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Impaired processing of binaural temporal cues to auditory scene analysis in schizophrenia

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ABSTRACT

It is well established that individuals with schizophrenia demonstrate alterations in auditory perception beginning at the very earliest stages of information processing. However, it is not clear how these impairments in basic information processing translate into high-order cognitive deficits. Auditory scene analysis allows listeners to group auditory information into meaningful objects, and as such provides an important link between low-level auditory processing and higher cognitive abilities. In the present study we investigated whether low-level impairments in the processing of binaural temporal information impact upon auditory scene analysis ability. Binaural temporal processing ability was investigated in 19 individuals with schizophrenia and 19 matched controls. Individuals with schizophrenia showed impaired binaural temporal processing ability on an inter-aural time difference (ITD) discrimination task. In addition, patients demonstrated impairment in two measures of auditory scene analysis. Specifically, patients had reduced ability to use binaural temporal cues to extract signal from noise in a masking level difference paradigm, and to separate the location of a source sound in the presence of an echo in the precedence effect paradigm. These findings demonstrate that individuals with schizophrenia have impairments in the accuracy with which simple binaural temporal information is encoded in the auditory system, and furthermore, this impairment has functional consequences in terms of the use of these cues to extract information in complex auditory environments.

1. Introduction

Cognitive deficits represent a fundamental feature of schizophrenia and are recognized as an important predictor of functional outcome in the disorder (Green et al., 2000). While these deficits are often considered in the context of executive functions such as working memory and attention, they are likely underpinned by deficits in more basic perceptual processes (Braff and Light, 2004). Indeed, Vinogradov, Fisher, and de Villers-Sidani (2012) have argued that success in remediating cognitive deficits in schizophrenia will be hampered if underlying sensory processing limitations are not fully understood and addressed. In the case of audition, it is well established that individuals with schizophrenia demonstrate alterations in auditory perception beginning at the very earliest levels of information processing (Braff and Light, 2004). However, there has been little research on how these low-level impairments impact upon higher-level functions.

Auditory scene analysis is the organizing process by which we structure incoming acoustic signals, and as such forms an important link between low-level auditory information processing and higher-level cognitive processes. In complex acoustic environments, in which several sound sources are present, the composite acoustic waveform that reaches the ear must be decomposed into its constituent parts. Listeners use scene analysis to partition these complex sound waves into the various sources of sound that is present in the environment. This is achieved by identifying, grouping, and segregating sounds into separate mental representations, called auditory streams or objects, based, in part, on the physical similarity and temporal relationship between sounds (Bregman, 1990).

Once formed, these auditory objects become the basic units of attentional selection (Alain and Arnott, 2000; Scholl, 2001). For example, listeners can attend actively to only one auditory object at a time (Cusack et al., 2000), and are less able to make judgements about the relative timing of events when these events are ascribed to separate sound sources compared to when they come from the same source/object (Bregman, 1990), demonstrating that auditory object formation constrains further information processing. Further,

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impairments in the ability to perceptually organize acoustic information into auditory objects or streams have been linked to impaired speech comprehension with aging (Alain et al., 2006), and in developmental dyslexia (Helenius, Uutela, and Hari, 1999). Therefore, understanding the scene analysis processes in schizophrenia can provide essential information about how auditory information is structured for use by higher-level cognitive processes.

The accuracy of scene analysis is dependent upon the accuracy with which simple low-level auditory features are extracted from sounds (Bregman, 1990). An accurate representation of the spatial position of a sound greatly improves the listener's ability to segregate that sound from competing sounds and increases the listener's ability to extract meaningful information from complex auditory environments (Bregman, 1990). It is known that individuals with schizophrenia experience impairments on low-level auditory tasks requiring them to identify the spatial location of sounds (Balogh and Leventhal, 1982; Guterman and Klein, 1992), especially when they must rely on binaural temporal cues to location (Balogh and Leventhal, 1982; Matthews et al., 2007). Binaural temporal cues operate in the microsecond (μs) range and require the analysis of the temporal *differences* between signals arriving at the two ears: these interaural (between ear) time differences (ITDs and ongoing interaural phase differences: IPD) result from the increased time required for sound waves to reach the ear that is farther away from a sound source (Middlebrooks and Green, 1991). What remains unclear, however, is what consequence impaired binaural temporal processing may have for auditory scene analysis. Since we know that the output from low-level auditory analysis is instrumental in the creation of auditory objects, it is logical to assume that when there exist a lower-level deficit in processing information, which is then fed into a higher-level process, then a deficit in the former will transfer to the latter. Here we will systematically explore auditory scene analysis in schizophrenia using two tasks which model complex auditory environments in which sounds originate from multiple source; the masking level difference (MLD: Hirsh, 1948) and the precedence effect (Litovsky et al., 1999). We hypothesize that the reliance of auditory scene analysis on the accuracy of low-level perception will mean that impaired ITD processing and impaired auditory scene analysis will at a minimum co-occur in individuals with schizophrenia, and if monotonically related, the degree of deficit should correlate.

In noisy environments binaural cues provide an advantage for subjects in segregating a target sound source from competing masking sources (Saberi et al., 1991; Yost et al., 1996). In the MLD, this is evidenced by an improvement in the masked detection threshold for a pure tone signal (S) in a broadband noise mask (N) under conditions in which the signal is inverted in phase by 180° in one ear (NoSπ) giving the perception that the signal and noise occupy separate spatial locations (Moore, 1997), compared with conditions in which both the masking noise and the signal are presented in phase at the two ears (NoSo). Binaural cues can also provide essential information for the identification of the source of sounds in reverberant environments in which sounds propagate in multiple directions and are reflected from nearby surfaces. This is demonstrated in the *precedence effect* paradigm in which two spatially separate sounds (usually click stimuli) are presented; a source (*lead sound*) followed at a short delay by a single simulated reflection (*lag sound*). In order to avoid localization errors in such environments, the auditory system must resolve which cues belong to each sound source and, assign greater perceptual weight to the localization information contained in the preceding lead stimulus, relative to information contained in the lagging sound (Wallach et al., 1949; Litovsky et al., 1999). At short lead-lag delays (in the range of 1 to 5 ms) the two clicks are perceived as a single fused auditory image located near the location of the leading click. For large delays, the sound breaks into two images, one at each click location (Wallach et al., 1949; Litovsky et al., 1999). The boundary between the perception of one fused sound and two separate sounds is referred to as the *echo threshold* (Blauert, 1997).

The present study will combine, for the first time in the same group of individuals with schizophrenia, an investigation into the encoding of basic binaural temporal cues, as well as an assessment of patients' capacity to utilize binaural cues in auditory scene analysis of complex auditory environments. If the auditory scene analysis process is indeed sensitive to the accuracy with which low-level information is encoded, then impaired binaural temporal processing in schizophrenia should lead to a failure to properly ascribe a sound to the appropriate auditory source reducing patients ability to extract signal from noise in the masking level difference paradigm and to differentiate sounds from their reverberations in the precedence effect task. As our paradigms will examine sounds that are perceived as being located in either right or left hemispace, there is an opportunity to examine whether any deficits in patients are lateralized. Previous research has provided evidence of lateralized deficits for information presented in the right-hemispace in individuals with schizophrenia on a range of cognitive abilities such as; attention (Posner et al., 1998), working memory (Park, 1999) and mental number line bisection (Cavezian et al., 2007). The present study will explore whether this hemi-neglect is evident at the level of operation of the auditory scene analysis processes and thus whether it influences the quality of information individuals with schizophrenia can extract from stimuli presented to the right side of space.

2. Material and methods

2.1. Experimental participants

Nineteen individuals with schizophrenia (SZ) were recruited from outpatient sources including a volunteer register managed by the Schizophrenia Research Institute (SRI) and from the Inner North Brisbane Mental Health Services of the Royal Brisbane Hospital. A healthy comparison group (HC: N = 19) was recruited from students of the University of Newcastle, and from community volunteers in both the Newcastle and Brisbane areas. HC did not differ significantly from SZ on age, sex, or on estimates of pre-morbid verbal IQ (NART: Nelson, 1982, see Table 1). All participants were right handed (Oldfield, 1971). HC recruited from the University of Newcastle received course credit for participation; all other participants were reimbursed for travel costs and expenses. Ethics approval for the study was obtained from the Human Research Ethics Committees of the University of Newcastle, The Hunter Area Health Service, The University of Queensland, and Uniting Health Care. Written informed consent was obtained from all participants.

Participants were excluded if screening revealed a history of major head injury, epilepsy, hearing loss, or a recent history of substance abuse. HC were additionally excluded if there was a personal history of mental illness, as assessed by the Diagnostic Interview for Psychosis (DIP: Castle et al., 2005), or a history of schizophrenia in first-degree relatives. Audiometric testing confirmed that detection thresholds were normal (<20 dB HL) for all participants across 500–2000 Hz.

All SZ participants received an ICD-10 diagnosis within the schizophrenia spectrum (DIP: Castle et al., 2005). Ratings of current symptomatology for SZ were obtained on the Scale for the Assessment of Positive Symptoms (SAPS: Andreasen, 1984), and the Scale for the Assessment of Negative Symptoms (SANS: Andreasen, 1982, Table 1) and overall functional status was assessed using the Global Assessment of Functioning Scale (GAF: American Psychiatric Association, 2000). All SZ participants were prescribed with atypical antipsychotic medication (10 Clozapine, 3 Quetiapine, 4 Olanzipine, 1 Amisulpride) at the time of testing, except for one participant whose illness was managed without medication.

2.2. General procedure

Three tasks were presented to each participant. All testing took place in a sound attenuated room using Sennheiser HD 280 Pro