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Attention to voices is increased in non-clinical auditory verbal hallucinations irrespective of salience

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ABSTRACT

Alterations in the processing of vocal emotions have been associated with both clinical and non-clinical auditory verbal hallucinations (AVH), suggesting that changes in the mechanisms underpinning voice perception contribute to AVH. These alterations seem to be more pronounced in psychotic patients with AVH when attention demands increase. However, it remains to be clarified how attention modulates the processing of vocal emotions in individuals without clinical diagnoses who report hearing voices but no related distress. Using an active auditory oddball task, the current study clarified how emotion and attention interact during voice processing as a function of AVH proneness, and examined the contributions of stimulus valence and intensity. Participants with *vs.* without non-clinical AVH were presented with target vocalizations differing in valence (neutral; positive; negative) and intensity (55 decibels (dB); 75 dB). The P3b amplitude was larger in response to louder (*vs.* softer) vocal targets irrespective of valence, and in response to negative (*vs.* neutral) vocal targets irrespective of intensity. Of note, the P3b amplitude was globally increased in response to vocal targets in participants reporting AVH, and failed to be modulated by valence and intensity in these participants. These findings suggest enhanced voluntary attention to changes in vocal expressions but reduced discrimination of salient and non-salient cues. A decreased sensitivity to salience cues of vocalizations could contribute to increased cognitive control demands, setting the stage for an AVH.

1. Introduction

Listeners are continuously exposed to multiple concurrent sounds in the acoustic environment. Due to competition for limited resources (Marois and Ivanoff, 2005), sounds that are perceived as salient attract more attention. The emotional tone of the voice is one of the most salient cues in the social environment (Liu et al., 2012; Sauter and Eimer, 2009). Emotions are communicated by the voice through a combination of acoustic cues, including pitch, intensity, and duration (Schirmer and Kotz, 2006). The distinct combination of these acoustic cues gives rise to different discrete emotions (Banse and Scherer, 1996; Juslin and Laukka, 2003). The perception of vocal emotions seems to involve several interactive stages (Frühholz et al., 2012; Paulmann & Kotz, 2008a, 2008b; Pinheiro et al., 2013; Schirmer and Kotz, 2006), which include the sensory processing, emotional salience detection, and cognitive evaluation of the emotional significance of the voice (Schirmer and Kotz, 2006). Due to the high temporal resolution of the electroencephalogram (EEG), event-related potentials (ERP) may clarify how the processing of vocal emotions unfolds over time. In this context, specific ERP components have been proposed to index distinct stages of vocal emotional processing: the N1 reflects sensory operations, whereas P2 modulations are thought to reflect salience detection in vocal emotions (Paulmann & Kotz, 2008a, 2008b; Schirmer and Kotz, 2006). Later ERP components (e.g., P3; Late Positive Potential – LPP) reflect higher-order cognitive operations, such as the evaluation of the emotional significance of the voice (Chang et al., 2018; Pell et al., 2015; Pinheiro et al., 2015; Pinheiro et al., 2016). Selective attention towards or away from specific features of voices, such as their emotional quality, may be reflected in amplitude modulations of the P3, a positive deflection occurring between 250 ms (ms) and 500 ms post-stimulus onset (Duncan et al., 2009; Polich, 2007). Specifically, increased P3 amplitudes were reported for happy relative to both angry and neutral vocalizations (Pinheiro et al., 2017a), or for angry compared to neutral prosodic cues (Wambacq et al., 2004). Attention modulations in vocal

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emotional perception might be driven by changes in the acoustic properties of the voice that affect salience detection (Pinheiro et al., 2017a). Together, these findings suggest that attention may change how vocal emotions are processed (Frühholz and Grandjean, 2013). This evidence may contribute to the understanding of clinical conditions in which voice perception is altered, such as psychotic disorders (Pinheiro et al., 2013, 2014, 2017a, 2017b; Rossell and Boundy, 2005).

1.1. Vocal emotional perception in auditory verbal hallucinations

Alterations in the processing of vocal emotions have been consistently reported in schizophrenia patients (Bozikas et al., 2006; Gold et al., 2012; Jahshan et al., 2013; Leitman et al., 2005, 2010; Pinheiro et al., 2013, 2014; Rossell and Boundy, 2005). These deficits were found to be aggravated in patients with *vs.* without AVH (Alba-Ferrara et al., 2012; Rossell and Boundy, 2005; Shea et al., 2007). Compared to patients without AVH, hallucinating patients are also more likely to judge positive vocal expressions as negative (Rossell and Boundy, 2005), and neutral vocal expressions as emotional (Shea et al., 2007), which suggests altered emotional salience attribution.

AVH are predominantly experienced in the context of schizophrenia (with an estimated prevalence of 70% – Johns et al., 2004), although they may also occur in approximately 10% of the general population without need for psychiatric care (Maijer et al., 2018). Direct comparisons of clinical and non-clinical AVH revealed similarities, but also some differences in phenomenology. Specifically, similarities include the location (i.e., inside the head), loudness (i.e., less intense than one's own voice), and source (i.e., external) of the hallucinated voices (Daalman et al., 2011). Differences are mainly related to the emotional valence, experience of control, associated distress and frequency (Choong et al., 2007; Daalman et al., 2011; de Leede-Smith and Barkus, 2013; Honig et al., 1998; Larøi and van der Linden, 2005; Larøi, 2012). In particular, non-clinical AVH tend to be perceived as less unpleasant and more controllable (Choong et al., 2007; Daalman et al., 2011; de Leede-Smith and Barkus, 2013; Honig et al., 1998), as well as less distressful and frequent (Daalman et al., 2011; Larøi and van der Linden, 2005; Larøi, 2012) than AVH in psychotic disorders. Similarities in the cognitive (Allen et al., 2006; Brébion et al., 2016; Larøi, van der Linden and Marczewski, 2004) and neural (Barkus et al., 2007; Diederen et al., 2012; Linden et al., 2010) mechanisms underpinning clinical and non-clinical AVH support a psychosis continuum, i.e., the hypothesis that psychotic symptoms exist on a continuum in the general population (Baumeister et al., 2017; van Os et al., 2000; van Os et al., 2009). For example, both psychotic and non-clinical voice-hearers are less accurate at distinguishing between internal and external sources of information (Allen et al., 2006; Brébion et al., 2016). Non-clinical voice-hearing experiences offer an unprecedented opportunity to examine the neural and cognitive mechanisms of AVH, avoiding confounding factors typically related to schizophrenia such as medication, hospitalization, and concurrent presence of other symptoms such as negative symptoms (Badcock and Hugdahl, 2012).

Consistent with the hypothesis of a psychosis continuum (Baumeister et al., 2017; van Os et al., 2000, 2009), alterations in vocal emotional perception and recognition have been also reported in individuals presenting clinical (Addington et al., 2012; Amminger et al., 2012a, 2012b) and genetic (Kee et al., 2004; Tucker et al., 2013) vulnerability to psychosis. For example, Tucker et al. (2013) demonstrated that first-degree relatives of schizophrenia patients with AVH who were less able to discriminate intensity and pitch modulations of pure tones (i.e., neutral sounds) were also less accurate at recognizing vocal emotions, as well as more prone to AVH. Reduced accuracy in vocal emotional recognition was also observed in non-clinical individuals with psychotic-like symptoms (Addington et al., 2012; Amminger et al., 2012a, 2012b). Moreover, the processing of neutral (target) words preceded by positive or negative emotional (prime) words was found to be associated with longer reaction times in non-clinical individuals with high hallucination proneness relative to those with low hallucination proneness (van't Wout et al., 2004).

Altered perception of vocal emotions has been proposed to contribute to the formation of AVH, potentially via disruption of a common mechanism underpinning voice processing (Alba-Ferrara et al., 2012). Specifically, patients tend to describe their hallucinated voices as emotionally negative (Daalman et al., 2011; de Leede-Smith and Barkus, 2013; Nayani and David, 1996), and to be less accurate at recognizing negative vocal emotions (Pinheiro et al., 2013, 2014; Rossell and Boundy, 2005). Furthermore, negative AVH tend to be perceived as less controllable than AVH with positive content (Birchwood and Chadwick, 1997). Of note, attentional mechanisms have been suggested to modulate the interaction between impaired recognition of vocal emotions and AVH in schizophrenia patients (Alba-Ferrara et al., 2012): the tendency to display an attentional bias towards threat-related vocal cues was found to increase as a function of AVH proneness.

1.2. Contributions of attention to vocal emotional perception in AVH

Amplitude modulations of the P3 component may inform on how attention is directed towards the processing of vocal emotions (Duncan et al., 2009; Polich, 2007). Two P3 subcomponents are proposed to reflect distinct attention-related processes: the frontocentral P3a has been associated with stimulus-driven and automatic attention to novel and unexpected stimuli, whereas the centroparietal P3b has been related to voluntary attention allocation to task-relevant stimuli (Duncan et al., 2009; Polich, 2007). In the context of the current study, we focused exclusively on the P3b response to emotional vocalizations.

Reduced amplitude of the auditory P3b is one of the most robust electrophysiological findings in schizophrenia (e.g., Bramon et al., 2004; Ford, 1999; Hamilton et al., 2019; Jeon and Polich, 2003; Perlman et al., 2015). Decreased attention to vocal information has been proposed to contribute not only to an inability to recognize targets in oddball tasks (Ford, 1999), but also to the experience of AVH (Behrendt, 1998; Ilankovic et al., 2011; Liemburg et al., 2012; Papageorgiou et al., 2004). In particular, Liemburg et al. (2012) demonstrated that AVH proneness may result from increased attention to internally generated speech. Moreover, alterations in the attentional processing of salient vocal information were found to account for the external misattributions of self-generated speech typically observed in patients with AVH (Ensum and Morrison, 2003; Ilankovic et al., 2011). Despite the well-documented association between greater P3b amplitude reductions and increased severity of psychotic symptoms (Egan et al., 1994; Ford, 1999; McCarley et al., 1989; Perlman et al., 2015), some evidence suggests attenuation of the P3b amplitude before psychosis onset (i.e., in individuals at clinical and genetic risk for psychosis – Bramon et al., 2008; Frangou et al., 1997; Kidogami et al., 1991). Accordingly, P3b amplitude reductions are considered to reflect a potential vulnerability marker for psychosis (Hamilton et al., 2019; Jahshan et al., 2012; Turetsky et al., 2007). Much less is known about how attention to emotional voices modulates the P3b as a function of AVH proneness. Using ERPs, Pinheiro and Niznikiewicz (2019) reported a reduced P3b amplitude in response to positive relative to negative vocal targets in schizophrenia patients relative to controls. These differences were not modulated by AVH severity (Pinheiro and Niznikiewicz, 2019). To the best of our knowledge, no study has directly investigated how AVH proneness in non-clinical participants affects the P3b response to changes in vocal emotions.

1.3. The current study and hypotheses

Evidence from psychotic patients suggests that the ability to selectively orient attention to vocal emotions is altered (Pinheiro and Niznikiewicz, 2019). However, it remains to be clarified whether similar changes are observed in non-clinical individuals prone to AVH. Attentional impairments may contribute to the observed vocal emotional recognition impairments in both psychotic voice-hearers (Rossell and Boundy, 2005; Shea et al., 2007) and non-clinical (Addington et al., 2012; Amminger et al., 2012a, 2012b) individuals with psychotic-like symptoms. Here, we probed for the first time whether attention allocation to vocal emotions is affected by AVH proneness, and whether these potential changes are modulated by two sources of salience: the valence (positive, negative, neutral) and intensity (loud, soft) of vocalizations. Intensity manipulations, which were found to change the acoustic saliency of sounds (e.g., Anikin, 2020; Castiajo and Pinheiro, 2021; Schirmer et al., 2007), may clarify whether attention allocation to vocal emotions is increased as a function of enhanced acoustic saliency: this would indicate an additive effect of valence and intensity. Non-verbal vocalizations were used to avoid potential confounds related to the concurrent processing of semantic information in emotional prosody, and as they represent a more primitive form of vocal emotional expression than speech prosody (Pell et al., 2015).

Given that P3b amplitude reduction is a robust finding in individuals with psychotic-like symptoms (Bramon et al., 2008; del Re et al., 2015; Fusar-Poli et al., 2011; Hamilton et al., 2019; van Tricht et al., 2010), we expected a reduced P3b amplitude to more complex vocal sounds (i.e., vocal emotions) as a function of increased AVH proneness in non-clinical participants. This amplitude reduction would reflect alterations in attention allocation to vocal emotions, supporting a psychosis continuum in the general population (Baumeister et al., 2017; van Os et al., 2000, 2009).

In addition, we hypothesized that the P3b amplitude in AVH proneness would be modulated by valence. Specifically, we expected a larger P3b amplitude to negative compared to neutral vocalizations. This hypothesis was grounded in prior studies revealing that AVH are associated with enhanced attention to threat-related voices in psychotic patients (Alba-Ferrara et al., 2012).

Finally, considering previous observations of preserved detection of intensity-based emotion in schizophrenia patients (Gold et al., 2012; Leitman et al., 2010), intensity manipulations were expected to change attention to vocal emotions irrespective of individual differences in AVH proneness.

2. Method

2.1. Participants

This study involved two stages. First, a group of college students (N = 354) from several Portuguese Universities were invited to participate in a study aiming to adapt and validate the Launay-Slade Hallucination Scale-Revised (LSHS – Larøi and van der Linden, 2005) for the Portuguese population (Castiajo and Pinheiro, 2017). The LSHS includes 16 items that assess current and lifetime hallucinations in distinct forms (auditory, visual, olfactory, tactile, hypnagogic, and hypnopompic) and critical dimensions (frequency, degree of control, and emotional content). The total score ranges between 0 and 64, with higher scores indicating higher hallucination proneness.

Second, after a screening interview by telephone, 45 participants from the initial sample who met the eligibility criteria were recruited for an EEG experiment on the basis of their total LSHS scores. Additional selection criteria included: 1) right-handedness (Oldfield, 1971); 2) European Portuguese as first language; 3) no hearing and vision impairment; 4) no history of neurological illness; 5) no history of drug or alcohol abuse in the past year (APA, 2000); and 6) no presence of medication for neurological or psychiatric disorders that could impact the EEG morphology.

Of the 45[1] eligible participants, 9 refused participation due to scheduling conflicts, and two had to be excluded due to EEG artifacts. The final sample consisted of 34 participants varying in their LSHS total scores (M = 22.85, SD = 11.74, range 4–47 points, Table 1) who did not meet clinical criteria for a specific psychotic disorder and had never received antipsychotic medication (mean age = 25.18, SD = 5.85, range 18–42 years; mean education level = 15.21, SD = 2.36, range 12–21 years; 25 female). Of those, 14 participants (mean age = 27.21, SD = 7.28, range 18–42 years; mean education level = 15.57, SD = 3.13, range 12–21 years; 12 female) reported the current occurrence of AVH (see Table 2) without need for clinical care. For a more complete characterization of AVH phenomenology, they were further screened with the Psychotic Symptom Rating Scale (PSYRATS – Haddock et al., 1999; Portuguese version – Telles-Correia et al., 2017). AVH experiences were predominantly perceived as controllable, not unpleasant, and not causing distress. Hearing a voice calling one's own name and/or telling one's thoughts or what one should do were the most common types of AVH. Participants with current AVH were assigned to the AVH subgroup if the LSHS score on at least one of the three items[2] related to AVH was ≥3 (3 = possibly applies to me; 4 = definitely applies to me). The clinical evaluation of the full sample included two additional relevant questionnaires: the Brief Symptom Inventory (BSI – Derogatis and Spencer, 1982; Portuguese version – Canavarro, 1999) to assess

Table 1
Frequency distribution of the LSHS total scores.

LSHS total scores	Frequency	Percent
4	1	2.8
7	1	2.8
8	1	2.8
9	1	2.8
10	2	5.6
11	1	2.8
12	1	2.8
14	2	5.6
15	2	5.6
17	3	8.3
18	2	5.6
19	1	2.8
25	1	2.8
27	2	5.6
29	1	2.8
30	1	2.8
31	3	8.3
33	1	2.8
36	1	2.8
37	1	2.8
38	1	2.8
39	1	2.8
40	1	2.8
41	1	2.8
47	1	2.8
	(N = 34)	(100%)

Note: LSHS = Launay-Slade Hallucination Scale – Revised.

[1] The current study used mixed-effects models to examine how attention modulates the processing of vocal emotions as a function of differences in AVH proneness. Since the literature is still developing in terms of how to calculate sample size for multilevel models (Maas and Hox, 2005; McNeish and Stapleton, 2016), sample size was determined based on previous studies probing the effects of hallucination proneness measured with the LSHS (e.g., n = 20 – Bentall and Slade, 1985; N = 33 – Castiajo and Pinheiro, 2021; n = 32 – Pinheiro et al., 2018; n = 40 – van't Wout et al., 2004; n = 42 – Vercammen and Aleman, 2010).

[2] "In the past, I have had the experience of hearing a person's voice and then found that no one was there"; "I often hear a voice speaking my thoughts aloud"; "I have been troubled by hearing voices in my head".

Table 2
Distribution of scores for each LSHS AVH-related item across participants ($n = 14$).

Participant	AVH-related items of the LSHS			Total Score
	Item 4[a]	Item 8[b]	Item 9[c]	
A	0	3	3	6
B	0	3	3	6
C	1	3	3	7
D	3	3	2	8
E	4	3	3	10
F	0	3	3	6
G	0	4	0	4
H	1	1	3	5
I	1	3	1	5
J	1	3	3	7
K	1	3	0	4
L	0	3	0	3
M	1	1	3	5
N	4	3	0	7

Note: [a] "In the past, I have had the experience of hearing a person's voice and then found that no one was there". [b] "I often hear a voice speaking my thoughts aloud". [c] "I have been troubled by hearing voices in my head".
AVH = auditory verbal hallucinations; LSHS = Launay-Slade Hallucination Scale – Revised; PSYRATS = Psychotic Symptom Rating Scale. All participants who reported AVH were currently experiencing AVH as assessed by the PSYRATS.

psychopathological symptoms (somatization, obsessive-compulsive symptoms, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, and psychoticism) and global psychological distress; and the Schizotypal Personality Questionnaire (SPQ – Raine, 1991; Portuguese version – Santos, 2011) to evaluate schizotypal traits. Demographic and clinical differences between participants with *vs.* without AVH are presented in Table 3. Table 4 shows the prevalence, frequency of occurrence, perceived degree of control, and emotional content of the hallucinatory experiences for each type of hallucination measured by the LSHS considering the full sample.

In this sample, the convergent validity among the self-reported clinical measures was good: the LSHS total score was positively correlated with the SPQ total score ($r = 0.627$, $p < .001$) and with the BSI positive symptom distress index ($r = 0.463$, $p = .006$); the experience of non-clinical AVH was positively correlated with the SPQ total score ($r = 0.429$, $p = .011$). Participants provided written informed consent and received vouchers or course credit for their participation. The experiment was approved by a local Ethics Committee (University of Minho, Braga, Portugal).

2.2. Stimuli

Three male vocalizations with positive (laughs), negative (growls),

Table 3
Demographic and clinical characteristics of participants with *vs.* without AVH.

Variable	With AVH ($n = 14$)	Without AVH ($n = 20$)	t, p-value[a]
Age (years)	27.21 (7.28)	23.75 (4.24)	−1.752, 0.089
Sex (n)	12 Female	13 Female	
Education (years)	15.57 (3.13)	14.95 (1.67)	
LSHS Total score	34.71 (6.04)	14.55 (6.19)	−9.435, <0.001***
SPQ Total score	24.36 (11.17)	13.45 (11.99)	−2.683, <0.011*
BSI Positive symptoms distress index	1.47 (0.26)	1.31 (0.29)	−1.653, 0.108

Note: All values represent mean ± SD. AVH = auditory verbal hallucinations; LSHS = Launay-Slade Hallucination Scale – Revised; SPQ = Schizotypal Personality Questionnaire; BSI = Brief Symptom Inventory.
[a] Independent sample t-tests tested for group differences in age, LSHS, SPQ, and BSI. ***$p < .001$; *$p < .05$.

Table 4
Proportion of different types of hallucinatory experiences (LSHS) according to prevalence, frequency of occurrence, perceived degree of control, and affective content.

Type of hallucination (LSHS)	Prevalence[a]	Frequency (rare/often)[b]	Control (low/high)[c]	Emotional content (negative/positive)[d]
Auditory verbal hallucinations	14 (41%)	3/11 (9/32%)	3/11 (9/32%)	3/5 (9/15%)
Visual hallucinations	6 (18%)	3/2 (9/6%)	2/4 (6/12%)	2/1 (6/3%)
Olfactory hallucinations	6 (18%)	2/3 (6/9%)	6/0 (18/0%)	0/3 (0/9%)
Tactile hallucinations	4 (12%)	1/2 (3/6%)	4/0 (12/0%)	1/2 (3/6%)
Vividness of daydreams	11 (32%)	0/8 (0/34%)	1/9 (3/27%)	0/6 (0/18%)
Intrusive or vivid thoughts	27 (79%)	1/7 (3/21%)	7/19 (21/56%)	1/9 (3/27%)
Sleep-related hallucinations	20 (59%)	6/6 (18/18%)	6/14 (18/41%)	5/7 (15/21%)

Note.
[a] Percentage of participants who answered "possibly applies to me" or "definitely applies to me".
[b] Percentage of participants who answered "it occurs very rarely" (rare) and "it occurs very often" (often).
[c] Low control is represented by the percentage of participants who answered "it is very difficult to cease the experience" and "it is very difficult to avoid the experience," whereas high control is represented by the percentage of participants who answered "it is very easy to cease the experience" and "it is very easy to avoid the experience".
[d] Percentage of participants who answered "the experience is very negative" (negative) and "the experience is very positive" (positive). LSHS = Launay-Slade Hallucination Scale – Revised.

and neutral (the vowel /ɑ/ with neutral intonation) quality were selected from the Montreal Affective Voices (MAV) battery (Belin et al., 2008) based on valence and arousal ratings for the Portuguese population (Vasconcelos et al., 2017).

The selected MAV vocalizations were acoustically manipulated to an equalized duration of 700 ms (ms). Given the original duration of each stimulus, the neutral vocalization had to be increased to 700 ms by gradually adding less variable segments of the sound to its waveform, while the two emotional vocalizations had to be shortened to 700 ms by cutting the endpoint of their waveforms. To test whether the manipulated vocal samples still conveyed the intended emotions, they were first judged by a sample of participants who did not take part in this experiment ($N = 52$; mean age = 23.42, $SD = 7.80$ years, age range 18–49 years; 27 females – see Castiajo and Pinheiro, 2019). The overall mean recognition accuracy (proportion of correct responses) for the three types of vocalizations with 700 ms was high (i.e., 0.91 [negative - 0.81; positive - 1.00; neutral - 0.91] - Castiajo and Pinheiro, 2019). Each vocalization was also manipulated into two different levels of intensity (55 dB *vs.* 75 dB[3]). The manipulation of stimulus duration and intensity was performed with Praat software (Boersma and Weenink, 2005; www.praat.org).

2.3. Procedure

Participants were seated comfortably at a distance of 100 cm from a computer screen in a sound and light-attenuating chamber. The experimental session included six oddball task blocks, each of them comprising frequent (standard) emotional vocalizations differing in valence intermixed with infrequent (target) emotional vocalizations

[3] The audio files are available at: https://osf.io/62yat/?view_only=8deb2e89165e43f486e94c466a09a090.

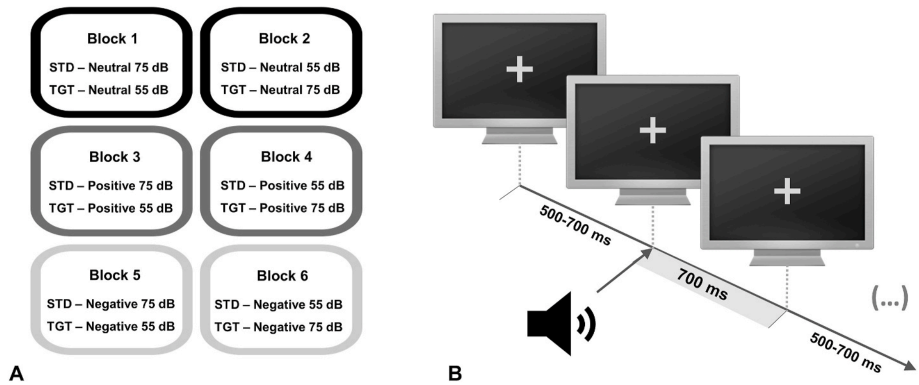

Fig. 1. Schematic illustration of the structure of the experimental blocks **(A)** and of an experimental trial **(B)**. *Note:* Vocalizations were presented binaurally. Growls and laughs represented exemplars of negative and positive vocalizations, respectively. The order of the experimental blocks was counterbalanced across participants. STD = standard; TGT = target.

with the same valence but differing in intensity (see Fig. 1). In each block, participants were presented with 295 standard (P = 85%) and 40 target (P = 15%) vocalizations. Fifteen standards were presented sequentially at the beginning of each block (Polich, 2007). Stimuli were delivered by headphones and presented in a random sequence within each block, but with a minimum of five standards between targets. The presentation order of the six blocks was counterbalanced across participants. Presentation software (Neurobehavioral Systems, Albany, CA, USA) was used to control stimulus presentation and timing.

Before stimulus onset, a fixation cross was presented centrally on the screen and was kept during sound presentation to minimize eye movements. The time interval between two successive stimuli (inter-stimulus interval – ISI) varied between 500 and 700 ms. Fig. 1 illustrates the design of an experimental trial. Participants were instructed to focus their attention on the sounds and to silently count the number of targets. The total number of counted targets was asked at the end of each block to make sure that the participants directed their attention towards the stimulus sequence. A short pause was provided after each block, and no feedback was given during the experiment. The experimental session lasted approximately 50 min. The EEG signal was recorded while participants performed the task.

2.4. EEG data acquisition and analysis

The EEG was recorded at 512 Hz using a 64-channel BioSemi Active Two System (http://www.biosemi.com/products.htm). External reference electrodes were placed on both mastoids (left and right). In addition, eye blinks and movements were monitored with two external electrodes placed on both left and right temples (horizontal electrooculogram, HEOG), and one below the left eye (vertical electrooculogram, VEOG).

EEG data were analyzed using Brain Vision Analyzer 2.0.4 software (www.brainproducts.com). Data were filtered offline with a 0.1–30 Hz 2nd order Butterworth bandpass filter and referenced to the average of the left and right mastoids. Individual ERP epochs for each vocalization type in each acoustic condition were created using a −150 ms pre-stimulus baseline and 700 ms post-stimulus duration. Ocular artifacts were corrected using the method of Gratton et al. (Gratton et al., 1983) after applying a baseline correction from −150 to 0 ms. Single trial epochs containing excessive eye blinks or motor artifacts (±100 μV criterion) were rejected. ERP epochs were averaged separately for standards (STD) and targets (TGT) per participant ($STD_{Positive\ 55\ dB}$; $TGT_{Positive\ 55\ dB}$; $STD_{Positive\ 75\ dB}$; $TGT_{Positive\ 75\ dB}$; $STD_{Negative\ 55\ dB}$; $TGT_{Negative\ 55\ dB}$; $STD_{Negative\ 75\ dB}$; $TGT_{Negative\ 75\ dB}$; $STD_{Neutral\ 55\ dB}$; $TGT_{Neutral\ 55\ dB}$; $STD_{Neutral\ 75\ dB}$; $TGT_{Neutral\ 75\ dB}$). For each participant, ERP averages were based on at least 70% of the trials per condition ($STD_{Positive\ 55\ dB} = 281.74 \pm 11.12$; $STD_{Negative\ 55\ dB} = 281.26 \pm 15.55$; $STD_{Neutral\ 55\ dB} = 282.88 \pm 10.83$; $STD_{Positive\ 75\ dB} = 282.21 \pm 13.06$; $STD_{Negative\ 75\ dB} = 278.71 \pm 16.56$; $STD_{Neutral\ 75\ dB} = 280.85 \pm 16.73$; $TGT_{Positive\ 55\ dB} = 38.50 \pm 1.99$; $TGT_{Negative\ 55\ dB} = 38.26 \pm 2.11$; $TGT_{Neutral\ 55\ dB} = 38.44 \pm 2.31$; $TGT_{Positive\ 75\ dB} = 38.06 \pm 1.67$; $TGT_{Negative\ 75\ dB} = 38.21 \pm 2.09$; $TGT_{Neutral\ 75\ dB} = 38.88 \pm 1.39$). The number of discarded epochs did not differ significantly between conditions (all $ps > .05$).

The P3b was isolated from overlapping brain activity by creating a target-minus-standard difference waveform. Difference waves eliminate brain activity that is common to the two conditions and are, therefore, recommended for a precise assessment of the time course and magnitude of the processes that differ between conditions (Kappenman et al., 2021).

Considering previous studies and existing recommendations (e.g., Duncan et al., 2009; Polich, 2007), mean P3b amplitudes were extracted from 300 to 500 ms post-stimulus onset for target-minus-standard difference waves, as well as for standards and targets separately. Given that P3b amplitudes were largest over midline electrode sites (Duncan et al., 2009; Polich, 2007), mean amplitudes were extracted from midline electrodes: Fz (frontal), Cz (central), and Pz (parietal). We opted to include the Fz electrode site to assess differences in the midline scalp distribution of the P3, in particular the typically observed frontal-smaller-than-centroparietal P3b voltage asymmetry (Duncan et al., 2009; Polich, 2007). Moreover, the selection of midline electrodes for the statistical analyses offers the possibility to compare our experimental data with other ERP experiments with non-clinical individuals experiencing psychotic-like experiences that have used the same electrode sites to measure auditory P3b amplitudes (e.g., Bramon et al., 2008; van der Stelt et al., 2005).

2.5. Statistical analyses

Linear mixed-effects models were used to describe the relationship between the number of counted targets (behavioral data) and AVH proneness (with *vs.* without), as well as the relationship between the P3b amplitude to vocalizations differing in valence and intensity (ERP data) and AHV proneness (with *vs.* without). The multilevel models were fitted with the lmer 4 (Bates et al., 2014) and lmerTest (Kuznetsova et al., 2017) packages in the R environment (R3.4.3. GUI 1.70). By accounting for individual variance (random effects), the linear mixed-effects models overcome some of the limitations of conventional inferential statistics, yielding more generalizable results (Jaeger, 2008).

Behavioral data: To specify the effects of AVH proneness on the number of counted targets, a linear mixed-effects model was conducted. Specifically, the number of counted targets was included as outcome, participants as random effects and AVH proneness (with; without), intensity (soft [55 dB]; loud [75 dB]), and valence (neutral; negative; positive) as fixed effects.

ERP data: The hypothesis that the P3b response to vocalizations

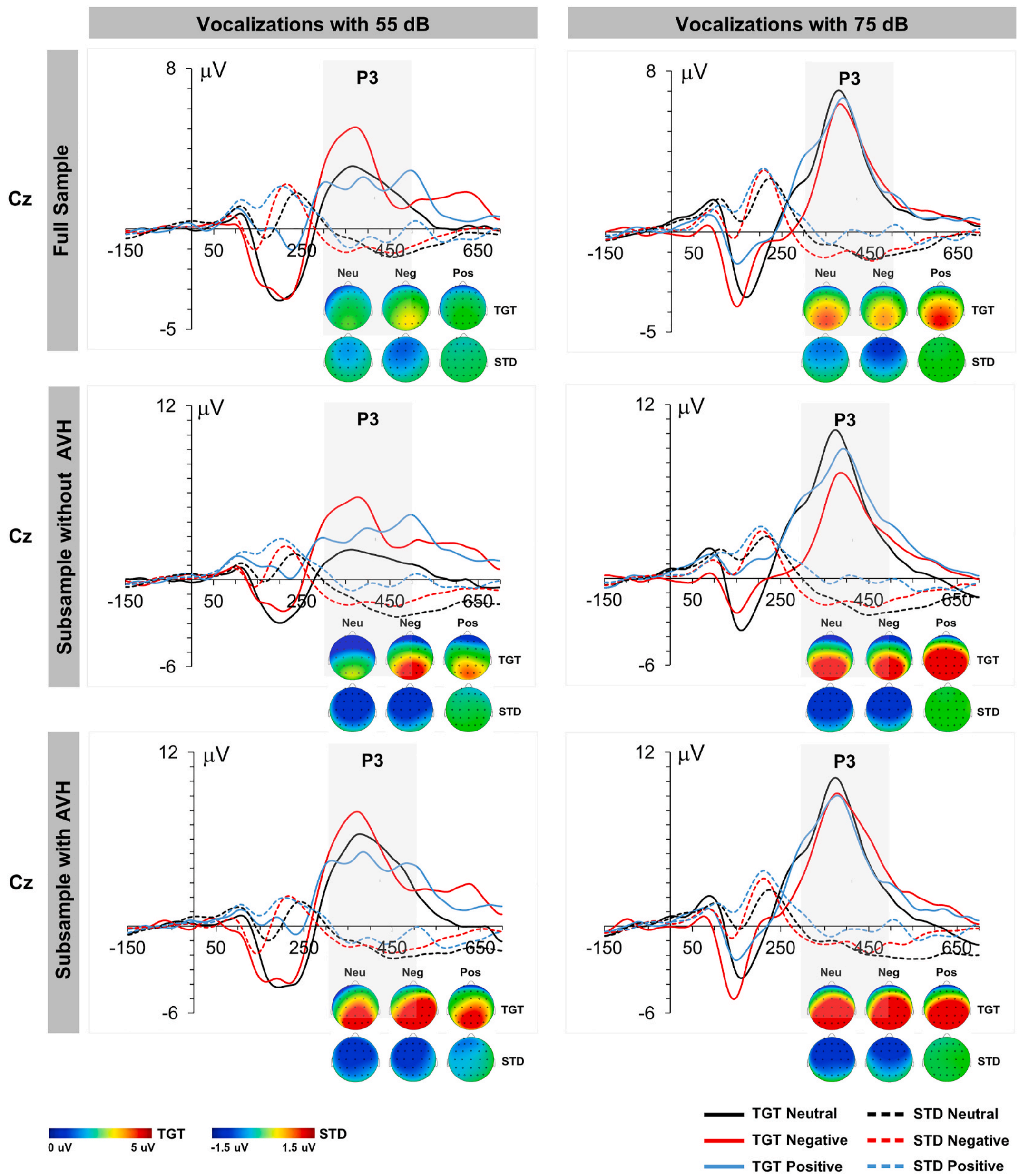

Fig. 2. Grand average waveforms contrasting neutral, negative, and positive vocalizations as a function of intensity manipulations over Cz electrode. Topographic maps show the spatial distribution of the P3b effects in the full sample (N = 34) and in the subsamples without (n = 20) *vs.* with (n = 14) AVH. *Note:* Neu = neutral; Neg = negative; Pos = positive; TGT = target; STD = standard; AVH = auditory verbal hallucinations.

differing in valence and intensity would decrease as a function of AVH proneness was tested with a mixed-effects model including amplitude as outcome (on the basis of target-minus-standard difference waves), participants as random effects, and AVH proneness (with; without), intensity (soft [55 dB]; loud [75 dB]), valence (neutral; negative; positive), and electrode (frontal [Fz]; central [Cz]; parietal [Pz]) as fixed effects. In an additional analysis, we also probed whether AVH proneness affected distinctly the processing of task-irrelevant *vs.* task-relevant vocalizations, by analyzing the P3b amplitude elicited by standard *vs.* target sounds. The statistical model was the same except that an additional factor (task-relevance: STD, TGT) was included as fixed effect. Bonferroni-corrected pairwise comparisons using the "emmeans" R package (Lenth et al., 2018) were conducted to examine how valence and intensity modulated the P3b response in the two groups (with *vs.* without AVH proneness).

3. Results

3.1. Behavioral data

Neither stimulus valence and intensity nor AVH proneness affected the number of times each type of target was counted ($p > .05$; Negative$_{softer}$ = 39.66 ± 1.64; Negative$_{louder}$ = 40.06 ± 2.22; Positive$_{softer}$ = 39.71 ± 2.61; Positive$_{louder}$ = 40.06 ± 1.88; Neutral$_{softer}$ = 39.40 ± 1.50; Neutral$_{louder}$ = 40.46 ± 1.60).

3.2. ERP data

Fig. 2 illustrates grand average waveforms for standards and targets as a function of valence and intensity manipulations considering the global sample and contrasting participants with and without AVH. Fig. 3 shows ERP waveforms for the target-minus-standard difference waves. Mean amplitudes for neutral and emotional vocalizations in each

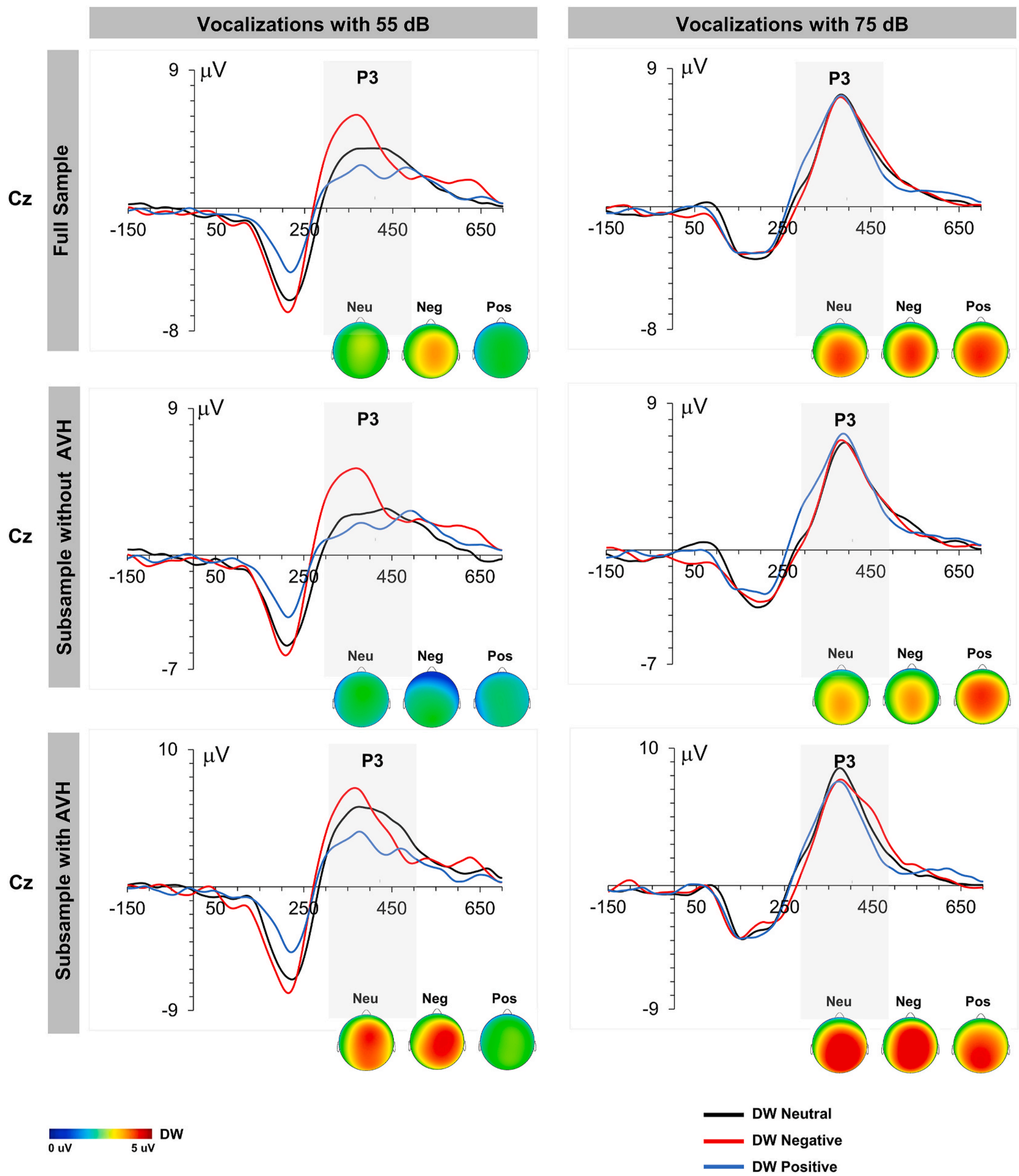

Fig. 3. Grand average difference waveforms contrasting neutral, negative, and positive vocalizations as a function of intensity manipulations over Cz electrode. Topographic maps show the spatial distribution of the P3b effects in the full sample ($N = 34$) and in the subsamples without ($n = 20$) *vs.* with ($n = 14$) AVH. *Note:* Neu = neutral; Neg = negative; Pos = positive; DW = target-minus-standard difference waves; AVH = auditory verbal hallucinations.

acoustic condition in the full sample and in participants with *vs.* without AVH are presented in Figs. 4 and 5.

3.2.1. *P3b amplitude: difference waves (targets minus standards)*

The P3b amplitude was modulated by valence and intensity: the P3b was increased in response to negative compared to neutral vocalizations ($\beta = 1.815$, SE = 0.624, $t(578) = 2.907$, $p = .004$, 95% CI: [0.589, 3.040]) and to loud compared to soft vocalizations ($\beta = 2.578$, SE = 0.624, $t(578) = 4.130$, $p < .001$, 95% CI: [1.352, 3.803]). As expected, the P3b amplitude was more positive over Cz compared to Fz ($\beta = 4.002$, SE = 0.339, $t(578) = 11.822$, $p < .001$, 95% CI: [3.337, 4.667]) and over Pz compared to Fz ($\beta = 5.682$, SE = 0.339, $t(578) = 16.784$, $p < .001$, 95% CI: [5.017, 6.346]).

The P3b amplitude was also modulated by AVH proneness: the P3b was globally more positive in participants with *vs.* without AVH, irrespective of valence and intensity of the vocalizations ($\beta = 2.426$, SE = 1.152, $t(68) = 2.106$, $p = .039$, 95% CI: [0.135, 4.717]; see Figs. 3 and 4).

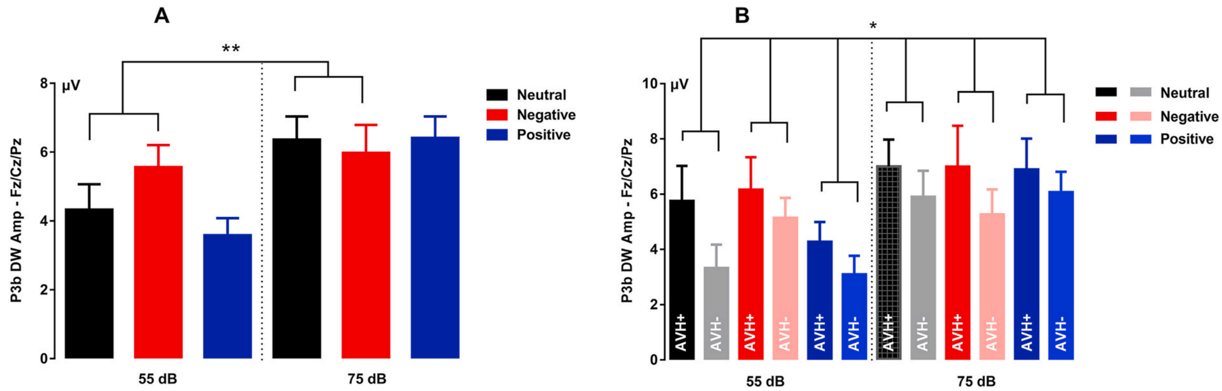

Fig. 4. P3b amplitude differences (on the basis of difference waveforms) as a function of valence and intensity manipulations in the full sample (A) and in the subsamples with *vs.* without AVH (B). *Note.* Bars represent mean amplitudes collapsed across electrodes Fz, Cz, and Pz. Standard error (SE) of the means is represented in error bars. Amp = amplitude; DW = difference waves; AVH = auditory verbal hallucinations; AVH+ = with AVH; AVH- = without AVH. $^{**}p < .01$; $^{*}p < .05$.

3.2.2. P3b amplitude: task-relevance effects (targets vs. standards)

AVH proneness interacted with task-relevance to affect the ERP response to targets but not standards ($p = .445$). The P3b was globally more positive for targets in participants with *vs.* without AVH ($\beta = 2.225$, SE = 0.912, $t(1190) = 2.439$, $p = .015$, 95% CI: [0.436, 4.015]; see Fig. 2).[4] Post-hoc pairwise comparisons revealed no differences in the P3b response to targets as a function of valence or intensity in AVH-prone participants ($p > .999$ for all pairwise comparisons, see Fig. 5 and Supplementary Material). In contrast, the P3b amplitude in participants without non-clinical AVH was increased in response to soft negative *vs.* soft neutral vocal targets ($\beta = -2.227$, $p = .005$), loud positive *vs.* loud negative vocal targets ($\beta = -2.005$, $p = .025$), loud neutral *vs.* soft neutral vocal targets ($\beta = -2.524$, $p = .006$), and loud positive *vs.* soft positive vocal targets ($\beta = -2.607$, $p = .003$). No other significant group effects were observed ($p > .05$).

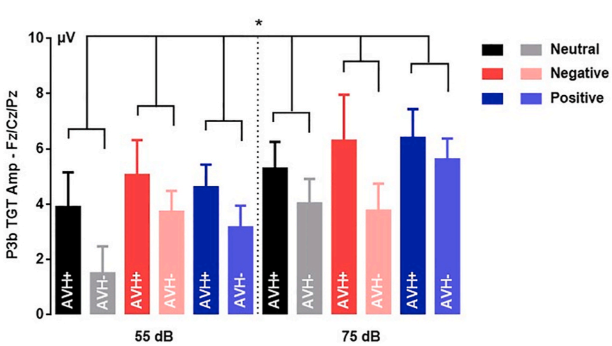

Fig. 5. P3b amplitude differences as a function of valence and intensity manipulations in the subsamples with *vs.* without AVH. *Note.* Bars represent mean amplitudes collapsed across electrodes Fz, Cz, and Pz. Standard error (SE) of the means is represented in error bars. Amp = amplitude; TGT = target; AVH = auditory verbal hallucinations; AVH+ = with AVH; AVH- = without AVH. $^{*}p < .05$.

[4] Additional analyses were also conducted by including schizotypal traits (total score of the SPQ), mood symptoms (positive symptoms distress index of the BSI), or total hallucination proneness (total score of the LSHS) as fixed factors, but none of these factors modulated the P3b response to vocal targets.

4. Discussion

The current study aimed to clarify whether attention allocation to vocal emotions is altered as a function of AVH proneness, and whether these potential changes are modulated by stimulus valence and intensity. The P3b showed significant main effects of intensity, valence, and AVH proneness. Specifically, its amplitude was larger for loud *vs.* soft vocal targets, and for negative *vs.* neutral vocalizations. Of note, the P3b amplitude was generally increased in response to vocal targets in participants reporting AVH, with no significant differences between targets as a function of valence and intensity. These findings suggest that AVH proneness in non-clinical participants is related to enhanced voluntary attention to changes in vocal expressions but also to a less discriminative response to voices as a function of salience cues.

Studies probing effects of emotion on the auditory P3b amplitude are still scarce. The existing studies revealed attention modulations by valence, with the P3b amplitude being increased in response to positive (Pinheiro et al., 2017a) and negative (Wambacq et al., 2004) compared to neutral vocal cues. Adding to previous evidence (Wambacq et al., 2004), our study demonstrated an increased P3b amplitude for negative *vs.* neutral vocal targets, irrespective of intensity. This finding suggests that vocalizations signaling an emotional (i.e., negative) change attract more attention than those signaling a neutral change. From an evolutionary perspective, negative information is associated with a specific adaptive function: threat-related stimuli may indicate an imminent threat or danger (Frühholz and Grandjean, 2012; Pell and Kotz, 2011; Pell et al., 2015). The current P3b findings corroborate the high adaptive relevance of negative vocal emotions and suggest that emotional valence *per se* intensifies the perceived salience of sounds. It further supports an attentional bias towards negative information (Carretié et al., 2001; Ito et al., 1998), even though we note this is not a consistent effect in auditory perception (for example, see Pinheiro et al., 2017a).

In good agreement with previous studies supporting the contribution of sound intensity to selective attention (Huang and Elhilali, 2017; Kaya and Elhilali, 2014; Kim et al., 2014), loud vocal targets elicited a larger P3b amplitude than soft vocalizations irrespective of valence. Attention modulations driven by arousal (Coull, 1998) may account for this effect. Specifically, sound intensity tends to increase the perceived arousal of vocal emotions (Schirmer et al., 2007), which in turn affects attention: the higher the perceived arousal, the more attention is devoted to the sound (Coull, 1998).

4.1. Attention to vocal emotions as a function of AVH proneness

As expected, the current study revealed alterations in attention allocation to vocal stimuli as a function of AVH proneness, despite similar behavioral accuracy in the two groups of participants. Notwithstanding, contrary to our hypothesis, we found that the P3b was globally increased (rather than reduced) in response to vocal targets in participants reporting AVH, indicating increased voluntary attention to change detection in voices. Specifically, the P3b response was less responsive to the emotional (valence) and acoustic (intensity) salience of vocal targets. An increased P3b denotes an amplified contrast between an expected (standard) response and a surprising (deviant) response. This finding stands in contrast with previous observations of reduced P3b to pure (neutral) tones in both non-clinical individuals with psychotic-like symptoms (Bramon et al., 2008; del Re et al., 2015; Fusar-Poli et al., 2011; Hamilton et al., 2019; van Tricht et al., 2010) and psychotic patients (e.g., Bramon et al., 2004; Ford, 1999; Hamilton et al., 2019; Jeon and Polich, 2003; Perlman et al., 2015). However, we note that the current study is not the first to observe an increased auditory P3b in AVH-prone individuals. Using an active auditory oddball task, van Lutterveld et al. (2010) documented an increased P3b amplitude in response to deviant tones in non-psychotic individuals with AVH relative to healthy controls. Given the absence of delusions and negative symptoms in those participants, the P3b reduction in schizophrenia patients with AVH was interpreted as reflecting the effects of concurrent positive, negative, and cognitive symptoms (van Lutterveld et al., 2010). In the current study, the relationship between AVH and attention is also less likely to be biased by the presence of other clinical symptoms. First, the observed increase in the P3b amplitude to vocal targets was specifically related to the experience of AVH, i.e., the P3b amplitude to vocal targets was not modulated by schizotypal traits (SPQ), mood symptoms (BSI), or the total hallucination proneness score (LSHS). Second, the current sample includes participants who did not meet criteria for a psychotic disorder or psychosis high-risk state. Therefore, the current results are not affected by the confounding effects of other clinical symptoms (e.g., negative symptoms or cognitive deterioration) and antipsychotic medication (Liu et al., 2004; Morales-Muñoz et al., 2017; Umbricht et al., 1998), typically observed in studies with psychotic patients.

The similarly increased P3b response to all types of vocal targets suggests that selective attention to voices for change detection is less effectively modulated by stimulus salience in AVH-prone participants. More recently, voice-selective alterations were related to increased hallucination proneness in a sensory prediction task contrasting tones and vocalizations (Pinheiro et al., 2018; Pinheiro et al., 2020): specifically, self-generated voices elicited larger N1 amplitudes compared to tones in non-clinical voice-hearers (Pinheiro et al., 2018; Pinheiro et al., 2020). This pattern of findings suggests that specific alterations in the processing of vocalizations may establish a core feature of the psychosis continuum (Pinheiro et al., 2018; Pinheiro et al., 2020). Accordingly, in the current study we observed a P3b amplitude enhancement in response to vocal changes in AVH-prone participants. This enhancement reveals that any change in a vocal stimulus attracts more attention (a task-relevance effect). Notwithstanding, it also shows that attentional resource allocation is less sensitive to two common sources of salience: sound valence (emotional > neutral) and intensity (loud > soft). In a competition for limited resources (Marois and Ivanoff, 2005), the less discriminative P3b response could indicate a less effective modulation of attention by salience cues and, therefore, imply increased cognitive control demands (Alderson-Day et al., 2019; Hugdahl et al., 2013; Weber et al., 2020). As selectivity is lost, the expenditure of neural and cognitive resources increases. These results could reflect atypical salience processing (i.e., increased attribution of salience to irrelevant stimuli), which has been proposed to play a central role in psychotic symptoms (Heinz, 2002; Howes and Murray, 2014; Kapur, 2003). In particular, altered salience of acoustic representation of emotions (Castiajo and Pinheiro, 2021) could contribute to the less discriminative P3b response. Furthermore, the current findings agree with previous evidence showing that AVH may be driven not only by auditory sensory (bottom-up) processing abnormalities (Castiajo and Pinheiro, 2021; McLachlan et al., 2013), but also by disrupted top-down processing of auditory stimuli (e.g., decreased top-down inhibitory control – Aleman et al., 2003; Hugdahl, 2009; Marschall et al., 2020).

4.2. Limitations and future directions

Some limitations should be considered. First, the current results should be interpreted with caution due to the small sample size. Second, the severity of non-clinical AVH of this sample is not representative of the full spectrum of severity in the general population. Future studies should address these limitations.

Further studies are required to examine whether the decoding of emotional information from vocalizations varies as a function of task instructions (e.g., explicit *vs.* implicit emotional processing) in non-clinical individuals with AVH proneness. For example, some studies failed to identify effects of hallucination proneness on the explicit categorization (Castiajo and Pinheiro, 2021) or valence ratings of vocal emotions (e.g., Pinheiro et al., 2019). Since the neural networks involved in explicit and implicit processing of vocal emotions may be dissociated (Roux et al., 2010), future studies should specify whether attention orienting and selective attention are similarly modulated by the emotional properties of vocalizations. Moreover, as our experimental design does not allow isolating attentional processes from other cognitive operations (e.g., memory or context updating – e.g., Donchin and Coles, 1988; Gray et al., 2004; Polich et al., 1996; Verleger, 2020), the specific role of attention in voice perception should be clarified in future studies with AVH-prone individuals.

5. Conclusions

The current study demonstrated a globally increased P3b response to vocal targets, irrespective of their valence and intensity, in AVH-prone participants. This finding indicates that increased AVH proneness is associated with enhanced voluntary attention to change in vocal stimuli. Additionally, it suggests that a decreased sensitivity to the emotional and acoustic salience of the voice may be specifically related to the experience of AVH. If vocal stimuli attract similar attentional resources irrespective of their salience (valence, intensity), cognitive control demands may increase. Consequently, events in the environment may be perceived as less controllable, which could set the stage for an AVH.

Longitudinal investigations of non-clinical individuals with AVH are warranted to specify how an increase in AVH severity affects selective attention to social stimuli such as voices, and to clarify the role of altered salience processing in AVH proneness along the psychosis continuum.

Open practices statements

The data analyzed in the current study are not available as the conditions of our ethics approval do not permit sharing of the data supporting the conclusions of the study with any individual outside the author team under any circumstances. The experiment was not preregistered. The materials used in the current study are available at: https://osf.io/62yat/?view_only=8deb2e89165e43f486e94c466a09a090.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuropsychologia.2021.108030.

Credit author statement

APP conceived and designed the study. PC collected, analyzed, and interpreted the data, and produced the drafting of the manuscript. APP supervised all steps in the study and provided a critical revision of the manuscript.

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