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ORIGINAL CONTRIBUTION

A longitudinal exploratory study of changes in sensory processing in children with ASD from the ELENA cohort

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Abstract

Atypical sensory processing (SP) is a diagnostic criterion of autism spectrum disorder (ASD). However, little is known about its course during development. In this exploratory longitudinal study, we aimed to investigate the course of SP among children with ASD and identify clinical variables associated with changes. We used a subsample of 51 children with confirmed ASD, aged from 3 to 10 years, recruited from the ELENA cohort. SP was assessed using the Sensory Profile questionnaire at baseline and three years later. Our preliminary results highlight the heterogeneity of the evolution of SP during the children's development and the existence of three subgroups based on the course of SP (improvement, stable, and worsening). In addition, the children's adaptive skills and maladaptive behaviors were related to the course of SP. These results could be confirmed in future studies with a larger sample size using a longitudinal approach to capture individual variability in SP. In addition, our results highlight the importance of accounting for temporal changes in the sensory needs of individuals with ASD in clinical practice.

Keywords Autism spectrum disorder · Sensory processing · Developmental change · Longitudinal data analysis

Introduction

Sensory processing (SP) allows the selection, organization, and association of a range of sensory information from the environment. In typical development, this process contributes to the adaptation of behaviors and develops during childhood as a consequence of neurological maturation and sensory experiences [1–5]. Atypical SP is described as elevated reactivity to sensory input (sensory over-responsivity, *e.g., children put their hands over their ears*), low reactivity to sensory input (sensory under-responsivity, *e.g., children miss sensory cues that others notice easily*), or high interest for sensory stimulation (sensory seeking, e.g., *children fascinated by visual stimuli)* [6]. These sensory behaviors can be observed for various sensory modalities (e.g., visual, auditory, vestibular, oral, touch) for the three patterns of behavioral responses.

Atypical SP is common in neurodevelopmental disorders [2, 7, 8], prematurity [1], and genetic disorders [9, 10], as shown by the high prevalence of atypical behavioral responses to sensory stimuli in these populations. A high prevalence of atypical behavioral responses to sensory stimuli is also observed in individuals with ASD [11–13]. Since the publication of the DSM-5 (Diagnostic and Statistical Manual of Mental Disorders, 5th Edition), atypical SP has been one of the diagnostic criteria for ASD in the area of "restricted and repetitive patterns of behavior, interests, or activities" [10]. It has also been suggested that atypical SP may negatively affect the quality of life of individuals with ASD [15, 16], as well as promote the development of exceptional abilities through improved perceptual functioning [17–19].

Recent reports have shown atypical SP to be a potential sign of ASD, as it occurs early during childhood development [20–22] and continues throughout life [12, 23].

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However, little is known about the evolution of SP in the context of a limited number of sometimes contradictory studies. A meta-analysis targeting cross-sectional studies showed that children with ASD exhibited more sensory-seeking behavior between six and nine years of age than typical children, which tended to decrease after this age [13]. However, the generalization of these findings is limited by the heterogeneity of the samples and measures. In contrast, two-year follow-up studies have suggested that SP remains stable during childhood in ASD [5, 24], but the samples were also small and heterogeneous. Another study with three-year follow-up study of 55 children with ASD aged from 2 to 12 years suggested that the severity of SP tends to decrease over time [25]. Recently, Dwyer et al. aimed to explore the heterogeneity of SP changes in ASD in a longitudinal study with a three-year follow-up on a large sample of children aged from 2 to 5 years [26]. This study was the first to present SP evolution subgroups using growth-mixture modeling. They presented three classes, one with stable SP, one with stable but high SP, and one with worsening SP over time. This study was the first to explore the heterogeneity of SP in toddlers with ASD but it is limited by the modeling growth-mixture analysis, which does not include enough measurement points.

Studies focusing on SP and clinical variables have reported contradictory results concerning the intelligence quotient (IQ). Several transversal studies have provided evidence that the level of atypical SP is similar in ASD children independently of their IQ [27, 28]. In their longitudinal study, Perez et al. found that the stability of SP was independent of differences in IQ [24]. However, other studies that attempted to characterize subgroups of populations of children with ASD based on their atypical SP found group-dependent differences in cognitive level estimated by caregivers [29] or based on nonverbal IQ [30, 31]. In terms of adaptive skills, published studies have suggested that children with ASD with atypical SP also show lower adaptive skills and more maladaptive behaviors [5, 29, 32–34]. In a previous study [27] on a sample of 197 children with ASD from the ELENA cohort, our results also suggested that atypical SP is associated with lower adaptive skills and more maladaptive behaviors. An important issue that is yet to be examined is whether the SP of children with ASD is associated with their clinical changes during development.

The discrepancy in the literature on the evolution of SP during childhood in ASD suggests the need for additional studies to better describe it [35]. Indeed, prospective studies are needed to ascertain whether sensory responses are stable, as reported in a previous study [25], or characterized by a heterogeneous pattern, as suggested by subgroup analysis [26]. Thus, a better understanding of the persistence of altered SP in adults with ASD requires that we understand how it evolves during childhood through longitudinal studies that can capture the heterogeneous character of the profiles of children with ASD and their individual experiences [35]. Improving our understanding of the evolution of SP will allow us to propose an individualized intervention plan adapted to the changes in sensory needs over time. In addition, although the literature has suggested that SP is related to adaptive and maladaptive behaviors, there is still little knowledge about the influence of changes in SP on the adaptive trajectories of children with ASD. In this context, we performed a longitudinal study to investigate the course of SP in children with ASD and identify clinical variables associated with it.

Methods

Participants

Participants were recruited from a large cohort of children diagnosed with confirmed ASD, the ELENA cohort [36]. Participants from the ELENA cohort (Longitudinal Study of Children with Autism) have a diagnosis of ASD ascertained by a multidisciplinary team using a standardized process, including the Autism Diagnostic Observation Schedule 2 (ADOS 2) [37] and the Autism Diagnostic Interview-Revised (ADI-R) [38], administered by licensed and trained psychologists, a parental interview about the child's adaptive functioning using the Vineland –II (VABS-II), and direct psychological examinations to assess IQ. Caregivers completed questionnaires electronically on a web database, including the Sensory Profile and the Aberrant Behavior Checklist (ABC).

For the current study, inclusion criteria were children included and followed for at least three years in the ELENA cohort between 3 and 10 years of age to fit within the age boundaries of the Sensory Profile. The Sensory Profile was completed at T1 (at baseline) and T2 (after three years of follow-up).

Measures

The Sensory Profile is a parent-reported 125-item questionnaire about children's sensory responses to sensory stimuli [4]. Parents rate the frequency of each item on a five-point Likert scale from 1 (always) to 5 (never). This scale simultaneously explores behavioral responses for six modalities (auditory, visual, touch, movement, oral and, multimodal). The results can also be presented in four quadrants (low registration, sensation avoiding, sensory sensitivity, and sensation seeking). A total score of the Sensory Profile can be calculated from 38 items extracted from the long version [39]. Lower scores indicate greater SP difficulties. Internal consistency of the Sensory Profile

ranges from 0.70 to 0.90 and internal validity correlations from 0.25 to 0.76 [4]. Although the psychometric quality of this scale is moderate, it is the most commonly used tool to assess SP and has been validated in samples of individuals with ASD [4].

ASD severity was examined using the Autism Diagnostic Observation Schedule second version (ADOS-2) [37], a semi-structured behavioral observation protocol assessing ASD symptomatology. This scale includes 25–30 items across the domains of social interaction, communication, repetitive and stereotyped behaviors, and play. For this study, we used the Calibrate Severity Score (CSS), ranging from 1 to 10 (a higher score corresponding to greater severity). The internal consistency ranged from poor to excellent ($\alpha = 0.50$–0.92), the test–retest reliability was acceptable (0.64–0.88), and the inter-rater reliability ranged from good to excellent (0.79–0.98).

The intelligence quotient (IQ) or, when not available, developmental quotient (DQ) (developmental age score/chronological age × 100), was estimated from several psychometric scales, depending on the age and developmental level of each participant [40]. At T1, IQ was calculated from Wechsler scales, WISC-IV ($n = 10$) or WPPSI-IV ($n = 7$) [41, 42], or the Kaufman Assessment Battery for Children second edition (K-ABC-II) ($n = 2$) [43] and DQ from the Psychoeducational Profile third edition PEP-3 ($n = 12$) [44] and Brunet-Lezine scales ($n = 13$) [45]. At T2, IQ was calculated from Wechsler scales, WISC-IV ($n = 2$), WISC-V ($n = 20$), or WPPSI-IV ($n = 10$), and DQ from the PEP-3 ($n = 15$). IQ was not determined at T1 for seven participants and at T2 for four, because they were unable to complete the full psychometric test.

Adaptive functioning was assessed using the Vineland Adaptive Behavior Scales second edition (VABS-II) [46]. This standardized caregiver interview of 297 items measures adaptive behaviors from childhood to adulthood in the subdomains of communication, daily living skills, and socialization. In our study, we used the standard scores of the three subdomains. The reliability of the VABS II for each domain was good ($\alpha = 0.80$) and the intra-class coefficient of the test/re-test was 0.89.

Maladaptive behaviors were assessed using the Aberrant Behavior Checklist (ABC) [47], a 58-item scale concerning maladaptive or problem behaviors, with each item scored from 0 (no problem) to 3 (severe problem). The scale includes five factors: (1) irritability, agitation, crying; (2) lethargy, social withdrawal; (3) stereotypic behavior; (4) hyperactivity, noncompliance; and (5) inappropriate speech. The ABC showed excellent internal consistency among subscales ($\alpha = 0.91$), an excellent test–retest reliability of 0.98, and a moderate inter-rater reliability of 0.63. Scores were reduced to a scale of 100 to allow comparison.

Data analysis

Descriptive and frequency statistical analyses were performed to characterize the sample according to sensory profile, socio-demographics, and clinical variables at baseline (T1) and three years later (T2). The study of the change in atypical SP scores was performed by calculating a time difference (Delta Δ) between inclusion (T1) and the three-year follow-up (T2) from the Sensory Profile questionnaire (total score, total score items, and quadrant and section scores). Changes in children's clinical characteristics were estimated from the time difference (Delta Δ). The time differences were analyzed using paired t tests or Wilcoxon's signed rank tests. Pairwise comparisons were performed using the Bonferroni post-hoc test. In addition, intra-individual differences in SP total score between the two time points were compared for children whose ΔSP remained stable, increased, or decreased. Participants were categorized into three groups using ± 5 points (one deviation response of the SP questionnaire). This cut-off was chosen to provide a sufficient number of observations in each group. Changes in children's clinical characteristics (VABS-II subdomains, ABC sub-scores, and ADOS-CSS) were compared between subgroups using ANOVA or Kruskal–Wallis tests as indicated. Results were considered to be statistically significant for $p < 0.05$. Analyses were performed using SAS®.

Results

Participants

Overall, there were 51 participants, mostly males (85%), with a mean age of 5.5 years (SD = 2.1) at T1 and 8.6 years (SD = 2.1) at T2. The mean time of follow-up of participants between T1 and T2 was 2.9 years (SD = 0.4). Their clinical characteristics at T1 and T2 are presented in Table 1. Approximately 58.1% had no intellectual disability (over 70), 11.6% a mild intellectual disability, 18.6% a moderate intellectual disability, and 11.6% a severe intellectual disability. VABS-II socialization scores declined between T1 and T2 and the IQ showed a trend towards increasing. There was no change in the other clinical variables.

At T1, 57% of the Sensory Profile questionnaires were completed by the mothers only, 8% by the fathers only, 33% by both parents, and 2% by other caregivers. At T2, 85% of the questionnaires were completed by the mothers only, 2% by the fathers only, and 13% by both parents. Overall, 44% of the mothers and 58% of the fathers had a high school-level education and 56% of the mothers and 42% of fathers had an education level beyond high school.

Table 1 Clinical characteristics of the children at T1 and T2 and their change over time

	T1	T2	Intra individual change (Delta Δ)	
	Mean (SD)	Mean (SD)	Mean (SD)	*P* value
ADOS- CSS	6.9 (1.8)	7.3 (2.0)	0.4 (2.3)	0.2
IQ	71.2 (25.3)	78.4 (30.1)	6.0 (19.1)	0.056
VABS-II score				
Communication	69.9 (16.4)	71.5 (17.1)	1.8 (15.0)	0.2
Socialization	**70.6 (10.8)**	**68.6 (14.2)**	**− 1.5 (12.3)**	**0.001**
Daily living skills	75.1 (11.9)	70.9 (15.9)	− 3.47 (14.2)	0.5
ABC score				
Irritability	35.3 (17.5)	31.0 (20.6)	− 2.8 (16.9)	0.3
Lethargy	27.6 (18.8)	26.7 (21.5)	0.5 (16.2)	0.8
Stereotypy	29.4 (22.3)	32.0 (24.6)	1.6 (14.5)	0.5
Hyperactivity	45.4 (22.8)	42.9 (24.8)	− 1.8 (19.3)	0.5

SD: standard deviation, IQ: intelligence quotient, VABS-II: Vineland II, ADOS-CSS: autism diagnostic observation schedule calibrated severity score, ABC: aberrant behavior checklist

Significant results are presented in bold

Intra-individual changes in the SP scores over time

A comparison of the intra-individual changes in the Sensory Profile scores between T1 and T2 is presented in Table 2. Overall, the total scores of the Sensory Profile decreased with time, indicating that atypical SP increased with time. There was also a significant change for two quadrants scores—"Low registration" and "Sensory sensitivity"—which decreased over time. Among the sections of the Sensory Profile questionnaire, we found a significant change for the "Oral section" scores only, which decreased over time, indicating that atypical SP increased.

We analyzed each item to more accurately identify changes in the SP total scores. The items that significantly changed between T1 and T2 are indicated in Table 3. Two items showed an increase in their score at T2 and the rest a decline.

Clinical characteristics associated with the evolution of SP over time

Three subgroups were identified according to changes in the SP scores: those showing an increase of more than five points (SP-improvement group: SPI), those showing a decrease of more than 5 points (SP-worsening group: SPW), and those for which the score was stable, between − 5 and + 5 (SP-stable group: SPS). A spaghetti plot was conducted to present individual trajectories, showing the slopes to be relatively homogenous within each subgroup (Fig. 1). Intergroup comparisons showed no significant differences between groups at T1 for the total SP score ($p = 0.58$), whereas there was a significant difference at T2 ($p < 0.001$). The SPI group had a higher score at T2 ($M = 146.6$, SD = 20.7) than the SPW group ($M = 115.8$, SD = 22.7).

The intergroup comparison analyses at T1 showed no significant differences in the three SP groups in terms of age, gender, severity of ASD (ADOS-CSS), IQ, VABS-II scores (for communication, socialization, and daily living skills), ABC sub-scores (irritability, lethargy, stereotypy and

Table 2 Intra-individual comparison of Sensory Profile scores between T1 and T2

	T1	T2	Intra-individual change (Delta Δ)	
	Mean (SD)	Mean (SD)	Mean (SD)	*P* value
Total score	**133.4 (22.5)**	**127.5 (26.3)**	**− 5.9 (18.6)**	**0.03**
Quadrant				
Low registration	**57.3 (10.0)**	**54.7 (14.2)**	**− 3.0 (10.0)**	**0.04**
Sensation seeking	92.4 *(15.5)*	92.1 (18.8)	− 0.6 (15.2)	0.78
Sensory sensitivity	**74.1 (13.5)**	**69.7 (14.2)**	**− 4.8 (11.9)**	**0.03**
Sensation avoiding	97.9 *(17.3)*	94.3 (19.0)	− 3.5 (13.0)	0.08
Section				
Auditory processing	26.7 (5.8)	24.2 (7.0)	− 1.2 (5.6)	0.2
Visual processing	33.2 (7.1)	31.7 (7.8)	− 0.9 (5.8)	0.6
Vestibular processing	44.6 (6.7)	44.2 (6.8)	− 0.7 (6.2)	0.4
Touch processing	67.4 (10.9)	66.2 (13.6)	− 1.3 (10.8)	0.4
Multisensory processing	25.0 (5.2)	25.5 (4.7)	− 0.5 (3.6)	0.3
Oral sensory processing	**44.6 (10.9)**	**42.1 (12.0)**	**− 3.9 (10.0)**	**0.03**

SD: standard deviation

Significant results are presented in bold

Table 3 Intra-individual comparison of the change in the Sensory Profile total score between T1 and T2 for those items that showed a significant change

	T1	T2	Intra-individual change (Delta Δ)	
	Mean (SD)	Mean (SD)	Mean (SD)	*P* value
3.Has trouble completing tasks when the radio is on	3.6 (1.6)	3.1 (1.3)	− 0.4 (1.4)	0.04
5.Can't work with background noise	4.2 (1.2)	3.0 (1.3)	− 1.3 (1.4)	< 0.001
9.Is bothered by bright lights after others have adapted to the light	4.0 (1.3)	3.5 (1.4)	− 0.4 (1.1)	0.01
30. Expresses distress during grooming	2.8 (1.4)	3.5 (1.3)	+ 0.7 (1.6)	0.003
31. Prefers long-sleeved clothing when it is warm or short sleeves when it is cold	4.5 (0.9)	4.1 (1.2)	− 0.5 (1.4)	0.02
69. Seems to have weak muscles	4.0 (1.3)	3.6 (1.5)	− 0.4 (1.3)	0.04
70. Has a weak grasp	4.0 (1.2)	3.5 (1.5)	− 0.5 (1.4)	0.01
71. Can't lift heavy objects	4.0 (1.3)	3.5 (1.4)	− 0.5 (1.3)	0.006
73. Poor endurance/tires easily	3.7 (1.3)	3.3 (1.5)	− 0.5 (1.2)	0.003
77. Fears falling or heights	4.0 (1.3)	3.6 (1.5)	− 0.5 (1.5)	0.03
123. Jumps from one activity to another so that it interferes with play	2.8 (1.2)	3.2 (1.2)	+ 0.4 (1.3)	0.01

SD standard deviation

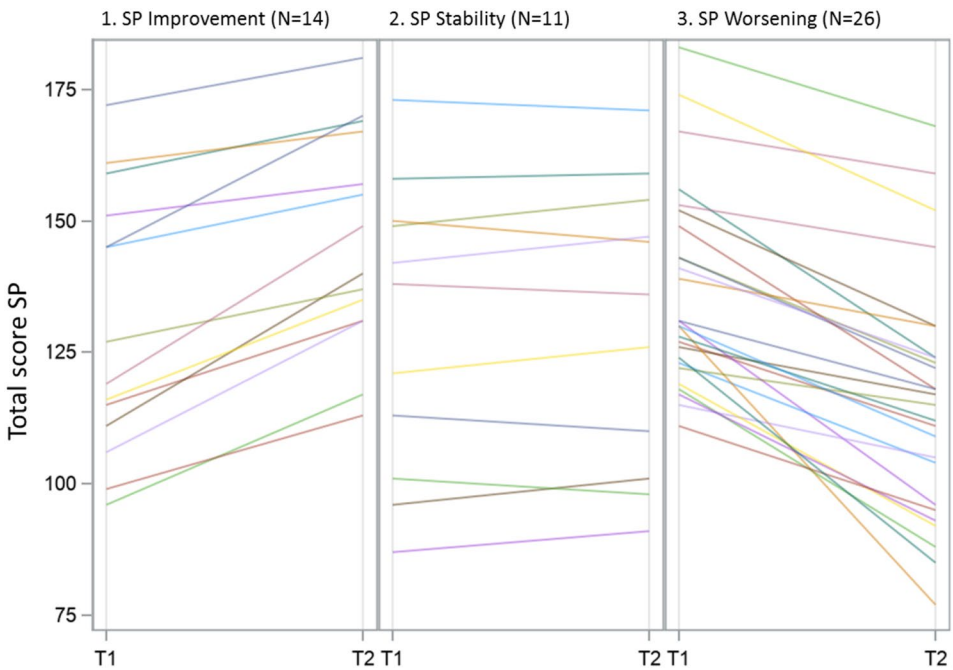

Fig. 1 Total change in individual SP scores between T1 and T2 divided by subgroup

hyperactivity), school or specialized school attendance, or parents' educational level.

The intergroup comparison of changes in the SP scores over time is presented in Table 4. Overall, SP increased more in the SPI than SPW group for all quadrants and sections of the Sensory Profile questionnaire.

Intergroup comparisons of the changes that occurred between T1 and T2 for the clinical characteristics of the children are presented in Table 5. Over time, IQ improved significantly more in the SPI than SPS group. In addition, the socialization and daily living VABS-II -scores increased significantly more in the SPI than SPW group. Finally, the ABC irritability, and lethargy scores decreased more in the SPI and SPS groups than in the SPW group.

Table 4 Intergroup comparisons of changes in the Sensory Profile scores between T1 and T2

	SP groups				
	Improvement (SPI) $N=14$	Stable (SPS) $N=11$	Worsening (SPW) $N=26$	Comparison Post hoc	
	Mean (SD)	Mean (SD)	Mean (SD)	*P* value	
Quadrant					
Δ Low registration	5.14 (7.2)	− 2.7 (6.5)	− 7.6 (9.8)	< 0.001[α]	SPW < SPI
Δ Sensation seeking	16.8 (10.7)	− 2.2 (11.8)	− 9.9 (9.2)	< 0.001[α]	SPW, SPS < SPI
Δ Sensory sensitivity	4.2 (6.2)	2.0 (5.1)	− 13.9 (10.3)	< 0.001[α]	SPW < SPS, SPI
Δ Sensation avoiding	10.8 (6.6)	− 1.8 (6.1)	− 11.8 (10.9)	< 0.001[α]	SPW < SPS < SPI
Section					
Δ Auditory processing	4.0 (4.3)	0.8 (3.3)	− 4.7 (4.8)	< 0.001[α]	SPW < SPS, SPI
Δ Visual processing	2.3 (3.8)	0.5 (3.6)	− 3.1 (3.6)	0.03[α]	SPW < SPI
Δ Vestibular processing	5.5 (3.9)	0.11 (4.4)	− 4.5 (4.9)	< 0.001[α]	SPW < SPS < SPI
Δ Touch processing	8.6 (6.9)	2.7 (6.8)	0.8 (3.8)	< 0.001[α]	SPW < SPS, SPI
Δ Multisensory processing	2.4 (2.8)	1.5 (2.8)	− 0.8 (3.7)	0.02[α]	SPW < SPI
Δ Oral sensory processing	3.8 (7.6)	− 1.7 (5.6)	− 9.5 (9.8)	< 0.001[α]	SPW < SPI

SD standard deviation, *SPI* sensory processing improvement, *SPS* sensory processing stable, *SPW* sensory processing worsening; [α]ANOVA test

Table 5 Intergroup changes in clinical characteristic between T1 and T2

	SP group				
	Improvement (SPI) $N=14$	Stable (SPS) $N=11$	Worsening (SPW) $N=26$	Comparison Post hoc	
	Mean (SD)	Mean (SD)	Mean (SD)	*P* value	
Δ IQ	18.6 (16.1)	− 3.5 (19.7)	5.3 (18.1)	0.04[α]	SPS < SPI
Δ ADOS-CSS	0.6 *(3.7)*	0.8 (2.2)	0.2 (1.6)	0.8[β]	
VABS-II score change					
Δ Communication	9.3 *(15.6)*	2.1 (11.8)	− 2.6 (14.5)	0.2[β]	
Δ Socialization	4.6 *(11.5)*	0.9 (7.4)	− 5.7 (12.7)	0.02[α]	SPW < SPI
Δ Daily living skills	5.9 *(9.8)*	− 4.5 (13.5)	− 8.2 (14.4)	0.01[β]	SPW < SPI
ABC score change					
Δ Irritability	− 9.2 (15.7)	− 9.3 (14.8)	4.7 (16.3)	0.02[β]	SPW < SPS, SPI
Δ Lethargy	− 5.7 (13.9)	− 6.0 (13.5)	7.4 (16.5)	0.02[β]	SPW < SPS, SPI
Δ Stereotypy	− 3.6 (13.2)	2.9 (13.3)	4.2 (16.2)	0.3[β]	
Δ Hyperactivity	− 7.5 (16.2)	− 7.3 (23.5)	4.0 (18.1)	0.2[β]	

SD standard deviation, *SPI* sensory processing improvement, *SPS* sensory processing stable, *SPW* sensory processing worsening, *ADOS-CSS* autism diagnostic observation schedule calibrated severity score, *ABC* aberrant behavior checklist, [α]ANOVA test; [β]Kruskal–Wallis test

Discussion

Evolution of SP over time

SP total scores tended to decrease over time in our sample, indicating that concerns of parents about atypical SP of the participants increased during their development. These preliminary results are consistent with a meta-analysis that highlighted an increase in parental concerns about SP in children with ASD between 6 and 9 years of age, whereas SP decreases with age in typically developing children [5, 13].

Our results showed strong heterogeneity in the evolution of SP in children with ASD, in accordance with the published longitudinal study using subgroup analyses [26], with the existence of three subgroups. In one subgroup, the responses to the sensory profile questionnaire remained stable (SPS; $N=11$), as in two previous longitudinal studies [5, 24], whereas concerns about SP decreased (SPI; $N=14$) for one group, as reported in a recent longitudinal study [25], and increased (SPW; $N=26$) for the last, as

suggested by a meta-analysis [13]. As reported by Dwyer et al. [26], we found a subgroup that remained stable and another for which atypical SP increased. However, we also found a small subgroup for which SP tended to decrease (SPI, $N = 14$). In summary, the development of SP appears to be divided into differing trajectories, implying the need to use analysis that accounts for changes in individual SP [35]. Moreover, such heterogeneity in SP appears to characterize ASD and is not found in typically developing children [5, 48]. It is possible that the heterogeneity of SP during development and intra-individual variability are influenced by the diversity of individual SP experiences and changes in the living environment over time.

Factors associated with the evolution of SP over time

We found an association between IQ and the evolution of SP in one subgroup. Indeed, the IQ was higher at T2 in the subgroup in which SP improved. This result differs from findings of the longitudinal study of Perez et al. [24]. However, they found that the SP remained stable over time for a follow-up of 2 years. These results were consistent with those of a previous study using several scales to measure IQ without a longitudinal approach [29–31]. Our preliminary results allow us to formulate two hypotheses: (1) when SP improves, children become more available to learning and develop cognitive skills or (2) children improve their strategies to manage SP following the development of their cognitive skills. More longitudinal studies using psychometric scales to assess IQ are needed to better describe and understand the course of SP and IQ in individuals with ASD.

The three subgroups identified based on changes in SP were associated with the children's adaptive trajectories. Indeed, the SPI subgroup showed an improvement in socialization and daily living skills, whereas they worsened in the SPW group. Many past studies that have highlighted strong heterogeneity in adaptive trajectories in children with ASD [49–51] did not take into account the influence of SP. Our results, suggesting that SP influences the adaptive trajectories of children with ASD. Our preliminary results relating to childhood suggest that SP influences the adaptive trajectories of children with ASD. Consistent with this notion, a recent prospective study that focused on early development in children found that "sensation-seeking" behaviors at 24 months were predictive of socialization disturbances at 36 months in children at risk of ASD, leading the authors to suggest that there is a cascading negative impact of atypical SP on early adaptive trajectories [52].

Maladaptive behaviors, especially irritability and lethargy, were more common in the group for which concerns about SP increased and less common in those which showed improved or stable SP. Previous studies [32, 34, 53], including one of our own from the ELENA cohort [27], showed maladaptive behaviors in ASD to be associated with atypical SP. The association between the evolution of SP and maladaptive behavior trajectories during development observed in our sample reinforces these findings, suggesting the need to consider SP when children with ASD show maladaptive behaviors [54].

Strengths and limitations of the study

The main strengths of our study were a sample of children with a confirmed diagnosis of ASD, an extensive data collection, and a long-term longitudinal examination of the evolution of SP. However, our findings should be interpreted in the light of several limitations. First, as this study was exploratory the cut-offs used for subtyping participants into subgroups were subjective. However, the homogeneity observed in each subgroup of the changes over time in SP scores seems to validate the relevance of the cut-off. The sample size of this exploratory study was limited. Second, SP was assessed using the Sensory Profile parental questionnaire, which contains a number of emotional/social items that may be confused with core features of ASD and could contribute towards sub-threshold changes [55]. Moreover, parental reports may have introduced a bias, in that parents may be better able to identify SP in their children over time. Finally, the ages of the children in our sample varied widely at T1, which limited the investigation of the heterogeneity in sensory changes. In addition, as we did not specifically collect information on interventions between T1 and T2, it is not possible to identify whether they contributed to changes in SP.

Clinical implications

Our observation of the heterogeneity of the course of SP during development suggests the importance of regular monitoring throughout the lifetime of people with ASD. Once sensory issues have been identified, the daily environment particularly that at school, can be appropriately adapted. In addition, this would allow specific interventions to be proposed for sensory needs, for which clinical improvement has been reported [56]. Moreover, the significant relationship between maladaptive behaviors and concerns about sensory processes implies that this dimension must be taken into account in an intervention plan to manage problem behaviors [57].

Future research

Our preliminary results could be confirmed in future studies with a larger sample size using a longitudinal approach to capture individual variability in SP. The subgroup with higher atypical SP during childhood provides researchers the challenging opportunity of better understanding risk factors associated with the worsening of SP. In any case, the persistence of SP during development highlights the need for future studies of people with ASD to identify their sensory needs throughout life and specific intervention strategies.

Conclusion

Our exploratory study showed there to be heterogeneity in the evolution of SP in children with ASD over a three-year follow-up, highlighted by the identification of three subgroups according to changes in SP (improvement, stable, or worsening). Moreover, changes in SP were associated with changes in the children's clinical characteristics. IQ, adaptive skills (socialization and daily living skills), and maladaptive behaviors improved in the subgroup in which SP improved. Conversely, socialization, deficits in daily living skills, and maladaptive behaviors worsened in the group in which SP worsened. These findings suggest the need to study the evolution of SP in individuals with ASD and to adapt their care to changes in their sensory needs to improve their adaptation to the environment and their quality of life.

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Author contributions FD and AB conceived the study, contributed to the collection, analysis, and interpretation of the data, and drafted the manuscript. AB is the PI of the ELENA cohort. CM and MCP analyzed and interpreted the data and critically revised it for the principal intellectual content. All authors read and approved the final version.

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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 were approved by the Ethics Committee on the Research of Human Subjects at Marseille Mediterranean and the National Commission for Computing and Liberties (CNIL. number DR-2015-393).

Informed consent All participating families signed an informed consent form.

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