorer melodic streaming, and (3) discrimination of modulated pure tones (temporal condition) would be worse in hallucinators than non-hallucinators that would be reflected in worse prosodic classification.

2. Method

2.1. Participants

Fifty-one participants (32 male) were recruited to the study, including 17 controls, 15 non-hallucinators and 19 hallucinators. Patients with a diagnosis of schizophrenia or schizoaffective disorder were recruited via community health and support groups. No patients were currently experiencing an acute psychotic episode, or reported experiencing any auditory hallucinations during testing. Diagnosis was confirmed using the Structured Clinical Interview for DSM-IV Axis I Disorders (SCID-I: First et al., 1997), with symptoms measured using the Andreasen's Scales for the Assessment of Positive and Negative Symptoms (SANS & SAPS: Andreasen and Olsen, 1982). The sample was divided into hallucinators and non-hallucinators according to auditory hallucination history as shown in Table 1.

Healthy controls were recruited via local advertisements. Control participants were excluded if they had a personal or family history of major psychiatric disorder. Demographic and clinical characteristics of all participants are shown in Table 2. They were aged between 24 and 63 years, with no history of major head injury, neurological disorder, or recent treatment with electro-convulsive therapy. All participants had a Wechsler Test of Adult Reading (WTAR; Wechsler, 2001) estimated pre-morbid intellectual quotient (IQ) greater than 80. They were screened for significant hearing impairment using an audiogram. Ethics for this project was obtained from the University of Melbourne. All participants gave informed written consent and the procedures used abided by the Declaration of Helsinki.

Table 1
Criteria for assigning patients to hallucinator and non-hallucinator groups.

Hallucinator group	Non-hallucinator group
1. The participant had experienced at least one auditory hallucination in the past 10 weeks; OR	1. The participant had never had an auditory hallucination; OR
2. The participant had experienced auditory hallucinations intermittently throughout the illness in spite of medication; OR	2. The participant had only experienced auditory hallucinations briefly at the onset of the illness but not in the past 10 years.
3. The participant had experienced auditory hallucinations at the onset of the illness which was within the past 2 years.	

Table 2
Demographic information and symptom characteristics across groups.

	Controls ($n = 17$)	Non-hallucinators ($n = 15$)	Hallucinators ($n = 19$)
Mean age in years (SD)	43.1 (10.0)	43.5 (8.8)	41.2 (9.9)
Gender (n, %)	9 males	13 males	10 males
Mean estimated IQ (SD)	107.2 (6.0)	101.2 (9.7)	104.2 (8.8)
Mean years education (SD)	15.0 (2.5)*	12.9 (2.6)	13.2 (2.5)
Mean SANS score[a] (SD)		26.4 (17.5)	26.8 (21.1)
Mean SAPS score[b] (SD)		11.7 (16.6)	23.6 (18.0)
Mean SAPS − hallucination[c]		11.7 (16.6)	17.8 (13.3)
Past substance users[d] (n, %)	6 (35%)	7 (47%)	13 (68%)
Current substance users[d] (n, %)	2 (12%)	3 (20%) [c]	1 (5%)
Musical background[e] (n, %)	14 (82%)	11 (73%)	11 (58%)

* $p < .05$.
[a] Scale for the assessment of negative symptoms (Andreasen and Olsen, 1982). Total score of 125.
[b] Scale for the assessment of positive symptoms (Andreasen and Olsen, 1982). Total score of 170.
[c] Scale for the assessment of positive symptoms (Andreasen and Olsen, 1982) without auditory hallucination questions.
[d] Substance use was defined as at least 6 months of: (1) ≥6 standard drinks of alcohol every day; (2) cannabis use ≥3 times per week; (3) methamphetamine use ≥1 per week; (4) lysergic acid diethylamide ("LSD" or "acid") use once per week; and/or (5) diacetylmorphine ("heroin") use once per week. Only one participant (a non-hallucinator) had used heroin for a period of 18 months from 1990 to 1992.
[e] A musical background was defined as having achieved the equivalent of ≥Grade 3 musical training on any instrument or voice as assessed by the Australian Music Examination Board.

2.2. Materials and procedure

The pure tones used in the discrimination and streaming tasks were created using Adobe Audition software with 10 ms linear ramps at onset and offset to eliminate clicks. All stimuli were normalised according to equal loudness. Participants were individually tested in an anechoic chamber, with stimuli presented monaurally via Fostex T20RP MkII headphones. All tasks included practice stimuli and were administered prior to the clinical interview to ensure the examiner remained blind to participant hallucination group. The duration of testing lasted around 3 h for each participant.

2.2.1. Pitch discrimination of pure tones

Similar to the protocol used by Leitman et al. (2005), pairs of 100 ms duration tones were separated by a 500 ms interval. The first tone in each stimulus pair was synthesized at either 500, 1000 or 2000 Hz. The second tone in each pair differed in frequency by 0, 1, 2.5, 5, 10, or 20%, with counterbalanced rises and falls of pitch. At each reference frequency, 60 of the second tones were at the same frequency and 120 differed (24 at each of the 5 frequency differences listed above), resulting in a total of 180 stimuli. Stimuli were pseudo-randomly presented to avoid repetition in blocks of 90 tone-pairs that were counterbalanced across participants. Participants responded by pressing "same" or "different" on a 2-button press.

2.2.2. Modulation discrimination of pure tones

Pairs of 1000 ms duration pure tones were separated by a 500 ms interval. The first tone in each stimulus pair was an unmodulated sine tone synthesized at 500, 1000 or 2000 Hz. The second tone in each pair was frequency modulated at a depth of 0, 1, 2.5, 5, 10, or 20% and at a modulation rate of 2, 40 or 120 Hz. At each reference frequency, 30 of the second tones had no frequency modulation, and 60 were modulated, 12 at each modulation depth divided into 4 at each modulation rate, resulting in a total of 270 stimuli. To avoid repetition, stimuli were pseudo-randomly presented in four blocks of 67 or 68 tone-pairs that were counterbalanced across participants. Participants responded by pressing "same" or "different" on a 2-button press.