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# Sensory Gating Capacity and Attentional Function in Adults With ADHD: A Preliminary Neurophysiological and Neuropsychological Study

**Jean-Arthur Micoulaud-Franchi[1,2], Régis Lopez[3,4], Michel Cermolacce[5,6], Florence Vaillant[5], Pauline Péri[5], Laurent Boyer[5,7], Raphaëlle Richieri[5,7], Stéphanie Bioulac[2,8], Patricia Sagaspe[2], Pierre Philip[1,2], Jean Vion-Dury[5,6], and Christophe Lancon[5,7]**

**Abstract**

**Objective:** The inability to filter sensory input correctly may impair higher cognitive function in ADHD. However, this relationship remains largely elusive. The objectives of the present study is to investigate the relationship between sensory input processing and cognitive function in adult patients with ADHD. **Method:** This study investigated the relationship between deficit in sensory gating capacity (P50 amplitude changes in a double-click conditioning-testing paradigm and perceptual abnormalities related to sensory gating deficit with the Sensory Gating Inventory [SGI]) and attentional and executive function (P300 amplitude in an oddball paradigm and attentional and executive performances with a neuropsychological test) in 24 adult patients with ADHD. **Results:** The lower the sensory gating capacity of the brain and the higher the distractibility related to sensory gating inability that the patients reported, the lower the P300 amplitude. **Conclusion:** The capacity of the brain to gate the response to irrelevant incoming sensory input may be a fundamental protective mechanism that prevents the flooding of higher brain structures with irrelevant information in adult patients with ADHD. *(J. of Att. Dis. XXXX; XX(X) XX-XX)*

**Keywords**

ADHD, adult, sensory gating, P50 suppression, P300, attentional function.

## Introduction

Inattention, hyperactivity, and impulsivity are the core symptoms of ADHD (American Psychiatric Association [APA], 2000). However, attention has recently been drawn to perceptual abnormalities in ADHD that can also be core symptoms of the disorder both in children (Miller, Anzalone, Lane, Cermak, & Osten, 2007; Miller, Nielsen, & Schoen, 2012; Yochman, Alon-Beery, Sribman, & Parush, 2013) and adults (Micoulaud-Franchi, Lopez, et al., 2015; Sable et al., 2012). For example, adult patients with ADHD may report being "very sensitive towards sounds that are unheard by others such as the humming of a refrigerator, a clock ticking, or fans" (Ghanizadeh, 2011; p. 91). These perceptual abnormalities have been related to an inability in patients with ADHD to control sensitivity to sensory stimuli, giving rise to the feeling of being inundated with sensory stimuli and being easily distracted by many irrelevant environmental stimuli (Biederman, 2005; Faraone et al., 2000; Venables, 1964). Moreover, the inability to filter sensory input correctly, which has been related to an elementary form of pre-attentive information processing deficit (Braff & Geyer, 1990), may impair higher cognitive function, in particular

[1]Clinique du sommeil, CHU de Bordeaux, France
[2]USR CNRS 3113 SANPSY / Université de Bordeaux, France
[3]Unités des troubles du sommeil, Hôpital Gui-de-Chauliac Montpellier, France
[4]Inserm U1061, Montpellier, France
[5]Département de Psychiatrie, CHU de Marseille, France
[6]UMR CNRS 729 / Aix-Marseille Université, Marseille, France
[7]EA 3279 / Aix-Marseille Université, Marseille, France
[8]Pôle Universitaire de Psychiatrie de l'Enfant et de l'Adolescent, Bordeaux, France

**Corresponding Author:**
Jean-Arthur Micoulaud-Franchi, Services d'explorations fonctionnelles du système nerveux, Clinique du sommeil, CHU de Bordeaux, Place Amélie Raba-Leon, 33076 Bordeaux, France.
Email: jarthur.micoulaud@gmail.com

attentional and executive function (Venables, 1964). The impact of earlier sensory gating deficit on later and higher cognitive function has been investigated in adult patients with schizophrenia (Boutros, Korzyukov, Jansen, Feingold, & Bell, 2004; Gjini, Arfken, & Boutros, 2010), but remains largely unexplored in adult patients with ADHD (Micoulaud-Franchi, Vaillant, et al., 2015).

The inability to filter sensory input correctly in ADHD patients has been confirmed with neurophysiological measures and a validated self-report questionnaire. The decrement of a middle latency positive event related potential (ERP) component occurring approximately 50 ms after the onset of a brief auditory stimulus (the so-called "conditioning-testing paradigm") is considered to be a measure of the sensory gating capacity of the brain (Light & Braff, 2003). P50 amplitude decrement is altered in children with ADHD (Davies, Chang, & Gavin, 2009; Durukan et al., 2011), and in adults (Holstein et al., 2013; Micoulaud-Franchi, Vaillant, et al., 2015), despite some contradictory studies (Olincy et al., 2000; Sable et al., 2013). Auditory sensory gating is a multistage mechanism and occurs not only in P50 response but also in the subsequent ERP components that are designated N100 and P200. However, N100-P200 amplitudes decrement received only limited attention in ADHD.

Perceptual abnormalities related to sensory gating deficit may also be investigated with a dedicated validated self-report questionnaire: the Sensory Gating Inventory (SGI; Hetrick, Erickson, & Smith, 2012; Micoulaud-Franchi et al., 2014; Micoulaud-Franchi, Lopez, et al., 2015). Adult patients with ADHD report more perceptual abnormalities on the SGI than healthy participants (Micoulaud-Franchi, Lopez, et al., 2015; Sable et al., 2012). Recently, we found that the more adult patients with ADHD have neurophysiological deficit in P50 amplitude decrement, the more they report being inundated with sensory stimuli on the SGI (Micoulaud-Franchi, Vaillant, et al., 2015).

The attentional and executive function deficits in ADHD have been confirmed with neuropsychological tests and with neurophysiological measures. Neuropsychological tests found impaired high-level cognitive processes in ADHD, especially in functions that allow sustained selective attention, goal-directed behavior, cognitive flexibility, and inhibition capacity (Armstrong, Hayes, & Martin, 2001; Barkley, 1997; Boonstra, Oosterlaan, Sergeant, & Buitelaar, 2005). The amplitude of a late ERP component occurring approximately 300 ms after the onset of a target auditory stimulus (the so-called "oddball paradigm") is also thought to reflect the involvement of attentional and executive functions (Polich, 2007). P300 amplitude is reduced in children with ADHD (Barry, Johnstone, & Clarke, 2003; Strandburg et al., 1996) and in adults (Itagaki et al., 2011; Szuromi, Czobor, Komlosi, & Bitter, 2010). This reduction in P300 amplitude is congruent with impairment in high-level cognitive function in ADHD.

The present preliminary exploratory study investigated the relationship between a deficit in sensory gating capacity (pre-attentive function) and attentional and executive performances (high-level cognitive function) in adult patients with ADHD. P50 and N100-P200 amplitudes decrement and perceptual abnormalities as assessed by the SGI, and P300 amplitude and attentional and executive performances as investigated with a neuropsychological test, were investigated in a sample of adult patients with ADHD. The main hypothesis was that P50 (and N100-P200) amplitudes decrement or perceptual abnormalities related to sensory gating deficit would be inversely related to P300 amplitude or attentional and executive performance. The relationship between P300 amplitude and attentional and executive performances was also explored.

## Method and Materials

### *Participants*

Adult patients with ADHD were recruited from the Department of Psychiatry, Marseille University Hospital, France. Patients with ADHD were diagnosed by a psychiatrist according to the Conners' adult ADHD diagnostic interview for *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.; *DSM-IV-TR*; APA, 2000; CAADID; Conners, Epstein, & Johnson, 2001). The Adult ADHD Self-Report Scale (ASRS) was used to assess the clinical severity of patients with ADHD (Kessler et al., 2005; Morin, Tran, & Caci, 2013). This scale consists of 18 items reflecting the *DSM-IV-TR* diagnostic criteria and rated from 0 = *never* to 4 = *very frequently*. Scores were computed from the ASRS to obtain an inattention dimension and a hyperactivity dimension. The Wender Utah ADHD Rating Scale (WURS-25) was used to screen the presence of ADHD symptoms when the patients were children. This short form of the scale consists of 25 items reflecting the *DSM-IV-TR* diagnostic criteria and rated from 0 = *not at all or very slightly* to 4 = *very much* (Ward, Wender, & Reimherr, 1993). A cutoff score of 46 is predictive of having childhood ADHD (Ward et al., 1993). The Trait Anxiety Inventory (TAI) was used to assess symptoms of anxiety (Spielberger & Vagg, 1984). The number of adults with ADHD medicated with methylphenidate was collected. None of the patients was receiving any other form of medication.

Exclusion criteria were as follows: reduced capacity to consent, mental retardation, auditory impairment, current depression, current or lifetime history of bipolar disorder, current anxiety disorder, drug or alcohol addiction, neurological illness, brain injury, or severe medical disorders. 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 French Good Clinical Practices. The data collection was approved by the *Commission nationale de l'informatique et des libertés* (CNIL number: 1223715).

## Description of the Sample Characteristics

Twenty-four adult patients with ADHD were included in this study (eight female, 16 male). This is the same sample as in a previous study (Micoulaud-Franchi, Vaillant, et al., 2015). The mean age was 30.25 (*SD* = 7.92), and the mean educational level was 13.29 (*SD* = 3.02). The mean overall ASRS score for adults with ADHD was 51.62 (*SD* = 8.07), ASRS inattention score was 28.25 (*SD* = 4.54), and ASRS hyperactivity score was 23.37 (*SD* = 6.21), which indicated severe symptoms of ADHD. The mean WURS was 61.33 (*SD* = 12.87). Of the patients, 87.2% (*n* = 21) had a score above 46, which is in line with its psychometric properties to detect ADHD in childhood (Ward et al., 1993). Eight patients (33%) were medicated with methylphenidate. The mean dose was 31.5 mg (*SD* = 8.33). The mean TAI score was 46.43 (*SD* = 6.56), which indicates moderate symptoms of anxiety (Table 1).

## Evaluation of Sensory Gating Capacity

*Assessment of perceptual abnormalities related to sensory inhibitory deficit.* The SGI is composed of 36 items addressing a broad range of perceptual abnormalities related to sensory gating deficit.

The participants scored the 36 items of the SGI on a 6-point Likert-type scale (from 0 = *never true* to 5 = *always true*; Hetrick et al., 2012). The items have already been translated and validated in French (Micoulaud-Franchi et al., 2014; Micoulaud-Franchi, Lopez, et al., 2015).

The psychometric properties of the SGI indicate that it provides valuable information on four dimensions:

- A dimension of perceptual abnormalities related to hypersensitivity: the Perceptual Modulation (PM) dimension (linked to 16 items, for example, "My hearing is so sensitive that ordinary sounds become uncomfortable")
- A dimension related to the feeling of being overwhelmed and inundated by sound: the Over-Inclusion (OI) dimension (seven items, for example, "I notice background noises more than other people")
- A dimension of perceptual abnormalities related to attentional deficit: the Distractibility (D) dimension (eight items, for example, "There are times when I can't concentrate with even the slightest sounds going on")
- A dimension related to aggravation of the perceptual abnormalities in the context of fatigue or stress: the Fatigue–Stress Modulation (FS) dimension (five items, for example, "It seems that sounds are more intense when I'm stressed")

**Table 1.** Neurophysiological, Perceptual, and Neuropsychological Characteristics.

| | ADHD *N* = 24 | |
|---|---|---|
| | *M* | *SD* |
| Neurophysiological assessment | | |
| Sensory filter ability (conditioning-testing paradigm) | | |
| P50 S1 amplitude (μV) | 2.85 | 1.62 |
| P50 S2 amplitude (μV) | 1.65 | 1.58 |
| P50 S1 latency (ms) | 57.83 | 14.99 |
| P50 S2 latency (ms) | 55.52 | 14.45 |
| P50 S2/S1 ratio (%) | 60.51 | 39.43 |
| P50 S1 − S2 difference (μV) | 1.20 | 1.56 |
| N100–P200 S1 amplitude (μV) | 10.25 | 5.95 |
| N100–P200 S2 amplitude (μV) | 3.66 | 2.24 |
| N100 S1 latency (ms) | 114.29 | 25.08 |
| N100 S2 latency (ms) | 127.90 | 25.31 |
| P200 S1 latency (ms) | 218.13 | 38.13 |
| P200 S2 latency (ms) | 222.88 | 38.67 |
| N100–P200 S2/S1 ratio (%) | 52.38 | 63.11 |
| N100–P200 S1 − S2 difference (μV) | 6.58 | 6.16 |
| Attentional function (auditory oddball paradigm) | | |
| N200 amplitude (μV) | 4.30 | 3.62 |
| N200 latency (ms) | 205.25 | 21.32 |
| P300 amplitude (μV) | 7.45 | 3.31 |
| P300 latency (ms) | 349.63 | 31.23 |
| Perceptual assessment | | |
| Overall score | 97.95 | 36.78 |
| Perceptual modulation | 34.75 | 18.43 |
| Over-inclusion | 20.33 | 9.12 |
| Distractibility | 30.12 | 6.61 |
| Fatigue–Stress Modulation | 12.75 | 5.57 |
| Neuropsychological assessment | | |
| D2 concentration performance | 99.33 | 10.56 |
| TMT-A Time | 25.83 | 8.48 |
| TMT-B Time | 61.21 | 18.63 |
| TMT-A Time − TMT-B Time | 35.08 | 14.14 |
| Stroop golden 45 s (correct response) | 43.79 | 12.72 |
| Stroop interference | 2.98 | 10.47 |

*Note.* TMT = Trail-Making Test.

The algebraic sum of the Likert-type rating for each participant was computed for the overall SGI score and each of the four dimensions (PM, OI, D, and FS).

*Neurophysiological measure of sensory gating capacity.* Participants were seated in a comfortable recliner in a quiet room, wore headphones for the presentation of auditory stimuli, and were instructed to stay awake and relaxed. They were asked to abstain from cigarette smoking for at least 1 hr before their arrival at the laboratory (Adler, Hoffer, Wiser, & Freedman, 1993). Electroencephalographic activity (EEG) was recorded by scalp gold disc electrodes affixed at the Fz, Cz, Pz according to the International 10/20 convention. The ground electrode was on the nose, and the reference electrode was on an ear. Electrode resistance was less than 10 kΩ. The scalp EEG was amplified by a factor of 5,000 and digitalized at 1,000 Hz onto the hard drive of a PC using a 12-bit analog-to-digital converter and EB-Neuro acquisition software (EB Neuro S.p.A. Firenze, Italy). The Electro-oculographic activity (EOG) was recorded by electrodes affixed above and below the left eye. The EOG was amplified by a factor 2,500 and digitalized as the EEG activity. Hardware filter settings for the EEG and the EOG were a band pass filter of 1 to 200 Hz. 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.

Each participant underwent two recording blocks: One block was for sensory gating using a conditioning-testing paradigm, and another block generated P300 ERP under oddball conditions (see below). Stimuli were presented using stimulus presentation software from EB-Neuro through calibrated headphones. The EEG measures were taken by the same investigator.

The sensory gating capacity of the brain was measured by using identical pairs of brief tones delivered in a *conditioning-testing P50 paradigm* (conditioning click, S1, followed by the testing click, S2) in a passive task. The inter-stimulus interval was set to 500 ms and the inter-pair interval to 10 s. The auditory clicks consisted of a 0.05 ms duration square wave pulse amplified in the 20 Hz to 12,000 Hz bandwidth. The auditory clicks were delivered through the headphones with an intensity of 100 dB sound pressure level (SPL; Baker et al., 1987; Jin et al., 1998; Micoulaud-Franchi, Vaillant, et al., 2015). A set of 60 auditory click pairs was delivered binaurally. P50 measurement was made from the Cz electrode. Data were segmented into single epochs of 1,200 ms, including a 200 ms prestimulus window. Time locked evoked potentials were obtained by averaging all artifact-free epochs and filtered with a band pass filter of 10 to 100 Hz. The conditioning P50 component was identified as the positive component presenting the largest peak occurring between 40 and 80 ms after the S1 onset (Cardenas, Gerson, & Fein, 1993; Nagamoto, Adler, Waldo, & Freedman, 1989). The testing P50 component was identified in a similar way after the S2 onset. The amplitudes of these components were defined as peak-to-peak amplitudes, that is, between the peak of the P50 component and the preceding negative peak (neg; Boutros & Belger, 1999; Clementz, Geyer, & Braff, 1997; Nagamoto, Adler, Waldo, Griffith, & Freedman, 1991). The N100 (between 80 and 150 ms) and P200 (between 150 and 250 ms) component was defined as a prominent negative–positive complex. The amplitude of this complex N100–P200 was defined between the peak of the P200 and the peak of the N100 (Figure 1a).

The auditory sensory filter capacity was measured (a) by dividing the amplitude of S2 responses by the amplitude of S1 responses (S2/S1 ratio) and multiplying this ratio by 100 (lower S2/S1 ratios are assumed to reflect stronger sensory gating capacity), (b) by subtracting S2 amplitudes from S1 amplitudes (S1 − S2 difference; higher differences are assumed to reflect stronger sensory gating capacity). The S1 − S2 difference has been described as more reliable than the S2/S1 ratio (Smith, Boutros, & Schwarzkopf, 1994).

## Evaluation of Attentional and Executive Functions

*Neuropsychological assessment.* Three paper and pencil neuropsychological tests administered by a trained psychologist were used to evaluate attention and executive function in ADHD.

The D2 test of attention is a task in which participants have to cross out critical letters on a working sheet. It requires focused selective attention. The concentration performance is calculated as the number of correctly canceled items minus the total number of incorrectly canceled items (Brickenkamp & Zillmer, 2005).

The Trail-Making Test (TMT) is a task in which the participants have to connect series of circles printed on a page. In Part A (TMT-A), they connect circles containing numbers (one through 25) in numerical order as quickly as possible. In Part B (TMT-B), they connect circles by alternating between numbers and letters (i.e., 1-A-2-B, etc.) as quickly as possible. The difference in time between Part A and Part B is considered indicative of reactive flexibility and switching cost (Reitan & Wolfson, 1985).

The Golden Stroop Test is a task in which the participants have to name as many items as they can in 45 s for a word card (i.e., a word list), a color card (i.e., a list of colored rectangles), and an incongruent color–word card (i.e., a colored word consisting of the name of a color written in a different color). The color–word card requires suppressing the automatic response of word reading. The Golden interference score is the difference between the predicted number of items named in 45 s (calculated on the basis of the number of items named in the word and color card) and the number of items in the color–word card (Golden, 1978). The score is considered being indicative of gating capacity.

*Neurophysiological measure of attentional and executive function.* The *auditory oddball paradigm* was used to generate the P300 component of the ERP. Two types of brief tones were delivered at random (frequent 83% and infrequent 17%) according to a sound sequence of 1,000 and 2,000 Hz in frequency, 2 s in interval, 85 dB SPL in intensity, and 100 ms in duration. The brief tones were delivered through

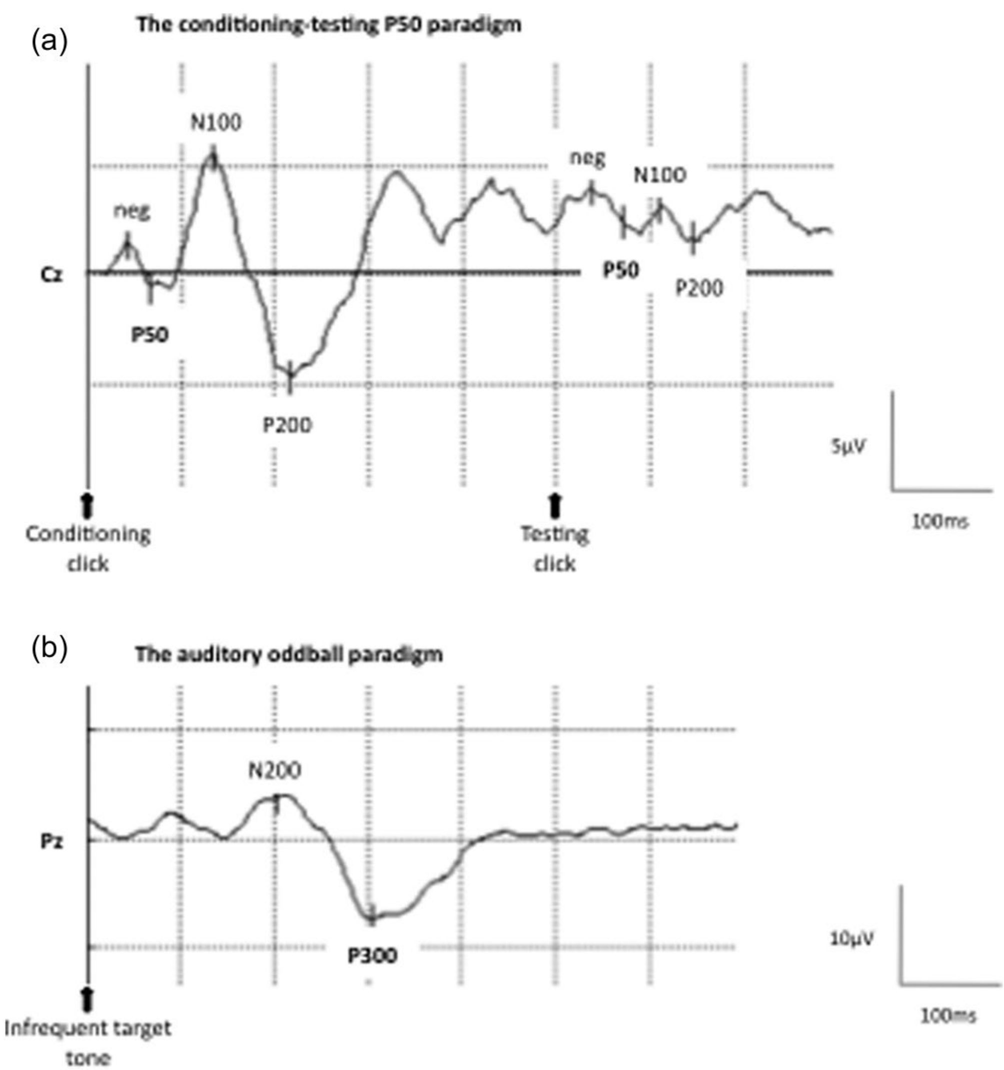


**Figure 1.** Example of waveform figures from both ERP tasks for a patient with ADHD included in the study.
*Note.* (a) P50, N100, and P200 waveforms in the conditioning-testing paradigm. (b) N200 and P300 waveforms in the auditory oddball paradigm. ERP = event-related potential.

the headphones. The high frequency sound was designated as the target stimulus. A set of 90 stimuli was delivered. Participants were required to maintain their gaze at a fixation point while silently counting the number of target stimuli presented.

Data were segmented into single epochs of 1,200 ms, including a 200 ms prestimulus window, which was used as baseline amplitude. Time locked evoked potentials were obtained by averaging all artifact-free epochs and filtered with a band pass filter of 1 to 30 Hz. Epochs were averaged separately for the frequent target and infrequent non-target ERPs. The N200 and P300 peaks (amplitudes and latencies) were measured from averaged ERPs to target (infrequent) tones. The N200 was identified as the negative component presenting the largest peak occurring at Fz between 150 and 250 ms. The P300 was identified as the positive component presenting the largest peak occurring at Pz between 250 and 500 ms after the stimulus onset. The amplitudes of the component were defined as peak-to-baseline amplitude (Figure 1b).

## *Statistical Analysis*

Descriptive statistics of the sample included frequencies and percentages of categorical variables, together with means and standard deviations of continuous variables. Data analyses were performed using SPSS software (Version 18, PASW Statistics).

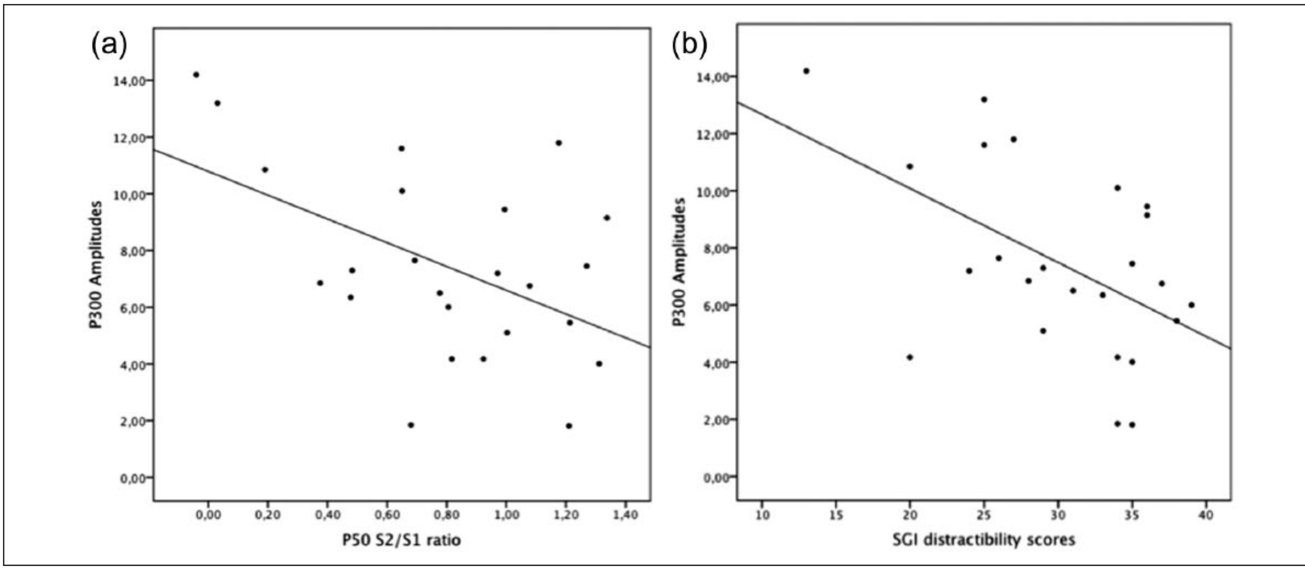


**Figure 2.** Scatterplots of the two significant correlations between sensory gating capacity (pre-attentive function) and attentional and executive performances (high-level cognitive function).
*Note.* (a) Scatterplot of the correlation between P50 sensory gating incapacity measured in a conditioning-testing paradigm and P300 amplitudes measured in an auditory oddball paradigm. (b) Scatterplot of the correlation between SGI distractibility scores related to sensory gating incapacity and P300 amplitudes measured in an auditory oddball paradigm. SGI = Sensory Gating Inventory.

Pearson correlation coefficients were used to examine the relationship between the sensory gating capacity variables (S2/S1 ratio, S1 − S2 difference, and perceptual scores on the SGI) and the attentional and executive variables (P300 amplitude, P300 latency, D2 concentration performance, TMT-A and TMT-B times, TMT A–B difference time, Golden interference score). The Pearson correlation coefficient was also used to examine the relationship between P300 amplitude and neuropsychological variables (D2 concentration performance, TMT-A and TMT-B times, TMT A–B difference time, Golden interference score) and clinical variables (ASRS overall score, inattention score, and hyperactivity score). Bonferroni correction was applied.

When the Pearson correlation coefficient was significant, a linear regression was performed to explore the association after adjustment for age, sex, education, treatment, and TAI (anxiety symptoms), which are variables known to have an effect on sensory gating capacity (Hetrick et al., 2012; Patterson et al., 2008) and attentional and executive variables (Boonstra et al., 2005; Polich, 2007; Szuromi et al., 2010).

For each analysis, effects were considered significant when the $p$ value was equal to or less than .05.

## Results

### *Relationship Between Sensory Gating Capacity and Attentional and Executive Function*

The Pearson correlation coefficients between the P50 S2/S1 ratio, $r(24) = -.50$, $p = .01$, and P300 amplitude were significant and remained significant after adjustment ($p = .04$). The lower the sensory gating capacity (higher S2/S1 ratio), the lower the P300 amplitude (Figure 2a). No significant correlation was found between N100-P200 S1/S1 ratio, N100-P200, and P50 S1-S2 differences and P300.

No significant correlation was found between P50 and N100-P200 S2/S1 ratio or S1 − S2 difference, and none of the neuropsychological variables (D2 concentration performance, TMT-A and TMT-B times, TMT A–B difference time, Golden interference score).

The Pearson correlation coefficients between the SGI Distractibility score and the P300 amplitudes were significant, $r(24) = -.52$, $p = .009$, and remained significant after adjustment ($p = .01$). The more the patients reported distractibility related to sensory gating incapacity, the smaller the P300 amplitude (Figure 2b).

The Pearson correlation coefficients between the SGI OI score and TMT-A times were significant, $r(24) = -.54$, $p = .006$, and remained significant after adjustment ($p = .02$). The more the patients reported over-inclusion related to sensory gating incapacity, the shorter the TMT-A times. No other significant correlation was found between perceptual variables (overall score and the four dimensions of the SGI) and other neuropsychological variables (D2 concentration performance, TMT-B times, TMT A–B difference time, Golden interference score).

### *Relationship Between P300 Amplitude and Neuropsychological Assessments*

No significant correlation was found between P300 amplitudes or P300 latency, and any of the neuropsychological variables (D2 concentration performance, TMT-A and TMT-B times, TMT A–B difference time, Golden interference score) or clinical variables (ASRS overall score, inattention score, and hyperactivity score).

## Discussion

The present study found a relationship between sensory gating capacity (pre-attentive function) and attentional and executive performances (high-level cognitive function) in adult patients with ADHD. Inability to filter sensory input as measured with the P50 paradigm or with the SGI (a validated questionnaire to evaluate perceptual abnormalities related to sensory gating deficit) was inversely related to P300 amplitude after controlling for age, sex, education, treatment, and anxiety symptoms, which are known to have an effect on sensory gating capacity (Hetrick et al., 2012; Patterson et al., 2008) and attentional and executive variables (Boonstra et al., 2005; Polich, 2007; Szuromi et al., 2010).

Deficits in pre-attentive brain capacity to filter intrusive sensory information, as measured by P50 neurophysiological responses to repetitive stimuli, were associated with smaller P300 amplitude. According to the P300 resource allocation theory, P300 amplitude reflects the effort to allocate attention (Isreal, Chesney, Wickens, & Donchin, 1980; Polich, 2007). Thus, the present findings raise the possibility that the sensory gating deficit in ADHD may also affect the resource allocation capacity of the brain. This explanation gives rise in turn to the hypothesis that the capacity of the brain to gate the response to incoming irrelevant sensory input may be a fundamental protective mechanism that prevents the higher structures of the brain from being flooded by irrelevant information (Venables, 1964). Thus, attentional and executive dysfunction, which characterizes the cognitive function of ADHD patients (Boonstra et al., 2005), could be the consequence of sensory input dysfunction in ADHD. The present result and explanation support the neurodevelopmental model of prefrontal cortex function in ADHD (Halperin & Schulz, 2006). Indeed, this model posit that although attentional and executive function deficits are common among patients with ADHD, these cognitive deficits may in fact reflect primary disturbances to lower level sensory pathways rather than higher level cognitive control region (Halperin & Schulz, 2006).

Perceptual abnormalities related to sensory gating deficit as measured with the SGI were also associated with smaller P300 amplitude. This finding is consistent with (a) the relationship found between P50 sensory gating capacity and P300 amplitude in this study, and (b) the relationship between sensory gating capacity and perceptual abnormalities related to sensory gating deficit found in a previous study in adult patients with ADHD (Micoulaud-Franchi, Vaillant, et al., 2015). Indeed, it was found that the more the patients reported perceptual abnormalities on the SGI, the lower the sensory gating capacity (Micoulaud-Franchi, Vaillant, et al., 2015).

However, in the present study, only the Distractibility dimension of the SGI was significantly correlated with P300 amplitude after Bonferroni correction, perhaps because this dimension of the SGI could be the most accurate for investigating the abnormal perceptual experience of being flooded with sensory stimuli in adults with ADHD. The SGI was previously developed for schizophrenia (Hetrick et al., 2012), but it can be used to investigate the clinical features of ADHD (Micoulaud-Franchi, Lopez, et al., 2015). It also reveals higher abnormal perceptual experience in ADHD patients than in patients with schizophrenia or healthy participants, particularly on the Distractibility dimension. Indeed, using a short version of the SGI developed by Kisley, Noecker, and Guinther (2004; 17 vs. 36 items) in a group of psychology students with probable ADHD, Sable et al. (2012) found that the Distractibility dimension of the SGI was the only one to be higher in ADHD than in healthy students (Kisley et al., 2004; Sable et al., 2012). Using the entire version of the SGI in a group of adults with confirmed moderate-to-severe ADHD, Micoulaud-Franchi, Lopez et al. (2015) found that all the dimensions of the SGI were significantly higher in ADHD than in schizophrenia. Moreover, the calculated effect sizes according to Cohen's d were higher for the Distractibility dimension ($d = 1.6$) than for PM ($d = 0.7$), OI ($d = 0.8$), and FS ($d = 0.8$; Cohen, 1988).

Note that the Distractibility dimension of the SGI could be more specific than the inattention dimension of the ASRS to evaluate perceptual abnormalities related to the feeling of being easily distracted by many irrelevant environmental stimuli. Indeed, the inattention dimension of the ASRS contains items related not only to distractibility but also to difficulties in organization, planning, and remembering (Kessler et al., 2005; Morin et al., 2013). Thus, as suggested by Sable et al. (2012) and Micoulaud-Franchi, Lopez et al. (2015), the SGI, particularly its Distractibility dimension, could be a useful self-report instrument to diagnose some under-evaluated clinical features of ADHD.

Only one relationship was found between sensory gating capacity and cognitive functions as measured by paper and pencil neuropsychological tests. The OI dimension of the SGI was significantly correlated with TMT-A times. The TMT-A is an easily administered task that requires connecting circles in numerical order as quickly as possible (Reitan & Wolfson, 1985) and which is considered an indicative measure of speed processing. The OI dimension of the SGI is related to the perception of being overwhelmed and inundated by stimuli. Participants with high scores on the OI dimension notice background noises more and pay more attention to little details than those with low scores. Thus, this sensory ability to detail that is related to the sensory gating deficit may lead to faster processing speed in an easy task requiring rapid detection of the target. Further studies are needed on the relationship between cognitive speed processing and sensory gating capacity at the different stage of information processing (pre-attentive: reflected by the P50, early attentive: reflected by the N100, and later attentive: reflected by the P200).

No other attentional or executive functions were correlated with sensory gating capacity. These results are in line with the study of Holstein et al. (2013), which found no significant relationship between neurophysiological measures of sensory gating and computer-assisted neuropsychological tests evaluating attentional, executive, and working memory functions in adult patients with ADHD (Holstein et al., 2013). These findings suggest that the current neuropsychological tests may not be sensitive to the cognitive dysfunction related to sensory gating deficit. However, given the sample sizes for these correlations ($n$ = 24), there may simply have been inadequate statistical power to detect what may be small effect sizes. Further studies are thus needed to continue to explore the cognitive correlate of sensory gating deficit in ADHD.

Finally, no relationship was found between P300 amplitude and clinical variables (ASRS overall score, inattention score, and hyperactivity score) nor between P300 amplitude and attentional and executive functions, as measured by paper and pencil neuropsychological tests.

The lack of correlation between P300 amplitude and the ASRS is in contradiction with a previous study by Woltering et al. in adults with ADHD, which found that smaller P300 amplitude was associated with more self-reported inattentive symptoms of the ASRS (Woltering, Liu, Rokeach, & Tannock, 2013). The difference could be due to the difference in the oddball paradigm. Woltering et al. used an oddball paradigm with a response task (Go/nogo) in which the participants had to press a button on a response pad when the infrequent target appeared, whereas we used an easier task in which the participant had solely to count the appearances of the infrequent target. Moreover, the stimuli were letters in the study by Woltering et al. whereas we used sound stimuli that were easily differentiable. Such a difference may induce different cognitive functions involved in P300 amplitude. Indeed, increased task requirements increase memory load, which interferes with attentional processes underlying P300 generation and result in decreased amplitude (Kok, 2001). In the Go/nogo oddball paradigm, executive and memory function may be involved more than in the present study, which may involve more attentional function. As previously suggested, the inattention dimension of the ASRS explores attention, executive, and memory complaints, and could better correlate with an oddball task, which requires high cognitive load. An oddball paradigm that requires low cognitive load would be more related to distractibility as evaluated by the SGI.

The lack of correlation between P300 amplitude and the neuropsychological tests is similar to other studies in adult patients with ADHD that found no close relationship between cognitive task performance and P300 amplitude (Szuromi et al., 2010). Further studies are thus needed to continue to explore the cognitive correlate of P300 amplitude deficit in ADHD. The present study suggests that P300 amplitude may be a psychophysiological indicator of distractibility in ADHD. Thus, the relationship between the neuropsychological evaluation of distraction, such as the Useful Field of View (UFOV) task (Laasonen et al., 2012), and P300 amplitude will need future consideration in ADHD.

The present study has several limitations. The main limitation is the lack of a healthy control group to perform a full factorial statistical analysis. However, the principal aim was to focus on adult patients with ADHD and to investigate the relationship between sensory gating capacity and attentional function in this group. Nevertheless, a similar comparative study on P300 amplitude with healthy participants is warranted in the future. In addition, larger sample sizes are needed to investigate the relationship between sensory gating capacity and attentional function and to investigate potential differences between ADHD subtypes (inattentive, hyperactive/impulsive, combined type) and the potential effect of methylphenidate on this relationship (Durukan et al., 2011). Last, this study was limited because it was cross-sectional and not prospective. Thus, no causal inference can be made formally between sensory gating and attentional deficits in ADHD. Replications with longitudinal approaches are required to investigate the effect of the timing of sensory gating deficit on attentional function.

Despite these limitations, this is the first study to our knowledge that has investigated P50 amplitude decrement and perceptual abnormalities with the SGI, on one hand, and P300 amplitude and attentional and executive performances, on the other, in a sample of adults with ADHD. The finding that sensory gating deficit may affect the resource allocation capacity of the brain in ADHD offers support for conceptual models in which the protective effect of sensory gating on higher cognitive function in ADHD is taken into account and where the link between low cognitive function and high cognitive function is considered, in line with the neurodevelopmental model of prefrontal cortex function in ADHD (Halperin & Schulz, 2006). This should enable the development of new cognitive remediation techniques in ADHD in which treating the sensory gating deficit would have positive consequences on the attentional function of the patient.

## Declaration of Conflicting Interests

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## Author Biographies

**Jean-Arthur Micoulaud-Franchi** is a medical doctor specialized in Psychiatry, Neurophysiology and Sleep Medicine in the sleep clinic at Bordeaux University Hospital. He received his PhD degree from Aix-Marseille University. His research addresses the link between neurophysiology, sleep and health perception in mental disorders at the USR CNRS 3413 SANSPY.

**Régis Lopez** is a medical doctor specialized in Psychiatry and Sleep Medicine in the Departement of sleep medicine at Montpellier University Hospital. His research addresses the link between hypersomnolence and ADHD at the Inserm U1061.

**Michel Cermolacce** is a psychiatrist. He received his PhD degree from Aix-Marseille University. His research is focused on Event Related Potential in mental disorders such as schizophrenia, depression and bipolar disorder.

**Florence Vaillant** is a licensed psychologist in the Department of Psychiatry at La Conception University Hospital, Marseille.

**Pauline Péri** is a licensed psychologist in the Department of Psychiatry at La Conception University Hospital, Marseille.

**Laurent Boyer** is a medical doctor specialized in Public Health, Epidemiology and Biostatistics at the Public Health and Epidemiology

department of Aix-Marseille University. His research addresses the problem of quality of life in chronic diseases including mental disorders such as schizophrenia, depression and bipolar disorder.

**Raphaëlle Richieri** received her MD and PhD degrees from Aix-Marseille University. She is a psychiatrist for adults and researcher in neuromodulation.

**Stéphanie Bioulac** is currently hospital practitioner in child and adolescent psychiatry department, Charles Perrens Hospital (Bordeaux, France). She is also responsible for the inpatient university unit for child and adolescent (University Hospital of Bordeaux). She conducts a specific outpatient for ADHD. She is PhD in Neurosciences and member of the USR CNRS 3413 SANSPY.

**Patricia Sagaspe** is a researcher specialized in the field of cognition in the USR CNRS 3413 SANSPY-University of Bordeaux. She received her PhD degree from University of Bordeaux and is a licensed psychologist.

**Pierre Philip** is a professor in the the sleep clinic at Bordeaux University Hospital. He is head of a CNRS research unit named sleep attention and neuropsychiatric disorders (USR CNRS 3413 SANSPY). He has vast experience in clinical research and is currently coordinator of clinical research for the University Hospital of Bordeaux. His research addresses the link between sleepiness, sleep disorders and mental disorders.

**Jean Vion-Dury**, MD, PhD, is an assistant-professor at the medical school of Marseille (Aix Marseille University) France, and Head of the Neurophysiology, psychophysiology and neurophenomenology unit of the Psychiatry department of Assistance Publique - Hopitaux de Marseille.

**Christophe Lancon** is a professor of Psychiatry and Addictology in the Department of Psychiatry at La Conception University Hospital, Marseille. His research addresses the problem of health perception in mental disorders at the Public Health and Epidemiology department of Aix-Marseille University.