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The influence of semantic top-down processing in auditory verbal hallucinations

Kirstin Daalman [a,*], Sanne Verkooijen [a], Eske M. Derks [b], André Aleman [c], Iris E.C. Sommer [a]

[a] Department of Psychiatry, Neuroscience Division, University Medical Center Utrecht & Rudolf Magnus Institute for Neuroscience, Heidelberglaan 100, 3584 CX Utrecht, The Netherlands
[b] Department of Psychiatry, Academic Medical Center, University of Amsterdam, Meibergdreef 5, 1105 AZ Amsterdam, The Netherlands
[c] BCN Neuroimaging Center, University Medical Center Groningen, University of Groningen, Antonius Deusinglaan 2, 9713 AW Groningen, The Netherlands

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ABSTRACT

Background: Auditory verbal hallucinations (AVH) are one of the most prominent symptoms of schizophrenia but have also been reported in the general population. Several cognitive models have tried to elucidate the mechanism behind auditory verbal hallucinations, among which a top-down model. According to this model, perception is biased towards top-down information (e.g., expectations), reducing the influence of bottom-up information coming from the sense organs. This bias predisposes to false perceptions, i.e., hallucinations.
Methods: The current study investigated this hypothesis in non-psychotic individuals with frequent AVH, psychotic patients with AVH and healthy control subjects by applying a semantic top-down task. In this task, top-down processes are manipulated through the semantic context of a sentence. In addition, the association between hallucination proneness and semantic top-down errors was investigated.
Results: Non-psychotic individuals with AVH made significantly more top-down errors compared to healthy controls, while overall accuracy was similar. The number of top-down errors, corrected for overall accuracy, in the patient group was in between those of the other two groups and did not differ significantly from either the non-psychotic individuals with AVH or the healthy controls. The severity of hallucination proneness correlated with the number of top-down errors.
Discussion: These findings confirm that non-psychotic individuals with AVH are stronger influenced by top-down processing (i.e., perceptual expectations) than healthy controls. In contrast, our data suggest that in psychotic patients semantic expectations do not play a role in the etiology of AVH. This finding may point towards different cognitive mechanisms for pathological and nonpathological hallucinations.

1. Introduction

Auditory verbal hallucinations (AVH) are among the most prominent symptoms of schizophrenia but have also been reported in other psychiatric disorders as well as in a significant minority of the general population (for reviews, see Beavan et al., 2011; Aleman and Larøi, 2008). AVH have been suggested to lie on a continuum (Verdoux and van Os, 2002), ranging from non-psychotic and otherwise healthy individuals with AVH on one end to psychotic patients on the other. On the phenomenological level, some differences between AVH in these groups were reported, mostly related to the emotional valence and associated distress (Daalman et al., 2011a), but there is also a substantial overlap in AVH on both ends of this continuum: loudness, number of voices, personification and location of voices were rather similar.

On the neurobiological level, brain activation during AVH measured with fMRI was found to be similar in non-psychotic and psychotic individuals (Diederen et al., 2011). However, increased striatal dopamine, known to play a key role in AVH in psychosis, was absent in non-psychotic individuals with frequent AVH (Howes et al., 2012). It so far remains unclear if similar or different processes underlie hallucinations at either ends of the continuum.

Different cognitive models have tried to explain the mechanism(s) behind AVH. A possible mechanism accounting for the vulnerability to hallucinate is increased reliance on top-down processing. In normal perception, bottom-up information coming from the senses is combined with top-down information that regards implicit prior knowledge based on previously encountered situations, leading to perceptual expectations (Behrendt, 1998; Meyer, 2011). The balance between bottom-up and top-down processing can be distorted in such a way, that it is influenced to a higher degree by top-down factors, which may trigger perceptual experiences in the absence of corresponding external stimulation, i.e., hallucinations (Behrendt, 1998; Grossberg, 2000).

The aim of this study was to investigate whether both psychotic and non-psychotic individuals with AVH indeed make more top-down errors, compared to healthy controls. A previous study revealed an increased number of top-down errors in university students selected for

* Corresponding author at: Neuroscience Division, University Medical Center Utrecht & Rudolf Magnus Institute for Neuroscience, B01.206, Heidelberglaan 100, 3584 CX, Utrecht, The Netherlands. Tel.: +31 8 8755 6370; fax: +31 8 8755 5509.
E-mail addresses: K.Daalman@umcutrecht.nl (K. Daalman), S.Verkooijen@umcutrecht.nl (S. Verkooijen), E.M.Derks@amc.uva.nl (E.M. Derks), a.aleman@med.umcg.nl (A. Aleman), I.Sommer@umcutrecht.nl (I.EC. Sommer).

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Table 1
Demographic characteristics of the participants: psychotic patients, non-psychotic individuals with AVH and healthy control subjects.

Group	Patients with AVH	Non-psychotic individuals with AVH	Healthy controls	Difference (significance)
n	40	40	40	
Male	21	17	18	$\chi^2 = 0.871$; $df = 2$; $p = 0.647$
(%)	(52.5%)	(40%)	(45%)	
Mean age	37.60	47.63	45	$F = 6.77$; $df = 2$; $p < 0.01$
(SD)	(12.17)	(10.48)	(14.87)	
Total years of education	13.15	13.75	13.60	$\chi^2 = 1.677$; $df = 2$; $p = 0.432$
(SD)	(2.60)	(2.12)	(2.37)	

hallucination-proneness compared to students without a proneness towards hallucination (Vercammen and Aleman, 2010). That is, subjects with higher levels of hallucination proneness were more likely to report hearing a word that fitted the sentence context, when it was not actually presented. The present study investigated whether such a finding would extend to a sample of people from the general population who experience AVH and to patients with schizophrenia and AVH. Investigating this effect in non-psychotic individuals with AVH as well as in patients with AVH would provide further evidence for the top-down model in AVH. To this end, three groups of participants were included: 40 healthy control subjects, 40 non-psychotic individuals with AVH and 40 psychotic patients with AVH. Patients are hypothesized to make more top-down errors than non-psychotic individuals with AVH, since they experience AVH more frequently (Daalman et al., 2011a). In addition, the Launay-Slade Hallucination Scale (LSHS; Larøi et al., 2004) was used to measure whether hallucination proneness would be associated with more top-down errors in the non-psychotic groups. For the patient group, the association between number of top-down errors and hallucinatory behavior (item P3 of the Positive and Negative Syndrome Scale; PANSS, Kay et al., 1987) was determined.

2. Methods

2.1. Participants

A total of 120 participants were included: 40 psychotic patients with AVH, 40 non-psychotic individuals with AVH and 40 non-hallucinating control subjects. The healthy control subjects and non-psychotic individuals with AVH did not meet criteria for a DSM-IV diagnosis, as assessed by an independent psychiatrist with the Comprehensive Assessment of Symptoms and History (CASH) interview (Andreasen et al., 1992) and the Structured Clinical Interview for Personality Disorder (SCID-II) (First et al., 1995). Depressive disorder in complete remission was not an exclusionary criterion. Additional exclusion criteria for all groups were alcohol abuse and drug abuse. For the non-psychotic individuals and psychotic patients with AVH, the minimum frequency to experience AVH was once a month and the minimum duration since onset of AVH was 1 year.

Both the non-psychotic individuals with AVH and the healthy controls were recruited with the help of a Dutch website called 'explore your mind' (www.verkenuwgeest.nl). An extended description of the recruitment and selection procedure is provided in prior studies by our group (Diederen et al., 2010; Sommer et al., 2010; van Lutterveld et al., 2010; Daalman et al., 2011a; de Weijer et al., 2011; Diederen et al., 2011).

The outpatients with a psychotic disorder were recruited from the University Medical Centre Utrecht. These patients visited our clinic for regular treatment for psychosis. In this group, clinical diagnoses were confirmed by an independent psychiatrist using the CASH interview. Twenty-five patients (62.5%) were diagnosed with paranoid schizophrenia, 6 (15%) with schizoaffective disorder, and 9 (22.5%) with psychosis not otherwise specified. Demographic and clinical details are shown in Table 1; the three groups were matched for gender and total years of education but differed on age. For a detailed overview of medication use in the three groups, see Supplementary Table 1.

The study was approved by the Humans Ethics Committee of the University Medical Center Utrecht. After complete description of the study to the subjects, written informed consent was obtained.

2.2. Measurements

2.2.1. Experimental tasks

2.2.1.1. Hearing task. To ensure proper hearing, a test was developed in which tones of various frequencies were presented (300 Hz, 500 Hz, 700 Hz, 900 Hz and 1100 Hz) at 65 dB. Participants were asked to press a response button when a tone was presented. After completing the test, the results were immediately calculated before proceeding to the semantic task. In case of an accuracy score below 75%, the experiment was aborted, since the performance on the top-down task would be influenced too much by a hearing deficiency. No participants had to be excluded because of this criterion.

2.2.1.2. Semantic expectation task. The semantic expectation (top-down processing) task was previously used by Vercammen and Aleman (2010). The task contained 150 Dutch sentences, in which the last word was masked by noise ($N = 100$) or the last word was replaced by noise ($N = 50$). Of the 100 masked stimuli, 50 ended with a word which was to be expected given the context of the sentence (e.g., The sailor sells his *boat*), whereas the other 50 of the sentences ended in an unpredictable manner (e.g., The sailor sells his *chair*). The participants were seated in front of a computer and listened to the task through headphones. After hearing a sentence, participants were asked to indicate with a button response whether they heard a word during the noise, and if so, to type in which word they had heard. In case of doubt, the participants were given the option of stating he or she had heard a word but that they were unsure about the answer. This way, participants were discouraged to guess and instead, only to report words they actually perceived.

Consequently five types of responses were possible: correct; missing (hearing only noise when in fact a word was presented); unsure (hearing a word but not knowing which); top-down (hearing a word that was predictable when in fact an unpredictable word or noise was presented); confabulation (hearing an incorrect word that was not predicted).

Responses on the task were all scored by two raters, both blind for condition/type of participant. To investigate whether patients would give more idiosyncratic responses (that did not fit in the sentence but were also not expected and would thus not count as a top-down error but could be due nevertheless to aberrant top-down processing) responses were also rated on "strangeness" on a 5-point scale (see supplementary material).

2.2.2. Questionnaires

2.2.2.1. Hallucination proneness. Participants filled out a modified version of the Launay-Slade Hallucination Scale (LSHS; Larøi et al., 2004),