View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Northumbria Research Link

Northumbria Research Link

Citation: Moseley, Peter, Alderson-Day, Ben, Common, Stephanie, Dodgson, Guy, Lee, Rebecca, Mitrenga, Kaja, Moffatt, Jamie and Fernyhough, Charles (2021) Continuities and discontinuities in the cognitive mechanisms associated with clinical and non-clinical auditory verbal hallucinations. Clinical Psychological Science. ISSN 2167-7026 (In Press)

Published by: SAGE

URL: https://doi.org/10.1177/21677026211059802 <https://doi.org/10.1177/21677026211059802>

This version was downloaded from Northumbria Research Link: http://nrl.northumbria.ac.uk/id/eprint/47586/

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: http://nrl.northumbria.ac.uk/policies.html

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)

Northumbria University NEWCASTLE

CUSTOMER SERVICE EXCELLENCE CSE UniversityLibrary

Continuities and discontinuities in the cognitive mechanisms associated with clinical and non-clinical auditory verbal hallucinations

Authors: Peter Moseley[1*], Ben Alderson-Day[2], Stephanie Common[3], Guy Dodgson[4], Rebecca Lee[2], Kaja Mitrenga[2], Jamie Moffatt[5], Charles Fernyhough[2]

Author affiliations:

1. Department of Psychology, Northumbria University, Northumberland Building, College Lane, Newcastle upon Tyne, NE1 8SG.
2. Department of Psychology, Durham University, Science Laboratories, South Road, Durham, DH1 3LE.
3. Tees, Esk, & Wear Valley NHS Foundation Trust, West Park Hospital, Edward Pease Way, Darlington DL2 2TS
4. Cumbria, Northumberland, Tyne, & Wear NHS Foundation Trust, St. Nicholas Hospital, Jubilee Road, Newcastle upon Tyne, NE3 3XT.
5. School of Psychology, University of Sussex, Falmer, UK.

* **Corresponding author**: Dr. Peter Moseley, Department of Psychology, Northumbria University, Northumberland Building, College Lane, Newcastle Upon Tyne, NE1 8SG. E-mail: peter.moseley@northumbria.ac.uk.

Running title: Cognition in clinical and non-clinical voice-hearing

Key words: hallucinations, psychosis, psychotic-like experiences, cognition, auditory perception

Abstract

Auditory verbal hallucinations (AVH) are typically associated with schizophrenia but also occur in individuals without any need for care (non-clinical voice-hearers; NCVH). Cognitive models of AVH posit potential biases in source monitoring, top-down processes, or a failure to inhibit intrusive memories. However, research across clinical/non-clinical groups is limited, and the extent to which there may be continuity in cognitive mechanism across groups, as predicted by the psychosis continuum hypothesis, is unclear. We report two studies in which voice-hearers with psychosis (*n* = 31) and NCVH participants reporting regular spiritual voices (*n* = 26) completed a battery of cognitive tasks. Compared to non-voice-hearing groups (*n* = 33 and 28), voice-hearers with psychosis showed atypical performance on signal detection, dichotic listening, and memory inhibition tasks, but intact performance on the source monitoring task. NCVH participants, however, only showed atypical signal detection, suggesting differences between clinical and non-clinical voices potentially related to attentional control and inhibition. These findings suggest that, at the level of cognition, continuum models of hallucinations may need to take into account continuity, but also discontinuity, between clinical and non-clinical groups.

Introduction

Auditory verbal hallucinations (AVH, or ‘voices’) are typically associated with schizophrenia or other psychotic disorders (Bauer et al., 2011), though are not specific to any diagnosis (Toh et al., 2015; Waters & Fernyhough, 2017). Evidence suggests that, compared to non-hallucinating patients, individuals with schizophrenia and AVH show biases or impairments in several cognitive domains, including reality monitoring (memory for the self/non-self source of information) (Brookwell et al., 2013; Woodward et al., 2007), auditory signal detection (argued to reflect the influence of top-down processes) (Bristow et al., 2014; Vercammen et al., 2008), attentional control (Hugdahl et al., 2013), and memory inhibition (Waters et al., 2003). Prominent cognitive models of AVH accordingly suggest that they result from an externalising bias in reality monitoring, and/or over-weighting of top-down processes (Moseley et al., 2013; Waters et al., 2012), leading to external misattribution of self-generated mental events (e.g., inner speech). Atypical attention and inhibitory processes have been proposed to underlie the uncontrollable and intrusive elements of AVH (Waters et al., 2003). Together, these mechanisms have been proposed as part of an influential multicomponent model of AVH (Waters et al., 2012).

One approach to studying hallucinations outside of psychopathology has been to administer self-report questionnaires to assess variability in ‘hallucination-proneness’ in general population samples. This approach avoids confounds of anti-psychotic medication usage and comorbid symptoms of psychosis. Such studies have showed mixed results regarding associations between cognition and hallucination-proneness in the general population. A number of studies provide evidence that biased performance on auditory signal detection (Bentall & Slade, 1985; Brookwell et al., 2013; Moseley et al., 2021) or on other similar tasks (de Boer et al., 2019) is associated with hallucination-proneness in the general population, while evidence regarding other cognitive domains is more mixed (Alderson-Day et al., 2019; Badcock & Hugdahl, 2012; Moseley et al., accepted; Laroi et al., 2004; Woodward et al., 2007). An alternative approach used in recent research has been to focus on individuals reporting AVH of comparable frequency and recurrence to people with psychosis, but who do not meet criteria for any psychiatric disorder (Peters et al., 2016; Powers et al., 2017; Sommer et al., 2010). Such non-clinical voice-hearers (NCVHs) tend to report fewer negative symptoms and less threatening appraisals (Peters et al., 2017), and their experiences tend to be less distressing and more controllable than in psychosis (Daalman et al., 2011; Powers et al., 2017).

Research into the cognitive mechanisms underlying AVH in NCVH is more limited, however. Daalman et al. (2011) administered a neuropsychological battery to a group of NCVHs, reporting lower scores (compared to non-voice-hearing controls) on executive function, working memory, abstract reasoning, and a verbal intelligence assessment, but not on long-term verbal memory, spatial reasoning, or processing speed. Neuroimaging has also indicated that NCVHs do not show atypical language lateralization in a verbal fluency task (Diederen et al., 2010), which is commonly observed in schizophrenia (Sommer et al., 2001). Others have provided evidence for over-weighted top-down processes in NCVHs (Alderson-Day et al., 2017; Powers et al., 2017), while there is mixed evidence regarding structural differences in the paracingulate sulcus (PCS), a brain region involved in reality monitoring, across clinical and non-clinical groups (Garrison et al., 2019; Powers et al., 2020). However, while studies have investigated these aspects of cognition in relation to general population hallucination-proneness, to our knowledge, no study has reported on reality monitoring, intentional inhibition, or dichotic listening (assessing both language lateralization and attentional control) in NCVHs, nor used the most common task linked to top-down processing in hallucinations research (auditory signal detection) in a NCVH group. Research in this area is crucial in order to untangle when atypical patterns of performance are specific to AVH broadly, as opposed to psychotic AVH specifically, or psychopathology more broadly.

We report on data from two studies, regarding cognition in AVH in psychosis and in NCVHs, covering the core mechanisms reviewed above. As part of a larger ongoing study (Alderson-Day et al., 2021), we recruited individuals in early intervention in psychosis services (henceforth referred to as the *patient* group) reporting distressing AVH (Study 1). Following prior research from other teams (Baumeister et al., 2017; Peters et al., 2016; Powers et al., 2017), we also recruited NCVHs who reported hearing spiritual voices (often referred to as 'clairaudient' or 'psychic'), with participating individuals reporting regular voices but not meeting criteria for a psychiatric diagnosis (e.g., they were not distressed) (Study 2). The patient and NCVH group were compared to matched controls on four cognitive tasks: source memory (reality monitoring) (Woodward et al., 2007), auditory signal detection (Bristow et al., 2014), consonant-vowel dichotic listening (Hugdahl et al., 2013), and intentional inhibition (Waters et al., 2003). These tasks were chosen as some of the most frequently used in hallucinations research with psychosis patients, and as key components of previous cognitive models (Waters et al., 2012), yet that have not previously been used with NCVH samples (not including general population 'proneness' studies). NCVH participants also completed assessments of hallucinations, delusions, anxiety, and depression to assess other aspects of psychopathology compared to the general population. We expected that, consistent with previous research, participants in the patient group would show atypical performance on all four tasks. If non-clinical experiences result from the same underlying mechanisms as psychosis, NCVHs would also show atypical performance on all four tasks. If underlying mechanisms are not continuous across the nonclinical/clinical divide, we would expect a different performance profile in NCVHs compared to patients. We set out to provide further data regarding links between cognition and hallucinations in both psychosis and NCVHs.

Method

Participants

A power analysis suggested at least 26 participants per group for comparisons using independent samples *t*-tests, assuming a large effect size based on previous meta-analytic evidence (Brookwell et al., 2013) ($\alpha = .05$, $d = 0.70$, power = 0.8), though recruitment proceeded flexibly based mainly on success recruiting into the voice-hearing groups. For study 1, the psychosis voice-hearer group (the *patient group*) consisted of service-users recruited from early intervention in psychosis services in northern England, UK ($N = 31$, age *M(SD)* = 28.55(10.22), *n* female = 14). All were of white British ethnicity (reflecting regional norms, with low racial diversity in this area of the UK). Service-users were invited to take part if they were aged 16–65, reported hearing voices at least once a week over the last month, were fluent English speakers, had normal/corrected-to-normal vision, and were within their first 9 months of using early intervention services (due to participation in another study of which this was an inclusion criteria). Exclusion criteria were the presence of neurological diagnoses, hearing impairments, or suspected duration of untreated psychosis of > 5 years. Information regarding diagnosis and medication usage is provided in Supplementary Materials (S1 & S2). The healthy control group ($N = 33$, age *M(SD)* = 27.91(10.41), *n* female = 19) was recruited using community advertisement, social media, and word-of-mouth.

For study 2, the non-clinical voice-hearer (NCVH) group was recruited from spiritualist communities across the UK ($N = 26$, age *M(SD)* = 58.72(11.72), *n* female = 18), using newsletters, online advertisements, and visits by researchers to spiritualist churches. Individuals were invited to participate if they reported hearing voices at least once a month that did not solely occur within a spiritualist church. This latter criterion was used to ensure participants were not solely reporting experiences associated with meditation or trance. Participants were screened via telephone. Exclusion criteria were the same as for study 1, with the addition of exclusion based on psychiatric diagnosis or severe distress. Specifically, participants were asked i) if they ever found voices distressing; ii) if they had ever received a psychiatric or neurological diagnosis; and iii) if they had ever been in contact with health services regarding their voices. An affirmative answer to any of these questions led to exclusion from the study. The non-voice-hearing control group (*N* = 28, age *M(SD)* = 58.68(11.60), *n* female = 17) were recruited as in Study 1. Further demographic information is presented in Table 1.

Assessment of hallucinations and delusions

Psychotic Symptom Rating Scale (PSYRATS) (Haddock et al., 1999) – the PSYRATS is an interviewer-administered symptom-rating scale, which provides scores for attributes relating to auditory hallucinations (11 items) and delusions (6 items), including frequency, duration, location, loudness, and distress (for hallucinations), and preoccupation, conviction, distress, and disruption (for delusions). Sum scores on the auditory hallucinations scale can be calculated for cognitive (scored between 0-12), emotional (0-16), and physical (0-12) attributes. Both hallucinations and delusions subscales were used in the patient group (Study 1), though only the hallucinations subscale was used for the NCVH group (Study 2), because it was judged inappropriate to pathologise spiritual beliefs, and also complex to unpick what could be classed as delusional ideation, in the non-clinical group.

Launay-Slade Hallucination Scale (LSHS) (Bentall & Slade, 1985; McCarthy-Jones & Fernyhough, 2011) – the LSHS is a 9-item self-report scale assessing hallucinatory experiences, with subscales for auditory experiences (5 items, e.g., *I have been troubled by hearing voices in my head*) and visual experiences (4 items, e.g., *I see shadows and shapes when nothing is there*) experiences. Participants are asked to respond on a 4-point Likert scale (1 = *Never*, 4 = *Almost always*), with scores ranging from 5-25 for the auditory subscale, and 4-16 on the visual subscale. Unlike the PSYRATS, the LSHS is suitable for use across both general population and clinical samples. Internal reliability in previous studies has been satisfactory (McCarthy-Jones & Fernyhough, 2011).

Peters Delusion Inventory (PDI-21) (Peters et al., 2004) – the PDI-21 is a 21-item self-report scale assessing delusional ideation (e.g., *Do you ever feel as if you are being persecuted in some way?*), with yes/no as response options (with scores ranging from 0-21). Where participants respond *yes*, they are prompted to provide ratings for distress, preoccupation, and conviction, on a 5-point Likert scale (with scores ranging from 0-105 for each subscale). The scale has previously been used in both clinical and general population samples, with high internal reliability (Peters et al., 2004). This scale was used in both Studies 1 & 2 – unlike the PSYRATS, the PDI-21 requires participants to answer a series of specific questions regarding specific topics of delusional ideation, and so does not require rating, for example, beliefs regarding spiritualism.

Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983) (Study 2 only) – the HADS is a commonly used 14-item self-report scale assessing anxiety (7 items, e.g., *In the past month, I have felt tense and wound up*) and depression (7 items, e.g., *In the past month, I have looked forward to things with enjoyment*). Each item is scored on a 4-point scale (0-3), with scores ranging from 0-21 for each subscale. Internal reliability has previously been shown to be satisfactory (Zigmond & Snaith, 1983). To reduce load for the patients, the HADS was only administered in Study 2 (while patients would have almost certainly scored higher than controls on this measure, it was not of primary interest in this study).

Cognitive tasks

National Adult Reading Test (NART) (Nelson, 1982) – this was used for descriptive purposes as a brief assessment of premorbid intelligence. Participants were required to read aloud from a list of 50 words in which correct pronunciation differs from the spelling, with scores given for correct pronunciation. Possible scores range from 0-50.

WASI Matrix Reasoning (MR) (Wechsler, 1999) – this was used as a brief assessment of non-verbal reasoning, taken from the Wechsler Adult Intelligence Scale. Participants were required to complete a series of up to 30 pattern completion trials, with possible scores ranging from 0-30.

Auditory signal detection (SD) – this task required participants to detect a speech clip embedded in pink noise, presented through over-ear headphones (Sennheiser HD201). The protocol was similar to that used in a number of previous studies (Barkus et al., 2007; Moseley et al., 2014, 2020). Participants were presented with 80 3.5s bursts of noise, with a 1.5s speech clip presented at one of four intensities in 48 trials (speech-present trials), and with no speech clip embedded in 32 trials (speech-absent trials). The intensity (volume) of the speech clips in the speech-present trials was determined in pilot testing separately for each study, and was set at detection rates of 25%, 50%, 75% and 95% in pilot testing. Note that, given the expected age gap between participants in the two studies, this task was calibrated separately for each study (i.e., the signal-to-noise ratio was higher for Study 2, for older participants), and so performance on this task is not directly comparable between studies. Specifically, based on pilot testing, and based on previous research by other groups (e.g., Powers et al., 2017), we expected the NCVH group to be older than the patient group (recruited from early intervention services). Signal-to-noise ratios were therefore based on pilot testing of two groups: 10 participants aged 18-40 (for Study 1) and 10 participants aged 40-75 (for Study 2). It was not appropriate to set signal-to-noise ratios on a by-participant basis (i.e., run separate calibrations for each participant) because this would eliminate individual differences in, for example, sensitivity – a key variable we aimed to investigate. In each study, each voice-hearing group was therefore presented with exactly the same stimuli as their respective control groups, so that differences in signal detection parameters between groups could be explored. In the main task, after each trial, participants were required to respond Yes/No with a button-press as to whether they believed speech to be present or not. The primary outcome variable was false alarm rate (the proportion of speech-absent trials on which the participant responded 'yes') with further analysis also conducted on signal detection parameters for sensitivity (*d'*), calculated as the standardised hit-rate minus the standardised false alarm rate, and bias (β), calculated as $\beta = e\left\{\frac{Z(FA)^2 - Z(H)^2}{2}\right\}$ (Stanislaw & Todorov, 1999). For both studies, performance was compared using independent-samples *t*-tests, or Mann-Whitney *U* tests for non-normally distributed data.

Reality monitoring (RM) (source memory) – the RM task required participants to recall whether previously presented words had been presented as spoken stimuli through headphones (heard items), or whether they had themselves spoken the word (said items). 120 words were split into six lists of 20, with stimuli selected from previous studies that had employed a source memory task (Moseley et al., 2018). In the encoding stage of the task, participants were presented with two of the lists (40 items), assigned as Heard and Said items. Participants were cued to either listen to, or speak aloud, each word (3.5s per item, presented in a random order). In the recall stages, participants were presented with the same words, plus words from a third list (20 new items), and were required to respond with a button-press as to whether they believed each item was originally heard, said, or was a new item. The primary outcome variable for this task was the number of said items in the recall stage which were incorrectly recalled as heard (say-to-hear errors). Further analysis was conducted with the proportion of items that were correctly recalled as old for which the source was also correctly recalled (reality monitoring accuracy), and for the proportion of items which were correctly recalled as old or new (old-new recognition accuracy). As previously recommended (Woodward, Menon, & Whitman, 2007; Woodward & Menon, 2011), we analysed group differences in both studies using ANCOVA, with say-to-hear errors as dependent variable, group as independent variable, and new-to-hear errors as a covariate (to correct for errors due to guessing).

Consonant-vowel dichotic listening (DL) – the DL task presented participants with conflicting single syllable verbal stimuli to each ear simultaneously, with stimuli taken from previous research with schizophrenia patients (Hugdahl et al., 2012). Across three conditions, participants were required to 1) select the syllable they could hear most clearly (non-forced condition), or select the syllable they believed was presented to 2) their right ear (forced-right condition) or 3) their left ear (forced-left condition). The non-forced condition has been argued to assess language lateralisation, whereas the two forced-attention conditions have been argued to assess cognitive and attentional control (Hugdahl et al., 2013). There were 36 trials per condition, consisting of every combination of six syllables used as verbal stimuli (ba, ta, ka, da, ga, pa, each lasting ~350ms), although homonymous trials (in which the same syllable was presented to each ear) were not used for analysis other than as a data quality check. Participants responded with a button press after each trial. The non-forced condition was always presented first, with the order of the forced-left and forced-right conditions counterbalanced across participants. The primary outcome variable for this task was the number of identified syllables that were presented to each ear in each condition. As in previous research (Hugdahl et al., 2013), for both studies we analysed this task data using a 3 × 2 × 2 [task condition × ear × group] ANOVA, expecting that a significant interaction would indicate that differential allocation of attention to different ears may be impaired in the voice-hearing groups.

Intentional inhibition of currently irrelevant memories (ICIM) – this task consists of three blocks: a continuous recognition block, and two inhibition blocks. In the first block, participants were presented with a series of black-and-white line drawings, and were required to respond as to whether each item had been previously presented, or not. In the second and third block, participants were instructed to forget the images they had seen so far, and respond as to whether each item had been previously presented, within the second/third block only. The second and third block therefore required intentional inhibition of items presented in earlier blocks. Images were displayed in the centre of the computer screen for 2000ms (ISI: 700ms), and participants were required to respond with a button-press within this time. There was a timed 30s break between blocks 1 and 2, and a 5-min break between blocks 2 and 3, during which time participants completed questionnaires. Each block contained the same images (60 unique images in total). Within each block, there were 95 trials: 40 images were presented once, 5 were presented twice, and 15 were presented three times. There were therefore 60 opportunities to make a ‘false alarm’ response (i.e., respond that an image had been repeated when it had not). The primary outcome variable from this task was the number of false alarm responses made in each block. As an alternative measure of performance, temporal context confusion (TCC) was calculated. TCC measures the extent to which participants confuse information between task blocks, taking into account block 1 performance (continuous recognition performance). It is calculated as follows: $\frac{Run2FAs}{Run2Hits} - \frac{Run1FAs}{Run1Hits}$. Study 1 used only the first two blocks of the task, to shorten the testing session and lessen fatigue in the patient group. Study 2 used all three blocks of the task. Data was analysed using a 2 × 2 (Study 1) or 3 × 2 (Study 2) [task block × group] ANOVA with number of false alarms as the dependent variable, expecting to observe a larger increase in false alarms in the second block in the voice-hearing groups, compared to controls.

	Study 1			Study 2		
	Patients	Healthy controls	*M* (95% CI)	NCVH	Non-VH controls	*M* (95% CI)
N	31	33	-	26	28	-
Age	28.55 (10.22)	27.91 (10.42)	0.64 [-4.52, 5.80]	58.72 (11.72)	58.69 (11.60)	0.03 [-6.59, 6.54]
Gender (*n* female)	14	19	[-0.49, 1.49]	18	17	[-1.50, 0.88]
Education (years)	12.36 (1.85)	12.88 (1.45)	0.55 [0.35, 1.39]	14.92 (3.12)	15.42 (2.24)	0.50 [-1.07, 2.07]
Matrix reasoning	15.37 (4.17)	18.46 (2.79)	**3.09** **[1.32, 4.86]**	16.58 (4.76)	20.26 (2.85)	**3.68** **[1.39, 5.98]**
NART	23.32 (11.07)	30.21 (6.26)	**6.89** **[2.43, 11.35]**	33.32 (10.10)	39.13 (6.92)	**5.81** **[0.74, 10.88]**

Table 1: *demographic information and assessments of intelligence in Study 1 & 2. Means represent mean difference between group, 95% confidence intervals represent the interval around the mean difference between groups, except gender which uses log odds ratio. NART = National Adult Reading Test. Bold font = 95% confidence intervals do not cross 0.*

For all tasks, in the event of non-normally distributed data, log-transformation was attempted. In all cases, this did not improve normality; therefore, non-parametric tests were used where possible. Where no significant difference between groups was evident, Bayesian *t*-tests using default Cauchy priors are reported, to assess the strength of evidence for the null hypothesis.

Procedure

Testing took place in a quiet room either at the participant's home, in a healthcare setting, or in a university room, with the session lasting 45–60 minutes. The voice-hearing groups in both studies were also interviewed regarding voice phenomenology (results from which are reported elsewhere; Alderson-Day et al., 2021), typically around one week before testing, at which PSYRATS data was gathered. Procedures were approved by a university ethics committee and local health research authorities (Study 1).

Results

Study 1 – patients vs. healthy controls

Assessment of hallucinations – the patient group scored higher than healthy controls on all measures of hallucination-proneness and delusional ideation (Table 2). PSYRATS subscale scores can be found in Table 2.

Auditory signal detection – as predicted, the patient group had a significantly higher false alarm rate (*M(SD)* = 40.52(19.04)) on the SD task than controls (*M(SD)* = 25.19(25.43); $U = 256.5$, $p = .002$, $d = 0.68$) (see Fig 1a). Secondary analysis using signal detection parameters showed that the patient group (*M(SD)* = 0.96(0.59)) had a lower response bias (β) than controls (*M(SD)* = 2.64(2.84); $U = 287.5$, $p = .007$, $d = 0.80$) – indicating a greater tendency to say speech was present – as well as lower sensitivity (*d'*), indicating reduced accuracy at detecting speech (patient group: *M(SD)* = 1.02(0.43); controls: *M(SD)* = 1.49(0.61); $U = 247$, $p = .001$, $d = 0.89$).

Dichotic listening – there was a main effect of ear ($F(1, 58) = 30.76$, $p < .001$, $\eta_p^2 = .347$), indicating a right ear advantage across both samples. There was also a main effect of condition ($F(2, 116) = 7.85$, $p < .001$, $\eta_p^2 = .119$), although not a significant main effect of group ($F(1, 58) = 3.98$, $p = .051$, $\eta_p^2 = .064$). There was no interaction between condition and group ($F(2, 116) = 0.63$, $p = .536$, $\eta_p^2 = .011$), but there was an interaction between ear and condition ($F(2, 116) = 112.16$, $p < .001$, $\eta_p^2 = .659$) indicating orienting of attention according to the instructions in each condition, across all participants.

There was a three-way interaction between condition, ear, and group ($F(2, 116) = 3.91$, $p = .023$, $\eta_p^2 = .06$). To explore this interaction further, we conducted three 2 × 2 ANOVAs (for the three conditions). In the non-forced and forced-left conditions, there was no interaction between ear and group (non-forced: $F(1, 58) = 0.35$, $p = .56$, $\eta_p^2 = .01$; forced-left: $F(1, 58) = 1.93$, $p = .170$, $\eta_p^2 = .03$). In the forced-right condition, there was a significant interaction between ear and group ($F(1, 58) = 5.26$, $p = .025$, $\eta_p^2 = .08$), though notably this test would not have been significant with a corrected alpha level (.05 / 3 = .017). Finally, we conducted two independent-samples *t*-tests (corrected alpha level = .05 / 2 = .025) using data from the forced-right condition, which indicated that controls (*M(SD)* = 19.56(4.66)) made more correct responses in the right ear than the patient group (*M(SD)* = 16.64(4.88); $t(58) = 2.37$, $p = .021$, $d = 0.61$), whereas the patient group made more correct left ear responses (*M(SD)* = 7.21(2.96)) than controls (*M(SD)* = 5.84(2.95)) though not at a statistically significant level ($t(58) = 1.79$, $p = .078$, $d = 0.46$).

	Study 1				**Study 2**			
	Patients	Healthy controls	*M* (95% CI)	*d*	NCVH	Non-VH controls	*M* (95% CI)	*d*
PSYRATS physical	9.42 (2.29)	-	-	-	5.31 (2.87)	-	-	-
PSYRATS cognitive	6.52 (1.59)	-	-	-	3.92 (2.28)	-	-	-
PSYRATS emotional	9.94 (3.92)	-	-	-	0.08 (0.39)	-	-	-
LSHS auditory	11.75 (3.17)	7.64 (2.13)	**4.11 [2.73, 5.50]**	1.56	10.60 (2.97)	7.16 (1.84)	**3.44 [2.04, 4.83]**	1.38
LSHS visual	8.37 (3.43)	5.18 (1.74)	**3.19 [1.81, 4.57]**	1.22	6.27 (2.03)	4.96 (1.51)	**1.31 [0.30, 2.32]**	0.73
PDI sum	10.79 (5.92)	6.06 (4.47)	**4.73 [2.02, 7.43]**	0.92	5.20 (2.92)	3.96 (2.88)	1.24 [-0.41, 2.89]	0.43
PDI distress	39.53 (25.42)	14.48 (11.54)	**25.05 [15.11, 34.99]**	1.32	7.54 (7.60)	8.04 (7.37)	0.51 [-3.76, 4.76]	-0.07
PDI conviction	39.36 (27.86)	17.11 (12.86)	**22.25 [11.33, 33.18]**	1.07	17.49 (14.71)	11.32 (9.08)	6.17 [-0.78, 13.12]	0.51
PDI preoccupation	37.30 (25.62)	14.19 (11.02)	**23.11 [13.20, 33.02]**	1.23	9.21 (9.33)	8.12 (7.99)	1.09 [-3.85, 6.03]	0.13
HADS anxiety	-	-	-	-	4.19 (2.83)	4.92 (3.74)	0.73 [-1.12, 2.58]	-0.22
HADS depression	-	-	-	-	1.42 (1.42)	2.19 (2.33)	0.77 [-0.31, 1.85]	-0.40

***Table 2:** assessments of hallucinations and delusional ideation in Study 1 & 2. PSYRATS = Psychotic Symptom Rating Scale; LSHS = Launay-Slade Hallucination Scale (9-item); PDI = Peters Delusion Inventory (21-item). Means represent mean difference between group, 95% confidence intervals represent the interval around the mean difference between groups. d = Cohen's d effect size. Bold font = 95% confidence intervals do not cross 0.*

Intentional inhibition – across all participants, there was a significant effect of task block, with more false alarms in the second block (*M* = 11.35, *SD* = 8.07) than the first block (*M* = 4.81, *SD* = 5.14) ($F(1, 60) = 57.02$, $p < .001$, $\eta_p^2 = .49$), indicating failures of intentional inhibition in the latter stage of the task, as expected. There was a significant effect of group, with the patient group (*M* = 20.17, *SD* = 11.93) making more false alarms than the control group (*M* = 12.64, *SD* = 10.04) across the whole task ($F(1, 60) = 7.30$, $p = .009$, $\eta_p^2 = .11$). There was also a significant interaction between task block and group ($F(1, 60) = 4.09$, $p = .048$, $\eta_p^2 = .06$). Two Mann-Whitney *U* tests (corrected alpha = .05 / 2 = .025) showed a significant difference between groups in the second task block ($U = 294.5$, $p = .009$, $d = 0.73$) but not the first block ($U = 350.5$, $p = .07$, $d = 0.39$). Using the temporal context confusion measure, the patient group showed a significantly higher score (*M(SD)* = 0.30(0.41)) than controls (*M(SD)* = 0.17(0.20); $U = 316$, $p = .02$, $d = 0.41$), indicating more confusion between task blocks.

Reality monitoring – An ANCOVA with say-to-hear errors as the dependent variable and new-to-hear errors as a covariate (to adjust for guessing (Woodward et al., 2007)) indicated no significant effect of group ($F(1, 60) = 3.47$, $p = .067$, $\eta_p^2 = .05$). Patients made numerically fewer say-to-hear errors (*M(SD)* = 8.70(4.20)) than controls (*M(SD)* = 10.52(5.14), in contrast to our hypothesis. This difference was also not significant without inclusion of the covariate ($t(61) = 1.53$, $p = .132$, $d = 0.38$), with Bayesian *t*-tests indicating evidence in favour of the null ($BF_{10} = 0.11$). Likewise, further analysis with overall source accuracy (proportion of words that were correctly recalled as old for which the source was also correctly recalled) ($t(61) = 0.48$, $p = .636$, $d = 0.12$) and old-new accuracy ($t(61) = 1.49$, $p = .142$, $d = 0.38$) showed no significant difference between groups.

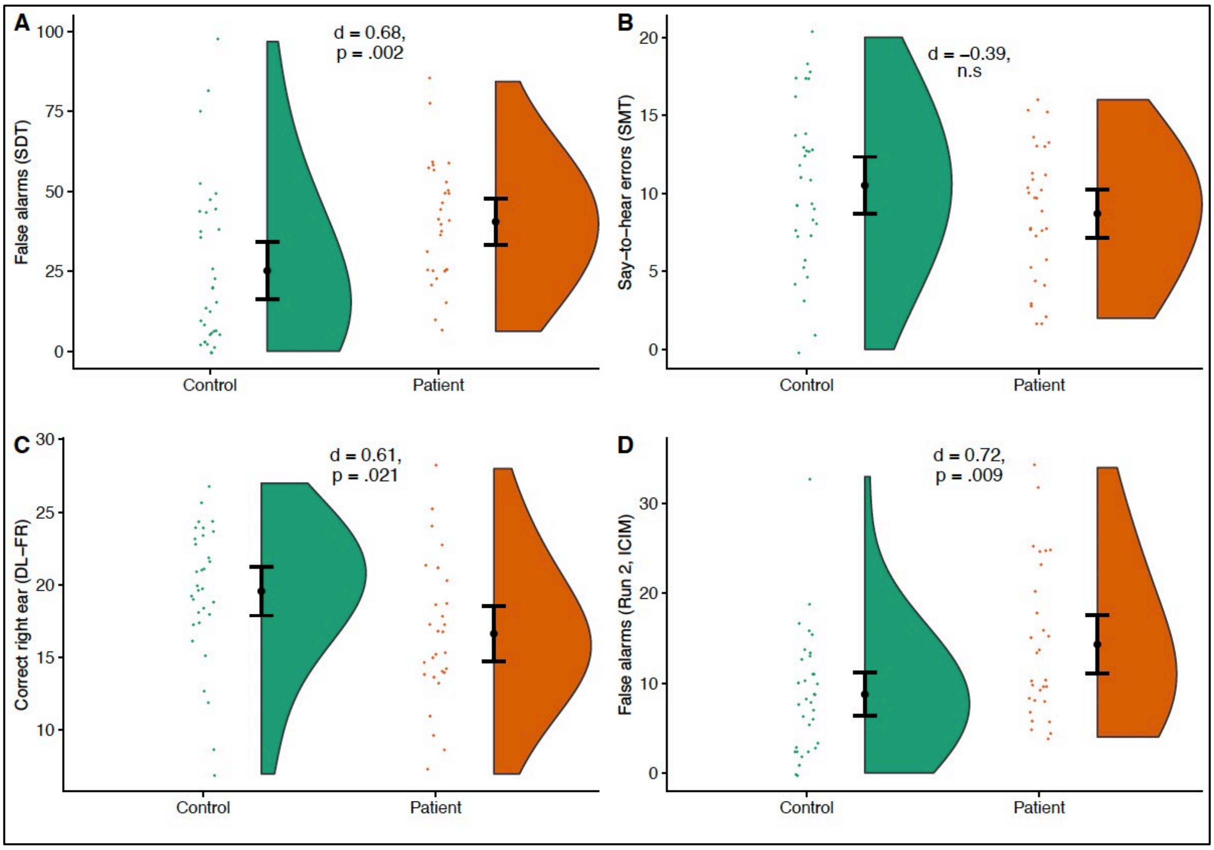

Figure 1: *task performance in patient group and healthy controls in Study 1. A = false alarms in the auditory signal detection task; B = Say-to-hear errors in the source memory task; C = Correct right ear responses in the forced-right condition of the dichotic listening task; D = False alarms in the second block of the intentional inhibition task. Negative effect sizes represent the opposite direction to hypothesized. n.s = non-significant difference. Error bars = 95% confidence intervals.*

Study 2 – NCVHs vs. non-voice-hearing controls

Assessment of hallucinations – the NCVH group scored higher than controls on self-report assessments of hallucinations (LSHS), with very large differences in reports of auditory hallucinations, and a lesser difference in visual hallucinations (see Table 2). Notably, only 1 participant in the NCVH group reported any distress linked to the voices (assessed using the PSYRATS). Differences between the groups in delusional ideation (PDI) were small, with all confidence intervals crossing 0. Likewise, differences between the groups in levels of anxiety and depression (HADS) were small, with confidence intervals crossing 0 (with the NCVH group scoring slightly lower than controls) (see Table 2).

Auditory signal detection – the NCVH group ($M = 20.43$, $SD = 22.22$) had a significantly higher false alarm rate than the non-voice-hearing controls ($M = 11.38$, $SD = 23.30$) ($U = 202.0$, $p = .019$, $d = -0.40$) (see Fig 2a). Further analysis using signal detection parameters showed that the NCVH group had a lower response bias (β) ($M = 2.79$, $SD = 2.97$) than controls ($M = 4.99$, $SD = 3.60$) ($U = 201.0$, $p = .020$, $d = 0.67$), and also lower sensitivity (d') (NCVH group: $M = 1.95$, $SD = 0.58$; controls: $M = 2.27$, $SD = 0.59$, $U = 177.0$, $p = .005$, $d = 0.55$).

Dichotic listening – there was a main effect of ear ($F(1, 46) = 29.62$, $p < .001$, $\eta_p^2 = .392$), indicating a right ear advantage across both samples. There was also a main effect of condition ($F(2, 92) = 5.23$, $p = .007$, $\eta_p^2 = .102$), although no significant main effect of group ($F(1, 46) = 0.14$, $p = .707$, $\eta_p^2 = .003$). There was not a significant interaction between condition and group ($F(2, 92) = 2.45$, $p = .092$, $\eta_p^2 = .051$), but there was an interaction between ear and condition ($F(2, 92) = 38.78$, $p < .001$, $\eta_p^2 = .457$) indicating orienting of attention according to the instructions in each condition, across all participants.

The three-way interaction was not significant ($F(2, 92) = 1.75$, $p = .179$, $\eta_p^2 = .037$), and no other main effects or interactions including group were significant (all *p*s > .092). Bayesian *t*-tests indicated evidence in favour of the null for the non-forced ($BF_{10} = 0.36$) and forced-right ($BF_{10} = 0.24$) conditions, although were equivocal in distinguishing between the null and alternative hypothesis in the forced-left condition ($BF_{10} = 0.99$).

Intentional inhibition – across both groups, there was a significant effect of task block with more false alarms in the second block ($M = 12.04$, $SD = 7.50$), and to a lesser extent the third block ($M = 8.63$, $SD = 6.31$), than the first block ($M = 4.13$, $SD = 4.09$) ($F(2, 100) = 44.09$, $p < .001$, $\eta_p^2 = .47$), indicating failures of intentional inhibition in the latter blocks. The pattern of fewer false alarms in the third block than the second block is consistent with previous research (Alderson-Day et al., 2019), and reflects the longer timespan between blocks 2 and 3. There was no main effect of group ($F(1, 50) = 0.01$, $p = .942$, $\eta_p^2 < .001$), and no interaction between task block and group ($F(2, 100) = 0.49$, $p = .613$, $\eta_p^2 = .01$), indicating that the NCVH group were no more likely to make false alarms in the inhibition blocks than controls. Bayesian *t*-tests indicated support for the null hypothesis for run 2 ($BF_{10} = 0.26$) and run 3 ($BF_{10} = 0.22$). Using the temporal context confusion measure, there was not a significant difference between the NCVH group (*M(SD)* = 0.26(0.24)) and the controls (*M(SD)* = 0.28(0.20); $U = 298.5$, $p = .475$, $d = 0.09$).

Reality monitoring – an ANCOVA with say-to-hear errors as dependent variable, group as independent variable, and new-to-hear errors as covariate indicated no significant effect of group ($F(1, 50) = 2.05$, $p = .158$, $\eta_p^2 = .04$). There was also not a significant difference between groups when the covariate was not included ($t(51) = 1.30$, $p = .201$, $d = 0.36$), indicating no difference between the NCVH group and the control group. Bayesian *t*-tests indicated support for the null hypothesis ($BF_{10} = 0.13$). There was no difference between groups in overall source accuracy ($t(51) = 0.10$, $p = .92$, $d = 0.03$) or old-new recognition ($t(51) = 1.25$, $p = .217$, $d = 0.34$).

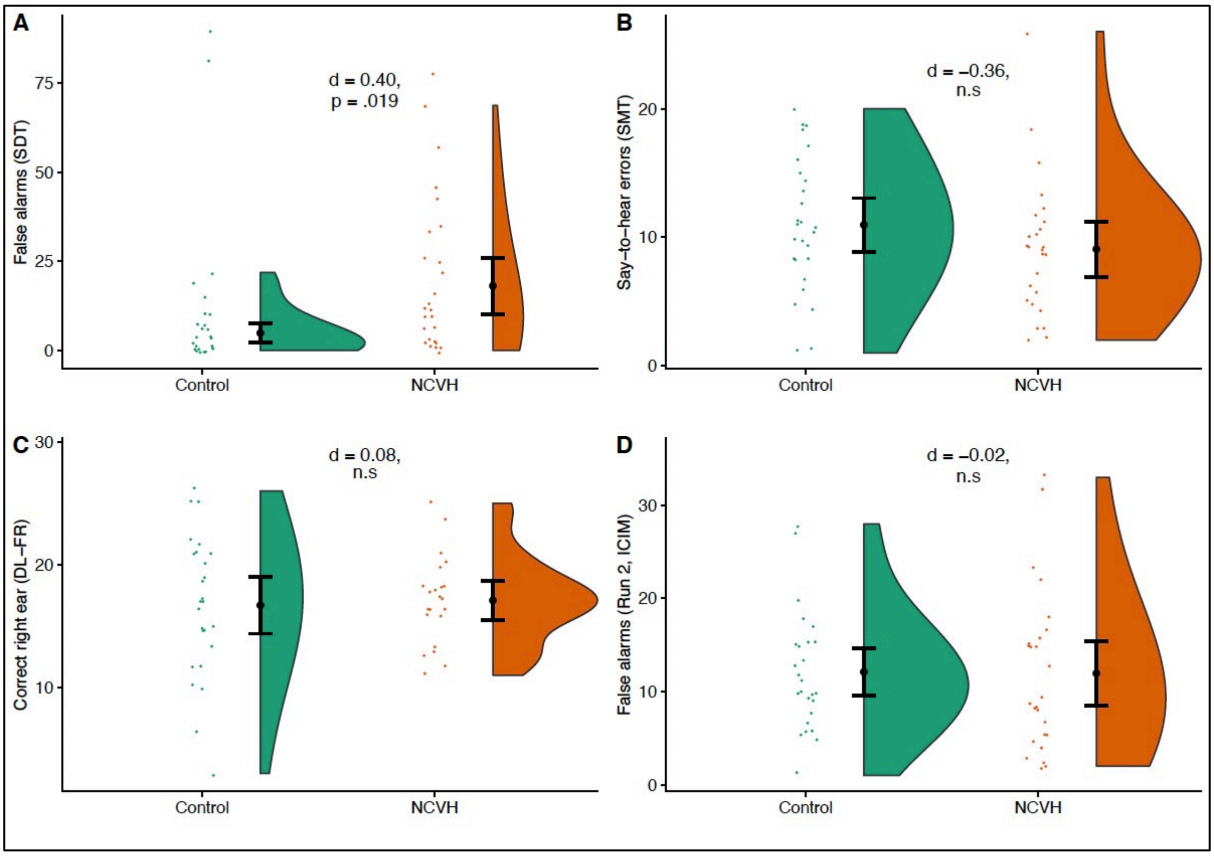

Figure 2: *task performance in NCVHs and non-voice-hearing controls in Study 2. A = false alarms in the auditory signal detection task; B = Say-to-hear errors in the source memory task; C = Correct right ear responses in the forced-right condition of the dichotic listening task; D = False alarms in the second task block of the intentional inhibition task. Negative effect sizes represent the opposite direction to hypothesized. n.s = non-significant difference. Error bars = 95% confidence intervals.*

Discussion

This study provides evidence for key similarities and differences in the cognitive profiles of voice-hearing psychosis patients and non-clinical voice-hearers (see Table 3 for summary). Across the two studies, we showed that the patient group and non-clinical voice-hearing participants had a lower criterion and lower sensitivity on an auditory SD task than controls, reflecting a higher false alarm rate and, to a lesser extent, a higher hit rate. In the patient group, we partially replicated previous results regarding impaired attentional control in a dichotic listening paradigm (Hugdahl et al., 2013), and lower performance on an intentional inhibition task (Waters et al., 2006). These patterns of performance were not found in the NCVH group, however, who did not differ from controls. Finally, we did not replicate previous findings regarding an externalising bias in reality monitoring (Brookwell et al., 2013), with neither voice-hearing group differing from their respective control groups. Our findings therefore suggest that biases in auditory signal detection seem to be associated with hallucinations specifically (rather than psychopathology more broadly), whereas impaired intentional inhibition and attentional control might be associated with psychosis more broadly – and potentially play a role in attributes of hallucinations that cause them to be distressing or clinically relevant. Our study is the first, to our knowledge, to use tasks across a number of domains (reality monitoring, intentional inhibition, signal detection, dichotic listening) within the same studies, as well as to use these tasks within a NCVH group. These findings raise important issues regarding i) the underlying cognitive mechanisms of AVH and ii) continuity and discontinuity between clinically relevant and non-clinical hallucinations.

Biased SD performance, observed in both of the present studies, may underlie AVH across clinical and non-clinical populations. This is consistent with a recent large general population study showing that biased SD task performance was associated with the number of hallucinatory experiences reported in the general population (Chinchani et al., 2021; Moseley et al., 2021). Taken together with meta-analytic evidence (Brookwell et al., 2013), there is strong evidence that SD biases are associated with hallucinations regardless of clinical status, and may track across the psychosis continuum. Theoretically, this is consistent with arguments regarding over-weighted top-down processes and the role of strong speech priors (e.g., Corlett et al., 2019), and with neuroimaging studies showing activation in brain areas associated with auditory perception (Jardri et al., 2011), though more work is required to understand which aspects of this task drive the association (e.g., verbal imagery; Moseley et al., 2016). Our findings also indicated lower sensitivity in both voice-hearing groups. One possible explanation for this regards the association between hearing impairment and hallucinations (Linszen et al., 2019), though this has not been systematically explored in relation to the SD task in hallucinations research. Further research into bottom-up processes (e.g., with audiometric testing) alongside cognitive tasks could test any mediating role.

	Signal detection	Dichotic listening	Intentional inhibition	Reality monitoring
Study 1 (patient group)	0.68	0.61	0.72	-0.39
Study 2 (NCVH group)	0.40	0.08	-0.02	-0.36

Table 3: *summary of findings in studies 1 & 2. Numbers indicate effect sizes (d) for the comparison between the voice-hearing group and the control group in each study, for each task. Negative effect sizes indicate opposite directionality to hypothesized. Shaded cells indicate statistically significant comparisons.*

A key insight provided from the two studies reported here concerns the role of memory inhibition, with our data indicating that lower performance on the ICIM task may be specific to psychotic hallucinations, rather than varying across a continuum. This is in contrast to previous studies indicating that ICIM performance was associated with hallucination-proneness in the general population (Alderson-Day et al., 2019; Paulik et al., 2007), and with theorising regarding continuity between clinical and non-clinical groups in inhibitory ability (Badcock & Hugdahl, 2012). Similarly, our data indicated atypical attentional control on the DL task in the patient group (reflected in differences in performance in the forced-right condition, but not the non-forced condition), but not the NCVH group. Intact inhibitory ability and attentional control in NCVHs may be reflected in higher level of control over voices, compared to individuals with psychosis. A fruitful area for future research would be to examine associations between specific attributes of hallucinations – for example, volitional control, which differs across clinical and non-clinical groups (Swyer & Powers, 2020) – and specific cognitive domains such as intentional inhibition of memories. Based on our findings, it could be hypothesized that performance on the ICIM task may be associated with reported control over voices. Alternatively, intact intentional inhibition ability observed here could reflect other clinically-relevant potential differences between the groups, for example, childhood trauma (Bailey et al., 2018). Future research should investigate whether factors such as trauma could mediate the association between intentional inhibition and hallucinations, or psychosis more generally.

Finally, we observed no difference in reality monitoring performance (using the source memory task) between either of the voice-hearing groups and controls. Reality monitoring has arguably been the domain most frequently associated with hallucinations in cognitive models (Brookwell et al., 2013; Waters et al., 2012), but the evidence regarding associations between task performance and hallucinations is mixed, with some studies showing associations in psychosis (Woodward et al., 2007) and associations with hallucination-proneness in the general population (Laroi et al., 2004), but more recent studies failing to replicate this finding using multiple different variants of the source memory task (Alderson-Day et al., 2019; Garrison et al., 2017). In particular, a large multisite general population study failed to find an association between hallucinatory experiences and reality monitoring (Moseley et al., 2020). There is therefore increasing evidence that this may not be a key cognitive mechanism associated with AVH. An unexplored alternative is that source monitoring biases may be evident only in psychosis patients with longer-term histories of illness and wider difficulties with functioning.

Our findings are of particular relevance to discussions of the continuum hypothesis, as applied to hallucinations. One (simplistic) model of the continuum, assuming continuity of cognitive processes, could be that psychosis patients sit at the extreme end of a continuum, with NCVHs lower down, and individuals in the general population who report occasional hallucinatory experiences lower still (Baumeister et al., 2017). To some extent, our data with the SD task may support this, with the patient group showing a difference from controls with a large effect size, and the NCVH group a difference with a medium effect size (and a recent general population study (Moseley et al., 2020) showing a small effect size). However, as noted, memory inhibition and attentional control did not appear to vary continuously in this fashion, suggesting discontinuity between AVH in psychosis and non-clinical variants. As others have suggested, this complexity could point to multiple continua (Waters & Fernyhough, 2019), with variations in, for example, distress, control, associated dysfunction (e.g., delusional frameworks), and neurodevelopmental structural brain changes (Garrison et al., 2019; Powers et al., 2020). An alternative viewpoint might be that, while clinical and non-clinical voices share some core cognitive components, they differ in terms of the kinds of cognitive mechanism drawn upon, rather than varying continuously at a cognitive level. In this way, clinical and non-clinical hallucinations would not be of fundamentally different kinds, but a continuum might not be the best model at the level of cognition. Providing an answer to this question will require larger-scale studies of cognition in both clinical and non-clinical samples.

There are a number of limitations to the two studies reported here. Firstly, both groups represent only one of many potential samples of clinical and non-clinical voice-hearers – that is, the patient group were early intervention service-users, and NCVHs all reported spiritual interpretations of their voices. Further studies should seek to recruit and compare a variety of voice-hearers – for example, NCVHs without spiritual interpretations may differ in important ways (e.g., control over voices, cultural and social background) to the sample reported here. As noted previously, much research into NCVHs has focused on similar groups (i.e., individuals with spiritual or paranormal interpretations of their voices) (Peters et al., 2016; Powers et al., 2017). The preponderance of spiritual beliefs in NCVH participants in the research literature could reflect a key element of their 'non-clinical' status – that is, such beliefs may play a protective role, helping individuals exert control or influence over voices. Secondly, the NCVH group scored somewhat lower on a standardised assessment of AVHs (PSYRATS) and delusions (PDI) than the patient group, which could feasibly account for differences in cognitive variables across the two studies. That said, one strength of the findings is that the NCVH group did not score notably higher than non-voice-hearing controls on other assessments of psychopathology which would typically be heightened in psychosis (delusional ideation, anxiety, depression), indicating that group differences in signal detection task performance were unlikely to be reflective of other psychopathological variables. The voice-hearing groups also scored lower than controls on matrix reasoning and the NART (assessing non-verbal and verbal intelligence, respectively), as indicated by non-overlapping confidence intervals. It could therefore be argued that the voice-hearing groups showed a general cognitive deficit, rather than deficits in any specific domains. However, given that *both* voice-hearing groups showed lower matrix reasoning/NART performance, yet showed divergent performance on other cognitive tasks, a general cognitive deficit does not seem to be the simplest explanation for the observed pattern of results. Similarly, the observation that neither group showed lower scores on the reality monitoring task indicates some level of specificity.

Thirdly, the sample sizes in both studies were powered to detect large effect sizes based on findings from previous research (Brookwell et al., 2013), meaning that the study would have been underpowered to detect smaller effects; future research could use a multisite approach (Moseley et al., 2020) to collect larger samples in these hard-to-recruit populations. This might be particularly important when recruiting NCVHs, who may show more subtle biases or impairments associated with less frequent and distressing experiences. In particular, future research with larger sample sizes could aim to recruit psychosis patients and NCVHs into the same study, matched on relevant demographic attributes (e.g., age). That said, it is possible that this approach would lead to non-representative samples – that is, it might be that NCVHs are, on average, older than patients with psychosis (Peters et al., 2016; Powers et al., 2017) and this could be a key attribute of the group. Artificially selecting for age could mask other important group differences. Future research with larger samples would allow variables such as age to be investigated in relation to variation in cognition across groups.

Fourthly, the two studies were designed and conducted separately, and by necessity were conducted with slightly different measures (e.g., a separately calibrated SD task, due to variability in age across the groups), which limits some of our conclusions. Nevertheless, we believe the core measures are sufficiently comparable to provide meaningful inferences regarding differences between groups on key cognitive mechanisms, for the first time. Furthermore, the voice-hearing groups differed on a number of demographics, notably age (NCVHs mainly reflecting older adults, as in previous studies; Powers et al., 2017); that said, the control participants were well matched on these demographics in the two studies. Further research is needed to explore trajectories of voices and their associated cognitive processes over time. Finally, the tasks we used represent only one variant of a number that have been used in the psychosis literature, and it is possible that different variants would give different findings (e.g., many source monitoring papers have increased cognitive load (Woodward et al., 2007) associated with self-generation). A greater understanding of cognitive processes such as those presented here will undoubtedly feed into lower-level mechanistic explanations of hallucinations (e.g., the predictive processing framework), as well as attempts to improve treatment options for people distressed by voices.

Author contributions

PM, BA-D, GD, and CF developed the study concept and contributed to the study design. Participant recruitment and data collection was carried out by PM, BA-D, GD, and SC. Data analysis and interpretation was carried out by PM, with contributions to interpretation from all other authors. PM drafted the paper, and all authors provided revisions. All authors approved the final version of the paper for submission.

Data availability

Data and analysis code for both studies can be found at the following link: https://osf.io/er5yx/

Acknowledgements

We would like to acknowledge Dr. David Smailes for input in the design and conceptualisation of this research.

References

Alderson-Day, B., Lima, C. F., Evans, S., Krishnan, S., Shanmugalingam, P., Fernyhough, C., & Scott, S. K. (2017). Distinct Processing of Ambiguous Speech in People with Non-Clinical Auditory Verbal Hallucinations. *Brain*, *140*(9), 2475–2489. https://doi.org/10.1093/brain/awx206

Alderson-Day, B., Smailes, D., Moffatt, J., Mitrenga, K., Moseley, P., & Fernyhough, C. (2019). Intentional Inhibition but Not Source Memory Is Related to Hallucination-Proneness and Intrusive Thoughts in a University Sample. *Cortex*, *113*, 267–278. https://doi.org/10.1016/j.cortex.2018.12.020

Alderson-Day, B., Woods, A., Moseley, P., Common, S., Deamer, F., Dodgson, G., & Fernyhough, C. (2021). Voice-Hearing and Personification: Characterizing Social Qualities of Auditory Verbal Hallucinations in Early Psychosis. *Schizophrenia Bulletin*, *47*(1), 228–236. https://doi.org/10.1093/schbul/sbaa095

Badcock, J. C., & Hugdahl, K. (2012). Cognitive Mechanisms of Auditory Verbal Hallucinations in Psychotic and Non-Psychotic Groups. *Neuroscience & Biobehavioral Reviews*, *36*(1), 431–438. https://doi.org/10.1016/j.neubiorev.2011.07.010

Bailey, T., Alvarez-Jimenez, M., Garcia-Sanchez, A. M., Hulbert, C., Barlow, E., & Bendall, S. (2018). Childhood Trauma Is Associated With Severity of Hallucinations and Delusions in Psychotic Disorders: A Systematic Review and Meta-Analysis. *Schizophrenia Bulletin*, *44*(5), 1111–1122. https://doi.org/10.1093/schbul/sbx161

Barkus, E., Stirling, J., Hopkins, R., McKie, S., & Lewis, S. (2007). Cognitive and Neural Processes in Non-Clinical Auditory Hallucinations. *British Journal of Psychiatry*, *191*, S76–S81. https://doi.org/10.1192/bjp.191.51.s76

Bauer, S. M., Schanda, H., Karakula, H., Olajossy-Hilkesberger, L., Rudaleviciene, P., Okribelashvili, N., Chaudhry, H. R., Idemudia, S. E., Gscheider, S., Ritter, K., & Stompe, T. (2011). Culture and the prevalence of hallucinations in schizophrenia. *Comprehensive Psychiatry*, *52*(3), 319–325. https://doi.org/10.1016/j.comppsych.2010.06.008

Baumeister, D., Sedgwick, O., Howes, O., & Peters, E. (2017). Auditory Verbal Hallucinations and Continuum Models of Psychosis: A Systematic Review of the Healthy Voice-Hearer Literature. *Clinical Psychology Review*, *51*, 125–141. https://doi.org/10.1016/j.cpr.2016.10.010

Bentall, R. P., & Slade, P. D. (1985). Reality Testing and Auditory Hallucinations—A Signal Detection Analysis. *British Journal of Clinical Psychology*, *24*(SEP), 159–169.

Bristow, E., Tabraham, P., Smedley, N., Ward, T., & Peters, E. (2014). Jumping to Perceptions and to Conclusions: Specificity to Hallucinations and Delusions. *Schizophrenia Research*, *154*(1), 68–72. https://doi.org/10.1016/j.schres.2014.02.004

Brookwell, M. L., Bentall, R. P., & Varese, F. (2013). Externalizing Biases and Hallucinations in Source-Monitoring, Self-Monitoring and Signal Detection Studies: A Meta-Analytic Review. *Psychological Medicine*, *43*(12), 2465–2475. https://doi.org/10.1017/s0033291712002760

Chinchani, A. M., Menon, M., Roes, M., Hwang, H., Allen, P., Bell, V., et al. (2021). Item-specific overlap between hallucinatory experiences and cognition in the general population: A three-step multivariate analysis of international multi-site data. *PsyArXiv*. https://doi.org/10.31234/osf.io/fkbvu

Corlett, P. R., Horga, G., Fletcher, P. C., Alderson-Day, B., Schmack, K., & Powers, A. R. (2019). Hallucinations and Strong Priors. *Trends in Cognitive Sciences*, *23*(2), 114–127. https://doi.org/10.1016/j.tics.2018.12.001

Daalman, K., van Zandvoort, M., Bootsman, F., Boks, M., Kahn, R., & Sommer, I. (2011). Auditory Verbal Hallucinations and Cognitive Functioning in Healthy Individuals. *Schizophrenia Research*, *132*(2–3), 203–207. https://doi.org/10.1016/j.schres.2011.07.013

Daalman, Kirstin, Boks, M. P. M., Diederen, K. M. J., de Weijer, A. D., Blom, J. D., Kahn, R. S., & Sommer, I. E. C. (2011). The Same or Different?: A Phenomenological Comparison of Auditory Verbal Hallucinations in Healthy and Psychotic Individuals. *The Journal of Clinical Psychiatry*, *72*(03), 320–325. https://doi.org/10.4088/JCP.09m05797yel

Diederen, K. M. J., Weijer, A. D. D., Daalman, K., Blom, J. D., Neggers, S. F. W., Kahn, R. S., & Sommer, I. E. C. (2010). Decreased Language Lateralization Is Characteristic of Psychosis, Not Auditory Hallucinations. *Brain*, *133*(12), 3734–3744. https://doi.org/10.1093/brain/awq313

Garrison, J. R., Fernyhough, C., McCarthy-Jones, S., Simons, J. S., & Sommer, I. E. C. (2019). Paracingulate Sulcus Morphology and Hallucinations in Clinical and Nonclinical Groups. *Schizophrenia Bulletin*, *45*(4), 733–741. https://doi.org/10.1093/schbul/sby157

Garrison, J. R., Moseley, P., Alderson-Day, B., Smailes, D., Fernyhough, C., & Simons, J. S. (2017). Testing Continuum Models of Psychosis: No Reduction in Source Monitoring Ability in Healthy Individuals Prone to Auditory Hallucinations. *Cortex*, *91*, 197–207. https://doi.org/10.1016/j.cortex.2016.11.011

Haddock, G., McCarron, J., Tarrier, N., & Faragher, E. B. (1999). Scales to measure dimensions of hallucinations and delusions: The psychotic symptom rating scales (PSYRATS). *Psychological Medicine*, *29*(4), 879–889. https://doi.org/10.1017/s0033291799008661

Hugdahl, K., Løberg, E.-M., Falkenberg, L. E., Johnsen, E., Kompus, K., Kroken, R. A., Nyg\aard, 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*(1–3), 59–64. https://doi.org/10.1016/j.schres.2012.06.019

Hugdahl, K., Nygård, M., Falkenberg, L. E., Kompus, K., Westerhausen, R., Kroken, R., Johnsen, E., & Løberg, E.-M. (2013). Failure of attention focus and cognitive control in schizophrenia patients with auditory verbal hallucinations: Evidence from dichotic listening. *Schizophrenia Research*, *147*(2), 301–309. https://doi.org/10.1016/j.schres.2013.04.005

Jardri, R., Pouchet, A., Pins, D., & Thomas, P. (2011). Cortical Activations During Auditory Verbal Hallucinations in Schizophrenia: A Coordinate-Based Meta-Analysis. *American Journal of Psychiatry*, *168*(1), 73–81. https://doi.org/10.1176/appi.ajp.2010.09101522

Laroi, F., Van der Linden, M., & Marczewski, P. (2004). The Effects of Emotional Salience, Cognitive Effort and Meta-Cognitive Beliefs on a Reality Monitoring Task in Hallucination-Prone Subjects. *British Journal of Clinical Psychology*, *43*, 221–233. https://doi.org/10.1348/0144665031752970

Linszen, M. M. J., van Zanten, G. A., Teunisse, R. J., Brouwer, R. M., Scheltens, P., & Sommer, I. E. (2019). Auditory hallucinations in adults with hearing impairment: A large prevalence study. *Psychological Medicine*, *49*(1), 132–139. https://doi.org/10.1017/S0033291718000594

McCarthy-Jones, S. R., & Fernyhough, C. (2011). The Varieties of Inner Speech: Links between Quality of Inner Speech and Psychopathological Variables in a Sample of

Young Adults. *Consciousness and Cognition*, *20*(4), 1586–1593. https://doi.org/10.1016/j.concog.2011.08.005

Moseley, P., Aleman, A., Allen, P., Bell, V., Bless, J., Bortolon, C., Cella, M., Garrison, J., Hugdahl, K., Kozáková, E., Laroi, F., Smailes, D., Say, N., Moffatt, J. A., Suzuki, M., Toh, W. L., Woodward, T., Zaytseva, Y., Rossell, S., & Fernyhough, C. (2020). *Correlates of hallucinatory experiences in the general population: An international multi-site replication study* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/4wbgc

Moseley, P., Fernyhough, C., & Ellison, A. (2013). Auditory Verbal Hallucinations as Atypical Inner Speech Monitoring, and the Potential of Neurostimulation as a Treatment Option. *Neuroscience & Biobehavioral Reviews*, *37*(10, Part 2), 2794–2805. https://doi.org/10.1016/j.neubiorev.2013.10.001

Moseley, P., Fernyhough, C., & Ellison, A. (2014). The Role of the Superior Temporal Lobe in Auditory False Perceptions: A Transcranial Direct Current Stimulation Study. *Neuropsychologia*, *62C*, 202–208. https://doi.org/10.1016/j.neuropsychologia.2014.07.032

Moseley, P., Mitrenga, K. J., Ellison, A., & Fernyhough, C. (2018). Investigating the Roles of Medial Prefrontal and Superior Temporal Cortex in Source Monitoring. *Neuropsychologia*, *120*, 113–123. https://doi.org/10.1016/j.neuropsychologia.2018.10.001

Moseley, P., Smailes, D., Ellison, A., & Fernyhough, C. (2016). The Effect of Auditory Verbal Imagery on Signal Detection in Hallucination-Prone Individuals. *Cognition*, *146*, 206–216. https://doi.org/10.1016/j.cognition.2015.09.015

Nelson, H. (1982). *National Adult Reading Test (NART): Test Manual*. Windsor.

Paulik, G., Badcock, J. C., & Maybery, M. T. (2007). Poor Intentional Inhibition in Individuals Predisposed to Hallucinations. *Cognitive Neuropsychiatry*, *12*(5), 457–470. https://doi.org/10.1080/13546800701394329

Peters, E., Joseph, S., Day, S., & Garety, P. (2004). Measuring Delusional Ideation: The 21-Item Peters et al. Delusions Inventory (PDI). *Schizophrenia Bulletin*, *30*(4), 1005–1022. https://doi.org/10.1093/oxfordjournals.schbul.a007116

Peters, E., Ward, T., Jackson, M., Morgan, C., Charalambides, M., McGuire, P., Woodruff, P., Jacobsen, P., Chadwick, P., & Garety, P. A. (2016). Clinical, socio-demographic and psychological characteristics in individuals with persistent psychotic experiences with and without a “need for care”. *World Psychiatry*, *15*(1), 41–52. https://doi.org/10.1002/wps.20301

Peters, E., Ward, T., Jackson, M., Woodruff, P., Morgan, C., McGuire, P., & Garety, P. A. (2017). Clinical Relevance of Appraisals of Persistent Psychotic Experiences in People with and without a Need for Care: An Experimental Study. *The Lancet Psychiatry*, *4*(12), 927–936. https://doi.org/10.1016/S2215-0366(17)30409-1

Powers, A. R., Mathys, C., & Corlett, P. R. (2017). Pavlovian Conditioning–Induced Hallucinations Result from Overweighting of Perceptual Priors. *Science*, *357*(6351), 596–600. https://doi.org/10.1126/science.aan3458

Powers, A., van Dyck, L., Garrison, J., & Corlett, P. (2020). *Paracingulate sulcus length is shorter in voice-hearers regardless of need for care | medRxiv* [Preprint]. MedRXiv. https://www.medrxiv.org/content/10.1101/2020.01.13.19015891v1

Powers, Albert R., Kelley, M. S., & Corlett, P. R. (2017). Varieties of Voice-Hearing: Psychics and the Psychosis Continuum. *Schizophrenia Bulletin*, *43*(1), 84–98. https://doi.org/10.1093/schbul/sbw133

Sommer, I. E. C., Daalman, K., Rietkerk, T., Diederen, K. M., Bakker, S., Wijkstra, J., & Boks, M. P. M. (2010). Healthy Individuals With Auditory Verbal Hallucinations; Who Are They? Psychiatric Assessments of a Selected Sample of 103 Subjects. *Schizophrenia Bulletin*, *36*(3), 633–641. https://doi.org/10.1093/schbul/sbn130

Sommer, I., Ramsey, N., Kahn, R., Aleman, A., & Bouma, A. (2001). Handedness, Language Lateralisation and Anatomical Asymmetry in Schizophrenia. *The British Journal of Psychiatry*, *178*(4), 344–351. https://doi.org/10.1192/bjp.178.4.344

Stanislaw, H., & Todorov, N. (1999). Calculation of Signal Detection Theory Measures. *Behavior Research Methods Instruments & Computers*, *31*(1), 137–149. https://doi.org/10.3758/bf03207704

Swyer, A., & Powers, A. R. (2020). Voluntary control of auditory hallucinations: Phenomenology to therapeutic implications. *Npj Schizophrenia*, *6*(1), 1–9. https://doi.org/10.1038/s41537-020-0106-8

Toh, W. L., Thomas, N., & Rossell, S. L. (2015). Auditory Verbal Hallucinations in Bipolar Disorder (BD) and Major Depressive Disorder (MDD): A Systematic Review. *Journal of Affective Disorders*, *184*, 18–28. https://doi.org/10.1016/j.jad.2015.05.040

Vercammen, A., de Haan, E. H. F., & Aleman, A. (2008). Hearing a Voice in the Noise: Auditory Hallucinations and Speech Perception. *Psychological Medicine*, *38*(8), 1177–1184. https://doi.org/10.1017/s0033291707002437

Waters, F., Allen, P., Aleman, A., Fernyhough, C., Woodward, T. S., Badcock, J. C., Barkus, E., Johns, L., Varese, F., Menon, M., Vercammen, A., & Laroi, F. (2012). Auditory Hallucinations in Schizophrenia and Nonschizophrenia Populations: A Review and Integrated Model of Cognitive Mechanisms. *Schizophrenia Bulletin*, *38*(4), 683–692. https://doi.org/10.1093/schbul/sbs045

Waters, F., Badcock, J. C., Maybery, M. T., & Michie, P. T. (2003). Inhibition in Schizophrenia: Association with Auditory Hallucinations. *Schizophrenia Research*, *62*(3), 275–280. https://doi.org/10.1016/S0920-9964(02)00358-4

Waters, F., Badcock, J., Michie, P., & Maybery, M. (2006). Auditory Hallucinations in Schizophrenia: Intrusive Thoughts and Forgotten Memories. *Cognitive Neuropsychiatry*, *11*(1), 65–83. https://doi.org/10.1080/13546800444000191

Waters, F., & Fernyhough, C. (2017). Hallucinations: A Systematic Review of Points of Similarity and Difference Across Diagnostic Classes. *Schizophrenia Bulletin*, *43*(1), 32–43. https://doi.org/10.1093/schbul/sbw132

Waters, F., & Fernyhough, C. (2019). Auditory Hallucinations: Does a Continuum of Severity Entail Continuity in Mechanism? *Schizophrenia Bulletin*, *45*(4), 717–719. https://doi.org/10.1093/schbul/sbz002

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence*. The Psychological Corporation.

Woodward, T. S., Menon, M., & Whitman, J. C. (2007). Source Monitoring Biases and Auditory Hallucinations. *Cognitive Neuropsychiatry*, *12*(6), 477–494. https://doi.org/10.1080/13546800701307198

Zigmond, A. S., & Snaith, R. P. (1983). The Hospital Anxiety and Depression Scale. *Acta Psychiatrica Scandinavica*, *67*(6), 361–370. https://doi.org/10.1111/j.1600-0447.1983.tb09716.x

Supplementary Materials

S1 – Patient group current diagnoses ($N = 31$)

Diagnosis	*%*
None	48.4
Unspecified psychosis	29.0
PTSD	6.5
EUPD	6.5
Depression with psychotic features	3.2
Schizophrenia	3.2
Substance-induced psychosis	3.2

Note that many patients had not yet received a diagnosis, having recently entered clinical services. In the UK, distressing symptom presence rather than fulfillment of diagnostic criteria is an entry requirement for early intervention services, and clinicians tend to hold off on making a diagnosis.

S2 – Patient group current medication usage ($N = 31$)

Nb. % does not sum to 100 as some participants on more than one medication

Medication	*%*
Quetiapine	22.6
Risperidone	19.4
Aripiprazole	16.1
None	12.9
Fluoxetine	12.9
Setraline	12.9
Olanzapine	9.7
Citalopram	6.5
Haloperidol	3.2
Mirtazepine	3.2

Methodological differences between studies 1 & 2

- The auditory signal detection task was calibrated separately for the two studies. That is, for each study, 10 participants (who did not participate in the main studies) were recruited within a similar age range to that expected for the main studies, and completed a short calibration task. For each study, speech volume was then set at a level where they were detected at 25%, 50%, 75% and 95% levels, based on the calibration data. Performance varies between the two studies (e.g., with higher d' in Study 2) because the ages of participants between calibration and the main studies varied – hence, statistical comparisons are restricted to contrasts between voice-hearing and control groups throughout the paper.

- The intentional inhibition of currently irrelevant memory task (ICIM) contained two blocks for the patient group (one continuous recognition block + one inhibition block) and three blocks for the NCVH group (one continuous recognition block + two inhibition blocks). This decision was made to minimise the length of the session for the patient group, to lessen fatigue and potential drop-out (e.g., due to boredom).
- The patient group completed both the hallucinations and delusions subscales of the PSYRATS, whereas the NCVH group completed only the hallucinations subscale. It was felt both inappropriate to pathologise spiritual beliefs, and also complex to unpick what could be classed as delusional ideation, in the non-clinical group.

S4 – participant exclusions

Participants were excluded from individual tasks if performance was below chance levels (indicating that they may have misunderstood the task or responded incorrectly). Exclusion criteria were the same as our previous preregistered study for the signal detection, dichotic listening, and source memory tasks, which can be found here: https://osf.io/cyu6j. For the ICIM, participants were excluded if they had a d' score of less than or equal to 0 (indicating at or below chance performance) in run 1. A small amount of data was also excluded due to technical difficulties resulting in lost data, or if a participant stopped participation in that task.

Study 1

Signal detection – one exclusion for a $d' < 0$ (patient group). One other exclusion due to task non-completion (patient group).

Intentional inhibition – one exclusion for a $d' < 0$ in run 1 (patient group), one other exclusion due to task non-completion (patient group).

Source memory – one exclusion due to technical difficulties resulting in missing data (patient group).

Dichotic listening – one exclusion for 100% laterality index (patient group) and one exclusion for < 50% performance on homonymous trials (patient group). Two other exclusions due to technical difficulties resulting in missing data (one patient group, one control group).

Study 2

One participant was excluded at the screening stage due to reporting high levels of current distress due to hearing a malevolent spiritual voice (and was not included in reported *n* in the manuscript).

Intentional inhibition – one exclusion for $d' < 0$ in run 1 (control group). One further exclusion due to task non-completion (control group).

Signal detection – one exclusion for $d' < 0$ (control group). Two other exclusions due to technical difficulties resulting in missing data (control group).

Dichotic listening – three exclusions for < 50% performance on homonymous trials (NCVH group). Three further exclusions (one patient, two controls) due to task non-completion or technical difficulties resulting in missing data.

Source memory – one exclusion based on task non-completion (control group).

S5 – associations between assessments of hallucinations and task measures (*r* [95% CI]) (Study 1, *N* = 31)

	PSYRATS (AH)	**LSHS (auditory)**	**SDT false alarms**	**SMT say-hear**	**DL nonforced**	**DL forced left**	**DL forced right**	**ICIM false alarms**
PSYRATS (AH)	—							
LSHS (auditory)	.62 [.31, .81]	—						
SDT false alarms	-.36 [.01, -.64]	-.22 [-.57, .20]	—					
SMT say-hear	-.15 [-.48, .22]	.010 [-.39, .40]	.26 [-.13, .58]	—				
DL nonforced	.11 [-.27, .46]	-.08 [-.48, .34]	.26 [-.14, .59]	.02 [-.36, .39	—			
DL forced left	.27 [-.11, .59]	.23 [-.20, .59]	-.17 [-.53, .23]	-.05 [-.41, .33]	.07 [-.31, .43]	—		
DL forced right	0.15 [-.23, .49]	-.32 [-.65, .11]	.22 [-.19, .56]	.02 [-.36, 39]	.68 [.41, .84]	.39 [.02, .67]	—	
ICIM false alarms	-.10 [-.46, .27]	-.03 [-.43, .38]	-.29 [-.61, .10]	-.05 [-.41, 32]	-.30 [-.61, .09]	-.29 [-.60, .10]	-.40 [-.68, .03]	—

This table presents correlations (Pearson's r) between two hallucinations measures and the cognitive task measures within the patient group only (Study 1). These are exploratory analyses, and are presented for descriptive purposes (i.e., they are not hypotheses-driven).

PSYRATS (AH) = Psychotic Symptoms Rating Scale; LSHS (auditory) = Launay-Slade Hallucination Scale (auditory subscale); SDT false alarms = signal detection task, false alarm rate; SMT say-hear = source memory task, say-to-hear errors; DL nonforced = dichotic listening, right ear responses in the nonforced condition; DL forced left = dichotic listening, left ear responses in the forced left condition; DL forced right = dichotic listening, number of right ear responses in the forced right condition; ICIM false alarms = intentional inhibition of currently irrelevant memories task, number of false alarms in run 2. Note that N may differ slightly for different variables due to exclusions (see S4, above).

S6 – associations between assessments of hallucinations and task measures (*r* [95% CI]) (Study 2, *N* = 26)

	PSYRATS (AH)	LSHS (auditory)	SDT false alarms	SMT say-hear	DL nonforced	DL forced left	DL forced right	ICIM false alarms
PSYRATS (AH)	—							
LSHS (auditory)	.09 [-.31, .46]	—						
SDT false alarms	.02 [-.37, .41]	-.04 [-.42, .35]	—					
SMT say-hear	.08 [-.32, .45]	.34 [-.06, .64]	-.17 [-.52, .23]	—				
DL nonforced	-.06 [-.47, .55]	.12 [-.32, .51]	.04 [-.39, .46]	-.25 [-.61, .19]	—			
DL forced left	.16 [-.28, .55]	-.11 [-.51, .33]	-.27 [-.62, .17]	.11 [-.33, .51]	-.08 [-.48, .36]	—		
DL forced right	.20 [-.24, .58]	-.11 [-.51, .33]	-.10 [-.50, .34]	-.19 [-.57, .25]	.65 [.31, .84]	.24 [-.21, .60]	—	
ICIM false alarms	-.24 [.16, -.58]	.27 [-.13, .59]	-.19 [-.54, .22]	-.06 [-.34, .44]	-.11 [-.51, .33]	-.48 [-.75, -.07]	-.42 [-.72, -.003]	—

This table presents correlations (Pearson's r) between two hallucinations measures and the cognitive task measures within the non-clinical voice-hearer group only (Study 2). These are exploratory analyses, and are presented for descriptive purposes (i.e., they are not hypotheses-driven).

PSYRATS (AH) = Psychotic Symptoms Rating Scale; LSHS (auditory) = Launay-Slade Hallucination Scale (auditory subscale); SDT false alarms = signal detection task, false alarm rate; SMT say-hear = source memory task, say-to-hear errors; DL nonforced = dichotic listening, right ear responses in the nonforced condition; DL forced left = dichotic listening, left ear responses in the forced left condition; DL forced right = dichotic listening, number of right ear responses in the forced right condition; ICIM false alarms = intentional inhibition of currently irrelevant memories task, number of false alarms in run 2. Note that N may differ slightly for different variables due to exclusions (see S4, above).