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ORIGINAL CONTRIBUTION

Sensory processing related to attention in children with ASD, ADHD, or typical development: results from the ELENA cohort

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Abstract

Autism-spectrum disorder (ASD) and attention-deficit hyperactivity disorder (ADHD) are early neurodevelopmental conditions that share clinical characteristics, raising important issues in clinical diagnosis. We aimed to compare (1) sensory processing in four groups of children: ASD alone, ASD + ADHD, ADHD alone, and typical development (TD) and (2) the association between sensory processing and attention in the three groups with neurodevelopmental disorders. Our sample included 120 children aged from 6 to 12 years divided into four groups: ASD alone ($N = 43$), ASD + ADHD ($N = 18$), ADHD alone ($N = 28$), and TD ($N = 31$). Atypical sensory processing was more frequent in ASD and/or ADHD than in TD, without a significant difference between ASD and ADHD. However, the variance analysis of attention problems revealed differences between the ADHD and ASD groups. Thus, the rate of atypical sensory processing was comparable between the ASD and ADHD groups, suggesting that further studies are needed to explore atypical SP in all neurodevelopmental disorders.

Keywords Autism spectrum disorders · Attention deficit disorder · Sensory processing · Attention · Children

Introduction

Autism-spectrum disorder (ASD) and attention-deficit hyperactivity disorder (ADHD) are neurodevelopmental disorders often associated with unusual responses to sensory stimulations [1–3]. ASD is defined by impairments in communication and socialization, associated with a pattern of repetitive behaviors and restricted interests [4] and ADHD is characterized by a persistent pattern of inattention and/or hyperactivity, and impulsivity [4]. The prevalence of ASD is estimated to be approximately one child in 68 [5] and the prevalence of ADHD is estimated to 7.2% [6].

There is an important overlap between the symptoms of ASD and ADHD [7–9], with 30 to 80% of children with ASD exhibiting significant co-occurring symptoms of ADHD [10, 11]. In addition, 20 to 50% of children with ADHD show ASD-related symptoms [11]. Furthermore, since the publication of DSM-5, ASD and ADHD have been recognized as potentially comorbid conditions [4]. Such comorbidity is found in 17.3% of preschoolers with ASD [12]. However, children with only ASD or ADHD can have similar clinical profiles [13, 14]. Thus, the differential diagnosis between the two conditions can raise important issues for clinicians and it is essential to better understand the clinical overlap by comparing the clinical profiles, including responses to sensory stimulation [3, 15].

Sensory information has to be selected from the environment and processed by the brain to produce an adapted behavioral response [16]. According to Dunn's model, reactivity to sensory stimulation can vary, depending on the individual and neurological threshold. Such neurological

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processes, called sensory processing (SP), can be disturbed, leading to two categories of atypical SP [17]. A high neurological threshold is involved in hypo-reactivity to sensory stimulation, whereas hyper-reactivity involves a low neurological threshold, with all sensory modalities (visual, auditory, tactile, olfactory, taste, vestibular, and proprioceptive) potentially affected. Atypical SP is found in 12% of children in the general population [18] and requires strategies to adapt their behavior to daily life.

Among neuro-developmental disorders, ASD is most often associated with atypical SP. Thus, hyper- and hypo-reactivity to sensory stimulation are crucial diagnostic criteria of ASD [4]. In addition, findings from the ELENA cohort show that the prevalence of atypical SP in children with ASD ranges from 82 to 97%, independently of age and cognitive level [19]. A systematic review based on 11 studies showed that atypical SP was more frequently reported among individuals with ADHD than among those with TD [20]. Approximately 50% of children with ADHD show atypical SP, as measured by the short version of the Sensory Profile questionnaire [21]. They also displayed distinct atypical SP in all modalities relative to that of TD children [22]. Another study found that ADHD traits are related to SP and can predict them in the general population, suggesting that atypical SP may be part of the ADHD phenotype [15]. A pilot study, which compared 13 children with ASD and comorbid ADHD to 17 children with ADHD alone, found that children with ASD and comorbid ADHD presented greater atypical SP than children with ADHD alone [23]. Two studies comparing children with ASD alone and those with ADHD alone reported similar frequencies and patterns of atypical SP relative to that of TD children [1, 2]. Children with ASD had greater atypical oral processing and children with ADHD greater atypical visual processing [2]. In addition, atypical neural reactions in ASD and ADHD are found to be related to visual and auditory processing [7]. Another study found more atypical touch processing among both children with ADHD and those with ASD + ADHD than among children with TD [3]. Due to the inconclusive nature of the literature, it is impossible to draw conclusions concerning the specificity of SP patterns in neurodevelopmental disorders and this underlie the need of more studies using a comparative design.

Although problems of attention are core signs of ADHD, they are also common in ASD [24]. A review on the overlap of symptoms between ASD and ADHD highlighted that attention problems are highly common between these two disorders but possibly related to divergent mechanisms [9]. However, very few studies have examined the links between inattention symptoms and SP in ASD [25]. Atypical SP in ASD are predicted by inattention described through parental questionnaires [26, 27]. Moreover, in ASD, SP difficulties appear to be associated with attention problems [28]. In the general population, ADHD traits are associated with sensory sensitivity [15]. In ADHD, atypical SP is associated with inattention and distractibility [1, 22]. These findings suggest that atypical SP could be related to attention problems in both ASD and ADHD.

Intergroup comparisons concerning the differences in SP between ASD, ADHD, and TD individuals need to be performed using standardized assessment tools for SP and samples of children with ascertained diagnoses to clarify the inconsistent findings in the literature. Moreover, the role of SP in problems of attention has to be investigated to better understand mechanisms and target interventions.

We aimed first to compare SP in four groups of children: with ASD alone, with ASD + ADHD, with ADHD alone, and with TD. The second aim was to compare the association between SP and attention in children with ASD alone, ASD + ADHD, and ADHD alone. We hypothesized that atypical SP occurs more frequently in children with ASD alone, ASD + ADHD, and ADHD alone than those with TD, and that children with ASD + ADHD have more atypical SP than those with ASD alone or ADHD alone. We also expected that children with atypical SP would have more severe problems of attention.

Methods

Participants

The current study included 120 participants aged from 6 to 12 years, divided into four groups:

The ASD group (N = 43) was recruited from the ELENA cohort [29] a large, multicentre and prospective study in which children with an ascertained diagnosis of ASD according to DSM-5 criteria were recruited. Included children have a validation established by a multidisciplinary team using a standardized process, including the Autism Diagnostic Observation Schedule 2 (ADOS 2: Lord et al. [30]) and Autism Diagnostic Interview-Revised (ADI-R: Le Couteur, Lord and Rutter [31]), administered by licensed and trained psychologists. For this study, we selected a subset of children from the ELENA cohort that fulfilled the following inclusion criteria: 6 to 12 years of age and questionnaires (Sensory profile, CBCL and SRS-2) completed by their parents. We excluded children with genetic syndromes (as they commonly exhibit atypical sensory reactions), a cognitive level under 80, or an ADHD diagnosis according to DSM-5 criteria [4].

The ASD + ADHD group (N = 18) was also recruited from the ELENA cohort and the diagnostic process was the same as for the ASD group. They also had a diagnosis of ADHD established by a multidisciplinary team according to DSM-5 criteria [4]. We also excluded children with genetic syndromes and a cognitive level under 80.

The ADHD group ($N = 28$) was recruited from the Department of Child and Adolescent Psychiatry of the University Hospital of Montpellier during parental therapeutic groups or child psychiatric consultations. Experienced child psychiatrists diagnosed children with ADHD according to the DSM-5 criteria and excluded the diagnosis of ASD [4]. The exclusion criterion was to have received treatment by medication for attention problems.

The TD group ($N = 31$) consisted of children in mainstream school, without any medical history of neurodevelopmental disorders, matched for age with the other clinical groups. The absence of a history of neurodevelopmental disorders in the TD group was verified first by asking the parents whether they were aware of a diagnosis of a neurodevelopmental disorder for their child and whether such a diagnosis had already been mentioned about him or her. In addition, SRS-2 and CBCL scales were used to systematically screen for ASD and ADHD, respectively. No children in this study reached the clinical thresholds of these scales.

Exclusion criteria for all groups were children with "blindness" or an "auditory deficit".

Measures

Sensory processing (SP) was assessed using the long-form of the Sensory Profile [17]. This 125-item parental questionnaire focuses on daily-life sensory responses in children aged from three to 11 years. The results are given according to four quadrants which summarize behavioral responses to sensory stimulation in four profiles: sensory-seeking, low-registration, sensory-avoiding, and sensory-sensitivity. The results can also be presented according to each sensory modality (auditory, visual, vestibular, oral, touch, and multisensory sections). Frequencies are recorded on a five-point Likert scale. Lower Sensory Profile scores imply greater SP difficulties. Atypical scores were defined in this study by probable and definite difference as scores over 1 to 2 standard deviations from the norm (less and much less than the other). Internal consistency of the Sensory Profile ranged from 0.70 to 0.90 and internal validity correlations from 0.25 to 0.76 [17].

Attention problems were assessed using the CBCL form [32], a norm-referenced measure exploring a wide range of emotional and behavioral disorders in children aged from 6 to 18 years. There are 10 items focusing on attention problems. Parents completed items on a three-point Likert scale, which provides raw scores. They were transformed into T-scores based on published norms: T-scores above 70 were considered to be indicative of clinical impairment for attention problem syndrome. Internal consistency ranged from 0.72 to 0.91, the inter-rater reliability from 0.63 to 0.88, and the test–retest reliability was 0.90 [32].

The non-verbal cognitive level was assessed from psychometric scales, depending on the age of each participant. The non-verbal cognitive level was estimated from the "fluid reasoning" of the WISC-V ($n = 21$) [33] and the WPPSI-IV ($n = 4$) [34], "perceptual reasoning" of the WISC-IV ($n = 42$) [35], "performance IQ" of the WPPSI-III ($n = 4$) [36], "simultaneous process" of the K-ABC II ($n = 4$) [37], or "cognitive verbal/pre-verbal" of the PEP-III ($n = 1$) [38]. Overall, the non-verbal cognitive level was assessed for 76 children.

Autism symptomatology was assessed using the SRS-2 [39], which assesses ASD-related symptoms. This scale assesses: social awareness (ability to pick up on social cues), social cognition (ability to interpret social cues), social communication (includes expressive social communication), social motivation (motivated to engage in social communication), and restricted interests and repetitive behaviors (includes stereotypic behavior) of children aged four to 18 years. Each of the 65 items was rated on a four-point scale ranging from 1 (Not True) to 4 (Almost Always True). The Total composite score (T) was used to assess the severity of symptoms.

A standardized questionnaire was used to collect the following information concerning the children: date of birth, presence of other neurodevelopmental disorders, presence of sensory deficit and we asked parents whether their child was receiving any medication for attention problems and the type of treatment.

Procedure

Parents of the children recruited in the ELENA cohort completed questionnaires electronically (CBCL, SRS-2, and Sensory Profile) on a web database. Parents of the children of the ADHD and TD groups completed paper questionnaires in the same order and returned them personally or by mail. The intellectual level of the children included in the ELENA cohort (ASD and ASD + ADHD groups) and those with ADHD were performed during the diagnostic process. The intellectual level of the TD children was not assessed but information on their class level in school was collected and corresponded to their age. Informed consent forms were completed by all parents and data were anonymized.

Data analyses

Descriptive statistics were calculated to characterize each group. Intergroup comparisons were conducted by ANOVA for parametric variables and the Kruskal–Wallis test for non-parametric parameters. In case of significant differences, a Bonferroni correction was applied for 2-by-2 comparisons.

The association between the Sensory Profile questionnaire and attention problems in each group were analysed using Pearson's or Spearman's correlation coefficient. Multiple linear regression analysis was performed for the ASD and ADHD groups using the attention score as the dependent variable and age, non-verbal cognitive level, and sensory-seeking score (and low-registration score for ADHD) as independent variables. Linearity was assessed by a plot of studentized residuals against the predicted values. A Durbin–Watson test statistic of 1.8 (for the ASD group) and 2.3 (for the ADHD group) showed independence of residuals. Other assumptions required for multiple regression (e.g., no multicollinearity, normality, homoscedasticity, etc.) were met. The goodness-of-fit (GOF) measure, consisting of the adjusted R^2, was used to assess the adequacy of the fitted model. Statistical analyses were performed using SAS 9.3 software. A two-sided $p < 0.05$ was considered to be statistically significant.

Results

A total of 120 participants were enrolled in the study. Their mean age was 9.2 years (SD = 1.8). The clinical characteristics of each group are reported in Table 1. Intergroup comparisons showed no difference according to gender, age, or nonverbal cognitive level (all $p > 0.05$). Males made up 61.3% of the TD group and 82.1% of the ADHD alone, 83.3% of the ASD + ADHD, and 86% of the ASD alone groups. However, there were significant differences in ASD-related symptoms between the groups as assessed by the SRS-2. Post hoc analysis showed that the three groups with neurodevelopmental disorders had higher total scores on the SRS-2 and higher scores for all subscales than the TD group ($p < 0.05$). As expected, the ADHD group showed a lower total SRS-score and lower social cognition and restrictive interest and repetitive behavior scores than the ASD and ASD + ADHD groups ($p < 0.05$). There were four participants in the ASD + ADHD group and two participants in the ASD group who received treatment for attention problems. These participants were similar to others of their clinical group for age, non-verbal cognitive level, and score for the Sensory Profile (all $p > 0.05$).

Prevalence of atypical sensory processing

The prevalence of atypical scores on the Sensory Profile for each group is reported in Table 2. Depending on the quadrant, more than the half of the three groups with neurodevelopmental disorders showed atypical SP: from 56.8 to 92.5% in the ASD group, 61.1 to 80.0% in the ASD + ADHD group, and 57.1 to 71.4% in the ADHD group, compared to 0.0 to 9.7% in the TD group. Depending on the sensory modality (sections), the three groups with neurodevelopmental disorders showed a high percentage of atypical auditory processing: 84.6% in the ASD + ADHD, 75.0% in the ADHD, and 51.2% in the ASD groups.

Description and intergroup comparison of sensory processing

The intergroup comparisons of Sensory Profile scores are reported in Table 2. There were significant differences between the groups for the quadrants and all sections of the Sensory Profile ($p < 0.0001$). Post hoc analysis of the quadrants showed the three groups with neurodevelopmental disorders to have

Table 1 Clinical characteristics of each group and intergroup comparison

Children's characteristics	ASD *n* = 43 Mean (SD)	ASD + ADHD *n* = 18 Mean (SD)	ADHD *n* = 28 Mean (SD)	TD *n* = 31 Mean (SD)	*p* value	Post hoc test[a]
Chronological age	9.4 (1.9)	8.7 (1.8)	9.2 (1.8)	9.3 (1.6)	0.61	
Non-verbal IQ	103.6 (14.3)	103.5 (15.9)	109.0 (16.2)	–	0.46	
TOTAL SRS-2	94.2 (15.0)	98.0 (12.5)	74.8 (27.6)	20.6 (11.2)	0.0001	TD < ADHD < ASD + ADHD,ASD*
Social awareness	10.1 (2.4)	10.6 (2.9)	10.0 (3.9)	4.2 (2.6)	0.0001	TD < ALL
Social cognition	18.7 (3.9)	18.7 (3.4)	13.6 (5.6)	3.9 (2.7)	0.0001	TD < ADHD < ASD + ADHD,ASD
Social communication	31.7 (6.1)	32.3 (5.0)	24.9 (10.9)	6.4 (4.2)	0.0001	TD < ALL; ADHD < ASD
Social motivation	13.5 (3.1)	15.2 (2.8)	12.1 (4.4)	4.0 (2.6)	0.0001	TD < ALL; ADHD < ASD + ADHD
RIRB	20.2 (5.6)	22.0 (5.3)	14.2 (7.4)	2.2 (2.5)	0.0001	TD < ADHD < ASD + ADHD,ASD
Attention problems	8.7 (4.0)	12.0 (4.4)	12.3 (3.8)	1.7 (2.0)	0.0001	TD < ASD < ADHD, ASD + ADHD

ASD autism spectrum disorder, *ADHD* attention deficit hyperactivity disorder, *ASD + ADHD* comorbidity form, *TD* typical development, *ALL* all other groups, *RIRB* restricted interests and repetitive behaviors

*e.g. The TD Total SRS score is lower than that of all other groups and the score for the ADHD group is lower than that of the ASD and ASD + ADHD groups

[a]Bonferroni correction

Table 2 Percentage of atypical score and intergroup comparison mean score on quadrants and sections of the Sensory Profile

	ASD $n=43$		ASD + AD HD$n=18$		ADHD $n=28$		TD $n=31$		Intergroup comparison of p values	Post hoc test[a]
	Mean (SD)	% Atypical SP	Mean (SD)	% Atypical SP	Mean (SD)	% Atypical SP	Mean (SD)	% Atypical SP		
Quadrant										
Low registration	57.2 (11.1)	58.1	54.4 (10.3)	77.8	59.5 (8.0)	71.4	72.3 (4.6)	6.5	0.0001	TD > ALL
Sensation seeking	100.2 (14.4)	56.8	96.3 (20.7)	61.1	95.0 (15.8)	67.9	118.0 (10.4)	9.7	0.0001	TD > ALL
Sensory sensitivity	74.8 (12.6)	60.0	73.5 (11.2)	76.9	78.2 (9.5)	57.9	93.4 (5.5)	0.0	0.0001	TD > ALL
Sensation avoiding	94.5 (15.6)	92.5	89.6 (18.9)	80.0	106.9 (12.2)	64.3	128.7 (7.4)	0.0	0.0001	TD > ADHD > ASD + ADHD,ASD
Section										
Auditory processing	26.3 (5.6)	51.2	20.0 (6.0)	84.6	24.4 (4.8)	75.0	36.8 (2.9)	0.0	0.0001	TD > ALL; ASD > ASD + ADHD
Visual processing	32.0 (7.6)	39.0	31.4 (5.6)	64.3	35.2 (6.1)	17.9	41.5 (3.4)	3.2	0.0001	TD > ALL
Vestibular processing	45.4 (6.8)	26.8	43.3 (6.4)	31.3	43.5 (7.0)	35.7	51.6 (3.4)	0.0	0.0001	TD > ALL
Touch processing	69.6 (13.6)	51.3	68.9 (10.6)	56.3	75.9 (8.6)	21.4	85.2 (4.3)	0.0	0.0001	TD > ALL
Multisensory processing	27.0 (4.1)	39.5	24.4 (3.3)	70.6	25.0 (3.8)	57.1	32.7 (2.7)	3.2	0.0001	TD > ALL; ASD > ASD + ADHD
Oral sensory processing	47.4 (10.2)	37.5	50.9 (10.5)	11.1	48.5 (9.5)	25.0	54.7 (7.1)	9.7	0.002	TD > ASD, ADHD

ASD autism spectrum disorder, *ADHD* attention deficit hyperactivity disorder, *TD* typical development, *ASD + ADHD* comorbidity form, *ALL* all other groups

[a]Bonferroni correction

significantly more atypical SP than the TD group ($p<0.05$). There were significant intergroup differences for the Sensation-Avoiding quadrant between the three groups with neurodevelopmental disorders ($p<0.05$). Indeed, the ASD and ASD + ADHD groups showed greater atypical SP than the ADHD group ($p<0.05$). Post hoc analysis of the sections of the Sensory Profile showed that the three groups with neurodevelopmental disorders showed significantly more atypical SP than the TD group ($p<0.05$) (except for oral processing, for which the TD group score was similar to that of the ASD + ADHD group). There were also significant differences in auditory processing and multisensory processing, with the ASD + ADHD group showing more atypical SP than the ASD alone group ($p<0.05$).

Association between sensory processing and attention problems

Significant correlations between the Sensory Profile and attention problems scores for the ASD, ADHD, and ASD + ADHD groups are reported in Table 3. Children of all groups who presented more atypical multisensory processing also showed more attention problems. Only children of the ASD group who had atypical touch processing also presented more attention problems. Children of the ADHD and ASD + ADHD groups with higher vestibular processing scores also had more attention problems. The increase of atypical sensory seeking in the ASD and ADHD groups was associated with greater attention problems.

We performed two multiple linear regressions for the ADHD and ASD groups for significant associations found by univariate analysis. For the ADHD group, the results of the regression provided a significant model ($p=0.0009$) that explained 64% of the variance of the attention score and the intercept was significant ($\beta_0=35.8$; $p<0.0001$). The non-verbal cognitive level and the sensory-seeking profile had a negative effect on the attention score; such that the attention score decreased when the non-verbal cognitive level increased by one-unit ($\beta_1=-0.12$; $p<0.01$) as well as that of the sensory-seeking profile ($\beta_2=-0.10$; $p<0.02$). For the ASD group, the results of the regression provided a significant model ($p=0.0028$) which explained 30% of the variance of the attention score and the intercept was significant ($\beta_0=31.09$; $p<0.0001$). There was no effect of the non-verbal cognitive level ($\beta_1=-0.07$; $p=0.09$), but the attention score decreased when the sensory-seeking profile increased by one-unit ($\beta_2=-0.16$; $p=0.0011$).

Table 3 Correlations between the Sensory Profile and attention problems scores among children of the ASD, ADHD, and ASD + ADHD groups

	ASD $n=43$		ASD + ADHD $n=18$		ADHD $n=28$	
	r	*p*	*r*	*p*	*r*	*p*
Quadrant						
Low registration	−0.12	0.49	−0.29	0.3	**−0.46**	**0.01**
Sensation seeking	**−0.56**	**0.001**	−0.51	0.06	**−0.57**	**0.001**
Sensory sensitivity	−0.25	0.2	−0.42	0.22	−0.33	0.09
Sensation avoiding	−0.15	0.4	−0.43	0.19	−0.35	0.06
Section						
Auditory processing	**−0.42**	**0.02**	−0.03	0.93	**−0.47**	**0.01**
Visual processing	−0.28	0.11	−0.50	0.14	−0.12	0.55
Vestibular processing	−0.20	0.25	**−0.74**	**0.005**	**−0.64**	**0.0002**
Touch processing	**−0.46**	**0.007**	−0.52	0.08	−0.22	0.25
Multisensory processing	**−0.51**	**0.002**	**−0.60**	**0.03**	**−0.40**	**0.03**
Oral sensory processing	−0.23	0.19	−0.16	0.59	−0.19	0.33

Significant associations (*p* value < .05) are presented in bold

ASD autism spectrum disorder, *ADHD* attention deficit hyperactivity disorder, *ASD + ADHD* comorbidity form

Discussion

The results confirm that atypical SP is more frequent in children with ASD and/or ADHD than those with TD, in accordance with the literature [1]. Thus, atypical SP in children can be a non-specific marker of multiple neurodevelopmental conditions. Indeed, atypical SP was highly frequent in both ADHD and ASD children and more similar than expected. In addition, the two conditions only differed for one profile, atypical avoidance being more severe in ASD alone than in ADHD alone. Atypical sensory seeking was related to attention problems and explained a large proportion of them in the ADHD group and a smaller proportion in the ASD group.

Although atypical SP is widely studied in ASD and currently used as a core diagnostic criteria, it is just beginning to be investigated in ADHD. Our findings suggest that atypical SP is more similar and frequent than expected in ASD and ADHD, and reinforce recent published results [1, 2]. Moreover, diagnoses based on SP results in the misclassification of children with ASD or ADHD in 45.9% of cases [1], supporting the findings of an overlap between the symptoms of these two disorders [9, 13]. Consequently, in clinical practice, the presence of atypical SP cannot help in the differential diagnosis between ASD and ADHD, and further studies are needed to determine to what extent atypical SP is also present in other developmental disorders.

In our sample, the avoiding-sensation profile was more severe in children with ASD (with or without ADHD) than those with ADHD alone. In addition, studies of the general population have shown that avoidance behaviors are associated with anxiety [40], whereas hyper-reactivity to sensory stimuli is related to anxiety in ASD [41, 42]. Thus, it is possible that children with ASD resort to more avoidance behavior strategies to manage their hyper reactivity to sensory stimulation than children with ADHD.

As expected, children with ASD and comorbid ADHD presented more overall atypical SP than those with ASD alone or ADHD alone, in accordance with previous studies [3]. Moreover, psychiatric comorbidities can be observed early in the life in preschoolers and are more severe [12]. This result reinforces the necessity to investigate the presence of comorbid ADHD during the diagnostic process of ASD to provide specific support and intervention.

Our results suggest that most of the attention problems of children with ADHD alone is related to the presence of an atypical sensory-seeking profile and a lower cognitive level. We also found this to be true for children with ASD, but most of their attention problems were unexplained by the regression model. Based on our regression analysis, we can hypothesize that heterogeneity within the ASD and ADHD groups may be related to the wide variation in atypical sensory processing and its negative impact on attention. In ADHD children, patterns of sensory seeking (especially for the vestibular sensory modality) were negatively associated with attention problems, consistent with the results of a previous study [22], suggesting that body movement symptoms, such as motor hyperactivity in ADHD, can be interpreted as vestibular stimulation seeking. Thus, the role of atypical SP on ADHD symptoms, especially motor hyperactivity and inattention, needs to be further investigated. The effect of treatment that focuses on atypical SP in ADHD could also be considered, as we found that atypical SP increased attention problems in ADHD.

We found auditory SP to be the sensory dimension that was the most affected in the groups with neurodevelopmental disorders. In addition, auditory SP was more disturbed in children with ASD and comorbid ADHD than in those with ASD alone, as reported in another study [3]. Atypical SP was associated with more attention problems but with intergroup and sensory-modality differences. We also found a trend for a link between atypical multisensory processing and greater attention problems for all clinical groups. Greater attention problems were associated with tactile SP in the ASD group alone and vestibular SP in the ADHD and comorbid groups. Atypical sensory seeking predicted more attention problems for the ASD alone and ADHD alone groups. These findings are concordant with those of a study demonstrating that children with ASD had greater physical reactivity and worse cognitive performance in a noisy environment than TD children [43]. We believe that these results underline the need to assess SP and manage the environment to limit the negative impact of SP and improve children's attention skills, especially at school. Moreover, a study showed that atypical SP in the early life of children with ASD predicts their later social impairment, as this association is mediated by social attention and children with atypical SP are less sensitive to social stimulation [44]. The authors suggested that atypical SP influences attention skills from early development. Future studies need to focus on SP and the role of attention in ADHD during early development.

An important strength of our study was the comparison of our clinical groups with a TD group matched for age. Also, children with ASD alone or ASD + ADHD recruited from the ELENA cohort were rigorously diagnosed and children with ADHD alone were also thoroughly diagnosed. Finally, SP was assessed with a validated and standardized tool. Nevertheless, our study had several limitations. First, data on SP were collected from parental questionnaires and not direct examinations, as is common practice in published studies. However, positive correlations have been found between direct measures and parental reporting of behavior using the Sensory Profile [17]. Second, we selected children who were not receiving medication for attention problems for the ADHD group and thus the disorder may have been of lower severity than that of the general patient population. However, the results were statistically significant, despite this potential bias. Third, children with ASD and those with ADHD were all diagnosed according to DSM 5 criteria and multidisciplinary assessments, but their recruitment from different sources (Child and Adolescent Psychiatry Department for the ADHD group and Elena cohort for the ASD group) resulted in a potential risk of selection bias. However, this risk was limited by standardization of the diagnostic process for the two groups. Finally, since the sample size for each group was small, further studies are required to verify our observation of the same intensity of SP in ADHD and ASD. In addition, the small sample size of the ASD + ADHD group prevented regression analysis for this group.

In conclusion, our findings confirm that atypical SP is more frequent in children with neurodevelopmental disorders than children with TD. In addition, we found that atypical SP was as prevalent in ASD as ADHD. Thus, the rate of atypical sensory processing was comparable between the ASD and ADHD groups, suggesting that further studies are needed to explore atypical SP in all neurodevelopmental disorders. SP has to be systematically explored in children with neurodevelopmental disorders and not only in those suspected of having ASD to propose specifics supports. Indeed, atypical SP contributes to attention problems in ASD, but even more so in ADHD, highlighting the need for further studies to better understand the underlying processes to better adapt treatment and the sensory environment. Especially, it is important to take into account the child's sensory characteristics in learning setting and their potential negative impact on attention to adapt environment and propose psychoeducational strategies.

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Author contributions FD conceived of the study, contributed in collection, analysis, and interpretation of the data and drafted the manuscript; AB is the PI of ELENA cohort, she also participated in the design of the current study, drafted the work and revised it critically for main intellectual content; CV participated in the design of the study and contributed to revised it critically. CM and M-CP analyzed and interpreted data; FM and NB revised critically the final manuscript. All authors read and approved the final version to be published.

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Compliance with ethical standards

Conflict of interest The authors have no conflict of interest to declare.

Ethical approval The study and informed consent procedure have been approved by the Ethics Committee on the Research of Human Subjects at Marseille Mediterranean (CNIL. number DR-2015-393).

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References

1. Cheung PPP, Siu AMH (2009) A comparison of patterns of sensory processing in children with and without developmental disabilities. Res Dev Disabil 30(6):1468–1480

2. Little LM, Dean E, Tomchek S, Dunn W (2018) Sensory processing patterns in autism, attention deficit hyperactivity disorder, and typical development *Phys*. Occup Ther Pediatr 38(3):243–254
3. Sanz-Cervera P, Pastor-Cerezuela G, González-Sala F, Tárraga-Mínguez R, Fernández-Andrés M-I (2017) Sensory processing in children with autism spectrum disorder and/or attention deficit hyperactivity disorder in the home and classroom contexts. Front Psychol 8:1772
4. American Psychiatric Association (2013) Diagnostic and statistical manual of mental disorders, 5th edn. American Psychiatric Publishing, Arlington
5. Christensen DL et al (2016) Prevalence and characteristics of autism spectrum disorder among 4-year-old children in the autism and developmental disabilities monitoring network. J Dev Behav Pediatr JDBP 37(1):1–8
6. Thomas R, Sanders S, Doust J, Beller E, Glasziou P (2015) Prevalence of attention-deficit/hyperactivity disorder: a systematic review and meta-analysis. Pediatrics 135(4):e994–e1001
7. Lau-Zhu A, Fritz A, McLoughlin G (2019) Overlaps and distinctions between attention deficit/hyperactivity disorder and autism spectrum disorder in young adulthood: systematic review and guiding framework for EEG-imaging research. Neurosci Biobehav Rev 96:93–115
8. Russell G, Rodgers LR, Ukoumunne OC, Ford T (2014) Prevalence of parent-reported ASD and ADHD in the UK: findings from the Millennium Cohort Study. J Autism Dev Disord 44(1):31–40
9. Visser JC, Rommelse NNJ, Greven CU, Buitelaar JK (2016) Autism spectrum disorder and attention-deficit/hyperactivity disorder in early childhood: a review of unique and shared characteristics and developmental antecedents. Neurosci Biobehav Rev 65:229–263
10. Murray MJ (2010) Attention-deficit/hyperactivity disorder in the context of autism spectrum disorders. Curr Psychiatry Rep 12(5):382–388
11. van der Meer JMJ et al (2012) Are autism spectrum disorder and attention-deficit/hyperactivity disorder different manifestations of one overarching disorder? Cognitive and symptom evidence from a clinical and population-based sample. J Am Acad Child Adolesc. Psychiatry 51(11):1160–1172
12. Muratori F et al (2019) Parental perspectives on psychiatric comorbidity in preschoolers with autism spectrum disorders receiving publicly funded mental health services. Front Psychiatry 10:107
13. Kern JK, Geier DA, Sykes LK, Geier MR, Deth RC (2015) Are ASD and ADHD a continuum? A comparison of pathophysiological similarities between the disorders. J Atten Disord 19(9):805–827
14. Mayes SD, Calhoun SL, Mayes RD, Molitoris S (2012) Autism and ADHD: overlapping and discriminating symptoms. Res Autism Spectr Disord 6(1):277–285
15. Panagiotidi M, Overton PG, Stafford T (2018) The relationship between ADHD traits and sensory sensitivity in the general population. Compr Psychiatry 80:179–185
16. Ayres AJ (1979) Sensory integration and the child. Western Psychological Services, Los Angeles
17. Dunn W (1999) The sensory profile: user's manual. Psychological Corporation, San Antonio, TX
18. Adams JN, Feldman HM, Huffman LC, Loe IM (2015) Sensory processing in preterm preschoolers and its association with executive function. Early Hum Dev 91(3):227–233
19. Dellapiazza F, Vernhet C, Blanc N, Miot S, Schmidt R, Baghdadli A (2018) Links between sensory processing, adaptive behaviours, and attention in children with autism spectrum disorder: a systematic review. Psychiatry Res. 270:78–88
20. Ghanizadeh A (2011) Sensory processing problems in children with ADHD, a systematic review. Psychiatry Investig 8(2):89–94
21. Mimouni-Bloch A, Offek H, Rosenblum S, Posener I, Silman Z, Engel-Yeger B (2018) Association between sensory modulation and daily activity function of children with attention deficit/hyperactivity disorder and children with typical development. Res Dev Disabil 83:69–76
22. Shimizu VT, Bueno OFA, Miranda MC (2014) Sensory processing abilities of children with ADHD. Braz J Phys Ther 18(4):343–352
23. Mattard-Labrecque C, Ben Amor L, Couture MM (2013) Children with autism and attention difficulties: a pilot study of the association between sensory, motor, and adaptive behaviors. J Can Acad Child Adolesc 22(2):139–146
24. Konst MJ, Matson JL, Goldin R, Rieske R (2014) How does ASD symptomology correlate with ADHD presentations? Res Dev Disabil 35(9):2252–2259
25. Mannion A, Leader G (2013) Comorbidity in autism spectrum disorder: a literature review. Res Autism Spectr Disord 12(7):1595–1616
26. Ashburner J, Ziviani J, Rodger S (2008) Sensory processing and classroom emotional, behavioral, and educational outcomes in children with autism spectrum disorder. Am J Occup Ther 62(5):564–573
27. Sanz-Cervera P, Pastor-Cerezuela G, Fernández-Andrés M-I, Tárraga-Mínguez R (2015) Sensory processing in children with autism spectrum disorder: relationship with non-verbal IQ, autism severity and attention deficit/hyperactivity disorder symptomatology. Res Dev Disabil 45–46:188–201
28. Howe FEJ, Stagg SD (2016) How sensory experiences affect adolescents with an autistic spectrum condition within the classroom. J Autism Dev Disord 46(5):1656–1668
29. Baghdadli A et al (2019) Investigating the natural history and prognostic factors of ASD in children: the multicentric longitudinal study of children with ASD-the ELENA study protocol. BMJ Open 9(6):e026286
30. Lord C, Rutter M, Di Lavore P, Risi S, Gotham K, Bishop S (2012) Autism diagnostic observation schedule, second edition (ADOS-2) manual (part I): modules 1–4. Western Psychological Service, Torrance
31. Le Couteur A, Lord C, Rutter M (2003) Autism diagnostic interview, revised (ADI-R). Western Psychological Services, Los Angeles, Calif
32. Achenbach TM, Rescorla CA (2001) Manual for the ASEBA school-aged forms and profiles. University of Vermont, Burlington
33. Wechsler D (2014) WISC-V: administration and scoring manual. NCS Pearson, Incorporated
34. Wechsler D (2014) WPPSI-IV, échelle d'intelligence de Wechsler pour enfants. ECPA.
35. Wechsler D (2003) Wechsler intelligence scale for children-WISC-IV. Psychological Corporation
36. Wechsler D (2002) Wechsler preschool and primary scale of intelligence™-third edition (WPPSI™-III). Wechsler
37. Kaufman A, Kaufman N (2004) Kaufman assessment battery for children: Technical manual, 2nd edn. American Guidance Service, Circle Pines, MN
38. Schopler E (1990) Individualized assessment and treatment for autistic and developmentally disabled children. Psychoeducational profile revised (PEP-R)
39. Constantino JN, Gruber CP (2012) The social responsiveness scaleTM, second edition (SRSTM-2). Western Psychological Services, Torrance, CA
40. Rudaz M, Ledermann T, Margraf J, Becker ES, Craske MG (2017) The moderating role of avoidance behavior on anxiety over time: is there a difference between social anxiety disorder and specific phobia? PLoS ONE 12(7):e0180298

41. Green SA, Ben-Sasson A, Soto TW, Carter AS (2012) Anxiety and sensory over-responsivity in toddlers with autism spectrum disorders: bidirectional effects across time. J Autism Dev Disord 42(6):1112–1119
42. Joosten AV, Bundy AC (2010) Sensory processing and stereotypical and repetitive behaviour in children with autism and intellectual disability. Aust Occup Ther J 57(6):366–372
43. Keith JM, Jamieson JP, Bennetto L (2019) the influence of noise on autonomic arousal and cognitive performance in adolescents with autism spectrum disorder. J Autism Dev Disord 49(1):113–126
44. Damiano-Goodwin CR et al (2018) Developmental sequelae and neurophysiologic substrates of sensory seeking in infant siblings of children with autism spectrum disorder. Dev Cogn Neurosci 29:41–53