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Sensory processing in children with autism spectrum disorder and the mental health of primary caregivers

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Abstract

Background: Sensory processing difficulties, which commonly occur in autism spectrum disorder (ASD), are expected to have negative effects on the primary caregiver's mental health. The aim of this study was to examine the association between sensory processing difficulties in children with ASD and the mental health of primary caregivers.

Methods: A total of 707 primary caregivers (mothers in the present study) and their children with ASD (4–18 years of age) participated in this study. Sensory processing difficulties were indexed using the Short Sensory Profile (SSP). The mental health of primary caregivers was indexed using the General Health Questionnaire (GHQ12).

Results: Higher scores on Auditory Filtering as measured with the SSP were associated with poorer mental health of primary caregivers, even after an adjustment for ASD symptom severity. Analyses of two age sub-groups, a young (4–10 years) and an old age group (11–18 years), revealed that higher scores on Tactile Sensitivity and Auditory Filtering were associated with poorer mental health of primary caregivers in younger children, whereas only higher scores on Auditory Filtering were associated with poorer mental health of primary caregivers in older children.

Conclusions: Our findings suggest that practitioners who support primary caregivers of children with ASD need to focus not only on the social and communication-related symptoms of the child but also on their specific sensory processing difficulties.

Keywords: Autism spectrum disorder; Sensory processing; Sensory profile; Mental health; Mothers; Children; Tactile; Auditory; Social responsiveness scale

1. Introduction

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental disorder characterized by deficits in social communication and the presence of restricted, repetitive behaviors [1].

Sensory processing involves various domains, such as touch, smell, taste, hearing, sight, and movement; hyper- or hyporeactivity can occur in all of these modalities. Difficulties in sensory processing commonly occur in developmental disorders, including ASD [2–4], and are observed more often in children with ASD than in

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typically developing children [3]. Estimates of the prevalence of sensory processing difficulties in ASD are quite high, ranging from 69 to 95% [2–6]. Further comparison between children with ASD and typically developing children reveals that they differ in their experiences of and reactions to various sensory stimuli in daily life [4–6].

Caregivers of children with ASD and, perhaps to a lesser extent, other developmental disabilities are known to have higher stress levels than parents of children without disabilities [7]. Parenting a child with ASD may confront parents with unique challenges, as children with ASD are significantly impaired in social interactions and communication and show restricted and stereotyped patterns of behaviors. Previous literature suggests that sensory processing difficulties in children with ASD can affect family functioning, routines, parent-child relationship patterns, and increase parenting stress and strain [8,9]. Qualitative research using interviews with caregivers has revealed that the characteristics of the sensory processing of children with ASD affect the activities and lifestyle of the entire family [10]. Sensory processing difficulties in children with ASD are thus expected to influence their caregiver's mental health.

At present, reports on the association between patterns of sensory processing and the mental health of primary caregivers are scarce. Epstein and colleagues revealed that sensory processing difficulties in children with Asperger syndrome aged 5–12 years were significantly correlated with parenting stress of caregivers [9]. Ben-Sasson and colleagues reported that sensory over-responsivity in toddlers with ASD was associated with higher family-life impairment and parenting stress [11]. Kirby and colleagues suggested that sensory processing difficulties, including over-reactions, under-reactions, and unusual interest in sensations, may predict caregiver strain for children with ASD aged 2–12 years [12]. Hyperresponsiveness and Hyporesponsiveness in particular are associated with financial strain and affected family routines, and hyperresponsiveness also contributes to increased levels of worry and sadness in caregivers.

Despite the progress made by the three aforementioned studies, two questions remain to be addressed. First, whether the modalities of sensory processing differentially influence the mental health of primary caregivers has not been examined. Epstein's study used the total score of the Short Sensory Profile (SSP) [13], a measure of sensory processing difficulties that consists of seven sensory subsections, for analysis. Previous studies have reported that the frequency of processing abnormalities varies across sensory subsections of the SSP [4,5,14], and research has revealed separate neurophysiological mechanisms underlying disruptions of different sensory modalities in ASD [15]. This suggests that each sensory subsection influences the mental health of primary caregivers differently. Second, the potential covariates expected to affect the mental health of primary caregivers of children with ASD have not been adequately considered. Overall, the cognitive abilities and ASD symptom severity of the child are the two most frequently reported potential confounders [16–18]. Additionally, Fitzgerald and colleagues reported that having an older child with autism (mean age = 15.84 years) is associated with less family burden in comparison with having a younger child with the condition (mean age = 10.53 years) [19]. Some studies showed that sensory processing difficulties in ASD decrease with age [2,20]. In a meta-analytic study, Ben-Sasson and colleagues reported that sensory processing difficulties were highest between the ages of 6 and 9 years and then decreased after 9 years of age [3]. In other words, the association between sensory processing difficulties and the mental health of primary caregivers may not be straightforward and is thus likely to be affected by the age of the child.

The aim of this study was to examine the association between sensory processing difficulties in children with ASD using the SSP [13], translated to and validated in Japanese [21], and the mental health of primary caregivers. We focused on the following three points: (1) to clarify the influence of each sensory section on the mental health of primary caregivers, (2) to analyze additional covariates (the severity of ASD symptoms and the cognitive abilities of the child), and (3) to stratify the overall results by age. Clarifying the influence of sensory processing difficulties in children with ASD on the mental health of primary caregivers will help us understand the unique needs of their caregivers; furthermore, these findings will be important for practitioners who work with children with ASD when choosing the appropriate intervention.

2. Methods

2.1. Subjects

In this study, we enrolled the primary caregivers of children participating in two support groups for ASD. One is a support group targeting children with developmental disabilities and their families (Support Group A); the author K.S. is involved as an expert leader in this group. Most of the families participating in the Support Group A live in the greater Nagoya metropolitan area, the third most populated metropolitan area in Japan. The support provided includes learning support, social skill training by experts, the opportunity to participate in a summer camp combined with special support for ASD, and lectures on ASD-related knowledge that is relevant for families. The other group provides a nationwide network (Support Group B); the majority of the participants and families in this group live in the greater

Tokyo metropolitan area. The support provided by this group includes learning support tailored to the children's individual characteristics and social skill training. The diagnosis of all participants was provided by registered psychiatrists and/or pediatricians based on DSM-IV-TR or DSM-5.

To 947 primary caregivers of children participating in these support groups, questionnaires were distributed through experts who were leaders of the groups. The following exclusion criteria were applied to the 947 samples: 1) age of the child with ASD younger than 4 years or older than 18 years, 2) the primary caregiver is not the mother, 3) a diagnosis other than ASD including intellectual disability, attention deficit hyperactivity disorder, fragile X syndrome, Down's syndrome, Williams syndrome, cerebral palsy, or uncorrected visual or hearing impairments. In addition, we excluded those who did not provide total scores for either the General Health Questionnaire (GHQ12) or the SSP, or information regarding the gender and age of the child, the primary caregiver's age, education of the primary caregiver, or the child's general cognitive abilities. The sample of the present study thus totaled to 707 primary caregivers.

Concerning exclusion criterium 2), we limited primary caregivers to mothers for two reasons. First, 90% of the primary caregivers who expressed interest in participating in our study were mothers. Second, the aforementioned questions we sought to address in this study have been informed by literature concerning the mental health of mothers with children with ASD. Accordingly, we limited our scope to female caregivers.

Difference between support groups: To ascertain differences, if any, between the two different support groups, the gender and age of the children were compared using chi-square and t-tests. As for gender, this comparison did not reveal any statistically significant difference in the male-female ratio between Support Group A and B (male: female = 116:43 vs. 398:150; $\chi^2(1) = 0.01$, $p = 0.94$). For age, there was a statistically significant difference in mean age between Support Group A and B (mean = 11.96 (SD = 3.68) vs. 10.55 (SD = 3.40); $t(705) = 4.529$, $p < 0.001$).

2.2. Measurements

All measures were selected for their good psychometric properties and their applicability to children with ASD.

2.2.1. Outcome: mental health of primary caregivers (GHQ12)

We used the 12-item version of the GHQ12 to measure the mental health status of the primary caregivers. The GHQ12 is a self-reported measure of mental health state referring to the past 2–3 weeks [22]. The scale consists of 12 items rated on a 4-point Likert scale from 1 ("much less than usual") to 4 ("much more than usual"). Lower scores indicate better mental health (range: 12–48). A Japanese version of the GHQ12 was validated and published in 2013 [23].

2.2.2. Exposure: sensory processing (SSP Japanese version)

The SSP is a parent-report questionnaire that consists of 38 items designed to assess sensory sensitivity across seven sensory subsections, namely Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Underresponsive/Seeks Sensation, Auditory Filtering, Low Energy/Weak, and Visual/Auditory Sensitivity. Parents are asked to rate the frequency with which their child engages in behaviors related to sensory sensitivity in each subsection. Examples of the item questions for each subsection are as follows: "(She/he) expresses distress during grooming" (Tactile Sensitivity); "(She/he) will only eat certain tastes" (Taste/Smell Sensitivity; "(She/he) dislikes activities where head is upside down" (Movement Sensitivity); "(She/he) seeks all kinds of movement and this interferes with daily routines" (Underresponsive/Seeks Sensation); "(She/he) appears to not hear what you say" (Auditory Filtering); "(She/he) seems to have weak muscles" (Low Energy/Weak); "(She/he) responds negatively to unexpected loud noises" (Visual/Auditory Sensitivity). Possible scores range from 1 point to 5 points, ranging from "never responds in this manner" (1 point) to "always responds in this manner" (5 points). Low raw scores indicate typical performance, while higher scores on the SSP are indicative of greater sensory dysfunction. In the original version, the higher the score of each item, the lower the frequency of the reaction. The primary variable of interest for analysis was the raw score of each subsection.

The questionnaire was completed simultaneously by the study participants and their primary caregivers in March 2013 irrespective of receiving any assistance from the staff of the support groups and irrespective of the timing of such assistance. They were asked to complete the survey by themselves.

2.2.3. Covariates

2.2.3.1. Demographic variables. We selected the child's gender and age, the primary caregiver's age, and the level of education attained by the primary caregivers as potential confounding variables.

2.2.3.2. General cognitive ability of the children. Information on the presence or absence of intellectual disability was available in all samples. That is, when a child's IQ was 70 or higher, or when a child did not have a diagnosis of intellectual disability confirmed by registered psychiatrists or pediatricians, we concluded that the child did not have an "intellectual disability". When a child's

IQ was 69 or lower, or when a child had a diagnosis of intellectual disability, we concluded that the child had an "intellectual disability". The IQ data, available for 403 individuals, were provided either with the Wechsler Intelligence Scale for Children-Third edition [24], the Wechsler Intelligence Scale for Children-Fourth Edition [25], the Wechsler Intelligence Scale for Adults-Third edition [26], or the Tanaka-Binet Intelligence Scale V [27].

2.2.3.3. Severity of ASD symptoms (Social Responsiveness Scale-2). The Social Responsiveness Scale-2 (SRS-2) [28] identifies social impairment associated with ASD and quantifies its severity. It is a 65-item Likert-scale questionnaire, and each item has four response options, yielding a score of 0–3. SRS-2 total raw scores range from 0 to 195, with higher scores indicating increased social impairment. For reference, we have also converted the raw scores to the standardized, T-score [29]. The standardized score of the Japanese SRS-2 is available only for individuals aged from 6 to 15 years, therefore the study participants aged 4–5 years and 16–18 years were treated as if they were either 6 or 15 years to assign the corresponding T-scores. For this technical reason, we prioritized use of the raw score.

2.3. Statistical analysis

Our main analysis consisted of six steps.

The first two steps address the first aim of this study: to clarify the influence of each sensory section on the mental health of the primary caregivers.

Step 1. The univariate models, expected to reveal any association of each subsection with the GHQ12.

Step 2. The multivariate base model, where all the subsection scores were compiled, expected to detect any significant associations while adjusting for associations among subsections.

We designed the following three multivariate analyses to address our second aim: to analyze effects stemming from additional covariates. Previous research has confirmed that "general cognitive ability" and "severity of ASD" are variables affecting both sensitivity and parental mental health.

Step 3. Multivariate model 1. We tested for any significant associations of SSP, which were to be found in Step 2 (multivariate base model), remained significant after an adjustment for demographic variables.

Step 4. Multivariate model 2. We then entered a proxy of general cognitive ability (intellectual disability) into multivariate model 1 to determine whether any associations thus far might be accounted for by general cognitive ability. If there would be no significant effect of general cognitive ability nor no significant contribution of improvement in model building, general cognitive ability is no longer used as a covariate.

Step 5. Full model. Severity of ASD symptoms was then entered into multivariate model 2 to identify any associations thus far might be accounted for by the severity.

Step 6. Full model with an interaction of age. We tested for any interaction of age in the full model. If any significant interaction (i.e. SSP subsection × age) was found, stratified analyses of the full model along with age, split by the median, were conducted for comprehensibility.

All data analyses were conducted with Stata software version 13.1.

2.4. Ethics

We obtained written informed consent from the primary caregivers and oral child assent of children above the age of 6 before the onset of this study. The study protocol was approved by the Hamamatsu University School of Medicine and University Hospital Ethics Committee (E14-062-1, E14-062-2, E14-062-3, E14-062-4).

3. Results

3.1. Characteristics of the study participants

Characteristics of the 707 children and primary caregivers are shown in Table 1. The mean level of education attained by the primary caregivers was 14.0 years. This is somewhat longer than the mean maternal educational history in our earlier cohort study in Japan (13.6 years) [30]. As expected, the mean scores on each subsection of the SSP were higher than those on the Japanese version of the standardized data sample [21]. The mean SRS-2 total raw score did not show substantial departure from the previously reported data based on a large sample of children and adolescents with ASD in Japan [31]. Finally, the mean GHQ12 total score of this sample, 27.6 (SD 6.2), was higher than that of the standardized data sample of adults, 26.3 [23].

3.2. Association between sensory processing and the mental health of primary caregivers

The associations between the SSP and the GHQ12 scores are shown in Table 2 (univariate model, multivariate base model) and Table 3 (multivariate model 1, multivariate model 2, full model).

Scores on each subsection of the SSP were statistically significant and positively associated with the GHQ12 score in the univariate model (all $p < 0.001$). In the multivariate base model, the associations for Tactile Sensitivity ($p = 0.02$) and Auditory Filtering ($p < 0.001$) remained statistically significant, even after adjustment of all SSP subsection scores.

Table 1
Sample descriptive statistics (N = 707).

Variables			
Gender, no (%)			
Male	514	(73%)	
Female	193	(27%)	
Child age in years, mean (SD), range	10.87	(3.5)	4–18
Primary caregiver's age in years, mean (SD), range	42.83	(5.0)	28–59
Level of education attained by the primary caregiver in years, mean (SD), range	14.02	(1.5)	9–16
Short Sensory Profile (SSP), mean (SD), range			
Tactile Sensitivity	14.1	(5.1)	7–30
Taste/Smell Sensitivity	5.0	(1.8)	4–14
Movement Sensitivity	4.6	(2.0)	3–15
Underresponsive/Seeks Sensation	10.4	(3.5)	7–27
Auditory Filtering	11.5	(4.3)	6–29
Low Energy/Weak	12.1	(5.6)	6–30
Visual/Auditory Sensitivity	8.7	(3.4)	5–20
SRS-2 total score, mean (SD), range	69.3	(27.1)	4–166
Intellectual disability, no (%)	196	(28%)	
GHQ12 score, mean (SD), range	27.6	(6.2)	12–47

Table 2
Associations between the subsection scores of the SSP and the total score on the GHQ12 (N = 707).

Variables	Univariate model[a,b]		Multivariate base model[c]	
	Coefficient (95% CI)	p	Coefficient (95% CI)	p
Short Sensory Profile				
Tactile Sensitivity	**0.28** (0.19 to 0.36)	<0.001	**0.13** (0.02 to 0.23)	0.016
Taste/Smell Sensitivity	**0.52** (0.27 to 0.78)	<0.001	0.02 (−0.27 to 0.31)	0.881
Movement Sensitivity	**0.54** (0.32 to 0.77)	<0.001	0.01 (−0.27 to 0.29)	0.953
Underresponsive/Seeks Sensation	**0.31** (0.18 to 0.44)	<0.001	0.02 (−0.15 to 0.18)	0.852
Auditory Filtering	**0.41** (0.31 to 0.51)	<0.001	**0.32** (0.18 to 0.46)	<0.001
Low Energy/Weak	**0.17** (0.09 to 0.26)	<0.001	−0.06 (−0.17 to 0.05)	0.264
Visual/Auditory Sensitivity	**0.39** (0.26 to 0.52)	<0.001	0.12 (−0.07 to 0.31)	0.221
Adjusted R^2	–		0.09	

Coefficients in bold indicate the statistical significance of $p \leq 0.05$.

[a] In the univariate model, the association of each of the subsections of the SSP with GHQ12 was tested independently. The magnitude of the association was shown in regression coefficients with the P values.

[b] Statistical significance of the each univariate model was tested using the F test; Tactile Sensitivity: $F (1, 705) = 38.89$, $p < 0.001$, adjusted $R^2 = 0.05$; Taste/Smell Sensitivity: $F (1, 705) = 16.42$, $p < 0.001$, adjusted $R^2 = 0.02$; Movement Sensitivity: $F (1, 705) = 22.28$, $p < 0.001$, adjusted $R^2 = 0.03$; Underresponsive/Seeks Sensation: $F (1, 705) = 22.61$, $p < 0.001$, adjusted $R^2 = 0.03$; Auditory Filtering: $F (1, 705) = 62.29$, $p < 0.001$, adjusted $R^2 = 0.08$; Low Energy/Weak: $F (1, 705) = 18.04$, $p < 0.001$, adjusted $R^2 = 0.02$; Visual/Auditory Sensitivity: $F (1, 705) = 34.01$, $p < 0.001$, adjusted $R^2 = 0.05$).

[c] In the multivariate base model, the association for each of the subsections was tested simultaneously. The lack of statistical significance indicates that an association between one subsection with the GHQ12 was confounded by another subsection. (Statistical significance of the multivariate base model was tested using the F test: $F (7, 699) = 10.67$, $p < 0.001$).

In multivariate model 1, gender was significantly and positively associated with the GHQ12 score. That is, the primary caregivers of girls in our sample had poorer mental health than the primary caregivers of boys. Level of education attained by the primary caregiver was significantly and negatively associated with the GHQ12 score. In multivariate model 2, intellectual disability was not associated with the GHQ12 score. In the full model, only the score on the Auditory Filtering subsection of the SSP was positively associated with the GHQ12 score. In addition, the SRS-2 score was positively associated with the GHQ12 score. We applied a

Table 3
Associations between the subsection scores of the SSP and the total score of the GHQ12 (N = 707).

Variables	Multivariate model 1		Multivariate model 2		Full model	
	Coefficient (95% CI)	p	Coefficient (95% CI)	p	Coefficient (95% CI)	p
Short Sensory Profile						
Tactile Sensitivity	**0.14** (0.03 to 0.24)	0.010	**0.13** (0.03 to 0.24)	0.012	0.10 (−0.01 to 0.20)	0.074
Taste/Smell Sensitivity	0.04 (−0.25 to 0.33)	0.789	0.03 (−0.26 to 0.32)	0.848	0.02 (−0.26 to 0.31)	0.867
Movement Sensitivity	0.06 (−0.22 to 0.34)	0.676	0.08 (−0.21 to 0.36)	0.595	0.02 (−0.26 to 0.30)	0.869
Underresponsive/Seeks Sensation	−0.01 (−0.18 to 0.15)	0.874	−0.02 (−0.18 to 0.14)	0.811	−0.07 (−0.23 to 0.10)	0.426
Auditory Filtering	**0.36** (0.22 to 0.50)	<0.001	**0.36** (0.21 to 0.50)	<0.001	**0.31** (0.17 to 0.45)	<0.001
Low Energy/Weak	−0.07 (−0.17 to 0.04)	0.200	−0.07 (−0.18 to 0.03)	0.180	−0.08 (−0.18 to 0.03)	0.145
Visual/Auditory Sensitivity	0.12 (−0.07 to 0.32)	0.218	0.13 (−0.06 to 0.33)	0.188	0.09 (−0.10 to 0.29)	0.344
Female gender	**1.46** (0.46 to 2.46)	0.004	**1.48** (0.49 to 2.48)	0.004	**1.59** (0.57 to 2.55)	0.002
Child age	0.11 (−0.04 to 0.27)	0.149	0.12 (−0.03 to 0.28)	0.123	0.08 (−0.08 to 0.23)	0.339
Primary caregiver's age	0.04 (−0.07 to 0.14)	0.491	0.04 (−0.07 to 0.14)	0.464	0.05 (−0.06 to 0.15)	0.354
Level of education attained by the primary caregiver in years	**−0.30** (−0.59 to −0.02)	0.038	**−0.29** (−0.58 to −0.01)	0.043	**−0.33** (−0.62 to −0.05)	0.022
Intellectual disability			−0.82 (−1.80 to 0.17)	0.103		
SRS-2					**0.04** (0.02 to 0.06)	0.001
F	F (11, 695) = 8.57	<0.001	F (12, 694) = 8.10	<0.001	F (12, 694) = 8.95	<0.001
Adjusted R^2	0.11		0.11		0.12	

Coefficients in bold indicate the statistical significance of $p \leq 0.05$.

log likelihood ratio test to determine whether there was any improvement in the model selection. We found no improvement from multivariate model 1 to model 2 ($\chi^2(1) = 2.71$, $p = 0.10$). A statistically significant improvement was observed from model 1 to the full model (log likelihood ratio statistics = 11.75, df = 1, $p < 0.001$). In the full model, we repeated the same procedure mentioned above, where the raw scores of SRS-2 was replaced with the corresponding T scores. We found minimal differences in the coefficients.

3.3. Full model with statistical interaction of age

We first added each of subsection of the SSP × age into the full model, revealing that only Tactile Sensitivity × age was statistically significant ($p < 0.05$). After removing other interaction terms, the interaction, i.e. Tactile Sensitivity × age, remained significant ($p = 0.02$). Addition of this interaction term improved the model compared to the full model (log likelihood ratio statistics = 5.35, df = 1, $p = 0.02$).

To see this interaction more intuitively, we stratified the full model along with age, with the median point of age at 10 years. The stratified analysis showed that in younger children, Tactile Sensitivity (95% CI: 0.03–0.34, $p = 0.02$) and Auditory Filtering (95% CI: 0.01–0.40, $p = 0.042$) were positively associated with the GHQ12 score (Table 4). In contrast, in older children, only Auditory Filtering (95% CI: 0.18–0.61, <0.001) was positively associated with the GHQ12 score.

4. Discussion

This study shows that, in children with ASD aged 4–18 years who participate in two support groups in Japan, difficulties in Auditory Filtering as measured by the SSP were associated with poorer mental health of primary caregivers, even after an adjustment for general cognitive abilities and severity of ASD symptoms. Analyses of two age sub-groups, a young age group (4–10 years old) and an old age group (11–18 years old), revealed that Tactile Sensitivity and Auditory

Table 4
Associations between the subsection scores of the SSP and the total score of the GHQ12, full model, stratified by age (N = 707).

Variables	Young age (4–10 y) N = 336 Coefficient (95% CI)	p	Old age (11–18 y) N = 371 Coefficient (95% CI)	p
Short Sensory Profile				
Tactile Sensitivity	**0.19** (0.03 to 0.34)	0.017	−0.02 (−0.17 to 0.14)	0.839
Taste/Smell Sensitivity	0.03 (−0.37 to 0.44)	0.868	0.05 (−0.36 to 0.46)	0.812
Movement Sensitivity	0.14 (−0.25 to 0.54)	0.472	−0.16 (−0.57 to 0.25)	0.442
Underresponsive/Seeks Sensation	−0.03 (−0.30 to 0.23)	0.797	−0.08 (−0.30 to 0.14)	0.488
Auditory Filtering	**0.20** (0.01 to 0.40)	0.042	**0.39** (0.18 to 0.61)	<0.001
Low Energy/Weak	−0.07 (−0.23 to 0.08)	0.362	−0.07 (−0.21 to 0.08)	0.362
Visual/Auditory Sensitivity	0.02 (−0.24 to 0.28)	0.886	0.18 (−0.12 to 0.47)	0.242
Female gender	**2.34** (0.86 to 3.82)	0.002	0.92 (−0.44 to 2.28)	0.183
Child age	0.08 (−0.33 to 0.49)	0.703	0.15 (−0.19 to 0.49)	0.383
Primary caregiver's age	0.04 (−0.11 to 0.20)	0.560	0.04 (−0.11 to 0.18)	0.634
Level of education attained by the primary caregiver in years	−0.11 (−0.51 to 0.29)	0.587	**−0.54** (−0.95 to −0.12)	0.011
SRS-2	**0.05** (0.01 to 0.08)	0.004	**0.03** (0.00 to 0.06)	0.027
F	F (12, 323) = 6.06	<0.001	F (12, 358) = 3.95	<0.001
Adjusted R^2	0.15		0.09	

Coefficients in bold indicate the statistical significance of $p \leq 0.05$.

Filtering were associated with primary caregiver's mental health in younger children, whereas only Auditory Filtering was associated with the GHQ12 score in older children.

4.1. Interpretation of the results and comparison with prior research

A linear regression analysis on the SSP and GHQ12 scores revealed that the score on each subsection of the SSP was strongly associated with the GHQ12 score. Subsequently, when multiple linear regression was used to simultaneously adjust for all subsections of the SSP, only associations for Tactile Sensitivity and Auditory Filtering remained significant. Ashburner and colleagues [14] reported that, in the ASD group, the section score of the most abnormal SSP domain was Auditory Filtering (96%). Indeed, in our study, Auditory Filtering was statistically significantly associated with the mental health of primary caregivers. Higher subsection scores on Taste/Smell Sensitivity, Movement Sensitivity, Underresponsive/Seeks Sensation, Low Energy/Weak, and Visual/Auditory Sensitivity were however not associated with the mental health of primary caregivers.

It has been suggested that higher scores on the Taste/Smell Sensitivity is associated with feeding issues [32] and reduced participation in activity [33]. Children with ASD with higher scores on Movement Sensitivity, Underresponsive/Seeks Sensation, or Low Energy/Weak prefer to participate in activities inside the house rather than outside the house [33]. This suggests that the psychological burden will increase if difficulties in these subsections exist, because primary caregivers need to take care of their children who prefer activities inside the house. Underresponsive/Seeks Sensation, Auditory Filtering, Low Energy/Week and Visual/Auditory Sensitivity scores showed higher levels of behavioral and/or emotional problems for the children with ASD [5]. However, in our study, two subsections, that is, higher scores on Tactile Sensitivity and Auditory Filtering, were associated with mental health of primary caregivers.

4.2. Potential confounding effects of demographic variables

Within the SSP, Tactile Sensitivity and Auditory Filtering were associated with the mental health of primary caregivers. We had assumed that the child's gender and age and the primary caregiver's age and educational history are associated with the mental health of primary caregivers, and this is indeed what we found. These variables were added as covariates in the analysis of multivariate model 1 to ensure the assessment of the associations to be conservative. Even with these covariates, the coefficients of each subsection of the SSP hardly changed. In multivariate model 1, neither the child's gender and age nor the primary caregiver's age and educational history played any role as a confounding factor in the association between SSP scores and the mental health of primary caregivers.

4.3. Influence of general cognitive ability

Even after we controlled for general cognitive ability (i.e., intellectual disability), the associations for Tactile Sensitivity and Auditory Filtering remained statistically significant. Compared to the results of multivariate model 1, even when general cognitive ability was added to the model (multivariate model 2), the coefficients did not change. Research has consistently demonstrated that mothers of children with cognitive and intellectual disabilities report higher rates of depression [34], mental health problems [35], and stress [36]. Hence, we expected that intellectual disability of the child(ren) is a predictor for poorer mental health of primary caregivers. However, contrary to our expectation, presence of intellectual disability was not statistically significantly correlated with the mental health of primary caregivers in our study. Bishop and colleagues reported that the child's IQ has no significant influence on how the mother perceives the negative effects of parenting a child with ASD [18]. Our results are consistent with this finding. In our study, general cognitive ability was neither correlated with the mental health of primary caregivers, nor did it play a role as a confounding factor.

4.4. Influence of severity of ASD

By adding the SRS-2 that reflects the severity of ASD symptoms in multivariate model 2, the association between Tactile Sensitivity and the mental health of primary caregivers disappeared in the full model. This indicates that the association between Tactile Sensitivity and the mental health of primary caregivers is confounded and mostly explained by the ASD symptom severity of the children. Of note, some items on the SRS-2 assess sensory processing difficulties. As we confirmed, about nine items (13.8%) out of the 65 items of the SRS-2 were related to sensory processing. (e.g., "seems overly sensitive to sounds, textures, or smells"); it seems therefore natural that coefficients of the SSP subsections are reduced when we controlled for SRS-2.

The association with Auditory Filtering remained statistically significant, although the coefficient was reduced by about 10% when adding the SRS-2 to the model. The association between Auditory Filtering and the mental health of primary caregivers was only marginally explained by ASD symptom severity. In line with these observations, Ben-Sasson and colleagues reported that sensory processing difficulty is associated with parenting stress independently of ASD severity [11].

4.5. Influence of gender

A consistent finding in multivariate model 1, multivariate model 2, and the full model was that female gender is significantly and positively associated with poorer mental health of primary caregivers, that is, the primary caregivers of girls with ASD have poorer mental health than the primary caregivers of boys with ASD. However, when a stratification analysis was performed, gender was associated with the mental health of primary caregivers only in the younger age group. One might assume that the finding of poorer mental health of primary caregivers for the primary caregivers of girls is due to the severity of ASD symptoms being higher in girls than in boys. In our sample, however, there was no statistically significant difference in the severity of ASD symptoms in the younger age group [70.2 (SD 1.7) in male vs 65.3 (SD 2.7) in female; $t(334) = 1.48$, $p = 0.13$], while in the older age group, gender was not associated with the mental health of primary caregivers. These findings may be consistent with a report that parent–child relationships in families with children with ASD tend to be closer and better between mothers and daughters than between mothers and sons during adolescence and early adulthood [17]. There may thus be a higher risk for mothers of girls with ASD to suffer from mental health problems, but only when their children are young.

4.6. Influence of child age

We stratified the sample into a younger and older age group and repeated a full model analysis in each group. As we expected, higher scores on Tactile Sensitivity were statistically significant only in the young age group. Previous studies have reported some evidence that sensory processing, in general, changes and may lessen throughout the course of development in individuals with ASD [2,3,20]. In our study, only in Tactile Sensitivity there was a difference between the results of the young age group and the old age group. This is a new finding that has not been observed in previous studies.

4.7. Tactile sensitivity and the primary caregiver's mental health

From the viewpoint of the mother-child relationship, it is however possible to interpret this finding such that Tactile Sensitivity is an important factor only in the younger age group. Considering the meaning of tactile stimulation in early childhood, touch is an important channel of communication during mother-infant interactions [37]. Touch communicates security and tenderness, aids the reduction of the children's stress and distress, and promotes emotional regulation [37,38]. The nervous system of children with tactile hypersensitivity interprets tactile stimulation as harmful or dangerous. These children may feel their mothers' touch, which generally gives a sense of security, as a threat, and this may cause a fight or flight response as a defense from danger [39]. Mothers of children with tactile sensitivity thus have difficulties with general strategies of touch. A mother with a child that is sensitive to being hugged, stroked, or held by their hands may not know how to approach her child, and may lose confidence in parenting. Higher parenting self-efficacy predicts greater satisfaction with parenting [40]. In this way, our findings might show the relationship between tactile sensitivity in children with ASD of younger age and the negative effects on the mental health of their primary caregivers.

4.8. Auditory filtering and the primary caregiver's mental health

Higher scores on Auditory Filtering was statistically associated with the mental health of primary caregivers in both age groups. When comparing the coefficient of both age groups, Auditory Filtering showed an influence on the mental health of primary caregivers for all ages, but it was more influential in older children. Higher scores on Auditory Filtering mean, by definition [39], that the child has difficulties to distinguish important sounds such as the human voice from environmental noises (e.g., "is distracted or has trouble functioning if there is a lot of noise around"; "doesn't respond when name is called but you know the child's hearing is OK"). If a child with a higher score on Auditory Filtering is surrounded by various sounds, they cannot respond to important sound information such as their caregiver's voice, or they may be easily distracted when they should concentrate. This may thus interfere with voice-mediated parent-child communication as was also suggested by Bidet-Caulet et al. [41]. In turn, as the child grows, the language skills of the child improve and verbal interaction starts to play a more important role in parent-child communication. When the child's Auditory Filtering score is high, it becomes difficult for the child to communicate with their primary caregiver as the child gets older, and the mental health of primary caregivers may also worsen. This is consistent with our results. Therefore, in this study, we find it quite convincing that the magnitude of the association between higher scores on Auditory Filtering and the mental health of primary caregivers was stronger in the older age group than in younger age group.

4.9. Limitations

This study has several limitations. First, we did not compare an ASD group with a control group of typically developing children without an ASD diagnosis. We can therefore not be certain that the association between sensory processing and the mental health of primary caregivers in our study is specific to children with ASD.

Second, the subjects of this study are primary caregivers of children with ASD participating in support groups; we can thus not generalize this result to primary caregivers of all children with ASD in general. The support group provides learning support for children and knowledge related to developmental disabilities for primary caregivers. The learning support may have some influence on the children's ASD symptoms. The mental health of primary caregivers may also be influenced by the changes in the children's ASD symptoms and by the acquisition of knowledge on developmental disorders. According to a recent report [42], whether mothers belong to a support group does not affect their state anxiety and depression symptoms levels. The primary caregiver's mental health status found in this study may thus be similar to the status of primary caregivers not participating in support groups, but we cannot confirm this.

Third, the diagnostic validity of our subjects may be limited, as we do not use the research diagnostic tools, such as the Autism Diagnostic Observation Scale [43]. In addition to this, some preschoolers may not have fully developed social dysfunction problems on account of their youth, leading to relatively lower scores of the SRS-2.

Fourth, all the data obtained in this study are based on primary caregiver's reports. There are symptoms that are difficult to observe in sensory processing, and it is thus not certain whether the sensory processing of children with ASD can be accurately measured using such reports.

Fifth, in the final model, adjusted R^2 value was as high as 0.12, suggesting that there remain 88% of the variance should be accounted for by factors we have not measured. This may indicate that, even though sensory processing of ASD is of concern and would be a point of intervention, the overall effect size would be minor.

Last, since this is a cross-sectional study, it is not possible to infer causal relationships in our results. We cannot deny the possibility that primary caregivers who have poorer mental health are more likely to have children with compromised auditory filtering or with tactile sensitivity, which might have played a significant role in this study. In order to clarify causal relationships, a longitudinal study will be needed.

In conclusion, this study shows that sensory processing difficulties in children with ASD are associated with poorer mental health of the primary caregivers. These findings suggest that practitioners who support children with ASD need to focus not only on the ASD core symptoms of the child but also on their specific sensory processing difficulties, as well as on the mental health of the primary caregiver.

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