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Auditory feature perception and auditory hallucinatory experiences in schizophrenia spectrum disorder

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Abstract

Schizophrenia spectrum disorder (SZ) is associated with deficits in auditory perception as well as auditory verbal hallucinations (AVH). However, the relationship between auditory feature perception and auditory verbal hallucinations (AVH), one of the most commonly occurring symptoms in psychosis, has not been well characterized. This study evaluated perception of a broad range of auditory features in SZ and to determine whether current AVHs relate to auditory feature perception. Auditory perception, including frequency, intensity, duration, pulse-train and temporal order discrimination, as well as an embedded tone task, was assessed in both AVH (n = 20) and non-AVH (n = 24) SZ individuals and in healthy controls (n = 29) with the Test of Basic Auditory Capabilities (TBAC). The Hamilton Program for Schizophrenia Voices Questionnaire (HPSVQ) was used to assess the experience of auditory hallucinations in patients with SZ. Findings suggest that compared to controls, the SZ group had greater deficits on an array of auditory features, with non-AVH SZ individuals showing the most severe degree of abnormality. IQ and measures of cognitive processing were positively associated with performance on the TBAC for all SZ individuals, but not with the HPSVQ scores. These findings indicate that persons with SZ demonstrate impaired auditory perception for a broad range of features. It does not appear that impaired auditory perception is associated with recent auditory verbal hallucinations, but instead associated with the degree of intellectual impairment in SZ.

Keywords

Auditory verbal hallucinations; auditory perception; TBAC; HPSVQ

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Conflicts of Interest

Ashley M. Schnakenberg Martin, Lisa Bartolomeo, Josselyn Howell, William P. Hetrick, Amanda R. Bolbecker, Alan Breier, Gary Kidd, and Brian F. O'Donnell have no financial investments with commercial interests to disclose.

Introduction

Behavioral investigations of auditory perception in individuals with schizophrenia spectrum disorders (SZ) have shown deficits in tone matching on the basis of pitch [1–3]. A recent meta-analysis by Dondé et al. (2016) lends support to the individual studies reviewed in that the meta-analysis yielded a large effect size (standardized mean difference =1.17, [95% CI 0.926–1.418]) for the comparison of individuals with schizophrenia and healthy controls on pitch discrimination performance for non-verbal sounds [4]. These behavioral findings are consistent with auditory event-related potential deficits as well as neuroanatomical abnormalities affecting the auditory cortex [5].

Deficits in basic auditory processing can impact higher levels of cognition [6,5]. Moreover, degradation of sensory input has been associated with hallucinations in psychologically healthy people. For example, Cole et al. (2002) reported that 33% of an elderly sample referred to an audiology clinic for assessment of hearing impairment experienced auditory hallucinations [7]. Consequently, auditory perceptual deficits could contribute to hallucinatory experiences in persons with psychosis as well. Auditory verbal hallucinations (AVH) are reported by approximately 75% of individuals with the illness [8,9]. There have been few studies on the relationship between AVH and auditory perception, and have led to mixed results. An inverse relationship [10], as well as no relationship [11], has been observed between tone matching ability and positive symptoms. In a specific assessment of auditory hallucinations, SZ individuals with auditory hallucinations have been observed to perform worse than non-AVH peers on a task of pitch discrimination [12].

While the experience and subjective interpretation of AVHs undoubtedly involves many brain processes, such as deficits in memory operations, self-monitoring or interhemispheric miscommunication [13,8,5], the possible role of auditory perceptual deficits warrants detailed investigation. This study therefore had three aims. First, we tested whether patients with SZ showed impairments on discrimination of specific auditory features, or a more pervasive impairment of auditory processing using a well validated instrument, the Test of Basic Auditory Capabilities (TBAC)[14]. Secondly, we tested whether SZ patients who reported recent auditory hallucinations showed impaired auditory perception compared to those who did not. Finally, we tested whether more severe auditory hallucinations or more impaired cognitions would be associated with more impaired auditory perception in persons with SZs.

Methods

Subjects

Forty-four medicated SZ subjects (31 male) and twenty-nine healthy controls (14 male) were evaluated. SZ subjects were recruited through outpatient units at community and state hospitals. Healthy, non-psychiatric control subjects were recruited from the community via local and on-line advertisements. After detailed explanation of research procedures, subjects provided verbal and written informed consent. Study procedures were executed as approved by the Indiana University Institutional Review Board, and carried out according to guidelines of the Declaration of Helsinki.

SZ diagnoses were determined using the Structured Clinical Interview for Axis-I disorders (SCID-I, patient edition; [15]), symptom assessment, clinical observation and medical chart review. Subjects in the AVH group included all SZ subjects who self-reported experiencing AVHs in the week prior to study participation. All other SZ subjects, who did not endorse recent (one week) AVHs were in the Non-AVH group. SZ subjects were excluded if they met criteria as per the SCID-I for substance abuse or dependence over the previous 3 months, or evidence of positive urine toxicology at the time of screening.

Control participants were interviewed using the SCID-NP (nonpatient edition; [16]) to exclude individuals with psychiatric diagnoses including substance abuse or dependence (excluding nicotine), if they had a positive urine toxicology at the time of screening, or if they had a family history of an Axis-I psychiatric disorder. All subjects were excluded from participation if they had a lifetime serious head injury with a loss of consciousness greater than 5 minutes, a neurological disorder, or hearing deficits (as per a screening audiogram). All participants were at least 18 years of age.

Assessments

Auditory feature discrimination was assessed with the test of basic auditory capabilities (TBAC)[14]. The TBAC tests assessed the ability to detect a change in a single tone (frequency, intensity, and duration) as well as changes in sequences of tones. The measures with tone sequences were 1) pulse train; discrimination of a change in the relative timing of tone onsets in a sequence of six brief tones (i.e., rhythm), 2) temporal order; changes in the temporal order of the middle two tones in a four-tone sequence, and 3) embedded tone detection; detection of the presence of a tone (or a silent pause) in the middle of a sequence of nine (or eight) brief tones. All measures used a standard/two-alternative forced choice procedure in which a standard stimulus (tone or sequence) was followed by two stimuli, one of which was identical to the standard. The listener's task was to judge which comparison was different from the standard. For all TBAC tasks, performance is measured as percent correct for a sequence of trials varying in difficulty.

Auditory hallucinations were characterized with the Hamilton Program for Schizophrenia Voices Questionnaire (HPSVQ)[17]. If subjects reported hearing voices over the week prior to testing, subjects were asked to complete the HPSVQ which assess the subjective experience of voice hearing, asking questions regarding frequency and intensity of the voices, as well as feeling distress from the voices, feelings of worthlessness/uselessness from the voices, as well as addressing how often subjects follow the commands of the voices. The total HSPVQ is based on a series of 9 HPSVQ questions and a higher score is indicative of more severe auditory hallucinations. Two factors evaluating distress and intensity were calculated from the HPSVQ items for the correlational analysis, as per previous literature [18]. If subjects denied AVHs over the previous week, the HPSVQ was not administered as the questions related only to auditory voice hearing experiences over the past week. The Positive and Negative Syndrome Scale (PANSS) [19] was used to measure positive, negative and general symptoms in patients. The Full-scale intelligence quotient (IQ) was assessed with the Wechsler Abbreviated Scale of Intelligence (WASI) [20]. Working memory and capacity for psychomotor performance were assessed using the Digit

Span and Digit Symbol scaled scores, respectively, from the Wechsler Adult Intelligence Scale III (WAIS III) [21].

Statistical analysis

All statistical analyses were executed with SPSS statistical software from IBM [22]. Groups were first evaluated for differences in age, education, and age of psychosis onset (SZ groups) with a Student's t-test. Differences in ethnicity and gender were then determined using the computation of Chi-square. Demographic information is indicated in means ± standard deviation (SD), unless otherwise indicated. Next, to determine general group differences between the SZ and control groups on the six domains of the TBA, as well as group differences based on voice hearing experience a multivariate analysis of variance (MANOVA) was used. If significant, groups were compared with post-hoc comparisons with the Tukey HSD correction. An additional MANOVA was used to determine group differences between the SZ and control groups on measures of cognition, including IQ, as well as the digit span and digit symbol tasks. If significant, groups were compared with t-tests. In all MANOVAs Levene's Test for equality of variances was applied to assess the homogeneity of variance. T-tests were used to detect group differences between the AVH and Non-AVH groups on symptom domains of the PANSS (positive, negative, general, and total). All t-tests used in the analysis were two-tailed. Effect sizes were measured with Cohen's *d* for comparisons between the SZ and control groups, and when comparisons were made between AVH, non-AVH and control groups, partial eta squared was used. Finally, Pearson correlations were used to examine relationships between the TBAC, HPSVQ, PANSS, and cognitive measures.

Results

Demographic characteristics

Thirty-seven subjects in the SZ group met diagnostic criteria for Schizophrenia (AVH = 18; Non-AVH = 19) and seven for Schizoaffective Disorder (AVH = 2; Non-AVH = 5). The SZ and control groups were on average 37.07 ± 11.52 and 33.55 ± 10.75 years old, respectively. All subjects in the SZ group, with the exception of four individuals, had experienced auditory verbal hallucinations over the course of their lifetime, as per the SCID and chart review. Twenty of the 44 SZ individuals reported hearing voices during the week prior to testing (14 male). The AVH and Non-AVH groups were on average 37.25 ± 13.27 and 36.92 ± 10.13 years old, respectively. Groups (SZ, Controls, AVH SZs and Non-AVH SZs) did not differ significantly in age or gender ($p > .05$). Demographic information and clinical assessment measures with means and standard deviations are shown in Table 1. Most patients (39/44) were receiving anti-psychotic medication. Medication records at the time of testing for the SZ group are listed in Table 2.

Auditory feature discrimination in SZ

The SZ group demonstrated a deficit in performance on all domains of the TBAC compared to the control group, with the exception of pulse-train discrimination (Figure 1). A MANOVA revealed a significant multivariate main effect of group, Roy's Largest Root = .269, $F(6,66) = 2.96$, $p = .013$, and partial eta squared =.212. Given the significance of the

overall test, post-hoc testing using Tukey's test as a correction for multiple comparisons was to determine which of the six domains of the TBAC domains differed between the groups. Results indicated that there was a significant difference between the groups ($p < .05$) on frequency ($p = .010$, mean difference = 7.97, $d = .64$), intensity ($p = .021$, mean difference = 9.16, $d = .56$), duration ($p = .003$, mean difference = 10.39, $d = .75$), embedded tone test ($p = .001$, mean difference = 12.83, $d = .83$) and temporal order discrimination ($p = .004$, mean difference = 8.77, $d = .70$). Groups did not differ on the pulse-train discrimination domain ($p = .093$, mean difference = 6.66, $d = .41$). The control group scored higher on all six domains of the TBAC. Thus, SZ was associated with a pervasive disturbance of auditory feature perception, rather than deficits for specific features.

Group differences on TBAC based on voice hearing experience

Compared to controls, the non-AVH group showed more severe deficits on the TBAC compared to their SZ peers who reported recent AVHs (Figure 2). A MANOVA revealed a significant multivariate main effect of group, Roy's Largest Root = .269, $F(6,66) = 2.96$, $p = .013$, and partial eta squared =.212. Given the significance of the overall test, between-subject effects were evaluated to determine which of the six domains of the TBAC domains differed between the groups.

Tests of between-subjects effects indicated differences on the TBAC for all domains except the intensity and pulse-train discrimination tasks. Specifically, group differences were observed on tests of frequency ($F(2, 70) = 3.68$, $p = .030$, partial eta squared = .10) and duration ($F(2,70) = 4.84$, $p = .011$, partial eta squared = .12) discrimination, on the embedded tone test ($F(2,70) = 6.47$, $p = .003$, partial eta squared = .16) and for temporal order discrimination ($F(2,70) = 4.31$, $p = .017$, partial eta squared = .11). There was a trend for group differences on the intensity discrimination test ($F(2,70) = 2.92$, $p = .061$, partial eta squared = .08) and pulse-train discrimination ($F(2,70) = 2.05$, $p = .14$, partial eta squared = .06).

Post-hoc multiple comparisons with Tukey HSD correction indicated that the Non-AVH group was more consistently impaired on TBAC tests compared to the AVH group. The non-AVH SZ showed a deficit compared to the control group on frequency ($p = .031$; mean difference = 9.00), duration ($p = .025$; mean difference = 10.31), embedded tone test ($p = .003$; mean difference = 14.80) and temporal order discrimination ($p = .024$; mean difference = 9.32). There was also a trend towards a significance difference on the domain of intensity discrimination between the non-AVH group and controls ($p = .059$; mean difference = 10.49). The only observed significant difference between the AVH SZ and control groups were deficits in the AVH SZ group on duration discrimination ($p = .031$; mean difference = 10.49). There were also trends towards significant differences between these groups, with deficits observed in the AVH SZ group, on the embedded tone test ($p = .058$; mean difference = 10.47) as well as temporal order discrimination ($p = .075$; mean difference = 8.09). The AVH and non-AVH groups did not differ on any of the TBAC tests. See Table 3 for details of TBAC performance with percent correct and standard deviation by group.

Group differences on cognitive measures

Overall, group differences were observed between the SZ and control groups on measures of IQ and the Digit Symbol task (Table 1). A MANOVA determined a significant main effect of group (2 levels: SZ and control), Roy's Largest Root = .488, $F(3,69) = 11.22$, $p < .001$, and partial eta squared =.328. Given the significance of the overall test, post-hoc t-tests were used to determine SZ and control group differences. The SZ group showed a significant deficit in IQ ($t(71) = 4.003$, $p < .001$, $d = .96$), and on the digit symbol task ($t(46.40) = 5.03$, $p < .001$, $d = 1.29$), but not on the digit span task ($t(71)= 1.22$, $p = .228$, $d = .29$).

Group differences in symptoms

Group means and SDs for the PANNS factor scores are shown in Table 1. The AVH group showed higher PANSS positive symptom ($t(42)=-2.34$, $p = .024$, $d = .71$) and general symptom scores ($t(27.93)=-2.11$, $p = .044$, $d = .67$) compared to the non-AVH group. The groups did not statistically differ in negative symptoms scores ($t(42)= .99$, $p = .328$, $d = .30$) or total scores ($t(42)= -1.81$, $p = .077$, $d = .55$).

Correlations

Across all SZ participants (Table 4) measures of the TBAC were highly intercorrelated ($r= .4\text{-}.8$; $p < .05$). PANSS total scores were observed to negatively correlate with frequency discrimination ($r = -.31$, $p = .042$) and temporal order discrimination ($r = -.31$, $p =.044$). Temporal order discrimination was also observed to be negatively associated with PANSS negative domain scores ($r = -.30$, p .05). With respect to cognitive measures, IQ was observed to positively correlate with all measures of the TBAC, including frequency ($r(n = 44) = .55$, $p < .001$), intensity ($r = .57$, $p <.001$), duration ($r = .41$, $p = .006$), pulse-train ($r = .54$, $p <.001$), and temporal order discrimination ($r = .59$, $p <.001$), as well as the embedded tone test ($r = .55$, $p < .001$). The digit symbol was positively associated with frequency ($r = .31$, $p =.038$), pulse-train ($r = .39$, $p =.010$), and temporal order discrimination ($r = .34$, $p = .025$). Digit span failed to significantly correlate with any TBAC measure ($p >.05$). In controls, all measures of the TBAC were significantly correlated with IQ for healthy controls ($p < .05$, $r = .45$ - $.57$).

For those in the AVH SZ group (Table 4), none of the six domains of the TBAC correlated with either factor of the HPSVQ (distress or intensity) ($p >.05$). PANSS negative symptoms were negatively associated with the HPSVQ factor of distress ($r(n = 20) = -.48$, $p = .034$) as well as with frequency ($r = -.60$, $p = .005$), and pulse-train discrimination ($r = -.58$, $p = .008$) measures from the TBAC. PANSS positive scores were positively associated with the HPSVQ factor of intensity ($r = .50$, $p = .025$), but were not observed to be significantly associated with any of the six domains of the TBAC. PANSS general scores were also negatively associated with intensity discrimination ($r = -.60$, $p =.006$) of the TBAC.

Discussion

This study demonstrates that persons with SZ are impaired in the discrimination of a broad range of auditory features, consistent with our hypothesis. Contrary to our initial hypothesis, however, the non-AVH SZ individuals were observed to have the more pronounced deficits

in auditory perception compared to controls, than their AVH SZ peers. Auditory perceptual performance instead was correlated with overall intellectual function.

The SZ group demonstrated deficits in auditory perception for single auditory features (frequency, intensity and duration) as well as more complex stimulus properties, such as temporal order. In a factor analysis by Kidd et al. (2007), these tests loaded most strongly on the loudness-duration factor and pitch and time factor of the entire set of TBAC tests [14]. The results are consistent with a recent meta-analysis of pitch discrimination deficits [4], as our study yielded medium to large effect sizes for discrimination tasks on frequency, intensity, duration and temporal order, as well as the embedded tone task (Cohen's d = .56 - .83). These findings suggest that impaired processing of non-speech sounds is relatively non-specific to a specific feature or category. Since previous studies have generally focused on a single domain of auditory feature perception, especially pitch or frequency discrimination, these data implicate a broad spectrum of dysfunction in the perceptual domain. This conclusion is also supported by the wide range of deficits across studies of SZ, including impaired in duration [23] intensity [24], phoneme [25] and sound location [26] discrimination, as well as detection of abnormal melodies on the Distorted Tunes Task [27].

The entire set of TBAC scores were robustly correlated with IQ scores, suggesting that these deficits are driven by a general deficit in task performance in schizophrenia. To our knowledge, this is the first study to examine the relationship of auditory perceptual performance to standard tests of IQ in SZ subjects. In schizophrenia, deficits on tasks of tone matching have been related to deficits in encoding of information [28,29] and more impaired spatial discrimination and localization have been associated with more severe cognitive symptoms on the PANSS [26]. These findings are consistent with the argument by Javitt (2009) that sensory deficits may negatively impact cognitive processes [6]. It is important to acknowledge that in healthy controls, general intellectual capacity, as measured by SAT scores, was determined to account for less than 5% of the variance in performance on the TBAC [14].

Given that the current study and previous research indicate that SZ is associated with impairment on a wide range of auditory tasks, it was somewhat surprising that our voice hearing group was less severely affected than the voice hearing group compared to the controls. Similarly, Perrin et al. (2010) found that greater severity of hallucinations was associated with better accuracy on a sound localization task in SZ patients [26]. On the other hand, a lack of a relationship between auditory discrimination and the presence or absence of auditory hallucinations has been found by some investigators [25] or superiority for patients with no hallucinations [12]. These heterogeneous results may reflect the variety of neurobiological mechanisms and responses to treatment which modulate the experience of hallucinations [30,13]. There has also been substantial methodological variation among studies, such as the method of assessment of hallucinatory experiences and the time frame over which these were evaluated. For instance, the study by McLachlan et al. (2013) reported that individuals with schizophrenia and a history of auditory hallucinations performed worse on tasks of pitch discrimination, compared to non-hallucinating peers [12]. While these findings initially appear in contrast to our study, the use of different operational definitions to explore auditory hallucinations makes direct comparison of results difficult.

McLachlan et al. classified groups based on those with and without a history of auditory hallucinations in the past 10 weeks, who experienced intermittent auditory hallucinations throughout illness even while taking medication, or who experienced auditory hallucinations at the start of their illness which occurred within the past two years. Our study, explored recent AVH experience, as defined by occurrence within the past week. Therefore, given the difference in group inclusion definitions, it is plausible that at least some subjects in McLachlan's hallucinatory group would have been considered in the non-AVH group using our study criteria. These methodological inconsistencies support the need for further investigation using more granular temporal assessment of current and past history of AVHs.

Additionally, the AVH SZ group also showed a significant deficit in duration discrimination, as compared to controls. It is important to consider that duration discrimination may also represent, in additional to basic feature detection, a perceptual timing task. In this light, it is important to denote that both SZ groups performed significantly worse than controls and thus recent AVH experience may be independent of timing perception. A caveat to this, however, is that the AVH group did not perform significantly worse on the temporal order task, which could also be considered a perceptual timing task. It will be important for future research to investigate the relationship between AVH and experience of time.

There are several limitations to this study which should motivate future research. Whether subjects experienced AVHs during testing was not evaluated and this might impact auditory perception. Studying AVH in SZ comes with inherent limitations associated with this population. SZ individuals vary in current and past medications, duration of illness, symptom expression, substance use, and other comorbid diagnoses. Such factors hinder the unambiguous interpretation of relationships between symptoms and perceptual measures. The findings of this study therefore need to be replicated in independent samples using similar inclusion criteria. Studies of relatives and persons at high risk for SZ could clarify whether auditory perceptual deficits are related to genetic risk or predate the onset of the initial psychotic episode. Tucker et al (2013), for example, found that relatives of persons with SZ showed deficits for tone duration discrimination, but not pitch discrimination, suggesting that features may differ in their sensitivity to genetic or other familial risk factors [31]. Other behavioral studies of auditory perception in SZ individuals with AVHs have utilized dichotic listening tasks, finding that AVHs were associated with a decrease in the traditionally observed right ear advantage, which investigators suggested may indicate left primary auditory cortex dysfunction with increased severity of hallucinations [32,33]. Future research should thus consider the role of differences in hemispheric processing.

In conclusion, this study makes several contributions to the characterization of auditory perception and hallucinations in schizophrenia. First, it indicates that persons with SZ show deficits in the perception of a broad range of auditory features. Second, the data suggest that it is unlikely that these auditory perceptual deficits play a major role in the experience of current auditory hallucinations. Rather, auditory perceptual deficits are strongly associated with overall cognition, and support the hypothesis that degradation of sensory input may disrupt subsequent cognitive processing.

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References

1. Jonsson CO, Sjöstedt A (1973) Auditory perception in schizophrenia: a second study of the Intonation test. Acta Psychiatrica Scandinavica 49 (5):588–600 [PubMed: 4760956]
2. Rabinowicz EF, Silipo G, Goldman R, Javitt DC (2000) Auditory sensory dysfunction in schizophrenia: imprecision or distractibility? Archives of general psychiatry 57 (12):1149–1155 [PubMed: 11115328]
3. Strous RD, Cowan N, Ritter W, Javitt DC (1995) Auditory sensory (“ echoic”) memory dysfunction in schizophrenia. American Journal of Psychiatry 152 (10):1517–1519 [PubMed: 7573594]
4. Dondé C, Luck D, Grot S, Leitman DI, Brunelin J, Haesebaert F (2016) Tone-matching ability in patients with schizophrenia: A systematic review and meta-analysis. Schizophrenia Research
5. Javitt DC, Sweet RA (2015) Auditory dysfunction in schizophrenia: integrating clinical and basic features. Nature Reviews Neuroscience 16 (9):535–550 [PubMed: 26289573]
6. Javitt DC (2009) When doors of perception close: bottom-up models of disrupted cognition in schizophrenia. Annual review of clinical psychology 5:249–275
7. Cole MG, Dowson L, Dendukuri N, Belzile E (2002) The prevalence and phenomenology of auditory hallucinations among elderly subjects attending an audiology clinic. International journal of geriatric psychiatry 17 (5):444–452 [PubMed: 11994933]
8. Ford JM, Dierks T, Fisher DJ, Herrmann CS, Hubl D, Kindler J, Koenig T, Mathalon DH, Spencer KM, Strik W (2012) Neurophysiological studies of auditory verbal hallucinations. Schizophrenia bulletin 38 (4):715–723 [PubMed: 22368236]
9. Larøi F, Sommer IE, Blom JD, Fernyhough C, Hugdahl K, Johns LC, McCarthy-Jones S, Preti A, Raballo A, Slotema CW (2012) The characteristic features of auditory verbal hallucinations in clinical and nonclinical groups: state-of-the-art overview and future directions. Schizophrenia bulletin 38 (4):724–733 [PubMed: 22499783]
10. Javitt DC, Shelley A-M, Ritter W (2000) Associated deficits in mismatch negativity generation and tone matching in schizophrenia. Clinical Neurophysiology 111 (10):1733–1737 [PubMed: 11018486]
11. Bruder GE, Wexler BE, Sage MM, Gil RB, Gorman JM (2004) Verbal memory in schizophrenia: additional evidence of subtypes having different cognitive deficits. Schizophrenia Research 68 (2):137–147 [PubMed: 15099598]
12. McLachlan NM, Phillips DS, Rossell SL, Wilson SJ (2013) Auditory processing and hallucinations in schizophrenia. Schizophrenia research 150 (2):380–385 [PubMed: 24054462]
13. Ćurčić-Blake B, Ford J, Hubl D, Orlov ND, Sommer IE, Waters F, Allen P, Jardri R, Woodruff PW, Olivier D (2016) Interaction of language, auditory and memory brain networks in auditory verbal hallucinations. Progress in Neurobiology
14. Kidd GR, Watson CS, Gygi B (2007) Individual differences in auditory abilities. The Journal of the Acoustical Society of America 122 (1):418–435. doi:doi:10.1121/1.2743154 [PubMed: 17614500]
15. First MB, Spitzer Robert L, Gibbon Miriam, and Williams Janet B.W (2002) Structured Clinical Interview for DSM-IV-TR Axis I Disorders, Research Version, Patient Edition. (SCID-I/P)
16. First MB, Spitzer Robert L, Gibbon Miriam, and Williams Janet B.W. (2002) Structured Clinical Interview for DSM-IV-TR Axis I Disorders, Research Version, Non-patient Edition. (SCID-I/NP)
17. Van Lieshout RJ, Goldberg JO (2007) Quantifying self-reports of auditory verbal hallucinations in persons with psychosis. Canadian Journal of Behavioural Science/Revue canadienne des sciences du comportement 39 (1):73–77. doi:10.1037/cjbs2007006

18. Kim SH, Jung HY, Hwang SS, Chang JS, Kim Y, Ahn YM, Kim YS (2010) The usefulness of a self-report questionnaire measuring auditory verbal hallucinations. Progress in Neuro-Psychopharmacology and Biological Psychiatry 34 (6):968–973 [PubMed: 20472012]
19. Kay SR, Fiszbein A, Opler LA (1987) The positive and negative syndrome scale (PANSS) for schizophrenia. Schizophrenia Bulletin 13 (2):261–276 [PubMed: 3616518]
20. Wechsler D (1987) WMS-R: Wechsler Memory Scale–revised manual. San Antonio, TX: The Psychological Corporation. Harcourt Brace Jovanovich,
21. Tulsky DS, Ivnik R, Price LR, Wilkins C (2003) Assessment of cognitive functioning with the WAIS-III and WMS-III: Development of a six-factor model. Clinical interpretation of the WAIS-III and WMS-III:147–179
22. CORP I (2013) IBM SPSS Statistics for Windows. Version 22.0. IBM Corp, Armonk, NY
23. Todd J, Michie P, Jablensky A (2003) Association between reduced duration mismatch negativity (MMN) and raised temporal discrimination thresholds in schizophrenia. Clinical Neurophysiology 114 (11):2061–2070 [PubMed: 14580604]
24. Todd J, Michie PT, Schall U, Karayanidis F, Yabe H, Näätänen R (2008) Deviant matters: duration, frequency, and intensity deviants reveal different patterns of mismatch negativity reduction in early and late schizophrenia. Biological psychiatry 63 (1):58–64 [PubMed: 17585889]
25. Li C-sR, Chen M-c, Yang Y-y, Chen M-c, Tsay P-k (2002) Altered performance of schizophrenia patients in an auditory detection and discrimination task: exploring the 'self-monitoring'model of hallucination. Schizophrenia Research 55 (1):115–128 [PubMed: 11955971]
26. Perrin MA, Butler PD, DiCostanzo J, Forchelli G, Silipo G, Javitt DC (2010) Spatial localization deficits and auditory cortical dysfunction in schizophrenia. Schizophrenia research 124 (1):161–168 [PubMed: 20619608]
27. Leitman DI, Foxe JJ, Butler PD, Saperstein A, Revheim N, Javitt DC (2005) Sensory contributions to impaired prosodic processing in schizophrenia. Biological psychiatry 58 (1):56–61 [PubMed: 15992523]
28. Javitt DC, Strous RD, Grochowski S, Ritter W, Cowan N (1997) Impaired precision, but normal retention, of auditory sensory (" echoic") memory information in schizophrenia. Journal of abnormal psychology 106 (2):315 [PubMed: 9131851]
29. March L, Cienfuegos A, Goldbloom L, Ritter W, Cowan N, Javitt DC (1999) Normal time course of auditory recognition in schizophrenia, despite impaired precision of the auditory sensory (" echoic") memory code. Journal of Abnormal Psychology 108 (1):69 [PubMed: 10066994]
30. Blom JD, Sommer IE (2010) Auditory hallucinations: Nomenclature and classification. Cognitive and Behavioral Neurology 23 (1):55–62 [PubMed: 20299866]
31. Tucker R, Farhall J, Thomas N, Groot C, Rossell SL (2007) An examination of auditory processing and affective prosody in relatives of patients with auditory hallucinations. Current perspectives on the mechanisms of auditory hallucinations in clinical and non-clinical populations:106
32. Hugdahl K, Løberg E-M, Falkenberg LE, Johnsen E, Kompus K, Kroken RA, Nygård M, Westerhausen R, Alptekin K, Özgören M (2012) Auditory verbal hallucinations in schizophrenia as aberrant lateralized speech perception: evidence from dichotic listening. Schizophrenia research 140 (1):59–64 [PubMed: 22796149]
33. Løberg E-M, Jørgensen HA, Hugdahl K (2004) Dichotic listening in schizophrenic patients: effects of previous vs. ongoing auditory hallucinations. Psychiatry research 128 (2):167–174 [PubMed: 15488959]

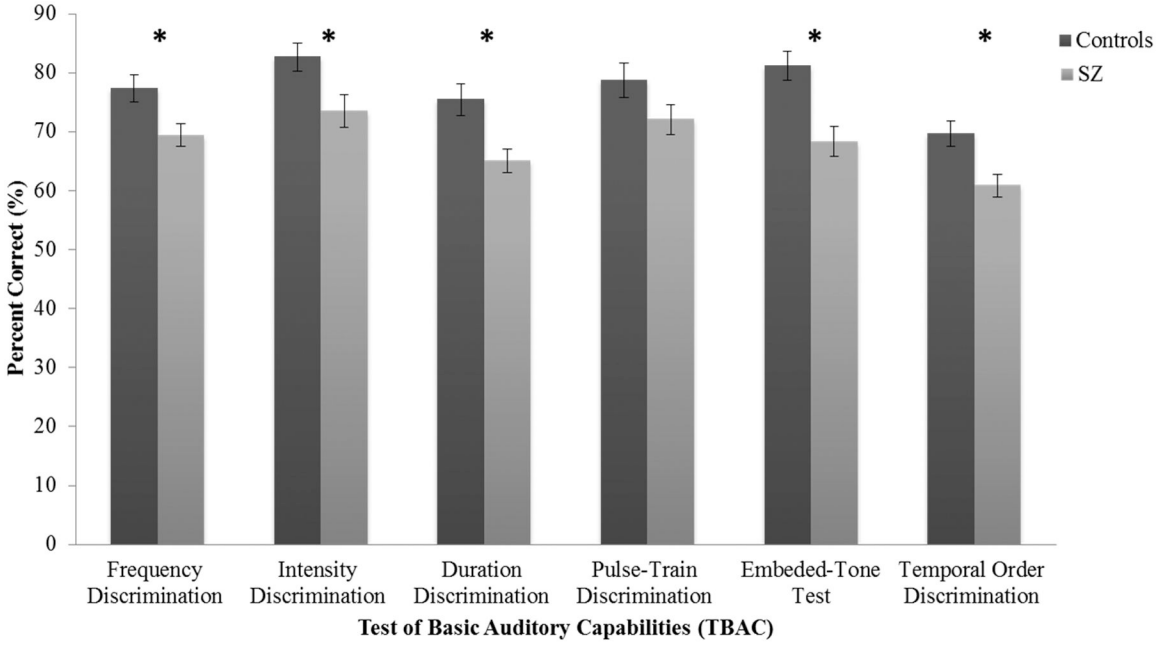

Figure 1: Primary Group Differences on the TBAC.

The dark and light gray bars represent the control and SZ groups, respectively. The asterisk (*) denotes significant differences between the groups ($p < .05$).

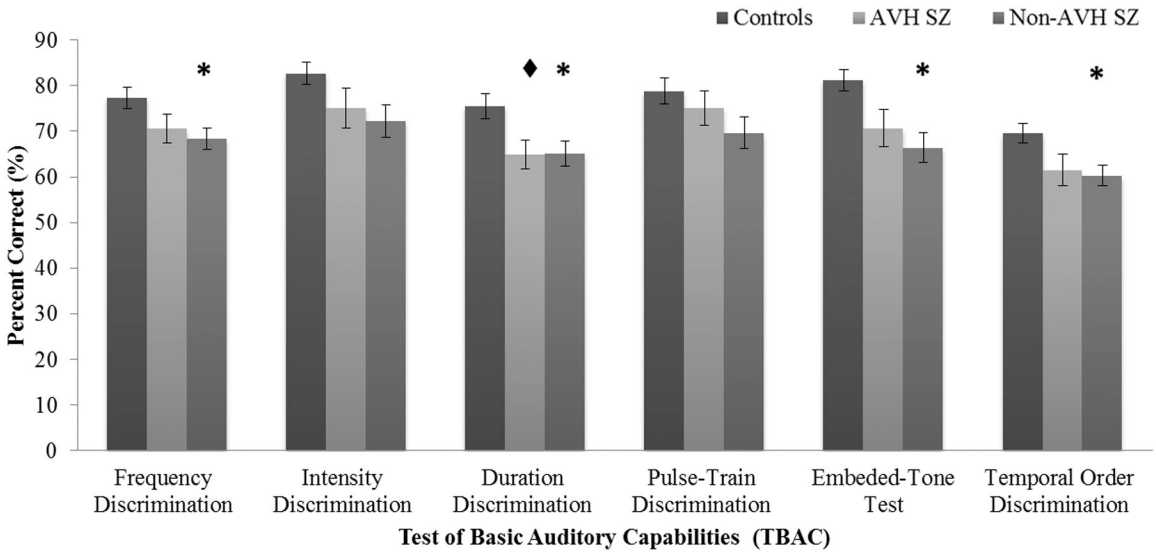

Figure 2: AVH vs Non-AVH Group Differences on TBAC.

The dark medium, and light gray bars represent the control, Non-AVH and AVH SSD groups, respectively. The asterisk (*) denotes significant differences between the control and Non-AVH SZ groups ($p < .05$), and a solid diamond (♦) represents a significant difference between the control and AVH SZ groups ($p < .05$).

Table 1:

Demographic Information

	Control Group (1)	SZ Group (2)	AVH Group (3)	Non-AVH Group (4)	*Significant Differences (<.05)*
N	29	44	20	24	.
Gender (M:F)	14:15	31:13	14:6	17:7	.
Age (Range;SD)	33.55 (20–55; 10.75)	37.07 (19–59; 11.52)	37.25 (19–59; 13.27)	36.92 (22–53; 10.13)	.
Ethnicity (C: AA: A: O)	15:14:0:0	15:26:1:2	5:13:0:2	10:13:1:0	.
Age Psychosis Onset	.	22.93 (9.36)	20.94 (9.67)	24.64 (8.95)	.
Years Education	15.93 (2.59)	12.74 (2.51)	12.45 (2.63)	13.00 (2.43)	1 > 2, 3, 4
IQ	110.55 (13.11)	96.77 (15.17)	96.90 (16.98)	96.67 (13.85)	1 > 2, 3,4
Digit Span	11.21 (2.55)	10.30 (3.45)	9.75 (3.02)	10.75 (3.78)	.
Digit Symbol	11.07 (3.18)	7.64 (2.26)	7.40 (2.35)	7.83 (2.22)	1 > 2, 3, 4
PANSS Positive	.	16.45 (5.82)	18.60 (6.18)	14.67 (4.96)	3 > 4
PANSS Negative	.	14.81 (5.61)	13.90 (5.54)	15.58 (5.67)	.
PANSS General	.	31.05 (14.01)	33.90 (9.97)	28.67 (5.36)	3 > 4
PANSS Total	.	62.32 (14.01)	66.40 (17.22)	58.91 (9.78)	.

Note: M = Male; F = Female; (Standard Deviation); SD = Standard Deviation; C: Caucasian; AA: African American; A: Asian; O: Other

Table 2:

Medication Information for SZ Group

	Group	
Medication	**AVH**	**Non-AVH**
Atypical antipsychotic	18	18
Typical antipsychotic	3	1
Lithium	2	1
Benzodiazepine	1	0
Antidepressant	11	9
Anticonvulsant	0	4
Anticholinergic	1	2
Stimulant	1	2
Total unmedicated	4	1
Total medicated	16	23
Total unknown	0	0

Note: AVH = Auditory Verbal Hallucinations

Table 3:

TBAC Performance

	Control Group (1)	SZ Group (2)	AVH Group (3)	Non-AVH Group (4)	*Significant Differences (<.05)*
Frequency Discrimination	77.35 (12.25)	69.38 (12.72)	70.62 (14.01)	68.35 (11.74)	1 > 2, 4
Intensity Discrimination	82.71 (12.65)	73.54 (18.25)	75.14 (19.67)	72.22 (17.30)	1 > 2
Duration Discrimination	75.48 (14.29)	65.08 (13.59)	64.99 (14.11)	65.16 (13.44)	1 > 2, 3, 4
Pulse-Train Discrimination	78.79 (15.59)	72.13 (16.83)	75.07 (16.79)	69.68 (16.83)	1 > 4
Embedded Tone Task	81.17 (13.06)	68.34 (16.78)	70.70 (17.79)	66.37 (15.99)	1 > 2, 4
Temporal Order Discrimination	69.62 (11.58)	60.86 (13.03)	61.53 (15.27)	60.30 (11.14)	1 > 2, 4

Note: (Standard Deviation)

Table 4:

Correlations with TBAC Domains and HPSVQ

		1	2	3	4	5	6	PANSS Positive	PANSS Negative	PANSS General	IQ	Digit Symbol	Digit Span
1	Frequency	1	**.77****	**.52****	**.82****	**.76****	**.72****	−.28	−.17	−.22	**.55****	**.31***	.21
2	Intensity		1	**.68****	**.80****	**.84****	**.74****	−.19	−.11	−.28	**.57****	.26	.26
3	Duration			1	**.44***	**.57****	**.63****	−.17	−.08	−.23	**.41***	.14	.10
4	Pulse-Train				1	**.82****	**.72****	−.11	−.28	−.16	**.54****	**.39***	.29
5	Embedded Tone					1	**.74****	−.05	−.24	−.16	**.55****	.25	.29
6	Temporal Order						1	−.07	−**.30***	−.27	**.59****	**.34***	.26
†	HPSVQ Distress	.13	−.16	−.10	.13	−.14	.15	−.05	−**.48***	−.03	.15	.26	.23
†	HPSVQ Intensity	−.21	−.28	−.20	−.15	−.05	.05	**.50***	−.03	.16	−.12	.03	−.02

Note:

** p <.001;

* p <. 05;

†= AVH SZ group only (n = 20);

HPSVQ = Hamilton Program for Schizophrenia Voices Questionnaire