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On the correlation between perceptual inundation caused by realistic immersive environmental auditory scenes and the sensory gating inventory in schizophrenia

A. El-Kaim [a,b,c], M. Aramaki [d], S. Ystad [d], R. Kronland-Martinet [d], M. Cermolacce [a,b,c], J. Naudin [a,b,c], J. Vion-Dury [a,b,c], J.-A. Micoulaud-Franchi [a,b,c,*]

[a] Pôle de Psychiatrie « Solaris », CHU de Sainte-Marguerite, 270, boulevard de Sainte-Marguerite, 13009 Marseille, France
[b] Unité de Neurophysiologie et Psychophysiologie, Pôle de Psychiatrie Universitaire, CHU Sainte-Marguerite, 270, boulevard Sainte-Marguerite, 13009 Marseille, France
[c] Laboratoire de Neurosciences Cognitives (LNC), UMR CNRS 7291, 31 Aix-Marseille Université, Site Saint-Charles, 3, place Victor-Hugo, 13331 Marseille cedex 3, France
[d] Laboratoire de Mécanique et d'Acoustique, LMA, CNRS, UPR 7051, Aix-Marseille Université, Centrale Marseille, 13402 Marseille cedex 20, France

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ABSTRACT

Background: In schizophrenia, perceptual inundation related to sensory gating deficit can be evaluated "off-line" with the sensory gating inventory (SGI) and "on-line" during listening tests. However, no study investigated the relation between "off-line evaluation" and "on-line evaluation". The present study investigates this relationship.
Methods: A sound corpus of 36 realistic environmental auditory scenes was obtained from a 3D immersive synthesizer. Twenty schizophrenic patients and twenty healthy subjects completed the SGI and evaluated the feeling of "inundation" from 1 ("null") to 5 ("maximum") for each auditory scene. Sensory gating deficit was evaluated in half of each population group with P50 suppression electrophysiological measure.
Results: Evaluation of inundation during sound listening was significantly higher in schizophrenia (3.25) compared to the control group (2.40, $P < .001$). The evaluation of inundation during the listening test correlated significantly with the perceptual modulation ($n = 20$, rho = .52, $P = .029$) and the over-inclusion dimensions ($n = 20$, rho = .59, $P = .01$) of the SGI in schizophrenic patients and with the P50 suppression for the entire group of controls and patients who performed ERP recordings ($n = 20$, rho = −.49, $P = .027$).
Conclusion: An evaluation of the external validity of the SGI was obtained through listening tests. The ability to control acoustic parameters of each of the realistic immersive environmental auditory scenes might in future research make it possible to identify acoustic triggers related to perceptual inundation in schizophrenia.

1. Introduction

Deficits in sensory gating in schizophrenia were suggested by the now-classic phenomenological study of McGhie and Chapman. In this study based on interviews, patients with schizophrenia reported being inundated by an overwhelming mass of sensory information, particularly in the auditory modalities [26,28,50]. Patients reported perceptual anomalies that they described as follows: "I listen to sounds all the time. I let all the sounds come in that are there. I should really get an earphone and a wireless and control these sounds coming in so that at least I know they are separate from me" [28].

Hetrick et al. offered a reliable and valid self-report questionnaire called the sensory gating inventory (SGI) to explore retrospectively four phenomenological dimensions of sensory gating: perceptual modulation, over-inclusion, distractibility and fatigue-stress modulation. The SGI confirmed that an abnormal sensory gating experience relies mainly upon perceptual inundations [21]. Patients with schizophrenia reported SGI scores that were higher than in healthy subjects [33].

* Corresponding author. Pôle de Psychiatrie « Solaris », CHU de Sainte-Marguerite, 270, boulevard de Sainte-Marguerite, 13009 Marseille, France. Tel.: +33 6 22 36 40 19.
E-mail address: jarthur.micoulaud@gmail.com (J.-A. Micoulaud-Franchi).

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In the meanwhile, an evaluation of perceptual dimensions obtained during listening tests was designed [32]. The experimental paradigm consisted in asking the participants to listen to non-verbal complex sounds (i.e., environmental sounds, abstract sounds[1]) and to evaluate (among other aspects) the feeling of "inundation" caused by the sounds by positioning a slider on a linear scale. Patients with schizophrenia evaluated environmental sounds (but not abstract sounds) as more inundating than healthy subjects [32]. This result was in line with previous studies, which revealed that patients with schizophrenia were more sensitive to urban noise than healthy subjects [45,46].

Sensory gating can also be assessed neurophysiologically with the auditory event-related potential (ERP) method by measuring P50 amplitude changes in a dual click conditioning-testing procedure [19]. The P50 component is a middle latency positive ERP component occurring around 50 msec after onset of a brief auditory stimulus [2]. In the conditioning-testing P50 procedure, the P50 amplitude is measured in a passive task in response to an auditory-paired click stimulus: S1 (conditioning stimulus) and S2 (testing stimulus). It is commonly observed in healthy subjects that the second P50 amplitude related to S2 is smaller than the first one (by more than half the amplitude of S1). By contrast, it was shown that this P50 suppression or "gating" after S2 could be deficient in schizophrenia patients [2,13] and that patients with high sensory gating deficit report the perception of being inundated and overwhelmed by external sensory stimuli assessed retrospectively by the SGI [33] or assessed during listening tests [32].

Although perceptual inundation is now considered as a core perceptual anomaly in schizophrenia [37,40], no study investigated the relation between retrospective evaluations of abnormal sensory gating experiences ("off-line evaluation"), evaluations obtained during listening tests ("on-line evaluation") and P50 suppression [31]. Thus, one of the aims of the present study was to investigate these relationships related to perceptual inundation in schizophrenia and healthy subjects.

For that purpose, we:

- generated a sound corpus of realistic environmental sounds obtained from a 3D immersive synthesizer and designed a user interface to evaluate perceptual inundation during the listening test;
- compared the evaluations from a group of patients with schizophrenia and a group of healthy subjects;
- used a French version of the SGI recently translated and formally validated to retrospectively evaluate daily sensory gating experiences in the two groups [34];
- recorded event-related potentials in a dual click conditioning-testing paradigm in order to measure the P50 suppression which is known to be a neurophysiological parameter related to sensory gating [52], and to perceptual inundation in schizophrenia [32,33].

Our main hypotheses were:

- that patients with schizophrenia would rate the perceptual inundation higher than healthy subjects when listening to the sounds;
- that the level of perceptual inundation in this case would correlate with the SGI scores (in particular with some dimensions of the SGI) and with the P50 suppression.

The correlation with the SGI scores would constitute an original way of evaluating the external validity of the SGI and an important argument in favour of the relevance of perceptual inundation in schizophrenia. The correlation with the P50 suppression would also confirm previous findings on the relation between anomalies of sensory gating and perceptual inundation in schizophrenia [33].

2. Methods and materials

2.1. Participants

Twenty patients with chronic schizophrenia recruited from the Department of Psychiatry, Marseille University Hospital, France, constituted the group of schizophrenic patients. DSM-IV criteria, based on Structured Clinical Interview (SCID) for DSM-IV interviews, confirmed the diagnosis of schizophrenia [4,17]. The control group comprised twenty psychiatrically healthy subjects who were screened for any current or lifetime history of the DSM-IV axis I disorder, based on the Mini-International Neuropsychiatric Interview (MINI) [41]. They had no first-degree relatives with schizophrenia.

Exclusion criteria were reduced capacity to consent, a diagnosis other than schizophrenia on Axis I of the DSM-IV, auditory impairment, neurological illness, brain injury, severe non-psychiatric disease and mental retardation.

After receiving a detailed description of the study, participants gave their written informed consent. This study was conducted in accordance with the Declaration of Helsinki and Good French Clinical Practices. The data collection was approved by the *Commission nationale de l'informatique et des libertés* (CNIL number: 1223715).

2.2. Clinical measures

The Positive and Negative Syndrome Scale (PANSS) assessed the patients' clinical severity of illness [23]. The Clinical Global Impression (CGI) assessed the severity of the disorder [20]. All patients were medicated, clinically stable and had not been submitted to any change in medications for at least one month. The mean equivalent dose of chlorpromazine was calculated [16,53]. Data regarding age of onset, duration of disorder and number of hospitalizations were collected.

2.3. Perceptual evaluation during sound listening

2.3.1. Sounds

We designed a corpus of environmental sounds with the 3D immersive synthesizer "SPAD" (*Spatialized Additive Synthesizer for Environmental Sounds*) developed at the LMA [51]. The synthesizer enabled the generation of sounds by precisely manipulating intuitive control parameters linked to the physical attributes of the sources. The system presents three main advantages:

- the possibility of synthesizing a large variety of realistic environmental sounds;
- a precise control and selection of a broad range of acoustic parameters for each synthesized sound;
- an efficient generation of immersive environmental scenes (sound sources are virtually spatialized in a 3D space) representing the real sonic world [51].

Such an immersive system is believed to constitute a powerful tool to induce the feeling of inundation during sound listening. Furthermore, the ability to precisely control acoustic parameters might in future research make it possible to identify acoustic

[1] Abstract sounds are defined as unusual sounds that could not be easily associated with a physical sound source or a consensual perceptual meaning.

triggers related to perceptual inundation experienced during the listening process.

We created 36 environmental scenes composed of one, two or three elementary sound sources corresponding to fire, rain, wind or wave. The characteristics of each elementary source could be controlled independently, based on the specificities of each source. Hence, the following characteristics were controlled:

- for the fire: the rate of crackling, the combustion gain and the overall intensity;
- for the rain: the gain of the background noise, rate of drops, rate of water streaming and the overall intensity;
- for the wind: the perceived strength and coldness of the blow;
- for the wave: the size of the wave.

The overall environmental scenes were generated by virtually positioning these elementary sources around the listener in a 3D space (we defined the source-listener distance and the perceived spatial width of each source) and then adapted for a binaural rendering (through headphones). Sounds are available at: http://www.lma.cnrs-mrs.fr/~kronland/SPAD_SGI/SPAD_SGI_P50.html.

We synthesized 15 seconds stereo sounds (16 bits, 44.1 kHz sampling frequency) for each environmental scene. The synthetic sounds were equalized by gain adjustments to minimize the influence of loudness variations on the sound evaluation.

2.3.2. Sound assessment

Smokers were asked to abstain from cigarette smoking during the hour preceding the test in order to minimize potential effects of nicotine on the perception of inundation [3]. The experiment was conducted in a quiet room, where participants were seated in front of a PC screen. Sounds were presented using the internal sound card of the computer and open headphones (HD650 Sennheiser) amplified with a Samsom (s-type) amp. Participants were free to adjust the intensity level of the sounds. The experimenter made sure that the sound level was high enough to provide a comfortable listening condition for each subject and that this level was approximately set to the same value across participants in both groups. The sound level was adjusted once at the beginning of the experiment and was not modified during the whole sound evaluation.

The experiment began with a 3-trial training session to familiarize participants with the task, and to ensure that the perceptual dimensions to be evaluated were well understood. Then, the 36 sounds were randomly presented in a single session. Participants were asked to listen to each sound while they evaluated the *inundation*, i.e. the "feeling of being inundated/flooded by the sound", as denoted by an item in the SIAPA [10] and some items of the perceptual modulation and over-inclusion dimensions in the SGI [21]. They were also asked to assess two emotional dimensions to evaluate the positive and negative emotional valences of each sound: *pleasant* ("pleasant/nice feeling related to the sound") and *frightening* ("frightening/unpleasant feeling related to the sound"). A graphical user interface developed with the Max/MSP software (http://www.cycling74.com/) was specifically designed for this experiment. Participants reported their evaluations by positioning a slider associated with each perceptual dimension on the graphical interface on a linear scale (represented by a horizontal bar). Each response scale was divided in five numeric anchors: 1 ("null"), 2 ("low"), 3 ("moderate"), 4 ("high"), 5 ("maximum"). Dimension labels displayed next to the scales on the screen were randomly balanced across participants.

2.4. The Sensory Gating Inventory (SGI)

The SGI is a retrospective 36-item questionnaire allowing the assessment of 4 abnormal perceptual dimensions related to the sensory gating deficit: perceptual modulation (linked to 16 items, e.g., "My hearing is so sensitive that ordinary sounds become uncomfortable"), over-inclusion (7 items, e.g., "I notice background noises more than other people"), distractibility (8 items, e.g., "There are times when I can't concentrate with even the slightest sounds going on"), and fatigue-stress modulation (5 items, e.g. "It seems that sounds are more intense when I'm stressed").

Participants assigned 6-point Likert ratings (from 0 "never true" to 5 "always true") to the 36 items [21,34]. The algebraic sum of Likert ratings for each participant was computed on the 36 items to obtain the overall SGI score and on each of the 4 sets of items to obtain the scores for each dimension.

2.5. ERP recordings and P50 measurement procedure

Half of the population of each group (i.e. 10 patients and 10 controls, randomly selected) was submitted to auditory ERP recordings. The population was restricted because of the availability of the apparatus in the neurophysiology department. For a given participant, the ERP recording was performed on the same day as the listening test and the SGI. Smokers were asked to abstain from cigarette smoking 1 hour before collecting electrophysiological measurements, thus minimizing possible effects of nicotine on the ERP amplitudes [3].

The subject, seated in a comfortable recliner in a quiet room, wore headphones for auditory stimuli presentation and was instructed to relax and to keep his or her eyes closed. A set of 60 pairs of clicks (S1 and S2) was delivered. Clicks were rectangular pulses of 0.05 msec with an intensity of 100 dB SPL. The interstimulus interval was set to 500 msec and the inter-pair interval to 10 sec [22,7].

Electroencephalographic measurements were recorded from 10 scalp gold disc electrodes according to the International 10/20 convention (Fz, Cz, Pz, Oz, F3, F4, C3, C4, P3, P4). The ground electrode was on the nose and the reference was the average of right and left earlobe electrodes. Electrode resistance was less than 10 kΩ. Data were acquired at a 1000 Hz sampling frequency and filtered with a band pass filter of 1–200 Hz. Data were segmented into single trials of 1200 msec, beginning 200 msec before the S1 stimulus onset. Electro-oculographic data were recorded, and trials contaminated by ocular movements and movement artifacts were rejected by visual inspection. The remaining trials (more than 90% for each participant) were then averaged for each participant.

The P50 components were measured at the Cz site since it was shown to be the best site for discriminating schizophrenic patients from healthy subjects [14]. The conditioning P50 component was visually identified, by a neurophysiologist blinded to the disease status of the subjects, as the positive component presenting the largest peak occurring between 40 and 80 msec after the S1 onset [12,35]. The testing P50 component was identified in a similar way after the S2 onset. Note that for two patients the P50 component after S2 was detected in an extended range of 40–100 ms, the P50 was thus identified as the most positive peak preceding the N100 [27]. The amplitudes of these components were defined as the difference between the peak of the P50 component and the preceding negative peak [9,13,36]. The percentage of reduction of the P50 amplitudes is labelled "P50 suppression". The percentage of P50 suppression (P50supp) was calculated using the following formula: $P50supp = [1 - (AS2/AS1)] \times 100$, where AS1 and AS2 are the P50 amplitudes of the conditioning and testing, respectively [13]. The difference between P50 amplitudes was also calculated [42]. Minimums of 100% suppression or 100% facilitation were used to prevent outliers from disproportionately affecting the group means [11,36].

2.6. Statistical analyses

Data analyses were performed using SPSS (Version 18 for Mac, PASW Statistics) and Prism software (Version 6, GraphPad). Demographic variables (age, gender and years of education), evaluations from the listening test, SGI scores and neurophysiological variables (P50 amplitudes, P50 latencies and $P50_{supp}$) were compared between schizophrenia and control groups. Qualitative variables were compared using Chi^2 tests (or Fisher's exact test if there were fewer than 5 observations in a group). Quantitative variables were compared using one-tailed independent samples *t*-tests.

Spearman's correlation coefficients were computed between evaluation of inundation during the listening test and demographic and clinical variables, SGI scores (overall score and scores for each of the 4 dimensions of the scale), and percentage of P50 suppression in the entire group and in the control and schizophrenia groups separately (two-tailed tests of significance). Correlations between inundation during sound listening and emotional valences were also performed. For each analysis, effects were considered as significant when the *P*-value was equal to or less than .05.

3. Results

Demographic and clinical variables are shown in Tables 1 and 2. Sex and years of education are different between patients with schizophrenia and controls (Table 1). Sex, age and years of education are different between the two groups submitted to auditory ERP recordings (Table 2).

Evaluation of inundation during sound listening was significantly higher in schizophrenia compared to the control group (Fig. 1). Concerning emotional valence, only the negative valence ("frightening") was significantly higher in schizophrenia compared to the control group (Table 1). Note that no significant differences on emotional valence ratings with respect to the type of sound sources (fire, wind, wave and rain) were found in the control group ($P = .53$ for pleasant and $P = .51$ for frightening) or in the patient group ($P = .87$ for pleasant and $P = .81$ for frightening).

The correlation between the evaluation of inundation during the listening test and overall SGI scores and each of the 4 dimensions were significantly positive for the entire group (i.e. increased inundation during sound listening was associated with increased SGI scores, Table 3). The correlation between the evaluation of inundation during the listening test and overall SGI scores, perceptual modulation and over-inclusion dimensions were significantly positive for schizophrenic patients (Table 3 and Fig. 2A and B). No significant correlation was found in the control group (Table 3).

Schizophrenic patients presented a significantly lower P50 suppression (31.42%) compared to controls (79.67%), indicating a P50 suppression deficit in patients. Fig. 3 shows the grand average for each group. Correlations between the evaluation of inundation during sound listening and the P50 suppression was significantly negative for the entire group of participants (Table 3 and Fig. 4) (i.e. increased inundation during sound listening was associated with decreased P50 suppression), but not for the control and schizophrenia groups separately (Table 3).

Note that significant correlations were found between P50 suppression and overall SGI scores ($n = 20$, rho = $-.60$, $P = .005$), perceptual modulation ($n = 20$, rho = $-.66$, $P = .001$), distractibility ($n = 20$, rho = $-.52$, $P = .02$) and over-inclusion ($n = 20$, rho = $-.54$, $P = .015$) dimensions for the entire group. This was not the case when the control and schizophrenia patient groups were considered separately. A significant positive correlation between the negative valence and the inundation was found for the entire group ($n = 40$, rho = .668, $P < .0001$) and for the schizophrenia group ($n = 20$, rho = .734, $P < .0001$). Finally, no correlation was found between the evaluation of inundation during sound listening and any demographical or clinical variables.

4. Discussion

The first main result of this study is that patients with schizophrenia rate the perceptual inundation during environmental

Table 1
Demographic, clinical, "on-line" and "off-line" evaluation of perceptual inundation for the control group and the schizophrenia patient group.

	Controls (n = 20)		Schizophrenia patients (n = 20)		Statistics	
	Mean	SD	Mean	SD	*t*	*P*
Sex (number of subjects)						
Male	9	–	16	–		0.048[a]
Female	11	–	4	–		
Age (years)	35.15	13.74	38.9	10.52	0.97	0.34
Smoker (number of subjects)	13	–	8	–		0.11[b]
Years of education	14.4	2.04	12.2	1.96	3.48	0.001
Clinical data						
Onset of illness (age)	–	–	21.65	4.25		
Duration of illness (years)	–	–	17.25	9.03		
Number of hospitalizations	–	–	8.7	6.09		
Chlorpromazine equivalent	–	–	967	710		
PANSS overall score	–	–	106	17		
CGI	–	–	4.45	1.05		
Evaluation during sound listening ("On-line" evaluation)						
Inundation	2.4	0.6	3.25	0.59	4.50	< 0.001
Pleasant	2.04	0.74	2.45	0.74	1.73	0.091
Frightening	1.82	0.68	2.67	0.85	3.51	0.001
Sensory Gating Inventory scores ("Off-line" evaluation)						
Overall score	43.1	22.51	102.67	32.66	6.6	< 0.001
Perceptual modulation	13.05	10.94	44.94	15.77	7.3	< 0.001
Distractibility	12.55	6.48	24.06	8.19	4.82	< 0.001
Over-inclusion	7.3	5.39	16.89	5.76	5.3	< 0.001
Fatigue-stress modulation	10.2	5.19	16.78	6.5	3.46	0.001

[a] Fisher's exact test.
[b] Chi^2 tests.

Table 2
Demographic, clinical, "on-line" and "off-line" evaluation of perceptual inundation and neurophysiological variables for the subgroups of controls and schizophrenia patients submitted to ERP recordings.

	Controls (n = 10)		Schizophrenia patients (n = 10)		Statistics	
	Mean	SD	Mean	SD	t	P
Sex (number of subjects)						
Male	2	–	7	–		0.07[a]
Female	8	–	3	–		
Age (years)	29.00	5.12	38.50	8.18	3.11	0.006
Smoker (number of subjects)	6	–	3	–		0.37[a]
Years of education	14.80	1.03	12.10	1.79	4.56	0.001
Inundation during sound listening ("On-line" evaluation)	2.36	0.66	3.09	0.54	2.68	0.01
SGI Perceptual Modulation scores ("Off-line" evaluation)	11.70	12.95	43.60	19.32	4.34	< 0.001
Stimulus S1						
P50 amplitude (μV)	1.09	0.99	2.04	2.04	1.203	0.25
P50 latency (msec)	62.25	12.16	65.49	13.03	0.54	0.60
Stimulus S2						
P50 amplitude (μV)	0.21	0.19	1.13	0.75	3.55	0.003
P50 latency (msec)	63.00	12.70	74.21	15.97	1.61	0.13
P50 suppression (%)	79.67	17.69	31.42	30.19	4.35	< 0.001
P50 difference	1.75	1.69	1.81	3.41	−0.048	0.96

[a] Fisher's exact test.

sound listening higher than healthy subjects. This confirms that the sounds used in the present experiment (realistic immersive environmental auditory scenes) were well suited to investigate perceptual inundation.

The second main result of this study is that the level of perceptual inundation during sound listening correlates with the SGI scores in schizophrenia, in particular with the perceptual modulation and the over-inclusion dimensions, which are the closest dimensions to the perceptual inundation construct. This relationship between "off-line" and "on-line" evaluation of perceptual inundation argues in favour of the relevance of the concept of perceptual inundation in schizophrenia [31]. This relationship signifies that an evaluation of the external validity of the SGI can be obtained through listening tests ("on-line evaluation") in schizophrenia. This means that new evaluation procedures related to the external validity of the SGI can be envisaged in addition to the already existing correlation with the Perceptual Abnormal Scale (PAS), which consists in a retrospective questionnaire [21,34]. In healthy subjects no correlation was found between perceptual inundation and the SGI scores. An explanation could be a floor effect with the SGI since the mean overall score for the SGI in the control group was 43.1 (SD = 22.51), whereas the overall score ranked from 36 to 180.

Patients with schizophrenia presented sensory gating deficit as measured by the P50 suppression paradigm. Note that the patient group was significantly older than the control group. This age effect

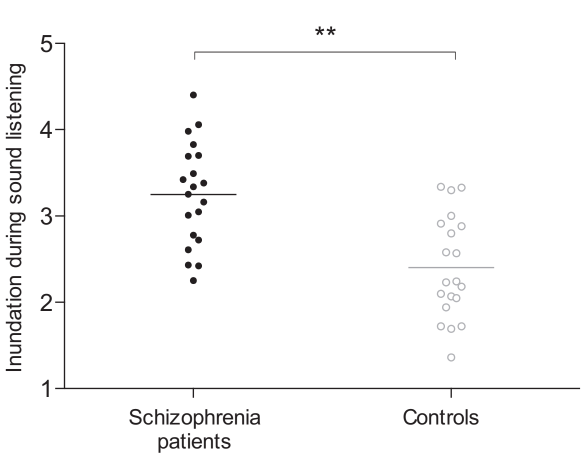

Fig. 1. On-line evaluation of inundation during sound listening in schizophrenia and control groups.

could also explain the P50 suppression difference, since it has been shown that the sensory gating ability decreases with age [39]. There were more men in the patient group compared with the control group. However this gender effect could not explain the P50 suppression difference, since it has been shown that men exhibited higher sensory gating compared with women [39].

Contrary to our hypothesis, the correlations between the P50 suppression and the level of perceptual inundation during sound listening and between the P50 suppression and the SGI scores were not significant for the groups when considered separately. However these correlations became significant when considering the two groups as a whole. The lack of correlation in the schizophrenia group might be attributed to the lack of power of the present study. The lack of correlation could be also related to the effect of antipsychotic. Indeed, it was found that antipsychotic might modify P50 suppression [30]. The effect of antipsychotic on perceptual inundation remains to be explored [30]. If the effect of antipsychotic is different on P50 suppression and on perceptual inundation, antipsychotic might disrupt the relation between these variables. Thus these relationships need to be investigated on a larger and more homogeneous group of patients with schizophrenia with respect to gender. Moreover, effect of antipsychotic need to be investigated in order to investigate his effect on the previous relationship found between P50 suppression and inundation assessed during listening tests [29] and between P50 suppression and the perception of being inundated and overwhelmed by external sensory stimuli assessed retrospectively by the SGI [33].

As far as the emotional valences are concerned, the evaluation of positive valence ("pleasant") did not differ between groups, in line with a previous study using a broad range of non-verbal environmental sounds [48]. This result also indicates that patients with schizophrenia did not over-evaluate all the perceptual dimensions during the listening test and consequently is a supplementary argument for the validity of the proposed on-line sound evaluation. By contrast, we found a significant difference for the negative valence ("frightening") with higher rates for patients with schizophrenia. These rates were higher than those previously found by Tuscher et al. who concluded on a lack of difference for positive and negative emotional valences [48]. This may be due to the fact that we used spatialized environmental scenes in our study, increasing the sensation of immersion, while recorded environmental monophonic sounds were used in Tuscher and al.'s study. The significant positive correlation between the negative

Table 3
Spearman's correlation coefficients between the evaluations of inundation during the listening test and the SGI scores (for overall scores and scores for each of the 4 dimensions of the scale) as well as P50 suppression, for the entire group and for the control and schizophrenia patient groups separately (two-tailed tests of significance).

Inundation during sound listening ("On-line" evaluation)	Sensory Gating Inventory scores ("Off-line" evaluation)					P50 suppression (%)
	Overall score (36 items)	Perceptual modulation (16 items)	Distractibility (8 items)	Over-inclusion (7 items)	Fatigue-stress modulation (5 items)	
Entire group	0.59*** (n = 40)	0.61*** (n = 40)	0.48** (n = 40)	0.50** (n = 40)	0.46** (n = 40)	−0.49* (n = 20)
Control group	0.12 (n = 20)	0.11 (n = 20)	0.096 (n = 20)	−0.072 (n = 20)	0.079 (n = 20)	−0.44 (n = 10)
Schizophrenia group	0.53* (n = 20)	0.52* (n = 20)	0.17 (n = 20)	0.59** (n = 20)	0.36 (n = 20)	0.12 (n = 10)

*** $P < 0.001$.
** $P < 0.01$
* $P < 0.05$.

valence and the inundation in our study is in line with this explanation. Further studies are needed to explore this relation in order to take better account of the effect of abnormal sensory gating on the emotional perception in schizophrenia [24,25]. We observed that high rates for "frightening" were not necessarily associated with low rates for "pleasant". This could be explained by the fact that frightening and unpleasant are not precisely the opposite construct. It could also be explained by an evaluative emotional system that is less contrasted (more "ambivalent") in schizophrenic compared to healthy subjects. Indeed, it was shown previously in a study using separate rating scales for each emotional valence (and not a continuous scale from negative to positive valence) that patients could both rate stimuli with positive valence as unpleasant and conversely stimuli with negative valence as more pleasant than controls [47]. Another explanation could be that controls better integrate the complete auditory scenes, taking it as a whole, compared with patients with schizophrenia who have difficulties to combine stimulus elements into coherent object representations [49]. Patients could respond more concretely, focusing on what is pleasant in the auditory scenes when rating pleasantness and focusing on what is frightening when answering the frightening aspect.

As a perspective, the relationship between sensory gating (especially the perceptual modulation and over-inclusion dimensions of the sensory gating inventory) and on-line evaluation enables to formulate an original hypothesis concerning acoustic triggers related to perceptual inundation during listening in schizophrenia. Actually P50 suppression measurements consist in the presentation of two identical brief stimuli (paired clicks) separated by a short time interval. Hence the sensory gating anomalies are revealed when using highly transient signals. This might suggest that patients are particularly sensitive to such nonstationary sounds that are also present in many environmental sounds and that the judgments of inundation observed in this study can be linked to the presence of transients in environmental sounds. The confirmation of this hypothesis would need a deeper exploration of acoustical characteristics of the environmental scenes (especially those that were perceived as inundating by schizophrenic patients) by computing the index of non-stationarity relatively to a given observation scale [54]. Thus it could be hypothesized that highly nonstationary sounds (i.e., with a high rate of impacted acoustic features) might be related to a higher perceptual inundation and might have higher distraction effects in patients with schizophrenia, as recently evaluated with urban noise stimuli during a Sustained Attention to Response Task (SART) [43].

In conclusion, our findings revealing that on-line evaluation of perceptual inundation in schizophrenia is related to off-line

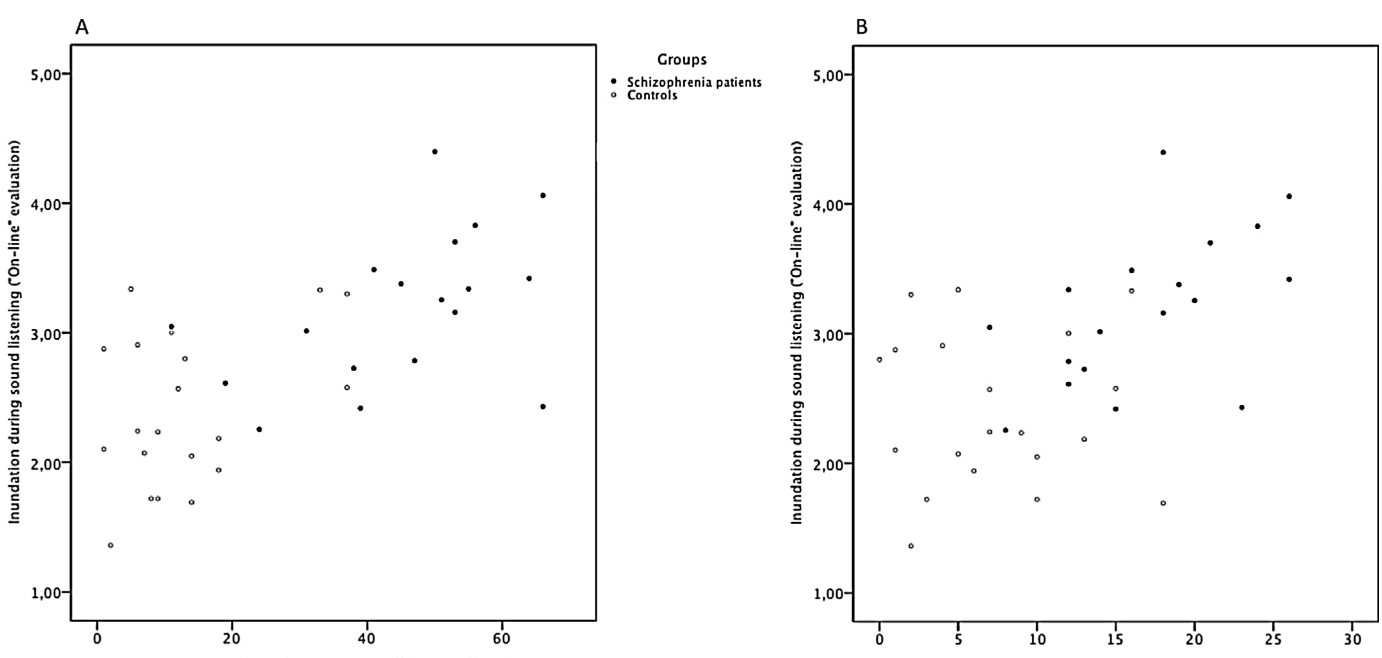

Fig. 2. Association between "on-line" and "off-line" evaluation of inundation during sound listening with perceptual modulation dimension scores (A) and over-inclusion dimension scores (B) of the sensory gating inventory.

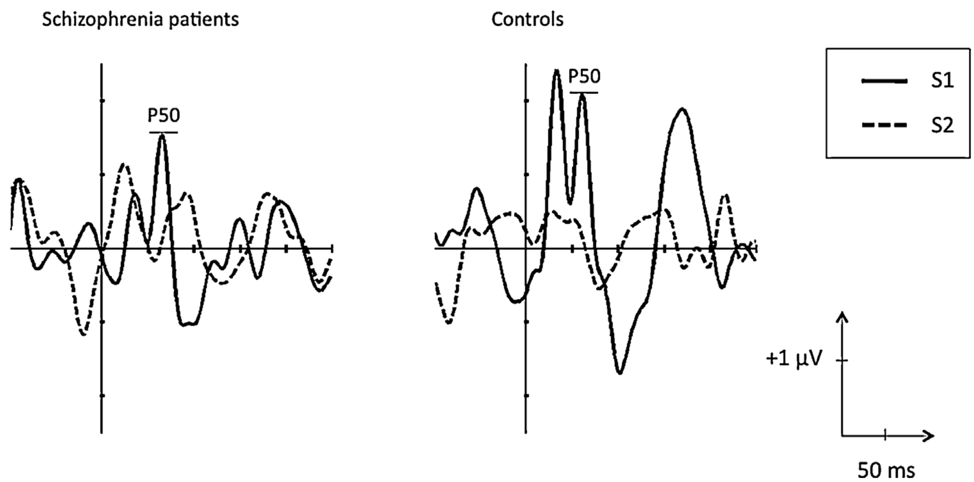

Fig. 3. Grand averaged P50 components for S1 (conditioning stimulus, solid line) and S2 (testing stimulus, dotted line) for 10 patients with schizophrenia (left) and 10 healthy controls (right). The data of each subject were epoched from 100 ms preceding (baseline) to 250 ms following S1 and S2 onsets and corrected for baseline activity. Prior to averaging, signals were filtered between 5 and 47-Hz to optimize the waveform of the P50 component.

evaluation supports the relevance of identifying acoustic triggers related to sensory gating and inundation. This should enable the development of future perceptual remediations in schizophrenia [1,18] using synthetic sounds that can be precisely controlled [5,6,15,38,44] such as environmental and immersive sounds in order to treat sensory gating deficit by teaching the patients, with an attentional procedure that focuses on the auditory processing of specific acoustic features [8]. The present study may enable us to propose an attentional control on acoustic features reflecting non-stationarities in the signal, in order to reduce inundation, overwhelming and distraction by external sensory stimuli in patients' real sonic world.

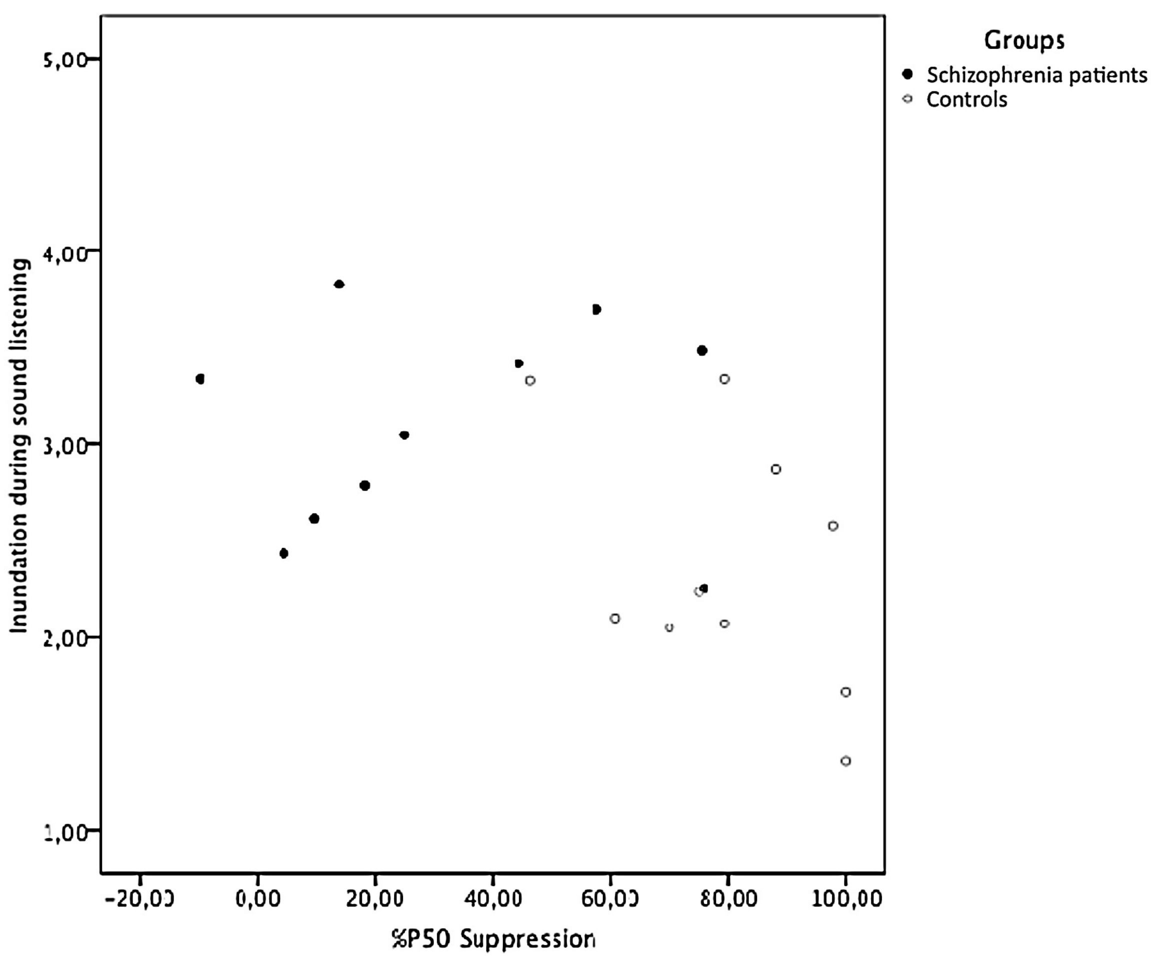

Fig. 4. Association between on-line evaluation of inundation during sound listening and P50 suppression.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.eurpsy.2015.01.005.

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