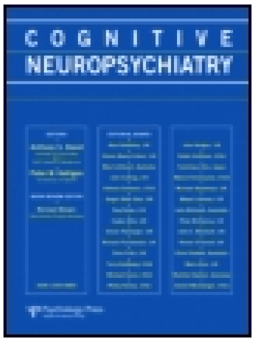

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The perceived salience of vocal emotions is dampened in non-clinical auditory verbal hallucinations

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ABSTRACT

Introduction: Auditory verbal hallucinations (AVH) are a cardinal symptom of schizophrenia but are also reported in the general population without need for psychiatric care. Previous evidence suggests that AVH may reflect an imbalance of prior expectation and sensory information, and that altered salience processing is characteristic of both psychotic and non-clinical voice hearers. However, it remains to be shown how such an imbalance affects the categorisation of vocal emotions in perceptual ambiguity.

Methods: Neutral and emotional nonverbal vocalisations were morphed along two continua differing in valence (anger; pleasure), each including 11 morphing steps at intervals of 10%. College students ($N = 234$) differing in AVH proneness (measured with the Launay-Slade Hallucination Scale) evaluated the emotional quality of the vocalisations.

Results: Increased AVH proneness was associated with more frequent categorisation of ambiguous vocalisations as 'neutral', irrespective of valence. Similarly, the perceptual boundary for emotional classification was shifted by AVH proneness: participants needed more emotional information to categorise a voice as emotional.

Conclusions: These findings suggest that emotional salience in vocalisations is dampened as a function of increased AVH proneness. This could be related to changes in the acoustic representations of emotions or reflect top-down expectations of less salient information in the social environment.

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Auditory verbal hallucinations; psychosis continuum; emotion; perceptual ambiguity; salience processing

Introduction

Auditory verbal hallucinations (AVH; perceiving a voice in the absence of corresponding acoustic input – Baumeister et al., 2017; Laroi et al., 2012) are a cardinal symptom of schizophrenia (Johns et al., 2014). However, approximately 13% of the general

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population without the need for clinical care also report AVH, consistent with a psychosis continuum (Baumeister et al., 2017; Johns et al., 2014). AVH in psychotic and non-clinical individuals are described as having perceptual qualities that are indistinguishable from real voices (Johns et al., 2014), even though they are perceived as more positive in content and more controllable by non-clinical voice hearers (Daalman et al., 2011). Similarities in the cognitive and neural mechanisms of AVH in psychotic and non-clinical participants (Baumeister et al., 2017; Zmigrod et al., 2016) suggest a neural substrate that is specific to AVH rather than psychosis in general. Notwithstanding, despite many efforts to explain this puzzling phenomenon, the neurocognitive mechanisms underpinning AVH remain elusive.

Different models have been proposed to account for AVH, focusing on different mechanisms (see Conde et al., 2016; Pinheiro et al., 2020; Waters et al., 2012 for a review). One of these accounts posits that hallucinated voices result from a failure to distinguish self- from externally-generated events due to source monitoring abnormalities (Griffin & Fletcher, 2017; Nelson et al., 2014b). Accordingly, altered self-other voice discrimination was reported in both psychotic voice hearers (Allen et al., 2004; Allen et al., 2007; Heinks-Maldonado et al., 2007) and hallucination-prone individuals (Pinheiro et al., 2019), reflected in an external misattribution of the self-voice. AVH have also been related to disrupted salience processing, i.e. an association process that makes certain stimuli (e.g. emotional) stand out compared to others (e.g. neutral), triggering attentional resources and guiding behaviour (Liddle et al., 2016). Specifically, the aberrant salience hypothesis (Kapur, 2003) posits that positive symptoms such as AVH occur due to alterations in dopaminergic neurotransmission and the subsequent assignment of salience to non-relevant stimuli. Aberrant salience might be manifested in a failure to suppress attention to irrelevant information in the environment (e.g. Alba-Ferrara et al., 2013), as well as in the attribution of emotional qualities to neutral stimuli. For example, a tendency to categorise facial and prosodic neutral stimuli as fearful was reported in ultra-high risk participants that transitioned to a psychotic disorder (Allott et al., 2014). This could reflect enhanced top-down expectations for negative cues.

These two accounts – altered source monitoring and salience assignment – are not mutually exclusive. Indeed, links between dysfunctional self-related processing and salience attribution have been identified (Nelson et al., 2014a, 2014b). Dysfunctional salience processing has also been linked to faulty predictive processing, namely an imbalance between top-down predictions (priors) about the environment and bottom-up information (Davies et al., 2018). This is reflected, for example, in an increased proneness to semantic expectation effects in AVH (Daalman et al., 2012; Vercammen & Aleman, 2010), indicating a bias in perceptual processing. In particular, an atypically strong expectation for voice percepts could lead to non-veridical voice perception (Alderson-Day et al., 2017; Powers et al., 2016).

The predictive processing framework might account for alterations in both source monitoring and aberrant salience processing (Corlett et al., 2019; Nelson et al., 2014b; Sterzer et al., 2018). For example, salience processing may be atypical due to expectation-based predictions that imbue non-relevant events with meaning (Galdos et al., 2011). In voice perception, the impact of prior expectation on sensory and salience processing can be examined using ambiguous vocal stimuli. Voice hearers show a stronger tendency to extract meaningful linguistic information from perceptually ambiguous sounds: when presented with unintelligible sine-wave speech, non-clinical voice hearers perceived speech before individuals who did not report AVH (Alderson-Day et al., 2017). AVH in psychotic and non-clinical voice hearers were also associated with an increased false alarms rate (i.e. detecting a specific sound when it was not present) in both tone detection tasks with a conditioning visual stimulus (Powers et al., 2017) and auditory signal detection tasks (Barkus et al., 2007; Vercammen et al., 2008). More recently, the increased bias toward speech perception in hallucination proneness was found to be related to altered perceptual weighting of the spectro-temporal modulations that characterise speech (Erb et al., 2020). These findings highlight a possible interplay between sensory-based and top-down evaluative processes in accounting for alterations in voice and speech perception in AVH.

Even though atypical processing of vocal emotions has been associated with AVH (Rossell & Boundy, 2005; Tseng et al., 2013), studies examining how AVH proneness affects the perception of emotionally ambiguous stimuli are scarce and report inconsistent findings. Compared to controls and psychotic patients without AVH, psychotic voice hearers were less accurate at categorising emotional nonverbal vocalisations and were more prone to mislabel fear as sadness and happiness as fear (Rossell & Boundy, 2005). However, hallucination proneness in non-clinical participants did not affect valence ratings of nonverbal vocalisations and spoken words (Pinheiro et al., 2019), which indicates that emotional categorisation and valence assessment are dissociable processes when evaluating vocal emotions. Specifying how emotional information is decoded in conditions of perceptual ambiguity might clarify the extent of salience disruption in AVH, and eventually link phenomenological and neurocognitive levels of enquiry. Indeed, the emotional quality of hallucinated voices seems to be a central aspect of AVH phenomenology: non-clinical voice hearers report less negative (e.g. derogatory demands, threats – Daalman et al., 2011; de Boer et al., 2016), and more positive and neutral AVH (e.g. advice, mundane content – de Boer et al., 2016; Laroi et al., 2012). Notably, the need for care in voice hearers is closely related to the emotional content of AVH (Larøi et al., 2019). Examining how ambiguous vocal emotions are perceived as a function of AVH proneness may shed light on how salience is assigned to sounds when there is increased uncertainty about their emotional significance, potentially revealing the effects of top-down expectations.

In this study, we probed how AVH proneness influences the perception of ambiguous vocal emotions. We morphed nonverbal neutral and emotional vocalisations to create anger-neutral and pleasure-neutral continua. Participants were asked to evaluate nonverbal vocalisations according to their emotion category, valence, and arousal. Hallucination proneness was measured using the Launay-Slade Hallucination Scale (LSHS; Castiajo & Pinheiro, 2017). Considering dimensional models of psychosis (Baumeister et al., 2017) and evidence for similarities in the cognitive and neural mechanisms underpinning AVH in psychotic and non-clinical participants (Baumeister et al., 2017; Zmigrod et al., 2016), we expected to observe differences in the categorical perception of emotionally ambiguous vocalisations in association with AVH proneness (Alderson-Day et al., 2017; Olano et al., 2020). Differences in vocal emotion categorisation were expected to be more pronounced for morphed stimuli containing lower percentages of emotional vocal information, consistent with the notion that AVH are associated with salience assignment to non-relevant stimuli (Allott et al., 2014). We also expected to observe changes in the perceptual representation of emotional voices, reflected in the point of subjective equality (PSE; i.e. the centre of symmetry of the categorisation-related psychophysical function): the threshold between neutral and emotional categorisations was expected to differ as a function of AVH proneness (Allott et al., 2014; Rossell & Boundy, 2005).

As for specific effects of emotion type (positive *vs.* negative) on categorisation, our approach was exploratory. A strong possibility is that even though vocal emotional perception is altered in both psychotic and non-clinical AVH, the pattern of these alterations is qualitatively different. On the one hand, evidence from psychotic patients supports a tendency to categorise neutral stimuli as negative (Allott et al., 2014). Considering dimensional models of psychosis, one should therefore expect more frequent categorisations of neutral vocalisations as 'angry' as hallucination proneness increases. On the other hand, phenomenological reports of AVH reveal that hallucinated voices in non-clinical voice hearers often have a less negative quality (e.g. de Boer et al., 2016). This could indicate that AVH proneness in the general population is associated with a general tendency to categorise voice percepts as more positive or as more neutral.

Methods and materials

Participants

College students were invited to enrol in the study in exchange for course credit (convenience sample, $n = 297$). Thirty-three participants were excluded as they did not report European Portuguese as their first language. Moreover, 30 additional participants were excluded for the following reasons: 17 participants did not complete the entire experimental procedure or presented a significant error rate (>25%) to the control question in the experimental task (see below); 13 participants reported having hallucinatory experiences under the effect of drugs. The final sample included 234 participants (200 females; $M_{age} = 20.16$ years, $SD = 3.66$ years).

All participants provided written consent before the experiment. The study was conducted in accordance with the Declaration of Helsinki and was approved by the local Ethics Committee of the Faculty of Psychology – University of Lisbon (Lisbon, Portugal).

Experimental stimuli

Morphed stimuli were generated from neutral, positive, and negative (2 male and 2 female voices per category) nonverbal vocalisations selected from the *Montreal Affective Voices* battery (MAV – Belin et al., 2008; validated for Portuguese – Vasconcelos et al., 2017), using TANDEM-STRAIGHT (Kawahara & Morise, 2011). Pleasure and anger were chosen as examples of positive and negative emotions, respectively. Pleasure-neutral and anger-neutral morphed continua were created, each including 11 morphing steps per speaker at intervals of 10%: 0/100%, 10/90%; 20/80%, 30/70%, 40/60%, 50/50%, 60/40%, 70/30%, 80/20%, 90/10%, and 100/0% neutral/emotional information. Stimuli with 100% and 0% of emotional information were considered non-ambiguous, and the remaining stimuli were considered ambiguous. This resulted in a total of 44 stimuli per continua. Stimuli were presented via headphones (Philips/SHP1900). More details on the morphing procedure are provided in the Supplement.

Procedure

The experimental task was programmed with Qualtrics (Qualtrics, Provo, UT). Before stimulus evaluation, participants were provided with an illustrative example and were told there were no correct responses. Participants could listen to the vocalisations as many times as they wanted. In each trial, participants indicated if the stimulus was produced by a female or a male speaker to ensure participants' attention was focused on the vocalisations. Participants rated the valence and arousal of each vocalisation using a 9-point scale (valence: ranging from 1 = "extremely unpleasant" to 9 = "extremely pleasant"; arousal: ranging from 1 = "extremely calm" to 9 = "extremely aroused"). They also categorised each vocalisation choosing one of four labels ("anger", "pleasure", "neutral", and "other emotion"). Each vocalisation was presented twice; stimulus presentation was randomised.

At the end of the session, participants completed the 16-item LSHS (Laroi & Van Der Linden, 2005; adapted for Portuguese by Castiajo & Pinheiro, 2017). Each LSHS item was rated using a 5-point scale (0 = "certainly does not apply to me"; 1 = "possibly does not apply to me"; 2 = "unsure"; 3 = "possibly applies to me"; 4 = "certainly applies to me"). Follow-up questions regarding frequency, valence, and degree of control were presented for each affirmative response (i.e. a score of 3 or 4). The total score ranges from 0 and 64. As the aim of the current study was to probe how the perception of vocal emotions is specifically modulated by individual differences in AVH proneness, we adopted the same strategy used in previous studies (e.g. Tucker et al., 2013). We computed an AVH score ($LSHS_{AVH}$), representing the sum of LSHS items that selectively target AVH: items 4 – "In the past, I have had the experience of hearing a person's voice and then found no one was there", 8 – "I often hear a voice speaking my thoughts aloud", and 9 – "I have been troubled by voices in my head". Previous studies using principal component analysis showed that this specific subset of items load under the same factor (Laroi & Van Der Linden, 2005; Larøi et al., 2004). This score ranges from 0 to 12 and reflects the participants' proneness to experience AVH.

Data analysis

Since the categorical ratings were the main focus of the current study, here we only describe results related to the categorisation of ambiguous vocal emotions as a function of AVH proneness. The analysis of dimensional ratings is presented in the Supplement. Categorical ratings were analysed separately by response label (i.e. "anger", "pleasure", "neutral", and "other emotion"). Generalised mixed linear analyses (glmer) were conducted with participants and items as random factors, whereas emotion type (anger, pleasure), percentage of emotion (90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, and 10%), and $LSHS_{AVH}$ were added as fixed factors.

To analyse how variability in AVH proneness modulates the perceptual representation of an emotional voice, as well as the plasticity of this perceptual boundary, we examined the PSE (see Supplement). These scores specify how much emotional information in each continuum is necessary for a correct categorisation of a given emotion (anger or pleasure) 50% of the time.

In all analyses, fixed and random effects coefficients were computed using the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) packages in the R environment (R3.6.2.). The statistical models with predictors were compared to null models, which only included the random factors (categorical analysis: participants and items; PSE analysis: participants). Through random effects parameters, mixed models take into account the dependency between data points, resulting in more accurate estimates of effects and non-inflated type I errors (Singmann & Kellen, 2019).

Results

LSHS scores

LSHS total scores ranged from 1 to 57 (M = 24.48, *SD* = 11.20) and $LSHS_{AVH}$ scores ranged from 0 to 11 ($M = 3.52$, $SD = 2.98$). Participants who reported AVH indicated that their hallucinatory experiences had a neutral content ($M = 2.87$, $SD = 0.68$; from 1 = "The experience was very negative" to 5 = "The experience was very positive"), were controllable ($M = 2.83$, $SD = 1.16$; from 1 = "It is very easy to end the experience" to 5 = "It is very difficult to end the experience"), and occurred with moderate frequency ($M = 2.72$, $SD = 1.15$; from 1 = "Occurs very rarely" to 5 = "Occurs very frequently"). The distribution of $LSHS_{AVH}$ scores, reflecting participants' proneness to experience AVH, is presented in Figure 1.

The categorisation of ambiguous vocal emotions is modulated by AVH proneness

Individual differences in AVH proneness affected how the labels "neutral" and "anger" were used by the participants to categorise an ambiguous (i.e. morphed)

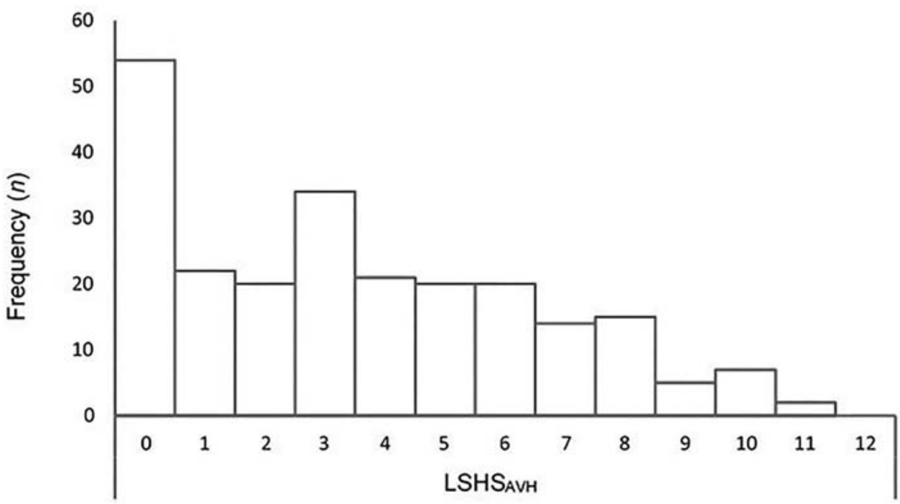

Figure 1. Distribution of $LSHS_{AVH}$ scores in the sample.
Note: *n* = number of participants.

vocalisation. Specifically, as AVH proneness increased, participants showed an increased tendency to categorise ambiguous vocalisations as “neutral” (AVH proneness effect: $\beta = 0.124$, SE = 0.043, z = 2.915, $p = .004$, 95% CI: [0.041, 0.208]), as shown in Figure 2.

A significant interaction between AVH proneness and emotion type ($\beta = 0.129$, SE = 0.056, z = 2.315, $p = .021$, 95% CI: [0.020, 0.239]) revealed that an increase in AVH proneness was associated with a less frequent selection of the “anger” label to categorise vocalisations from the anger continuum, but a more frequent selection of the “anger” label to categorise vocalisations from the pleasure continuum.

Further, an interaction between AVH proneness and morphing level showed that the “neutral” label was used more frequently to categorise ambiguous vocalisations containing higher percentages of emotional information (i.e. 90%) compared to those with lower percentages as AVH proneness increased: **80%** ($\beta = -0.110$, SE = 0.051, z = −2.157, $p = .031$, 95% CI: [−0.210, −0.010]), **50%** ($\beta = -0.107$, SE = 0.045, z = −2.384, $p = .017$, 95% CI: [−0.194, −0.019]), **40%** ($\beta = -0.100$, SE = 0.043, z = −2.335, $p = .020$, 95% CI: [−0.184, −0.016]), **30%** ($\beta = -0.084$, SE = 0.041, z = −2.035, $p = .042$, 95% CI: [−0.165, −0.003]), **20%** ($\beta = -0.104$, SE = 0.041, z = −2.546, $p = .011$, 95% CI: [−0.185, −0.024]), and **10%** ($\beta = -0.117$, SE = 0.042, z = −2.804, $p = .005$, 95% CI: [−0.198, −0.035]). However, AVH proneness did not affect the 70% ($\beta = -0.063$, SE = 0.048, z = −1.305, $p = .192$, 95% CI: [−0.158, 0.032]) and 60% ($\beta = -0.081$, SE = 0.046, z = −1.747, $p = .081$, 95% CI: [−0.172, 0.010]) morphing levels.

AVH proneness did not affect how the “pleasure” and “other emotion” labels were used to categorise morphed vocal emotions ($p > .05$).

The perceptual boundary of emotional categorisation is shifted by AVH proneness

The analysis of PSE values revealed that participants with increased AVH proneness relied on more emotional information to consider a voice as ‘emotional’ (main effect

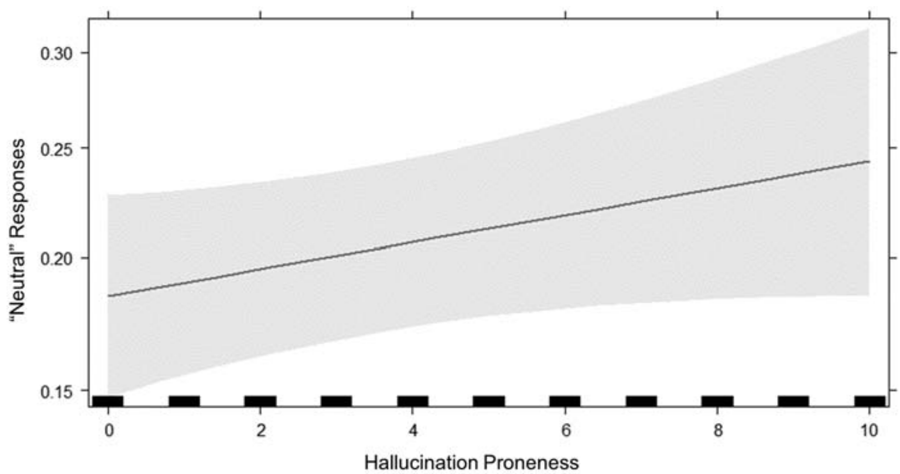

Figure 2. Proportion of “Neutral” responses as a function of AVH proneness.

of AVH proneness: $\beta = 0.103$, SE = 0.046, z = 2.215, $p = .027$, 95% CI: [0.012, 0.192]; Figure 3), regardless of valence.

Discussion

The current study specified how AVH proneness modulates the perception of ambiguous vocal emotions. The categorisation processes addressed in this study are likely more similar to the evaluation of emotions in everyday social interactions, as they often demand a fast interpretation of ambiguous emotional vocal signals compared to more prototypical expressions of basic emotions.

Our findings reveal that AVH proneness modulates the perception of nonverbal emotional vocalisations morphed on a continuum between anger and neutral, as well as between pleasure and neutral vocalisations. Irrespective of valence, ambiguous vocalisations were more frequently evaluated as "neutral" by listeners with higher AVH proneness. In good agreement with this finding, the PSE analysis revealed that increased percentages of emotional information were required to correctly identify the emotion present in the vocalisation as a function of higher AVH proneness. Hallucination-prone individuals also categorised vocalisations from the anger continuum less frequently as "anger", whereas vocalisations from the pleasure continuum were more frequently categorised as "anger".

Together, these results indicate that hallucination proneness is associated with atypical salience processing of ambiguous vocal emotions. The lower tendency to categorise an ambiguous vocalisation as 'emotional' contrasts with previous accounts of positive symptoms as a result from misassigning salience to irrelevant (e.g. neutral) stimuli (Kapur, 2003). For example, previous studies with individuals at risk for psychosis showed that neutral information may be perceived as threatening in psychosis, resulting in the categorisation of neutral information as "anger" (Allott et al., 2014). Structural alterations in brain regions engaged in emotional processing, such as the insula, were also found to be

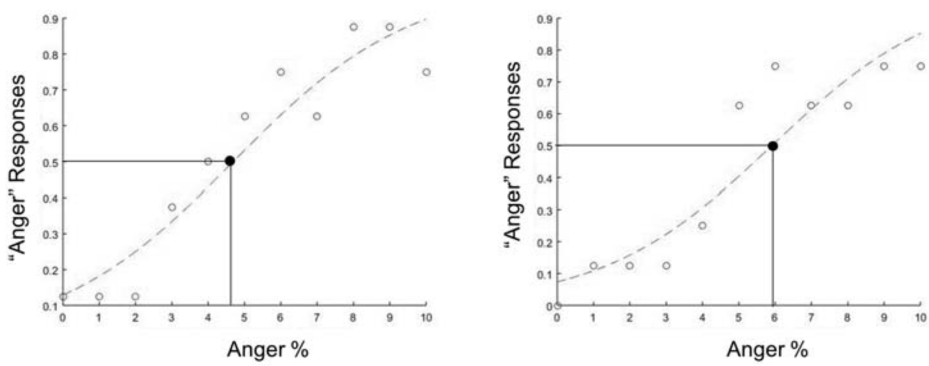

Figure 3. Examples of psychophysical curves/functions fitted for categorical ratings of vocalizations from the anger-neutral continuum.
Note: Proportion of "anger" responses in emotional categorization is shown in the y axis. The x axis shows the percentage of anger in the anger-neutral continuum: 0=0% and 10=100%. The left panel shows the psychophysical curve fitted for data belonging to a participant with a low hallucination proneness score ($LSHS_{AVH} = 0$). The right panel shows the psychophysical curve fitted for data from a participant with the highest hallucination proneness score ($LSHS_{AVH} = 11$). In each panel, the point of subjective equality (PSE) is represented by a dark circle.

similar in psychotic and non-clinical voice hearers (e.g. reduced right insula thickness – van Lutterveld et al., 2014). However, we note that striatal dopamine synthesis capacity, which would indicate aberrant salience, does not differ between non-clinical voice hearers and controls (Howes et al., 2013). It is possible that the tendency to categorise emotional information as "neutral" in the current study simply reflects a more conservative response tendency driven by increased hallucination proneness. However, the PSE results show that the perceptual representation of vocal emotional information is altered in hallucination-prone individuals: more emotional information was needed to correctly categorise a voice as an emotional voice (i.e. anger or pleasure) in half of the trials.

These findings therefore suggest that increased AVH proneness is linked to dampened emotional salience assigned to voices. This could be related to a sensory-driven impairment, namely in pitch discrimination (Tucker et al., 2013), which plays a critical role in the recognition of vocal emotions (Banse & Scherer, 1996). Altered pitch discrimination could, in turn, lead to differences in the acoustic representations of emotions (Castiajo & Pinheiro, 2021). Alternatively, bottom-up alterations could result in a greater weighting of prior knowledge in perception (Corlett et al., 2016) to resolve perceptual ambiguity, i.e. by considering a voice as non-emotional in the absence of further contextual information. This possibility agrees with previous phenomenological evidence showing that non-clinical (*vs*. psychotic) voice hearers characterise AVH content more frequently as neutral (de Boer et al., 2016; Kråkvik et al., 2015) and aligns with the neutral content of hallucinatory experiences reported by our participants.

Of note, compared to pleasure, anger categorisation was modulated by AVH to a greater extent. Whereas vocalisations from the anger-neutral continuum were less frequently categorised as "anger", vocalisations from the pleasure-neutral continuum were more frequently categorised as "anger". Our findings add to previous studies with psychotic patients showing that AVH are related to selective alterations in the perception of vocal emotions (Rossell & Boundy, 2005).

Studies probing a 'psychosis continuum' have identified similarities and differences between clinical and non-clinical samples. Even though we have not directly compared clinical and non-clinical groups, our findings point to some degree of continuity by evidencing that increased AVH proneness is associated with differences in vocal emotional categorisation (as previously shown in psychotic patients with AVH – e.g. Rossell & Boundy, 2005). However, we also identified dissimilarities: we observed an association between psychotic-like features (i.e. AVH) and a tendency to dampen (*vs*. enhance [e.g. Allott et al., 2014]) the salience of vocalisations in emotional categorisation. These qualitative differences could account for the distinct phenomenological reports of AVH and related distress along the psychosis continuum. Emotions are intrinsically related to the content, frequency, and beliefs about AVH (Waters et al., 2012), and represent a factor that contributes to the elicitation or persistence of AVH in psychotic disorders (e.g. Hoskin et al., 2014; Laloyaux et al., 2019). Notably, the most prominent differences in AVH between clinical and non-clinical samples relate to the emotional quality of the hallucinated voices (Baumeister et al., 2017; de Boer et al., 2016), with the former reporting more negative experiences that predict distress (Larøi et al., 2019) and the presence of a psychotic disorder in 88% of participants (e.g. Daalman et al., 2011). We speculate that the possible dampening of emotional salience could, in part, explain why non-clinical voice hearers not only report AVH with negative emotional content less frequently than psychotic voice hearers, but also do not report feeling distressed by the experience of hearing a voice (Larøi et al., 2019). However, this hypothesis remains to be further tested. Considering suggestions that multiple continua might be involved in AVH (Johns et al., 2014), more work is needed to understand whether alterations in vocal emotional perception in AVH in non-clinical and psychotic individuals reflect continuity in the underlying neurocognitive mechanisms (Waters & Fernyhough, 2019).

Limitations

Some limitations should be considered, namely the small number of participants with maximum hallucination proneness scores in the current sample. Further, our sample is mostly comprised of female participants, which constrains the generalisation of these results to the general population (Dickinson et al., 2012). Lastly, as we only manipulated vocalisations expressing anger and pleasure, further studies probing emotional ambiguity using a wide range of discrete emotional categories are needed to confirm to what extent the current results can be generalised to the full spectrum of emotions.

Conclusions

The current study revealed that differences in the categorisation of ambiguous vocal emotions may contribute to the experience of AVH in non-clinical samples. Specifically, our findings suggest that the perceived salience of vocal emotions is dampened in hallucination-prone individuals. Qualitative differences in vocal emotion processing between non-clinical and psychotic voice hearers could explain why individuals who share the experience of hallucinated voices, with perceptual qualities indistinguishable from real voices, may have different clinical outcomes (Sommer et al., 2010).

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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