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Sensory Processing in Preterm Preschoolers and Its Association with Executive Function

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Abstract

Background—Symptoms of abnormal sensory processing have been related to preterm birth, but have not yet been studied specifically in preterm preschoolers. The degree of association between sensory processing and other domains is important for understanding the role of sensory processing symptoms in the development of preterm children.

Aims—To test two related hypotheses: (1) preterm preschoolers have more sensory processing symptoms than full term preschoolers and (2) sensory processing is associated with both executive function and adaptive function in preterm preschoolers.

Study Design—Cross-sectional study

Subjects—Preterm children (34 weeks of gestation; n = 54) and full term controls (37 weeks of gestation; n = 73) ages 3-5 years.

Outcome Measures—Sensory processing was assessed with the Short Sensory Profile. Executive function was assessed with (1) parent ratings on the Behavior Rating Inventory of Executive Function- Preschool version and (2) a performance-based battery of tasks. Adaptive function was assessed with the Vineland Adaptive Behavior Scales-II.

Results—Preterm preschoolers showed significantly more sensory symptoms than full term controls. A higher percentage of preterm than full term preschoolers had elevated numbers of sensory symptoms (37% vs. 12%). Sensory symptoms in preterm preschoolers were associated with scores on executive function measures, but were not significantly associated with adaptive function.

Conclusions—Preterm preschoolers exhibited more sensory symptoms than full term controls. Preterm preschoolers with elevated numbers of sensory symptoms also showed executive function

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impairment. Future research should further examine whether sensory processing and executive function should be considered independent or overlapping constructs.

Keywords

preterm birth; sensory processing; executive function; adaptive function

1. Introduction

Sensory processing is the organization and interpretation of sensory stimuli from the body and surrounding environment. Symptoms of atypical sensory processing manifest as abnormal behavioral reactions in response to sensory stimulation. Behavioral reactions that are greater than expected are referred to as hypersensitivity; a child with hypersensitivity may respond negatively to bright lights or loud noises. Behavioral reactions that are less than expected are referred to as hyposensitivity; a child with hyposensitivity may have decreased awareness of pain or temperature [1]. Differences in sensory processing have been thought to cause children to exhibit sensation-seeking or sensation-avoiding behaviors [1], both of which could interfere with normal functioning. No consensus has been reached on whether symptoms of sensory processing problems constitute a unique disorder, or whether they represent behavioral characteristics coinciding with other conditions. Although no formal definition or diagnosis of sensory processing problems has been widely accepted in the medical and psychological fields, sensory processing symptoms are commonly identified in a wide range of clinical populations using a diverse set of methodologies, including neurophysiological testing and behavioral questionnaires [2–6].

Children born preterm (< 34 weeks gestational age) have been documented to have deficits spanning numerous cognitive domains [7], though sensory processing within the preterm population has not been thoroughly investigated. Research to date has found elevated levels of sensory symptoms to be associated with premature birth [8–10], and has primarily focused on preterm infants and toddlers. Sensory differences in preterm and late preterm (34–36 weeks of gestation) infants have been found to be modest to substantial, measured through both behavioral questionnaires and interactive sensory exams [11–13]. A study of preterm toddlers found impaired sensory profile patterns across all sensory modalities on a parent-report measure, including behaviors such as sensation seeking, sensation avoiding, sensory sensitivity, and low registration [8]. Atypical sensory profiles were also observed in a broad age range of preterm infants and children, ranging from 1 to 8 years of age [9]. A study of 9-year-old preterm children found reduced electrophysiological responses to auditory stimuli compared to the responses of full term children [14]. To our knowledge, sensory processing has not been evaluated specifically in preterm preschoolers, though the preschool period is important for consolidating development in multiple domains including communication, social development, and pre-academic skills.

Elevated levels of sensory symptoms in preterm children could be attributable to several factors associated with preterm birth. First, abnormal sensory exposure in the neonatal intensive care unit (NICU) during the critical period of sensory neurodevelopment has been postulated to alter and impair neural structures essential to processing sensory information [15, 16]. In addition, brain injury, including periventricular leukomalacia (PVL),

periventricular hemorrhage (PVH), and accompanying widespread neural and axonal disease, could disrupt the normal functioning of the sensory systems or association areas, leaving the preterm child with extreme or diminished reactions to sensory stimuli [17]. Finally, abnormal sensory processing could be part of a larger symptom complex of neurodevelopmental conditions that affect the preterm population. Measures of sensory processing have been found to correlate with measures of cognition and language in preterm toddlers [18].

The relationship between sensory processing in preterm preschoolers and other domains potentially impacted by sensory processing, specifically executive function and adaptive function, has not been investigated. Deficits in executive function and adaptive function have been well documented in preterm preschoolers and children [7, 19]. Executive function is a composite of skills involved in higher order and goal-directed thinking; it includes skills such as working memory, inhibition, and planning [20]. Sensory processing may be associated with executive function because sensory processing has been shown to be influenced by higher order cognitive control [21, 22]. Adaptive function describes how a child functions within the environment, completes personal tasks, and demonstrates social skills necessary for success in daily life [23]. Sensory processing may be associated with adaptive function because adverse behavioral reactions to sensory stimuli have been hypothesized to interfere with a child's ability to efficiently or effectively perform age-appropriate functional skills [1].

Associations between atypical sensory processing and impairment in either executive function or adaptive function have been found in several other clinical populations [2, 5, 24, 25]. Reduced auditory sensory gating has been found to coincide with poorer performance on executive function tasks in adults with autism [25] and Alzheimer's disease [24]. In toddlers with autism, sensory scores significantly predicted adaptive behavior scores, over and above the severity of autism symptoms [2]. Finally, in a study of children with Williams syndrome, children classified as having high sensory impairment had poorer scores on both executive function and adaptive function measures than children classified as having low sensory impairment [5].

1.1. Study aims and hypotheses

The first aim of the current study is to evaluate sensory processing in preschool-aged children born preterm. We hypothesized that preterm children have more symptoms of abnormal sensory processing than full term children, and that a higher proportion of preterm compared to full term children meet criteria for having elevated numbers of sensory symptoms, as defined by classification from the Short Sensory Profile.

The second aim of the current study was to investigate the association between sensory processing and both executive function and adaptive function within the preterm sample. We hypothesized that preterm children with elevated numbers of sensory symptoms have poorer executive function and lower adaptive function than do preterm children with typical numbers of sensory symptoms.

2. Methods

2.1. Participants

Participants were recruited from Palo Alto, California, and the surrounding communities. Preterm children were specifically recruited by letters sent to the families of children who were evaluated at High Risk Infant Follow-up Services at Lucile Packard Children's Hospital in Palo Alto, California. Full term children were recruited by distributing flyers in general pediatric clinics. Both groups were also recruited by postings on local parent message boards and by word of mouth. The sample consisted of 127 children, with 54 preterm and 73 full term participants, ranging from 3 to 5 years of age ($M = 4.3$ years). Participants were born from 2004 to 2009. Inclusion criteria for the preterm group required gestational age of 34 weeks or less and birth weight under 2500 grams. Inclusion for the full term group required gestational age of at least 37 weeks, birth weight of over 2500 grams, and no major medical complications. Exclusion criteria for both preterm and full term participants were genetic disorders, congenital heart disease, and major neurosensory impairment (i.e. blind or deaf). Medical complications and results from neonatal head ultrasound/MRI for the preterm sample are reported in Table 1. Ethical approval for the study was granted by the Stanford University Institutional Review Board. Informed consent was obtained from a parent or guardian on behalf of the children, and participants were compensated for participation.

2.2. Procedure

Parents completed a demographic questionnaire and standardized rating scales on site to assess child sensory symptoms, executive function, and adaptive function. Children ranged from ages 3–5 years of age at the time of testing, and completed a battery of executive function tasks that were administered by trained research assistants at a standard study unit.

2.3. Outcome measures and variables

2.3.1. Demographics and health information—A demographic and health questionnaire addressed child age, sex, race (white vs. non-white), maternal education, and parent report of services, including occupational therapy (Table 1). Maternal education (< 4 years in college, 4 years in college, Master's degree) was used as an indicator of socioeconomic status (SES). Health information, collected from parents and medical record review, included gestational age at time of delivery, birth weight, brain injury, and medical complications, such as respiratory distress syndrome, chronic lung disease, and necrotizing enterocolitis.

2.3.2 Parent-completed rating scales

1. Short Sensory Profile (SSP) [26]. The SSP is a parent-rated questionnaire used to discriminate children with sensory processing differences from children with typical sensory processing. It consists of 38 items that are classified into seven subscales, and an overall composite measure of sensory processing. The subscales are Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Underresponsive/Seeks Sensation, Auditory Filtering, Low Energy/Weak, and

Visual/Auditory Sensitivity. For each item, the parent determines the likelihood of the child responding in the manner listed using a 5-point Likert scale, with “always” scored the lowest and “never” the highest. Lower scores on the total score and subscales indicate more sensory symptoms. The SSP total score has high internal consistency (Cronbach’s $\alpha = 0.96$), as reported in the manual [26]. We used the total score as a continuous variable to assess the difference in sensory processing scores between the preterm and full term groups. For subscales and the total score, children can be classified categorically as “typical performance” (<1 *SD* below the mean), “probable difference” ($1-2$ *SD* below the mean), or “definite difference” (>2 *SD* below the mean). We classified children categorically as having elevated numbers of sensory symptoms if the total score was in either the probable or definite difference range.

2. Behavior Rating Inventory of Executive Function – Preschool Version (BRIEF-P) [20]. The BRIEF-P is a standardized parent-rated measure of executive function ability in children ages 2.0–5.11 years, with five subscales (Inhibition, Shift, Emotional Control, Working Memory, Plan/Organize) and a composite score (Global Executive Composite, GEC). Statements about the child’s behavior and tendencies are rated on a 3-point scale of “never”, “sometimes”, or “often”. Higher T-scores (mean of 50, *SD* of 10) indicate more executive function impairment. The GEC, which has high internal consistency ($\alpha = 0.95$) and test-retest reliability ($r = 0.90$) as reported in the manual [20], was the main outcome measure used in analyses.
3. Vineland Adaptive Behavior Scales, Second Edition, Parent/Caregiver Rating Form (Vineland-II) [23]. The Vineland-II is a parent-report measure of adaptive function spanning all ages. The parent rates each item by determining how often the child performs a particular behavior or skill. Four subdomain scale scores (Communication, Daily Living Skills, Socialization, and Motor Skills) and a composite score (Adaptive Behavior Composite, ABC) are generated. The ABC, which has high internal consistency ($\alpha = 0.97$) and test-retest reliability ($r = 0.94$) as reported in the manual [23], was used in our analyses.

2.3.3 EF Battery—Preterm children completed a performance-based battery of six interactive tasks [27, 28] to capture different aspects of executive function:

1. Six Boxes (working memory and planning) – Children are presented with a tray of six stationary boxes, and watch as each box is baited with a token and covered. They are then instructed to find all the tokens, one at a time. Between each reach, the tray is withdrawn for 5 seconds to increase the working memory component of the task. The child can use the position or lid color of the box to help remember which boxes have already been searched. A practice trial of three boxes is first presented to ensure comprehension. The dependent variable is the number of reaches it takes for the child to collect all the tokens, with higher scores indicating poorer performance.

2. Verbal Fluency (idea generation) – Children have two trials to name as many words in a category (i.e. animals, food/drinks) as they can in one minute. The dependent variable is the sum of unique category-appropriate words generated across the two trials.
3. Day/Night (complex response inhibition) – In a modified form of the Stroop task, children must hold a rule in mind and inhibit conflicting visual information. They are instructed to say “day” when presented with a picture of the moon and the stars, and “night” when shown a picture of the sun. The dependent variable is the number of correct responses reverse scored by subtracting the number of practice trials necessary to comprehend the task.
4. Bird/Dragon (complex response inhibition) – In a modified Simon Says task, children are instructed to follow the commands of the “nice” bird puppet while ignoring the commands of the “naughty” dragon puppet. Each puppet alternates telling the child a command (e.g. “Touch your nose”, “Pat your head”). The dependent variable is the number of correct responses reverse scored by subtracting the number of practice trials necessary to comprehend the task.
5. Dimensional Change Card Sort (cognitive flexibility/attention switching) – Children are presented with cards that can be sorted along two dimensions (color or shape). The child is first instructed to sort according to one dimension, and then shift to sort according to a second dimension. The dependent variable is the number of correct responses while sorting according to the second dimension.
6. Gift Wrap (inhibition/delayed gratification) – The child is instructed not to peek while the examiner noisily wraps a present for one minute. The dependent variable is the categorical measure of whether the child peeked or did not peek during the task.

2.4. Data Analysis

Data analysis was conducted using IBM SPSS Statistics 21. Significance was set at $p < 0.05$. We used independent samples t-tests for continuous variables and Chi-square analysis for categorical variables to compare groups on demographic variables, SSP total and subscale scores, and SSP classification proportions (i.e. elevated numbers of sensory symptoms vs. typical numbers of sensory symptoms). Associations between demographic factors and sensory processing scores were also investigated with linear regression.

To investigate the association between sensory processing, executive function, and adaptive function within preterm children, the preterm sample was divided into two groups on the basis of the SSP total score. We compared executive function and adaptive function scores between preterm children with elevated numbers of sensory symptoms (PT+S), defined as a score within the “probable” or “definite” difference ranges, and preterm children with typical numbers of sensory symptoms (PT–S), defined as a score within the “typical” range. When the continuous data were distributed normally, independent samples t-tests were used to evaluate group differences. If the distribution of the continuous data failed the Shapiro-Wilk test of normality, the nonparametric Mann-Whitney U test was used to evaluate group

differences. Categorical variables were evaluated using Chi-square analysis. Further post-hoc analysis was conducted using Spearman correlations and linear regressions.

Missing data occurred as a result of equipment failure, participants' failure to complete the task, parent reports not being returned, or inclusion of the task at a later point in the study (i.e., Verbal Fluency). Missing data is as follows: BRIEF-P, $n = 3$; Vineland-II, $n = 5$; Day/Night, $n = 1$; Bird/Dragon, $n = 1$; Verbal Fluency, $n = 13$; Gift Wrap, $n = 2$.

3. Results

3.1. Demographics

Demographic information is presented in Table 1. There were no significant differences between the preterm and full term groups in regard to age, sex, or race. Maternal education level, used as a marker for socioeconomic status, was lower in the preterm group than the full term group. The preterm group also had more children as part of a twin set than the full term sample. By design, preterm children had lower gestational age and birth weight than full term controls. No significant differences were found between PT+S and PT-S in demographic variables, brain injury, or medical complications. Additionally, there was no significant difference between PT+S and PT-S in the proportion of children in occupational therapy, $X^2(1) = 1.36, p = 0.24$.

3.2. Sensory Processing

The preterm group scored significantly lower than the full term group on the SSP total score, $t(125) = 4.40, p < 0.001$, indicating more sensory symptoms. The pattern was replicated in five out of seven SSP subscales, all p 's < 0.01 (Table 2).

A higher percentage of preterm than full term children were classified as having elevated numbers of sensory symptoms, 37% vs. 12%, respectively (Table 2). This association between birth status and sensory symptom classification was highly significant, $X^2(1) = 10.75, p < 0.001$. Further examination of the SSP total score classifications indicated that 5 full term children and 8 preterm children met criteria for classification as "probable difference", while 4 full term children and 12 preterm children met criteria for classification as "definite difference"; this distribution was significant, $X^2 = 11.29, p = 0.004$. The association between birth status and sensory symptom classification was also significant for six of seven SSP subscales (Table 2).

To investigate the factors that predict sensory processing symptoms, linear regression analysis was performed in the full sample. The outcome variable for the model was SSP total score and the predictor variables included gestational age, maternal education, sex, and twin status (Table 3). Gestational age was included due to our interest in the effects of degree of prematurity on sensory processing scores; maternal education due to the difference in SES between the full term and preterm samples; sex due to past studies finding that sex has an effect on sensory processing scores [8]; and twin status due to a possible effect on parent report. The model was significant at $p < 0.001$, and explained 16.4% of the variance in SSP total score. Gestational age was the only significant predictor, $p < 0.001$. The regression was repeated with birth weight included instead of gestational age; the model

remained significant ($p = 0.001$, $R^2 = 14.90$). Birth weight was a significant predictor ($p < 0.001$), while SES, sex, and twin status remained non-significant.

To investigate the effects of brain injury and medical complications on sensory processing symptoms, linear regressions were performed within the preterm sample. The first regression model predicted to SSP total score and included brain injury status as a predictor; brain injury was categorized as “normal”, “mildly abnormal”, or “abnormal”. The model was not significant ($p = 0.54$), indicating that brain injury classification was not significantly associated with sensory processing scores. A second linear regression predicting to SSP total score was performed, and included the presence or absence of respiratory distress syndrome, chronic lung disease, necrotizing enterocolitis, and small for gestational age as predictors. The model was not significant ($p = 0.28$), indicating that no medical complication was significantly associated with sensory processing scores.

3.3. Domains Associated with Sensory Processing in Preterm Children

On the parent-rated BRIEF-P GEC, the difference between PT+S and PT–S was significant, $U = 133.00$, $z = -3.42$, $p < 0.001$, $r = -0.48$ (Table 4). PT+S had higher scores than PT–S, indicating more executive function impairment. Within the preterm sample, the BRIEF-P GEC and SSP total score were significantly negatively correlated, $r = -0.59$, $p < 0.001$. Correlation coefficient values between BRIEF-P and SSP subscales ranged from non-significant to highly associated, and varied as a function of subscale (Table 5). The BRIEF-P subscales of working memory ($r = -0.63$, $p < 0.001$) and inhibition ($r = -0.55$, $p < 0.001$) had the highest correlations with SSP total score. The analysis was repeated with partial correlations controlling for gestational age and also birth weight, and the results remained largely consistent. The only difference was when controlling for gestational age, the correlation between the tactile and working memory subscales became significant ($r = -0.30$, $p = 0.04$).

On the performance-based EF battery, there was a significant difference between the performance of PT+S and PT–S on the Gift Wrap task, $X^2(1) = 5.68$, $p = 0.02$. More children in the PT+S group peeked before the allotted time than children in the PT–S group. No significant differences were found on the remaining EF Battery tasks using Mann-Whitney U tests (Table 4).

On the parent-rated Vineland-II ABC, no significant difference was found in scores between PT+S and PT–S, $t(47) = 1.45$, $p = 0.15$ (Table 4). We conducted post-hoc tests to further examine the absence of association between sensory processing and adaptive function. Linear regression analysis within the preterm sample predicting to the Vineland-II ABC included SSP total score and BRIEF-P GEC as predictors. The BRIEF-P GEC was a significant predictor ($p < 0.001$), though the SSP total score was not ($p = 0.40$).

4. Discussion

To our knowledge, this study is the first to specifically evaluate sensory processing in preterm preschoolers. As hypothesized, preterm preschoolers had significantly more sensory processing symptoms than full term children. These results were consistent with previous

studies investigating the association between premature birth and sensory processing at younger and older ages [8, 9, 11, 12]. The preterm group had lower mean scores compared to the full term group for the SSP total score and five of seven subscale scores, indicating that the sensory symptoms were not specific to a single sensory domain, such as vision versus audition. A recent study by Eeles et al. (2013) reported similar results, as preterm toddlers in their study had lower mean scores than full term toddlers across all five sensory processing subscales, indicating more sensory symptoms [8].

A higher percentage of preterm children, compared to full term children, met classification as having elevated numbers of sensory symptoms, defined as “probable” or “definite” difference in SSP total score. The percentage of preterm children classified as having elevated numbers of sensory symptoms (37%) was consistent with results of a study by Wickremasinghe et al. (2013), who found that 39% of their preterm sample ages 1 to 8 years was classified as having atypical sensory processing on the Sensory Profile [9]. Furthermore, our finding that 12% of full term children classified as having elevated numbers of sensory symptoms was consistent with the 13% rate found in a study of typically developing kindergarteners [29], suggesting that the SSP behaved similarly in our study.

We also found that gestational age was a significant predictor of sensory processing scores, consistent with previous studies [10]. Using similar analyses, Eeles et al. found that male sex was associated with scores on specific sensory subscales [8]; in our sample, sex was not a significant predictor of SSP total score. There was no significant association between either gross structural brain injury or medical complications and sensory processing ability within the preterm sample. This finding is in contrast to Eeles et al. [8], who found that moderate-severe white matter abnormality at term equivalent age was a significant predictor of sensory processing in preterm toddlers. Our sample may not have had enough power to detect an association between brain injury score and sensory processing, because only a few children were classified in the “mildly abnormal” or “abnormal” brain injury categories. Damage specifically to white matter, rather than general brain injury, may also be more closely associated with impairment in sensory processing ability. Additionally, white matter microstructure could be a more sensitive predictor of sensory processing in preterm children than gross structural injury, especially when measured at the time of sensory processing assessment. Previous studies using advanced imaging techniques such as diffusion tensor imaging have found reduced white matter microstructural integrity in children with atypical sensory processing [30], though this methodology has not been applied to the investigation of sensory processing in preterm children.

As hypothesized, within the preterm group, sensory processing was associated with executive function. On parent ratings of executive function, differences between the preterm groups with elevated or typical numbers of sensory symptoms were highly significant. While the mean GEC score of the preterm with typical numbers of sensory symptoms group fell within the average range, the mean GEC score of the preterm with elevated numbers of sensory symptoms group fell within the clinically elevated range for executive function impairment. Moreover, BRIEF-P subscales of working memory and inhibition had the highest associations with SSP total score; as sensory symptoms increased, working memory and inhibition decreased.

On performance-based tasks of executive function, differences between the preterm groups with elevated or typical numbers of sensory symptoms varied as a function of the task. Preterm children with elevated numbers of sensory symptoms performed significantly worse than preterm children with typical numbers of sensory symptoms on the Gift Wrap task. The Gift Wrap task measures the executive function domain of inhibition, which has been theorized to be an important component in sensory processing [22]. On the remaining tasks, the difference in performance between the groups did not reach significance. It is possible that with a larger sample these subtle differences may become significant.

Though the group differences are less consistent on the performance-based EF tasks, the results still provide valuable information with regard to the relationship between executive function and sensory processing. Previous research has demonstrated that performance-based and parent-rated measures of executive function contribute divergent but related information to the measurement of executive function ability [28]. Neuroimaging studies have also found that executive functions measured by both performance based-tasks and parent-rating scales are associated with neuroanatomical integrity [31]. Our findings of associations between sensory processing symptoms and executive function impairment in preterm children are consistent with the results of previous studies documenting similar associations in other clinical populations [5, 24, 25].

The strong association found between sensory processing and executive function in preterm children may be explained by the overlapping nature of the two domains. Executive functions such as working memory and inhibition have top-down control over prepotent responses and distracting stimuli. It is likely that executive function can also exert top-down control over sensory processing and influence which sensory stimuli gain conscious awareness [21, 22]. For example, working memory has been demonstrated to influence visual selective attention [32] and to exert top-down control on neural activity in the visual cortex [22]. In addition, the inability to filter irrelevant sensory stimuli may also impair performance on executive function tasks [33].

There was no significant difference in parent-rated adaptive function scores between preterm preschoolers with elevated and typical numbers of sensory symptoms. Additionally, sensory processing scores, in contrast with executive function scores, did not contribute to variance in adaptive function scores within the preterm sample. We found that parent-reported executive function is associated with adaptive function; this is consistent with results of the larger study from which this sample is drawn [28]. These results conflict with other studies that have shown associations between sensory processing and adaptive function in children with Williams syndrome [5] and autism [2]. The clinical populations in these previous studies may have had more severely impaired adaptive function than in this study or a wider range of adaptive function scores, allowing an association with sensory processing to be revealed.

Our data do not support our second hypothesis and suggest that sensory differences may not invariably limit adaptive function in preterm children. One possible explanation is that sensory processing symptoms, though detectable, may not delay or deter developmental progress in preterm children. In addition, sensory processing may have a different

neurobiological substrate than adaptive behavior, though adaptive behavior is likely to require a distributed neural network. Another possible explanation is that preterm children with elevated numbers of sensory symptoms may have found compensatory strategies to prevent their sensory differences from interfering with adaptive function. Finally, sensory processing may be associated with different domains at different eras within the life cycle.

A limitation of our study is the relatively high maternal education of the sample, which may not be representative of preterm and full term populations with lower SES. Restricted range of maternal education level may have limited the ability to identify contributions of SES to sensory processing outcomes. We also did not have brain imaging collected concurrently with sensory assessment to examine associations between underlying brain injury and outcomes, which may have further explained the results.

Another limitation of our study is the use of parent report measures as the only index of sensory processing. There are few standardized objective measures of sensory processing in infants and children [34]. Further, we do not believe the significant association between parent-rated sensory processing and parent-rated executive function was due solely to parent report bias. Preterm children with elevated numbers of sensory symptoms were rated as atypical or impaired on both the SSP and the BRIEF-P, while rated in the average range on the Vineland-II. The dissociation of the pattern observed with parent-rated sensory processing and executive function compared to adaptive function suggests that the results are not being driven by parent report bias. In addition, there was no difference in the receipt of occupational therapy services in preterm groups with elevated and typical levels of sensory symptoms, which may have influenced parent ratings of sensory symptoms.

The demonstrated association between parent-rated sensory processing and parent-rated executive function may be due in part to the similarity or overlap between the constructs measured by the SSP and BRIEF-P. The SSP and BRIEF-P both contain items that assess attention and inhibition. For example, items on the SSP ask parents to rate children on the following: “Is distracted or has trouble functioning if there is a lot of noise around”, and “Has difficulty paying attention”. Items on the BRIEF-P ask parents to rate children on the following: “Gets easily sidetracked during activities”, and “Has trouble concentrating on games, puzzles, or play activities”.

The significant association between sensory processing and executive function, and the similarity of the items on the respective measures, calls into question whether sensory processing and executive function are distinct or overlapping constructs. Larger samples of preterm children would allow for the investigation of whether and under what circumstances elevated numbers of sensory symptoms and executive function impairment are dissociable conditions. Identification of preterm children who had either elevated numbers of sensory symptoms or executive function impairment, but not both, would demonstrate that the two domains are distinct, even though impairment in both domains may commonly coincide. Future research should assess sensory processing in relation to executive function in older preterm children and adolescents to determine if sensory differences persist and whether the associations remain stable. The use of neuroimaging along with objective evaluation of sensory processing may allow for delineation of whether sensory processing and executive

function are neurobiologically distinct. Structural imaging studies have found white matter injury in samples of preterm children or toddlers with executive function impairment [35] and sensory processing abnormalities [8], but have not yet investigated the two domains in relation to each other. Future imaging studies could focus on whether damage or alteration to the same or different structures is associated with impairment in sensory processing and executive function in preterm children.

5. Conclusions

In this sample, over one-third of preschool age preterm children exhibited parent-reported elevated numbers of sensory processing symptoms. The findings fill a gap in previous research regarding the ages in which sensory processing has been studied in preterm children [8, 9, 11, 12]. The association found between sensory processing and executive function suggests that elevated numbers of sensory symptoms in preterm children are related to specific neurodevelopmental deficits [18], rather than occurring in isolation. Elevated numbers of sensory symptoms in preterm children were associated with executive function impairment, but not poor adaptive function. The relationship between sensory processing and executive function should be further explored in preterm children as well as in other clinical populations.

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Abbreviations

BRIEF-P	Behavior Rating Inventory of Executive Function-Preschool Version
PT+S	preterm children with elevated numbers of sensory symptoms
PT-S	preterm children with typical numbers of sensory symptoms
SSP	Short Sensory Profile

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Highlights

- Preterm preschoolers have more sensory symptoms than full term controls.
- Sensory symptoms in preterm preschoolers are associated with executive function.
- Sensory symptoms in preterm preschoolers are not associated with adaptive function.
- Research should examine the overlap between sensory processing and executive function.

Table 1

Demographic characteristics of full term compared to preterm participants and of PT+S compared to PT-S groups.

	Full Term (<i>n</i> = 73) <i>n</i> (%) or <i>M</i> ± <i>SD</i>	Preterm (<i>n</i> = 54) <i>n</i> (%) or <i>M</i> ± <i>SD</i>	<i>t</i> or χ^2	PT+S (<i>n</i> = 20) <i>n</i> (%) or <i>M</i> ± <i>SD</i>	PT-S (<i>n</i> = 34) <i>n</i> (%) or <i>M</i> ± <i>SD</i>	<i>t</i> or χ^2
Age (years)	4.3 ± 0.78	4.4 ± 0.76	5.79	4.4 ± 0.90	4.4 ± 0.70	0.40
Male	33 (45%)	28 (52%)	0.55	8 (40%)	20 (58%)	1.79
White	43 (59%)	37 (69%)	1.23	14 (70%)	23 (68%)	0.03
Maternal Education			7.46*			4.96
< 4 year College	6 (8%)	13 (24%)		8 (40%)	5 (15%)	
4 year College Degree	25 (34%)	20 (37%)		7 (35%)	13 (38%)	
Masters Degree	42 (59%)	21 (39%)		5 (25%)	16 (47%)	
Twins	4 (5%)	20 (37%)	20.17**	5 (25%)	15 (44%)	1.97
Gestational Age (weeks)	39.3 ± 1.4	29.5 ± 2.5	25.71**	28.8 ± 2.7	29.9 ± 2.4	1.62
Birth weight (g)	3333 ± 525	1336 ± 448	22.56**	1256 ± 494	1382 ± 419	1.00
Brain Injury						0.44
Normal	n/a	38 (70%)		13 (65%)	25 (74%)	
Mildly Abnormal	n/a	9 (17%)		4 (20%)	5 (15%)	
Abnormal	n/a	7 (13%)		3 (15%)	4 (12%)	
Respiratory Distress Syndrome	n/a	28 (52%)		10 (50%)	18 (53%)	0.04
Chronic Lung Disease	n/a	6 (11%)		3 (15%)	3 (9%)	0.49
Necrotizing Enterocolitis	n/a	4 (7%)		3 (15%)	1 (3%)	2.67
Small for Gestational Age	n/a	7 (13%)		3 (15%)	4 (12%)	0.12

Abbreviations: PT+S, preterm children with elevated numbers of sensory symptoms; PT-S, preterm children with typical numbers of sensory symptoms

* $p < 0.05$,

** $p < 0.01$

Table 2

Short Sensory Profile sensory symptom scores and sensory group classification.

	Full Term (<i>n</i> = 73)	Preterm (<i>n</i> = 54)		
Sensory Symptoms Scores				
	<i>M</i> ± <i>SD</i>	<i>M</i> ± <i>SD</i>	<i>t</i>	<i>p</i>
Total Score	171.29 ± 14.20	156.59 ± 21.29	4.40	< 0.001
Tactile Sensitivity	31.70 ± 3.18	30.63 ± 3.88	1.70	0.09
Taste/Smell Sensitivity	18.04 ± 3.22	17.00 ± 4.63	1.41	0.16
Movement Sensitivity	14.62 ± .88	13.54 ± 2.30	3.28	0.002
Underresponsive/Seeks Sensation	30.11 ± 4.46	25.72 ± 6.33	4.36	< 0.001
Auditory Filtering	25.73 ± 3.53	22.96 ± 4.53	3.72	< 0.001
Low Energy/Weak	29.15 ± 2.07	26.91 ± 5.07	3.07	0.003
Visual/Auditory Sensitivity	21.95 ± 3.08	19.83 ± 3.74	3.49	0.001
Elevated Numbers of Sensory Symptoms ^a				
	<i>n</i> (%)	<i>n</i> (%)	<i>χ</i> ²	
Total Score	9 (12%)	20 (37%)	10.75	0.001
Tactile Sensitivity	15 (21%)	17 (32%)	1.97	0.16
Taste/Smell Sensitivity	7 (10%)	12 (22%)	3.89	0.048
Movement Sensitivity	4 (6%)	13 (24%)	9.26	0.002
Underresponsive/Seeks Sensation	16 (22%)	27 (50%)	10.93	0.001
Auditory Filtering	12 (16%)	24 (44%)	11.99	0.001
Low Energy/Weak	5 (7%)	13 (24%)	7.57	0.006
Visual/Auditory Sensitivity	9 (12%)	16 (30%)	5.88	0.02

^aComprised of probable or definite difference categories.

Table 3

Linear regression model within the full sample predicting to Short Sensory Profile Total Score.

Outcome	Predictors	R ²	p (model)	B	SE B	β	p (predictor)
SSP Total Score	Constant	0.16	< 0.001	113.35	11.81		< 0.001
	Gestational Age			1.38	0.33	0.38	< 0.001
	Sex			-0.94	3.15	-0.03	0.77
	Maternal Education			2.53	2.24	0.10	0.26
	Twin Status			2.20	4.33	0.05	0.61

Note: SSP Total Score, Short Sensory Profile Total Score; B, unstandardized coefficient; SE B, standard error of B; β , standardized coefficient. Significance set at $p < 0.05$.

Table 4

Executive function and adaptive function scores in preterm children with elevated or typical numbers of sensory symptoms.

Outcome Measure	PT+S M ± SD or n (%)	PT-S M ± SD or n (%)	U, X ² , or t	p
BRIEF-P GEC	64.65 ± 16.38	48.48 ± 11.47	133.00	0.001
EF Battery				
Six Boxes	7.55 ± 1.79	6.82 ± 1.60	247.50	0.07
Verbal Fluency	5.18 ± 5.15	7.27 ± 3.63	106.50	0.08
Day Night	7.00 ± 7.69	6.67 ± 6.09	299.50	0.58
Bird Dragon	8.90 ± 5.90	11.03 ± 4.98	267.00	0.22
Card Sort	3.70 ± 2.52	3.71 ± 2.64	327.50	0.81
Gift Wrap ^a	13 (65%)	10 (31%)	5.68	0.02
Vineland-II ABC	93.25 ± 13.91	98.48 ± 10.79	1.45	0.15

Abbreviations: PT+S, preterm children with elevated numbers of sensory symptoms; PT-S, preterm children with typical numbers of sensory symptoms; U, Mann-Whitney U test; X², Pearson Chi-Square; t, Independent Samples t-test.

^aNumber (%) of children who failed task

Table 5
Spearman correlations between BRIEF-P and SSP subscale scores within the preterm group.

	BRIEF-P GEC	Inhibition	Shift	Emotional Control	Working Memory	Plan/Organize
SSP Total Score	−0.59**	−0.55**	−0.39**	−0.36**	−0.63**	−0.52**
Tactile Sensitivity	−0.21	−0.16	−0.24	−0.10	−0.27	−0.21
Taste/Smell Sensitivity	−0.57**	−0.49**	−0.55**	−0.36*	−0.56**	−0.57**
Movement Sensitivity	0.00	0.10	−0.13	0.21	−0.13	−0.04
Underresponsive/Seeks Sensation	−0.64**	−0.64**	−0.36**	−0.50**	−0.61**	−0.58**
Auditory Filtering	−0.60**	−0.54**	−0.33*	−0.44**	−0.61**	−0.46**
Low Energy/Weak	−0.35*	−0.35*	−0.34*	−0.16	−0.39**	−0.26
Visual/Auditory Sensitivity	−0.33*	−0.33*	−0.17	−0.09	−0.42**	−0.26

Abbreviations: BRIEF-P, Behavior Rating Inventory of Executive Function-Preschool Version; SSP, Short Sensory Profile.

* $p < 0.05$,

** $p < 0.01$