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Cognitive and phenomenological characteristics of hallucination-proneness across the lifespan

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ABSTRACT

Introduction: The impact of age on hallucination-proneness within healthy adult cohorts and its relation to underlying cognitive mechanisms is underexplored. Based on previously researched trends in relation to cognitive ageing, we hypothesised that older and younger adults, when compared to a middle adult age group, would show differential relations between hallucination-proneness and cognitive performance.

Methods: A mixed methods, between-groups study was conducted with 30 young adults, 26 older adults, and 27 from a "middle adulthood" group. Participants completed a source memory task, jumbled speech task, Launay-Slade hallucination scale, unusual experiences schedule, and control measures of delusion-proneness and attitudes to mental health.

Results: Compared to older age-groups, younger participants demonstrated better scores on the source memory task, and reported hearing more words in jumbled speech. Additionally, younger cohorts rated higher on hallucination-proneness and disclosed more unusual experiences on a customised schedule designed to gather further qualitative data. Jumbled speech scores positively correlated with hallucination-proneness scores, particularly for the "middle" age group. Source memory performance unexpectedly correlated positively with hallucination-proneness, although this may be the product of age differences in task performance.

Conclusions: Age differences in hallucination-proneness are evident on self-report and cognitive measures. Implications are discussed for potentially non-overlapping cognitive mechanisms underlying hallucination-proneness in non-clinical groups.

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Hallucination-proneness; continuum; source-memory; jumbled-speech; thematic

Introduction

Hallucinations are defined as a sensory-perceptual experience in the absence of a corresponding external stimulus (Slade & Bentall, 1988) and do not just occur as a symptom of psychosis: voice-hearing prevalence estimates in the general population are usually around 5%–15% (Johns et al., 2014; McGrath et al., 2015; Tien, 1991). The presence of

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these experiences in non-clinical groups suggests that hallucinatory experiences could lie on one continuum which extends into the general population (Van Os, 2003). Cognitive correlates of hallucination-proneness shared by clinical and non-clinical groups, such as biases to detect speech in noise, provide support for this idea (Brookwell et al., 2013; Varese et al., 2012; Bentall & Slade, 1985). However, the evidence linking source memory ability to non-clinical hallucinations is mixed, despite meta-analytic evidence for an association with clinical hallucinations (Alderson-Day et al., 2019; Brookwell et al., 2013; Garrison et al., 2017; Lavallé et al., 2020).

As with many areas of research, the majority of non-clinical hallucination-proneness research has been conducted with young, student participants (e.g., Bentall & Slade, 1985; Collignon et al., 2005). This broadly corresponds to the typical onset period for psychosis (18–25 years), but leaves open the question of what may drive hallucination-proneness at other life stages. Badcock et al. (2017) have argued that although hallucinations are commonly first reported amongst younger adults, the lack of literature on older populations does not reflect the reality of incidence rates: their meta-analysis found a sizeable minority of the aging population had hallucinatory experiences, although estimates varied hugely (0.4%–37%). Some other studies show that people over the age of 60 are more hallucination-prone than other ages (e.g., Tien, 1991; Turvey et al., 2001) and some suggest the opposite (Maijer et al., 2018).

It is important that more research is conducted looking at hallucination-proneness in older age groups because there may be differential cognitive mechanisms underlying hallucinations at different ages. Firstly, hallucinations are often associated with sensory decline in older people (Fischer et al., 2004; Sanchez et al., 2011; Tanriverdi et al., 2001), which is thought to be compensated for through a reorganisation of cognitive responses, including source monitoring (Daselaar et al., 2015). Second, worsening source monitoring, particularly source memory, is associated with healthy ageing in older adults (Mather et al., 1999; Mitchell et al., 2003). Given this, there is a *prima facie* case for source monitoring playing a prominent role in hallucination-proneness for older adults, perhaps more so than for younger adults. Additionally, older adults consistently perform worse than younger adults on speech-in-noise tasks, where top-down knowledge and expectation play a prominent role in detecting speech (Dubno et al., 1984). As such, they may be *less* likely to display top-down biases of the kind typically associated with false perception in younger cohorts. It therefore could be that perceptual bias towards signal detection acts as a marker for schizotypal psychosis-proneness in young adulthood especially. Therefore, cognitive markers of hallucination-proneness could change as a function of age.

To our knowledge, no study to date has looked at the cognitive mechanisms behind hallucinations in relation to age. Investigating this is challenging, due to the general changes in cognition and sensory processes that can occur with ageing. Source memory tasks have the built-in control of testing old-new distinctions (recognition memory) as well as self-other distinctions (self-recognition), but auditory signal detection tasks have a strong perceptual discrimination component (indexed by d'—sensitivity) separate to the measure of interest (response bias). Since it is likely that sensitivity would be linked to age, potentially counfounding any effect of age on response bias, we chose to use a "Jumbled Speech" task, in which participants are played audio tracks of garbled speech sounds and asked in which, if any, they heard intelligible words from (Fernyhough et al., 2007). This task assesses top-down effects on perception in a similar manner to sine-wave speech paradigms

(Alderson-Day et al., 2017). However, because the stimuli do not systematically vary in volume or intelligibility in order to discern a perception threshold, it does not present the same issues of perceptual discrimination sensitivity.

In the present study, we compared both self-reported and cognitive markers of hallucination-proneness in three age groups of participants: a "young adult" group (18–24), an "older adult" group (aged 60+), and a "middle adult" group (25–59), with the latter group acting as a comparison for ages which we expected to be more hallucination-prone. The young adult group was defined based on the peak age range for psychosis onset in the UK population (Kirkbride et al., 2012) while the older adult range followed previous research on hallucinations and age (e.g., Badcock et al., 2017). All participant completed a Source Memory Task, a Jumbled Speech Task, a hallucination-proneness scale, and control measures of mental health stigma and delusion-proneness.

Finally, we included a novel qualitative questionnaire about participants' personal experiences of unusual perception. As hallucination-proneness scales have been critiqued on their ability to capture nuanced and clinically relevant phenomenological features of hallucinatory experience (Stanghellini et al., 2012; Woods et al., 2015), this allowed us to examine both quantitative and qualitative qualities of hallucinations across the lifespan.

We hypothesised that:

I. There would be age-related differences on task performance; specifically, older people would have worse source memory, while younger participants would show a greater tendency to hear speech on the Jumbled Speech Task.
II. There would be quantitative and qualitative age differences in self-reported hallucination-proneness.
III. The relationship between task performance and hallucination-proneness would vary by age; specifically, source memory would correlate with hallucination-proneness in the older adult group, while jumbled speech performance would correlate with hallucination-proneness in the younger group.

Methods

Participants

A sample of 83 participants took part: 30 young adults (18–24, Age $M(SD) = 22.07(1.64)$, 24F), 27 "middle" adults (25–59, Age $M(SD) = 37.89$ (13.02), 16F) and 26 older adults (60–83, Age $M(SD) = 69.69$ (8.46), 21F). Participants were recruited via social media, university newsletters, and word-of mouth, and were reimbursed with shopping vouchers. All were fluent English speakers, gave informed consent, and no participants had hearing or visual impairments. Ethical approval was granted for this study from a university psychology department ethics committee.

Measures

Source Memory Task (SMT)

During the SMT, participants were presented with a series of emotionally neutral words and later required to recall their source. A set of 60 words were separated into three lists, matched on number of letters, syllables, Kucera-Francis frequency, imageability, concreteness, and meaningfulness, based on data from the MRC Psycholinguistic Database (Wilson, 1988). During the learning phase, participants were presented with 40 words in sequence (duration = 4.5s), randomly selected from two lists, and asked: "If you see the word HEAR, just listen to the voice read the word. If you see the word SAY, I would like you to speak that word aloud". After the learning phase, participants were tested on 60 words (40 familiar and 20 new from the third list) and asked to indicate with a button press if the word was said by them, heard, or new (Figure 1). Source memory is measured as the percentage of self-other items correctly identified out of all the items correctly recognised as being old (i.e., (self/self + other/other) / (self/self + other/other + self/other + other/self)). Specifically, this source memory task aims to assess "reality monitoring", which is one plausible model of hallucinations (i.e., that they occur when a self-generated event is misidentified as an externally generated event). Recognition memory score was the proportion of all trials correctly recognised as either old or new. This version of the task was run with two learning and two test phases, taking roughly 15 min to complete.

The Jumbled Speech Task (JST)

On the JST, participants were presented with 12.10-second tracks of jumbled speech (and one practice track) and then asked to type in any English words/phrases they had heard. The stimuli consisted of a "jumbled" female voice, and tracks were presented at a

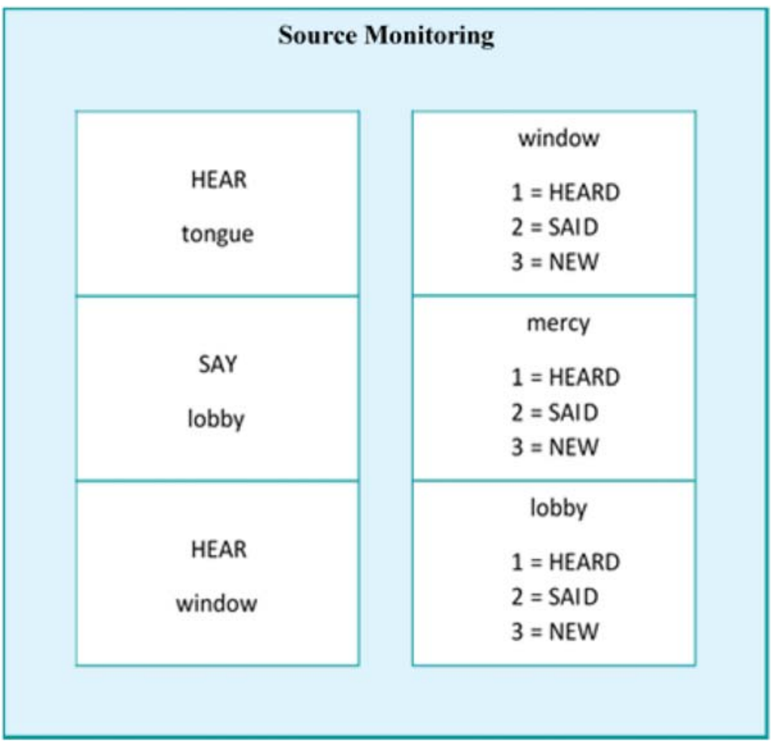

Figure 1. Example of stimuli used in the Source Memory task. The study phase is on the left and the test phase is on the right.

constant volume, pre-set to be comfortable and easily heard through headphones. The stimuli were formed through segmenting the speech at random silent intervals, reversing and then reassembling the audio to replicate the structure of conversational dialogue without salience. Mean minimum pitch of the stimuli was 110.8 Hz, and the mean maximum pitch was 447.2 Hz, with mean pitch typically falling within 250–300 Hz. The stimuli were identical to those used by Fernyhough et al. (2007). The dependent variable used was the number of syllables heard in the jumbled sounds. During analysis we focused on syllables—rather than words—as they provided greater variance for assessing individual differences. As a control question for general suggestibility, participants were asked if they heard an owl (absent in audio).

Launay-Slade Hallucination Scale—Revised (LSHS-R—Morrison et al., 2000)

This measure was used as a standardised scale for hallucination-proneness in non-clinical participants. The 9-item scale focuses on commonplace auditory and visual experiences, as developed by McCarthy-Jones and Fernyhough (2011) following Morrison et al.'s (2000) revision of the original scale. Participants are asked to respond to each item on a 4-point likert scale ranging from "Never" (1) to "Almost Always" (4), with a maximum score of 36. Higher scores denoted a higher predisposition toward hallucinatory experiences (Cronbach's $\alpha = .73$).

Unique Experiences Schedule (UES)

In this novel measure, we included open and closed questions to gather more qualitatively rich data about unusual experiences. The schedule consisted of seven items (see Table 1) that asked about participants' experience of the tasks and any unusual experiences relating to memory and perception they have had in the past. We invited participants to write freely to gather a clearer understanding of their experiences.

Control measures

Peters et al Delusions Inventory (PDI—Peters et al., 1999)

This 21-item inventory measures delusional thoughts in the general population by measuring the frequency of occurrence, distress caused and how much participants believe them to be true. We took the frequency score out of 21 as a control measure in our analyses (Cronbach's $\alpha = 0.82$; Peters et al., 2004).

Table 1. Questions from the unusual experiences schedule.

Item	Response
During the JST, did you notice any words?	Yes/No/Not Sure
If so, did the words have any significance to you, or did you notice any themes?	Open-ended
Did you find the source memory task difficult to complete?	Yes/No/Not Sure
Could you talk about any other experiences where you have struggled to remember whether it was you or someone else who said/did something?	Open-ended
Have you ever had a sensory or perceptual experience that you couldn't explain and/or others didn't have?	Yes/No/Not Sure
Have you ever held a strong belief/conviction that others may have found unusual or hard to understand?	Yes/No/Not Sure
If you're comfortable could you elaborate on these experience(s)/ your feelings about them?	Open-ended

Community Attitudes towards Mental Illness (CAMI; Taylor & Dear, 1981)

This scale contains 35 opinion statements regarding mental health and participants indicate their level of agreement on a Likert scale from 1 to 5 (strongly agree, agree, neutral, disagree, strongly disagree). For example, "The mentally ill should be isolated from the rest of the community." The two negative attitudes scales (maximum score of 100) were utilised as a measure of stigmatised views that could impact personal declarations (Cronbach's $\alpha = 86$; Taylor & Dear, 1981).

Siemens "Hearcheck Screener"

A Siemens "Hearcheck Screener" was used for all older participants to ensure a sufficient level of hearing to take part. This involved listening to 31,000 Hz tones at varying volume (55 dB HL, 35 dB HL, 20 dB HL) and 33,000 Hz tones (75 dB HL, 55 dB HL, 35 dB HL), with these 6 tones presented to each ear separately. No participants were excluded based on performance on the screener.

Procedure

Testing primarily took place in a university setting, although occasional home visits were conducted when preferred by participants. In both settings, testing took place at a desk in a quiet room with no-one other than one trained psychology researcher present. Participants were provided with information about the study and signed a consent form, and wore over-ear headphones for the cognitive tasks. Both the JST and SMT were programmed on E-Prime and run on a laptop, with a short practise trial. The order of the two cognitive tasks were alternated to avoid order effects. Questionnaires took place immediately following the cognitive tasks. Test length varied from 30 to 70 min, taking an average of 45 min.

Analysis plan

Comparisons between age groups were conducted using one-way ANOVAs, with all quantitative analyses being conducted in R (R Team, 2013). Correlations between independent measures were also analysed, first across the whole sample and then broken down across the three age groups. Power analysis indicated a sample size of 85 would give 80% power to detect a moderate effect size ($r = 0.3$, two-tailed, conducted using G*Power 3.1). Non-normal data was analysed using Kruskal–Wallis tests (for group comparisons) and Spearman tests (for correlation), with the "setcor" package in *R* used for moderation analysis. Where main effects were evident, Games-Howell and Dunn post-hoc tests were deployed for parametric and non-parametric data, respectively. Qualitative data was analysed against a coding framework developed via inductive thematic analysis (Braun & Clarke, 2006), which included (i) the thorough reading of all responses by two researchers (BAD & LH) and creation of initial code set, (ii) independent application of codes to 20% of the dataset, (iii) inter-rater reliability calculation (kappa = 0.77) and (iv) supervised coding of the rest of the dataset by a single researcher. Themes and codes were compared across age cohorts and in relation to quantitative results.

Results

Comparing task performance across age groups

As is typical for hallucinations research, much of our task and questionnaire outcomes were non-normally distributed, or did not meet other assumptions of parametric testing. Specifically, outcomes relating to the JST, LSHS and PDI were analysed using non-parametric tests, with the remainder analysed using parametric methods. Figure 2(a) and (b) display the mean task scores on the SMT for each age group. Using source memory score as dependent variable, a main effect of group was evident, $F(2,80) = 3.35$, $p = .040$, $\eta_p^2 = 0.07$, with young participants scoring significantly higher than older participants ($t = 2.44$, $p = .048$; Games-Howell test used). No other pairwise comparisons were significant (all $p > .10$). This was not the case for recognition memory performance (i.e., the ability to distinguish old and new items), where no significant difference was found between the young ($M = 0.84$, $SD = 0.08$), middle ($M = 0.83$, $SD = 0.09$), and older age groups ($M = 0.84$, $SD = 0.07$; $F(2,80) = 0.013$, $p = .941$, $\eta_p^2 = 0.0001$).

In the jumbled speech task, 60% reported noticing some words, with 25% hearing no words and 15% unsure. No-one responded affirmatively to the owl manipulation (although two said they had perhaps heard something, they were not excluded on this basis). Performance also differed across age groups on this task (figure 2b). A Kruskal–Wallis test indicated a main effect across the three groups, $X^2 = 18.15$, df = 2, $p < .001$, with older participants reporting fewer syllables (M(SD) = 7.69 (10.83)) than both younger participants (M(SD) = 21.37 (13.76); $Z = 4.13$, $p < .001$) and middle participants (M(SD) = 18.48 (15.66); $Z = 3.06$, $p = .004$); the difference between the younger and middle age groups was not significant ($Z = 1.00$, $p = .319$; Dunn-test with Holm corr.).

The data therefore provided partial support for our first hypothesis: older participants were selectively worse at source memory, and younger participants reported more syllables on the JST. For the latter, however, this was also true of participants from the middle age group, compared to the older group.

Comparing hallucination-proneness and relating it to task performance

78 participants provided complete data from the questionnaire pack, as shown in table 2. A Kruskal–Wallis ANOVA indicated a significant difference in hallucination-proneness between the groups, $X^2 = 18.29$, df = 2, $p < .001$. Pairwise Dunn tests (Holm-corrected) indicated that younger participants were more hallucination-prone than middle ($Z = 1.99$, $p = .046$) and older ($Z = 4.28$, $p < .001$) groups, while middle participants also scored higher than older participants ($Z = 2.29$, $p = .045$).

Pairwise correlations—using Spearman's tests—indicated that hallucination-proneness was positively related to the number of syllables participants reported hearing on the JST ($r_s = .36$, $N = 78$, $p = .001$). Source memory performance was also related to hallucination-proneness, although in an unexpected direction: *higher* source memory scores were associated with *greater* hallucination-proneness ($r_s = .23$, $N = 78$, $p = .048$). However, both of these results were likely confounded by the observed age differences in task performance: when age was partialled out correlations reduced to 0.14 for JST performance and 0.13 for SMT performance ($p = 0.20$–0.25).

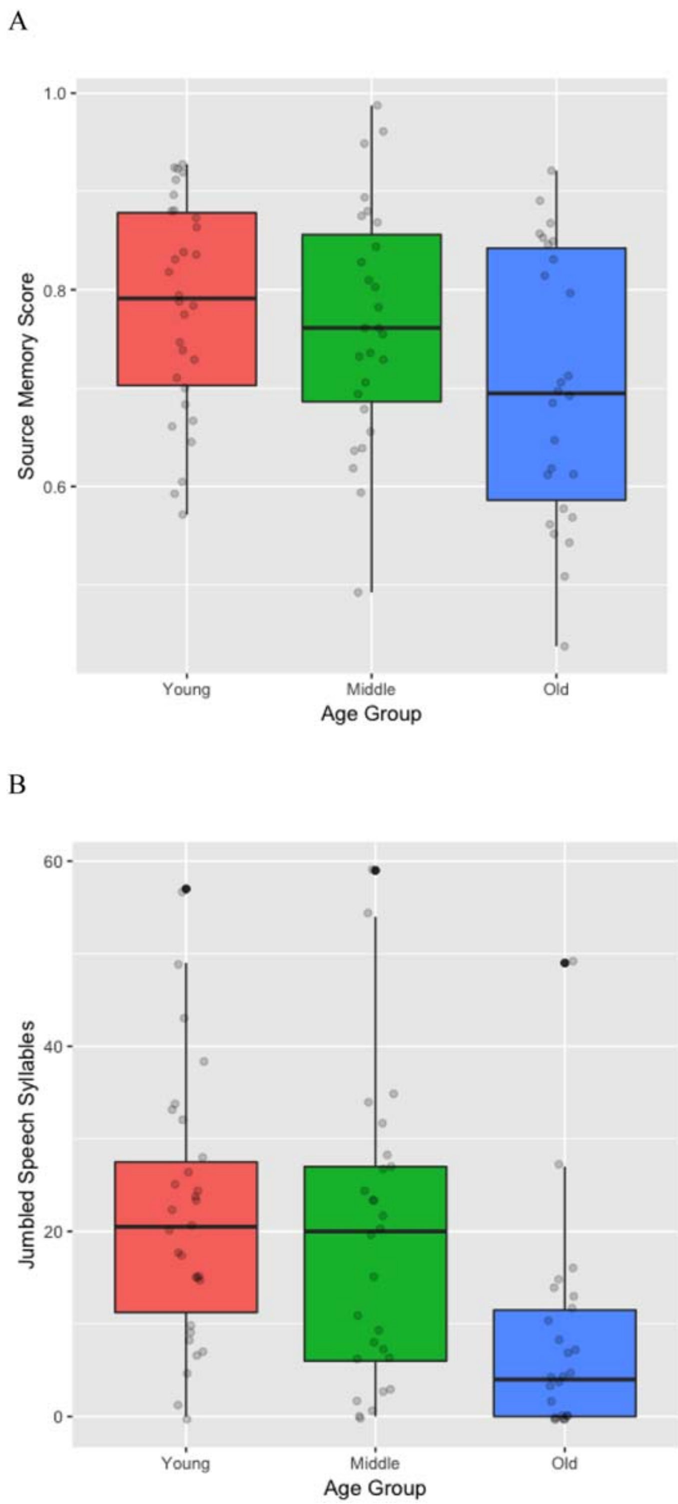

Figure 2. Source memory (a) and jumbled speech performance (b) across age groups.

Table 2. Mean questionnaire scores by age group.

	Young ($n = 28$)		Middle ($n = 26$)		Old ($n = 24$)			
	M	*SD*	*M*	*SD*	*M*	*SD*	*Sig.*	*pairwise*
LSHS	16.00	4.03	14.31	5.51	11.17	2.30	***	Y = M > O
PDI	66.14	29.36	50.73	44.59	26.42	28.35	***	Y > M > O
CAMI	36.32	8.98	35.96	8.41	36.25	10.44	n.s.	–

LSHS = Launay-Slade Hallucination Scale, PDI = Peters Delusion Inventory, CAMI = Community Attitudes to Mental Health. ***$p < .001$.

To examine whether these correlations were moderated—rather than mediated—by age, two different moderation models were specified: one in which membership of the *youngest* age group specifically would enhance a relation between JST performance and hallucination-proneness (i.e., a moderating factor of "young vs all other participants", model 1a), and another where membership of the *oldest* age group was predicted to influence SMT-LSHS relations specifically ("older vs all other participants", model 2). These were specified to test the hypothesis that source memory and perceptual bias would show stronger relations to hallucination-proneness at different times in life. Prior to analysis both predictors (task performances) and the dependent variable (LSHS) were mean-centred by group to mitigate the influence of group differences, and LSHS and JST performance were log-transformed prior to centring (to normalise distributions).

Using the *setcor* package in R, no moderating effect was observed for model 1a, i.e., younger participants vs. other participants on the JST ($t = -0.41$, $p = .68$, beta $= -0.01$). In fact, the correlation between task performance and hallucination-proneness appeared to be greatest for the middle age group ($r_s = .34$) and minimal in the younger ($r_s = .07$) and older groups ($r_s = -0.10$). We therefore conducted an exploratory analysis, in which a moderation effect was included that instead compared *middle-group* participants to the two other groups (Model 1b.), in which a significant interaction effect of age by JST performance was evident for predicting hallucination-proneness ($t = 2.19$, $p = .032$, beta $= 0.06$). There was partial evidence, therefore, of age moderating the relation between perceptual bias and hallucination-proneness, but not in the manner hypothesised: hearing speech amid jumbled sounds was associated with hallucination-proneness for the middle age group in particular. We also reran our analyses splitting the LSHS for auditory and visual subscales, to explore specificity of the above relation. This indicated similar correlations among the groups, but only a significant moderating effect for auditory LSHS (see Supplementary Materials).

For the SMT, no clear moderating effect of age was observed at all, with the specified term being non-significant (model 2; $t = -1.08$, $p = .29$, beta $= -0.56$), and evidence of positive relations to hallucination-proneness in young ($r_s = .26$) and middle ($r_s = .18$) age groups, but not for older participants ($r_s = .04$). Therefore, the relation between hallucination-proneness and source memory performance did not vary significantly with age, and even when it was most prominent (in young adulthood), it showed an unexpected, positive relationship.

Testing confounds of delusion-proneness and attitudes towards mental health

We then explored the potential role of confounding factors such as delusion-proneness (on the PDI) and attitudes to mental illness (on the CAMI). No significant group differences were observed on the CAMI, suggesting that positive and negative attitudes towards mental illness were unlikely to be driving group differences on other variables, $F(1,76) = 0.001$, $p = .973$, $\eta_p^2 \leq 0.001$ (see Table 2 for means). In contrast, a large group difference was evident on the PDI, c = 17.36, df = 2, $p < .001$: younger participants scored higher than participants in the older ($Z = 4.17$, $p < .001$) group specifically. As this broadly followed the pattern of LSHS scores, we then reran the correlation and moderation analyses with PDI as the dependent variable instead of hallucination-proneness. No correlation was evident between PDI and SMT performance ($r_s = .15$, $p = .192$), but higher delusion-proneness was associated with hearing more syllables on the JST ($r_s = .42$, $p < .001$). The latter relationship was then tested for moderation using the same moderating effects as specified previously for the JST (i.e., young vs all other participants and middle vs all other participants). Younger participants again showed no specific moderating effect (model 3a; $t = 0.27$, $p = 0.79$, beta = 0.04). The moderating effect for middle age participants was only evident at trend level (Model 3b; $t = 1.93$, $p = .058$, beta = 0.23).

Qualitative characteristics of hallucination-proneness across age groups

Finally, we used the responses from the UES to explore participants' experiences of the tasks and any other hallucinatory or unusual experiences they had had before. Within the JST, most did not see any significance to the words, e.g., "names of people I don't know". Frequent responses when asked to recount "other experiences where you have struggled to remember" were "I have been confused whether it was me or a friend that might have said something" and "can't remember what I've gone into a room to collect".

Of 85 respondents, 51 (60%) described an unusual experience from some point in their lives. Using thematic analysis these were coded into the themes "anomalous" (such as experiences of deja vu, or out of body experiences), "senses" (such as clearly auditory or visual experiences), "context" (experiences tied to specific contexts or events, such as sleep-related phenomena), and "reaction" (including immediate responses, and affect associated with the experience). Examples of each theme, their corresponding codes, and their frequency is provided in Table 3 (see Supplementary Materials for full definitions of each code).

The younger group included twice as many participants reporting unusual experiences ($n = 22$) as the older group ($n = 11$) with the middle-age group falling in between ($n = 18$). A few age distinctions emerged: bereavement contexts were described exclusively by older participants (9.8% of all codes), and most cited these as positive, comforting experiences. Correspondingly, the youngest age group were more likely to report negative and neutral experiences (across any context). All groups reported a variety of sensory experiences, but no auditory experiences were reported within the older cohort, and only one auditory example was provided by the middle age group. Only two experiences reported by the oldest group were technically hallucinations: the rest involved an unsual "feeling" that someone was present or that something will happen.

Discussion

We aimed to investigate whether the trends in cognitive performance and phenomenological experience associated with hallucination-proneness were equivalent across the lifespan. In keeping with previous research (Alganami et al., 2017; Bentall & Slade,

Table 3. Examples of each qualitative code used.

Themes	Codes	Examples	% of Code in data
Anomalous	*Hard to Explain*	For a while I had a phantom face numbness—I thought the left side of my face had reduced sensation though the doctor could not find a physiological cause.	19.6
	False Event	Sometimes I might have heard a noise and someone else feels strongly there was no noise and I strongly believe there was.	17.6
	Déjà vu	I have had experiences of déjà vu that felt powerful but that I couldn't explain. Deeply felt idea that I know all about an art exhibition, for example, that I had seen it before when I could not have.	9.8
	Premonition	I can sometimes feel energies and atmospheres around me and can sense when the air has changed (like a foreshadowing to something bad about to happen)	13.7
	OBE	When I was 13, I had an outer-body-experience during school time. During the experience my soul left my body and my body was frozen (I couldn't move) apart from my eyes, which I was not looking in the direction of where I should have been looking, but I was looking down on myself not moving and others continuing to move on around me as normal.	5.9
	Paranormal	As a child I was sure that an old man lived in our home and sat on my bed, depressing the cushions but I never saw him, just felt his presence. my mothers family all believe in the supernatural, we have all experienced feelings or experiences we can't explain.	7.8
Senses	Presence	I just see butterflies which make me feel the presence of my daughter, who sadly passed away 18 months ago	23.5
	Other	Sometimes I feel like someone has tapped me on the shoulder when no one has or no-one is around	23.5
	Auditory	I once woke up and thought I heard a voice saying "there's somebody in the room" that wasn't my own voice	13.7
	Visual	I have a really bad phobia of spiders and when I was little I would always see them but when I got my dad to kill them he wouldn't be able to find any, even though I was sure they were definitely there	25.5
Reaction Response	Defending	I can also tune in and know what people are thinking or feeling but I regard this as a normal thing that most people can do but don't know they can. Also as I work as a therapist it's what I do and use all the time	19.6
	Discounting	So silly as it sounds, I sometimes think a higher power gives me glimpses of whats to come—I can't explain it, it just happens	7.8
	Minimising	I recently saw a glowing orb? At night in the back garden—also seen by our dog who chased it, but I can't explain what it was	13.7
Affect	Neutral	Often hear name being called when it isnt. Have experienced phone ringing & believing it was real to the point of going to answer it, but there's no evidence of a call … Don't really mind this happening, it's not often	52.9
	Positive	I had 2 very vivid dreams relating to my recently deceased father. Felt very real. I found these experiences very reassuring!	13.7
	Negative	Sometimes I will wake up and be very very convinced that someone else is in my room. I can see them clearly for a minute or so, but I've learned that if I just keep staring at them then they eventually go away and I realise that nothing is there. It's very scary, first happened about a year ago and has happened ~4 times since	21.6
Context	Childhood	When I was about 10 I went for a walk with my mum, when we returned home my dad seemed to know some of what we had seen and done	11.8
	Sleep	I am thinking of dreams where I was awake in my bed but couldn't move and there was something big and scary in the room (e.g., a giant crab monster on the ceiling or somebody looking through the window)	13.7
	Bereavement	Quite soon after my mum died (12 years ago) I had a sense a few times that she was in birds that flew past- one nearly hit the window screen when I was driving the car.	9.8

1985; Mitchell et al., 2003), the younger two groups reported more language in the JST, and the oldest group displayed poorer source memory (despite not significantly differing on recognition memory). Hallucination-proneness was related to age but, contrary to our hypothesis, it significantly declined with age, rather than being higher in older as well as younger participants.

Consistent with previous research (Feelgood & Rantzen, 1994; Fernyhough et al., 2007; Hoffman, 1999), our measure of speech perception bias (the JST) was positively related to hallucination-proneness. This relationship was moderated by age, although surprisingly the correlation was greatest in the middle adulthood age group. This suggests an inverted U-shaped relationship across the lifespan for the correlation between speech perception bias and hallucination-proneness. This middle age group has not been subject to as much investigation as younger adults, and perhaps the relative lack of cognitive change and developmental variation during this period means this is a "steadier" period in which to look at mechanisms of hallucination-proneness. Alternatively, the relative contributions of different mechanisms to hallucinatory experience could vary with different phases of life.

Although poorer source memory has been proposed to increase hallucination-proneness, we surprisingly found the converse: better source memory corresponded to *greater* hallucination-proneness across the sample. On the one hand, this could be due to age playing a confounding role: as older participants were both less hallucination-prone and worse at source memory than younger participants, this may have manifested across the whole sample as a positive correlation between both constructs. Considering that the correlation between SMT and LSHS was no longer significant when age was partialled out, it seems likely that this reflects how each relate to age, rather than a "true" relationship. On the other hand, small within-group correlations were also positive for the two younger age groups, while problems with source memory and other neurocognitive difficulties could potentially have obscured correlations with LSHS in older participants. We cannot therefore rule out source memory and hallucination-proneness having an unusual relationship across the lifespan, although given the range of inconsistent findings elsewhere (e.g., Moseley et al., 2020), we are loath to overintepret this finding.

Together these findings suggest that a speech perception bias is related to non-clinical hallucination-proneness in the general population, but source memory problems are not. This—along with other recent research (Alderson-Day et al., 2019; Garrison et al., 2017)—supports the view that clinical and non-clinical hallucinations have some overlapping cognitive aetiology amidst multiple cognitive pathways to hallucination (Waters et al., 2012). Given that PDI scores and the visual subscale of the LSHS were related to JST performance, it seems likely that JST performance in our data indicated some general psychosis liability. Further, PDI scores and qualitative reporting of unusual experience followed a similar pattern to the JST and LSHS where the youngest group reported the most, the oldest group reported the least, and the middle age group fell somewhere in the middle.

Although we observed no group differences in our measure of mental health attitudes, it could still be the case that what people are willing to report differs with age (Badcock et al., 2017). Our use of open-ended questions provides useful insights on this issue: young participants reported twice the number of experiences compared to the older group, but also different kinds of experience. A context of bereavement was reported more by older participants (and spoken of as overwhelmingly positive), while only young participants reported having auditory experiences on the UES. Proneness to different *kinds* of hallucination in younger vs. older adults has been observed previously by Larøi et al. (2005), who observed greater rates of self-reported vivid daydreams and intrusive thoughts in younger participants and more auditory, visual, and sleep-related experiences in elderly participants. Their data and ours together highlight that the general focus on auditory experiences may be missing important variation in hallucinatory phenomena, in this case across the age range (indeed, auditory experiences were the least frequently mentioned modality in our UES results).

Some limitations must be noted for our findings. First, the JST is relatively unused in hallucination-proneness research compared to "white-noise" based signal detection tasks (e.g., Moseley et al., 2016). We chose this method to avoid detection sensitivity confounding differences in response bias across groups, but it does mean that standard measurements of response bias and sensitivity were not generated here for direct comparison with prior findings. Second, we used a relatively short version of the LSHS to measure hallucination-proneness, focusing on auditory and visual hallucinations (Jones & Fernyhough, 2009; McCarthy-Jones & Fernyhough, 2011). This was done for pragmatic reasons, but does entail asking about a smaller range of experiences than other LSHS variants (Larøi et al., 2005) or other scales (e.g., CAPS; Bell et al., 2006). This version of the LSHS has been successfully used in our prior work to identify relations between task performance and self-reported hallucination-proneness; nevertheless, we cannot rule out that alternative measures could have been more successful in picking out age-specific moderating effects. Finally, the relatively short length of responses is a qualitative limitation in this study, meaning that many of the responses were "bitty" in nature (Braun et al., 2014). Ideally, such responses would be followed with semi-structured interviews to ensure that data was sufficiently rich for thematic analysis. Nevertheless, we note that this tool was still sufficient to capture a broad range of unusual experiences in participants' accounts.

In conclusion, this study has been successful in showing some potentially important differences in hallucination-proneness and its underlying mechanisms across age groups. Quantitative and qualitative age-differences were found in hallucination-proneness: the association between JST performance and hallucination-proneness was moderated by age (most strongly related in the middle age group), and hallucinatory experiences varied with age in their content, context, sensory type, and frequency. As one of the only studies to approach this research from this lifespan perspective, our results offer an important starting point to be able to more thoroughly map and understand the hallucination continuum.

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