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Early and Concurrent Features of ADHD and Sensory Over-Responsivity Symptom Clusters

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Abstract

Objective—This study aimed to characterize clusters of children based on ADHD and sensory over-responsivity (SOR) symptoms, and to compare their markers.

Method—Parents of 922 infants completed the Infant–Toddler Social and Emotional Assessment (ITSEA) Sensory Sensitivity, Attention, and Activity/Impulsivity scales at three time points during early childhood and the Child Behavior Checklist (CBCL) and SensOR inventory during elementary school age.

Results—Four school-age clusters emerged from the CBCL ADHD and SensOR scores: (a) elevated SOR symptoms only (n = 35); (b) elevated ADHD symptoms only (n = 38); (c) elevated ADHD and SOR symptoms (ADHD + S, n = 35); and (d) low ADHD and SOR symptoms (n = 814). The SOR and ADHD + S clusters had higher early Sensitivity scores than the ADHD and Low clusters. The ADHD and ADHD + S clusters differed from the SOR and Low clusters in their early Attention and Activity/Impulsivity scores.

Conclusion—SOR and ADHD symptoms occur independently and consistently over time.

Keywords

ADHD; sensory over-responsivity; attention; children; cluster analysis

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Declaration of Conflicting Interests

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Introduction

Children with ADHD often experience a variety of sensory modulation disorder (SMD) symptoms including sensory over-responsivity (SOR), under-responsivity, and intense sensation seeking (Mangeot et al., 2001; Parush, Sohmer, Steinberg, & Kaitz, 2007). We focused on SOR as it is the most empirically supported as an independent clinical entity (Reynolds & Lane, 2008) and has been associated with poor social-emotional outcomes in ADHD (Mangeot et al., 2001; Reynolds & Lane, 2009). Children with ADHD have been described as hyper-responsive to stimuli from auditory, tactile, taste, smell, and vision sensory domains (Lane, Reynolds, & Thacker, 2010; Mangeot et al., 2001). Children with ADHD who also have SOR present with distinct behavioral and physiological profiles compared with typically developing children and those presenting with only ADHD (Lane et al., 2010; Miller, Nielsen, & Schoen, 2012; Parush et al., 2007; Reynolds & Lane, 2009); however, current diagnostic classifications of ADHD do not distinguish between the presence/absence of SOR. The co-morbidity of ADHD with SOR (Ahn, Miller, Milberger, & McIntosh, 2004; Parush et al., 2007) suggests that SOR may play a role in differentiating clinically meaningful subtypes of ADHD, with potential intervention implications (Chu & Reynolds, 2007). Estimates of the extent of SOR in children with ADHD vary, from 46% (Lane et al., 2010) to 69% (Parush et al., 2007). These studies were of convenience samples that were comprised largely of clinically referred children, limiting the generalizability of these estimates. This limitation in representativeness is addressed in this study by relying upon an epidemiological sample.

Sensory problems in children with ADHD have been associated with an increased likelihood of delinquency and aggression problems (Mangeot et al., 2001, $n = 19$ with ADHD; Miller et al., 2012, $n = 12$ out of 47 children with ADHD also had SMD as well as with higher levels of anxiety (Reynolds & Lane, 2009, $n = 13$ out of 24 with ADHD also had SMD). In addition, sensory symptoms in ADHD have been linked with lower performance and functioning in school and home (Dunn & Bennett, 2002, $n = 70$ with ADHD) as well as lower participation in a variety of leisure activities (Engel-Yeger & Ziv-On, 2011, $n = 29$ with ADHD). SOR may be a factor that exacerbates functional impairments in ADHD and requires a particular intervention approach (Ghanizadeh, 2011). This evidence underscores the importance of evaluating sensory symptoms in children with ADHD and of early identification of this subset of children. The goal of this study was to examine the prevalence of ADHD and SOR symptom clusters and their early manifestation.

In another report from this cohort, we found that early sensitivities predicted SOR at school age (Ben-Sasson, Carter, & Briggs-Gowan, 2010), demonstrating continuity in SOR symptom presentation. There is also evidence for continuity in attention skills from infancy to school age (von Stauffenberg & Campbell, 2011). At the same time, the evidence indicates that children with ADHD show early sensory sensitivity to environmental stimuli and difficulty adjusting to change in infancy before their attention, hyperactivity, and impulsivity problems become noticeable (Kaplan, Sadock, & Grebb, 1994). Understanding the unique early indicators of children who at school age have SOR and/or ADHD is critical for referral to adequate services and for the design of targeted interventions delivered before these conditions fully develop. Preliminary evidence shows promising outcomes of a multifaceted psycho-educational intervention program for children with ADHD that addresses sensory symptoms (Chu & Reynolds, 2007).

Dimensional Classification

Most of the reviewed studies applied a clinical classification of ADHD and SOR subgroups based on the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM*) and/or clinical referral criteria. As such, children with subthreshold symptoms such as symptoms that occur in only one setting or a symptom profile limited to five rather than six symptoms of ADHD are not included. In contrast, Healey, Gopin, Grossman, Campbell, and Halperin (2010) studied children who did *not* meet full *DSM* (*DSM-IV*; American Psychiatric Association [APA], 1994) criteria for ADHD, rather had at least six symptoms across settings. Nonetheless, children in their sample had functional impairments, supporting a broader classification approach. The present study adopted a dimensional clustering approach because both ADHD (Larsson, Anckarsater, Råstam, Chang, & Lichtenstein, 2012) and SOR (Goldsmith, Van Hulle, Arneson, Schreiber, & Gernsbacher, 2006) symptomatology are continuous constructs that vary among typically developing children. By using a dimensional approach, we aimed to capture children who have elevated symptoms in multiple domains and hence are equally impaired (i.e., early manifestations) as those who are extremely elevated in a single domain. Dimensional classification also enabled us to capture a larger subgroup with elevated symptoms in both domains than has been previously possible with categorical approaches (e.g., Miller et al., 2012).

Sex Differences in SOR and ADHD

The presence of SOR in children with ADHD has been inconsistently linked with child sex. Some studies have not identified differences between girls and boys with ADHD in their overall SOR symptoms (Iwanaga, Ozawa, Kawasaki, & Tsuchida, 2006; Miller et al., 2012) or specifically in the tactile domain (Ghanizadeh, 2008). Nonetheless, there are studies that suggest that girls tend to have more severe SOR than boys, particularly in the tactile domain. Examining SMD alone, girls have been reported to show higher levels of physiological arousal than boys during the structured administration of a series of sensory stimuli (Schoen, Miller, Brett-Green, & Nielsen, 2009). In a population twin study using parent report, sex differences appeared to be specific to the tactile domain with girls having a significantly higher rate of tactile over-responsivity than boys, but similar levels of auditory over-responsivity (Goldsmith et al., 2006). These differences were replicated within a sample of children with ADHD, with girls with ADHD presenting with higher levels of tactile over-responsivity than boys with ADHD, while boys with ADHD did not differ in tactile over-responsivity from typically developing boys (Broring, Rommelse, Sergeant, & Scherder, 2008). These inconsistencies in sex differences may be due to differences in methodology such as focusing on modality versus broader over-responsivity, criteria for defining over-responsivity, and sampling of clinical versus normative samples. Based on this evidence, we examined sex differences in the statistical models and hypothesized that girls would show higher levels of SOR specifically in the tactile modality compared with boys.

The research questions addressed in this study were as follows:

Research Question 1: What clusters emerge when school-age children are grouped on the basis of their SOR and ADHD symptoms?

Research Question 2: Are there sex differences within and across clusters in tactile and auditory SOR scores?

Research Question 3: How do children in the ADHD and SOR based clusters at school age differ with respect to early manifestations of sensory sensitivity and attention problems across three time points in early childhood?

Method

Participants

Participants included parents followed longitudinally, initially selected randomly from birth records provided by the State of Connecticut Department of Public Health for births at Yale New Haven Hospital from July 1995 to September 1997 to families living in the regional Standard Metropolitan Statistical Area of the 1990 Census. Children were eligible if they were born healthy (see Briggs-Gowan, Carter, Skuban, & Horwitz, 2001 for full details about sampling and retention). Only one child per family was eligible. Children who were of low birth weight (<2,200 grams), premature (gestational age <36 weeks), had birth complications likely to be associated with developmental delay, or who had been adopted were ineligible. A random probability sample of 1,788 was drawn from a total eligible sample of 7,433. The sample was selected to have equal proportions of boys and girls and to be equally distributed between 11 and 35 months of age. After initial sampling, the following inclusion criteria were applied: (a) at least one parent able to participate in English (excluded $n = 50$), (b) child still in the custody of biological parent (excluded $n = 17$), and (c) family living in the State (excluded $n = 116$). Two children were excluded because the only available biological parent was severely ill. Despite a year of intensive searching, 112 children were excluded because the family could not be located to verify eligibility. Compared with the post-sampling ineligible sample ($n = 297$), the final eligible sample of 1,491 was significantly higher in birth weight, paternal and maternal age, maternal education, and years at the birth address, and less likely to be of minority ethnicity (t values range from 2.84 to 6.26, $p < .01$); but these differences were small in magnitude (Cohen's d range from 0.18 to 0.41). There were no significant differences in gestational age, paternal education, or child sex.

After exclusions, 1,329 families participated in one or more of surveys of three annual surveys when children were between the ages of 12 and 48 months (early childhood surveys), with a response rate of 89%. Participants ($n = 1,329$) and non-participants ($n = 162$) were similar in socio-demographic characteristics and child birth weight and gestational age. Participants were also socio-demographically comparable with the Census region from which the sample was drawn.

Participants from the early childhood surveys were contacted at school age and invited to complete school-age surveys in the spring of the second grade year. Due to time required to locate families and obtain participation, some families did not participate until the child was in third grade, resulting in a second-grade/third-grade survey. Seventeen children were excluded from the study on the basis of significant genetic disorders or developmental delays that were identified in the course of the early childhood or school-age survey, resulting in an eligible sample of 1,312. A total of 1,039 families participated (79% retention rate from early childhood to school age). The families who were lost to follow-up (n = 273) were more likely to have lower maternal and paternal education, be living in poverty, be living in a single parent household, and be of minority ethnicity than the retained sample (*chi-square* ranged from 7.10 to 45.00, p < .01, *phi* ranged from −0.08 to −0.19). The effect sizes for these differences were small (*phi* = 0.08–0.19). The Sensory Over-Responsivity inventory (SensOR; Schoen, Miller, & Green, 2008) was added to the school-age survey after data collection had begun and thus was obtained for 925 families (71% of the school-age sample). This subsample did not differ significantly from the full school-age sample in demographic features. The final school-age sample included in this study was comprised of 922 children who had school-age surveys with SensOR and Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001) scores. One additional child, identified as an outlier and confirmed to be receiving special education services, was dropped from further analyses. Children were between 7 and 11 years (M = 8.08, SD = 0.52). Of this sample, 48% were boys and 69% were White. Most informants had a partner (83%), were working (92%), and had an education level that was greater than high school (90%).

To investigate differences in early sensory and attention symptoms across the school-age clusters, children were grouped based on their age at the time of parent survey completion, irrespective of wave of data collection, with only one score entered for each child at each time point. Thus, the first time point included children below 24 months (n = 520, M = 18.26, SD = 3.85), the second time point included children between 24 and 36 months (n = 866, M = 30.00, SD = 3.37), and the third time point included children above 36 months (n = 711, M = 41.14, SD = 3.00). Thirty-three percent of the parents rated their child at all three early childhood assessment time points (n = 305), 58.7% at two time points (n = 541), and 8% at one time point (n = 74).

Procedure

Five surveys have been completed since the study began in 1998, with separate parent consent obtained at each time point. The current study describes the first, second, third, and fifth surveys in the first 3 years of data collection (at ages 1–3 years) and at elementary school. Among other measures, the first 3 surveys included the Infant–Toddler Social and Emotional Assessment (ITSEA) questionnaire and demographic information, whereas the fifth survey included the SensOR inventory and CBCL. Parents received US$25 for each of the first three surveys and US$30 for the fifth survey.

Measures

Sensory Over-Responsivity Inventory (SensOR)—This questionnaire is a component of the Sensory Processing Scales. The inventory includes 76 items that describe sensations in all sensory domains that may bother a child (Schoen et al., 2008). In the present study, 41 items from the auditory and tactile modalities were included as sensitivities in these modalities are most frequently reported (e.g., Royeen & Fortune, 1990). Parents are asked to mark all items that apply to their child. Items are divided into five lists that assess tactile over-responsivity (garments, activities, experiences, surfaces, and materials) and three lists that assess auditory over-responsivity (specific sounds, background noises, and loud places). A total over-responsivity score as well as tactile and auditory modality scores are computed.

This inventory was validated through factor and reliability analyses as well as discriminant analysis. Scores on this measure were highly correlated with comparable scores on the Short Sensory Profile (Dunn, 1999) or Adult Sensory Profile (Brown & Dunn, 2002; see Schoen et al., 2008). Schoen and colleagues (2008) found that the sensitivity and specificity of the SensOR inventory in differentiating children with SOR ($n = 101$) from typically developing children ($n = 120$) were the highest (sensitivity = 69.09, specificity = 84.16) when at least four tactile *or* auditory items were present.

Previous publication from this cohort demonstrated that internal consistency of the SensOR was good as indicated by Cronbach's alpha of .74. There was no item that if deleted improved the consistency of the total, tactile, or auditory scales. The auditory and tactile scales' scores were significantly, but moderately, correlated ($r = .50$, $p < .001$; Ben-Sasson, Carter, & Briggs-Gowan, 2009).

CBCL—The CBCL is comprised of 113 items across three domains, namely, Internalizing, Externalizing, and Total Problems (Achenbach & Rescorla, 2001). Caregivers rate items from 0 "not true" to 2 "very true or often true." In addition, the CBCL provides *DSM* oriented scores, one of which is the ADHD problem scores that were applied in the current study. The CBCL for ages 6 to 18 has demonstrated good test–retest reliability ($r = .91$–.94 for the domains), cross-informant agreement (mother–father, $r = .72$–.85), and success in discriminating between referred and nonreferred children (Achenbach & Rescorla, 2001).

The ITSEA—The ITSEA is a parent report measure of socialemotional and behavioral problems and competencies in infants and toddlers (Carter & Briggs-Gowan, 2006). Parents rate their child's behavior in the past month on a 3-point scale from 0 "not true/rarely" to 2 "very true/often." This measure yields three problem domain scores: Internalizing, Externalizing, and Dysregulation and a Competence domain. In this study, we focused on the Sensitivity scale from the Dysregulation domain and the Attention scale from the Competence domain. Scores are interpreted both as continuous dimensions and relative to the 90th percentile cutoff points. The ITSEA has adequate psychometric properties, with good validity and test–retest and interrater reliability (Carter & Briggs-Gowan, 2006).

Data Analysis

Standard cluster analytic techniques were used to group children based on their standardized SOR total scores and CBCL *DSM* ADHD scores in elementary school. As a preliminary step to determine the appropriate number of clusters for the final solution, we used Ward's agglomerative hierarchical method to cluster cases (Gore, 2000). We then examined the values in the squared Euclidean distance matrix resulting from this algorithm to determine the optimal number(s) of clusters for the final cluster solution (Mandara, 2003). Finally, we used the K-means clustering algorithm, a partitioning method, to derive the final cluster solution, with the number of groups set based on the results of Ward's algorithm. To more deeply understand sensory and sex differences across clusters, two MANOVAs were conducted. First, a MANOVA was performed mainly to determine the presence of a cluster, sex, and cluster-by-sex interactions for the SOR total score and CBCL ADHD symptoms. Next, a MANOVA was conducted examining the main cluster, sex, and cluster-by-sex effects for two prominently involved sensory modalities, tactile and auditory over-responsivity, controlling for CBCL ADHD score.

Missing data analysis indicated that data were not missing completely at random (MCAR), Little's MCAR test: $\chi^2(744) = 1{,}804.37$, $p > .00$. None of the Year 1 cluster predictor variable data were missing. For the first 2 years, less than 5% of the data were missing for ITSEA Sensitivity or Attention. Because outcome variables had more than 12% of missing data at Year 3, multiple imputation method was implemented to utilize the full sample, thus maximizing power. This method is effective even with non-missing at random data (Schafer & Graham, 2002). The statistics presented are mean values across the five imputed data sets to increase reliability and confidence in findings. Ranges across data sets are available upon request. Preliminary analyses indicated that there was no significant interaction between cluster and sex for the ITSEA scores ($p > .20$); therefore, combined differences for boys and girls are presented. Repeated-measures MANOVA was conducted to examine cluster, year, and year-by-cluster effects for longitudinal ITSEA Attention, Activity/Impulsivity, and Sensitivity scores.

Results

Cluster Analysis

The distance matrix resulting from the application of Ward's agglomerative hierarchical algorithm to the data demonstrated support for either a six-cluster or three-cluster solution. Thus, we used the K-means algorithm to derive both a three-cluster solution and a six-cluster solution and then compared these solutions. While both the three-cluster solution and the six-cluster solution produced groups that differed significantly in their CBCL *DSM* ADHD and SOR scores, the six-cluster solution provided superior differentiation of these symptoms across groups (based on the effect size attributed to the cluster variable). As a result, the six-cluster solution was selected.

The six-cluster solution resulted in the following mutually exclusive clusters: (a) Low Symptoms cluster ($n = 424$), (b) Elevated SOR Only cluster (SOR: $n = 35$), (c) Elevated ADHD Only cluster (ADHD: $n = 38$), (d) Elevated ADHD and SOR cluster (ADHD + S; $n = 35$), (e) Mild SOR Only cluster ($n = 179$), and (f) Mild ADHD Only cluster ($n = 211$). In subsequent analyses, the two Mild and the Low Symptom clusters were combined ($n = 814$) and labeled Low cluster based on their similarly low frequency of SensOR and CBCL ADHD symptoms (see Figure 1 and Table 1).

Sex Differences

The percentage of boys and girls was not equally distributed across the clusters, $\chi^2(3) = 16.67$, $p = .001$. Pairwise Fisher's exact test comparisons showed that the elevated ADHD symptom cluster had a significantly higher percentage of boys (78.9%) relative to the other clusters (41%–58%, $p < .05$ for all three pairwise comparisons), which did not differ from one another.

A MANOVA was conducted examining cluster, sex, and cluster by sex interaction effects for SOR total and CBCL ADHD symptoms. As expected, given that the SOR and ADHD scores were entered into the cluster analysis, there was a significant cluster effect, Wilks's Lambda = 0.26, $F(6, 1826) = 293.94$, $p < .001$, $\eta^2 = .49$. There also was a significant cluster by sex interaction effect, Wilks's Lambda = 0.98, $F(6, 1826) = 2.43$, $p = .03$, $\eta^2 = .01$, but no main effect of sex ($p = .78$). The sex by cluster interaction effect was significant for the CBCL ADHD score ($p = .03$) but not for the SOR total score ($p = .11$). Pairwise comparisons (see Table 1) indicated that CBCL ADHD scores were significantly higher in boys relative to girls in the Low cluster; no other differences were observed. Thus, boys were both over-represented in the ADHD cluster and demonstrated higher CBCL ADHD scores than girls within the Low cluster.

This sex by cluster interaction effect supported the inclusion of the CBCL ADHD score as a covariate in the examination of cluster by sex differences in the manifestation of different types of sensory sensitivities. Previous research has suggested sex differences in both specific sensory modalities (Goldsmith et al., 2006) and in the rate of ADHD diagnoses (Broring et al., 2008). Hence, to better understand the sensory differences between clusters, we conducted a MANOVA examining cluster, sex, and cluster by sex interaction effects separately for tactile and auditory over-responsivity controlling for CBCL ADHD symptoms. There was a significant cluster, Wilks's Lambda = 0.46, $F(6, 1826) = 113.89$, $p < .001$, $\eta^2 = .32$, and cluster by sex effect, Wilks's Lambda = 0.98, $F(6, 1826) = 2.81$, $p = .01$, $\eta^2 = .01$, but no sex effect ($p = .14$).

The cluster effect was significant for both tactile and auditory scores—$F(3, 913) = 243.53$, $p < .001$ and $F(3, 913) = 143.36$, $p < .001$, respectively. See Table 1 for pairwise comparisons. Noteworthy is the finding that the SOR cluster had significantly higher tactile scores compared with the ADHD + S cluster ($p < .001$), but they did not differ in their auditory scores ($p > .05$).

Univariate analysis indicated that the cluster by sex interaction was significant for the tactile score, $F(3, 913) = 3.22$, $p = .02$, but only marginally significant for the auditory score, $F(3, 913) = 2.18$, $p = .09$. We were interested in unpacking the cluster by sex effect for tactile scores. Examination of pairwise comparisons of tactile scores indicated that the cluster by sex effect likely reflected marginally higher scores in girls ($n = 16$) than boys ($n = 19$) within the ADHD + S cluster ($p = .06$, Cohen's $d = 0.69$). Boys and girls in the other clusters did not differ significantly in their tactile scores.

Early Differentiating Markers

To evaluate the discriminant validity of the four clusters, ITSEA Sensitivity, Attention, and Activity/Impulsivity scores across early childhood Years 1, 2, and 3 were compared across clusters (see Figures 2a–2c). Pooled repeated-measures MANOVA results of the three measures at three time points for the four clusters indicated significant cluster, Wilks's Lambda = 0.86, $F(9, 2229.45) = 14.30$, $p < .001$, $\eta^2 = .05$; year, Wilks's Lambda = 0.93,

$F(6, 913) = 9.61$, $p < .001$, $\eta^2 = .07$; and year-by-cluster effects, Wilks's Lambda = 0.92, $F(18, 2582.84) = 3.40$, $p < .001$, $\eta^2 = .02$.

Pooled univariate test results showed that the *cluster effect* was due to significant differences in early Sensitivity scores, $F(1, 918) = 22.60$, $p < .001$, $\eta^2 = .08$; Attention Skills scores, $F(1, 918) = 18.51$, $p < .01$, $\eta^2 = .02$; and in Activity/Impulsivity scores, $F(1, 918) = 6.24$, $p = .04$, $\eta^2 = .09$. Results from pooled Tukey's post hoc tests showed that children in the SOR and ADHD + S clusters had significantly higher Sensitivity scores than in the Low and ADHD clusters ($p < .001$). Attention scores were lower in the ADHD and ADHD + S clusters than in the Low symptoms cluster ($p < .04$). Activity/Impulsivity scores were higher in the SOR, ADHD, and ADHD + S clusters compared with the Low cluster ($p < .01$). The ADHD and ADHD + S clusters had marginally ($p = .08$) higher Activity/Impulsivity scores than the SOR cluster.

Pooled univariate tests for *year-by-cluster effects* were significant for all scores, revealing that clusters differed in their patterns of change over time in each of the ITSEA scales; Sensitivity, $F(6, 1836) = 4.06$, $p = .001$, $\eta^2 = .01$; Attention, $F(6, 1836) = 2.49$, $p = .05$, $\eta^2 = .01$; and Activity/ Impulsivity, $F(6, 1836) = 5.34$, $p < .001$, $\eta^2 = .02$. We were interested in characterizing the differences in patterns of change in early childhood within each cluster. Therefore, we conducted univariate repeated-measures analysis models of Sensitivity, Attention, and Activity/Impulsivity scores in Years 1, 2, and 3 within cluster. Table 2 presents pooled pairwise comparisons between years within each cluster and between clusters within year. All clusters showed a significant increase in Sensitivity; however, the SOR and ADHD + S clusters started and ended higher. Attention competencies significantly increased across years in the Low cluster and increased from Year 1 to Year 2 in the SOR cluster and then remained steady. In contrast, Attention competencies did not increase across years in the ADHD and ADHD + S clusters. Activity/Impulsivity symptoms significantly decreased across years in the Low cluster and decreased between Years 1 and 3 in the SOR cluster. In contrast, Activity/Impulsivity was stable across years in the ADHD and ADHD + S clusters.

Discussion

The clusters that emerged from this study highlight the cooccurrence of SOR and ADHD symptoms strengthening previous research that has differentiated children with ADHD based on the presence or absence of SOR (Lane et al., 2010; Miller et al., 2012; Parush et al., 2007; Reynolds & Lane, 2009). What is unique to our study is that these patterns were found in a representative birth-cohort rather than a clinical sample and using a dimensional rather than diagnostic categorization approach. In a previous publication with a subset of our sample that had undergone a diagnostic evaluation, we reported that 24% of those with an elevated SOR score met criteria for any *DSM-IV* diagnosis (including 62% with ADHD) and 25.4% of children with a *DSM-IV* diagnosis had an elevated SOR score (Carter, Ben-Sasson, & Briggs-Gowan, 2012). In this broader school-age sample, 48% of those with elevated ADHD symptoms had elevated SOR and 50% of those with SOR had ADHD symptoms. These rates are similar to previous reports of the prevalence of SOR within children with ADHD (Lane et al., 2010). Diagnostic assessment requires meeting criteria such as prolonged duration, pervasiveness of symptoms across contexts and relationships, and associated functional impairment. Nonetheless, our findings suggest that children who have elevated symptoms in both areas have an extreme early profile that is similar to those with extreme symptoms in one area.

Our findings have direct clinical implications for the differentiation of children with elevated SOR symptoms only, elevated ADHD symptoms only, and those with elevated ADHD and SOR symptoms. The ADHD + S cluster could be differentiated from those with SOR only by their lower concurrent tactile scores. At the same time, these clusters shared extreme early sensitivities as well as concurrent elevated auditory scores. The finding that the SOR and ADHD + S groups differed with respect to tactile, but not auditory, scores is consistent with previous evidence (Lane et al., 2010). The consistency of this finding suggests that attending not only to SOR broadly but also to specific modalities may be clinically important. While SOR is prevalent in many developmental disorders, attending to specific modality scores may help clinicians and researchers to identify profiles that are unique to idiopathic SOR versus SOR that accompanies other developmental disorders. This has implications for intervention as some techniques are focused on specific sensory modalities such as auditory filtering techniques and visual therapies (Baranek, 2002). Research supports the efficacy of sensory interventions for children with ADHD consisting of techniques that addressed specific modalities such as the auditory system (sound-based intervention; Hall & Case-Smith, 2007). A few studies indicate that stimulant medication for children with ADHD affect modality specific sensory problems in the olfactory (Romanos et al., 2008) and auditory modalities (Ozdag, Yorbik, Ulas, Hamamcioglu, & Vural, 2004). More intervention research will allow examining differential intervention responses between such clusters.

Girls with elevated ADHD symptoms appear to be at unique risk of the presence of tactile over-responsivity, a specific form of SOR. Girls in the elevated ADHD + S cluster had higher tactile scores than boys, consistent with previous evidence in children with ADHD (Broring et al., 2008) and with previously noted sex differences in twin research of tactile and auditory over-responsivity regardless of ADHD symptomatology (Goldsmith et al., 2006). This provides another aspect to the reports of differences in symptom presentation for ADHD in girls relative to boys (Biederman et al., 2002; Broring et al., 2008) and suggests a need for closer attention to tactile problems in girls with ADHD.

The patterns of early changes in attention competencies, activity/impulsivity, and sensitivity problems suggest that difficulties in these areas that emerge early in childhood may be risk markers for later elevations in SOR and ADHD in school years. Initial high levels of early sensitivity symptoms in Years 1, 2, and 3 differentiated the ADHD + S and SOR clusters relative to the Low and ADHD clusters. In the attention domain, ADHD and ADHD + S clusters showed poorer attention competencies as well as elevated activity/impulsivity in early childhood than the Low cluster. These two ADHD clusters were also distinct in their lack of typical growth in attention competencies and lack of typical decline in levels of activity/impulsivity during early childhood compared with both SOR and Low clusters. In contrast to our prediction, within-year comparisons showed that most of the early attention and over-activity scores of the SOR cluster did not clearly differ from the ADHD and

ADHD + S clusters. It is possible that infants who later on present with SOR also show difficulties in attention and activity level in infancy. For these infants, distractibility and over-activity may be an outcome of their constant over-arousal and hyper-vigilance toward sensory stimuli. These findings provide clinical insight into the early developmental patterns of the dimensional clusters we identified.

Limitations

The school-aged inventory implemented focused on tactile and auditory SOR; however, there are reports of over-responsivity in other modalities as well in ADHD (Ghanizadeh, 2011; Lane et al., 2010; Miller et al., 2012). Measuring the profile of sensitivities across modalities in infancy and school age is important for designing and studying effective interventions to address sensory needs. Further research extending the search for common underlying mechanisms for those with early regulatory disorders and later ADHD + S would provide insight into the underpinnings of the link between SOR and ADHD. Finally, the non-significant results in the cross-sectional and longitudinal interactions tested may be a function of limited power.

Because individuals with intellectual disabilities have been shown to display elevated rates of sensory symptoms (Gorman, 1997; Wuang, Wang, Huang, & Su, 2008) and the inverse relation between ADHD symptoms and IQ (Frazier, Demaree, & Youngstrom, 2004; Seidman, Biederman, Monuteaux, & Doyle, 2001; Simonoff, Pickles, Wood, Gringras, & Chadwick, 2007), it would be warranted to examine the impact of intelligence when exploring the bidirectional relation between ADHD and SOR. This line of research would help determine whether SOR and ADHD and their comorbid associations with one another may be due to shared underlying cognitive issues that might contribute to both or their overlap.

Conclusion

Our findings indicate that children displaying elevated ADHD and SOR symptoms at an early age continue to present with this profile into school age. While evaluating the profile of a child's sensitivities across sensory modalities is important for the purpose of addressing his or her sensory needs, the tactile modality may be particularly useful for differentiating those with only SOR from those with SOR combined with ADHD. SOR is rarely considered in a broader mental health evaluation of school-age children with poor inhibition and impulsive and hyperactive behaviors. There is a need for mainstreaming the identification of SOR symptoms in children undergoing an ADHD diagnostic evaluation to rule out misdiagnosis and determine comorbidity. While this study aimed to establish school-age SOR and ADHD symptom clusters and compare the early manifestations of sensory sensitivity and attention problems across these clusters, future research should explore the bidirectional relation between ADHD and SOR symptoms in early childhood. Examining this relation would help distinguish the onset of these symptoms, thus aiding in the establishment of causal inference.

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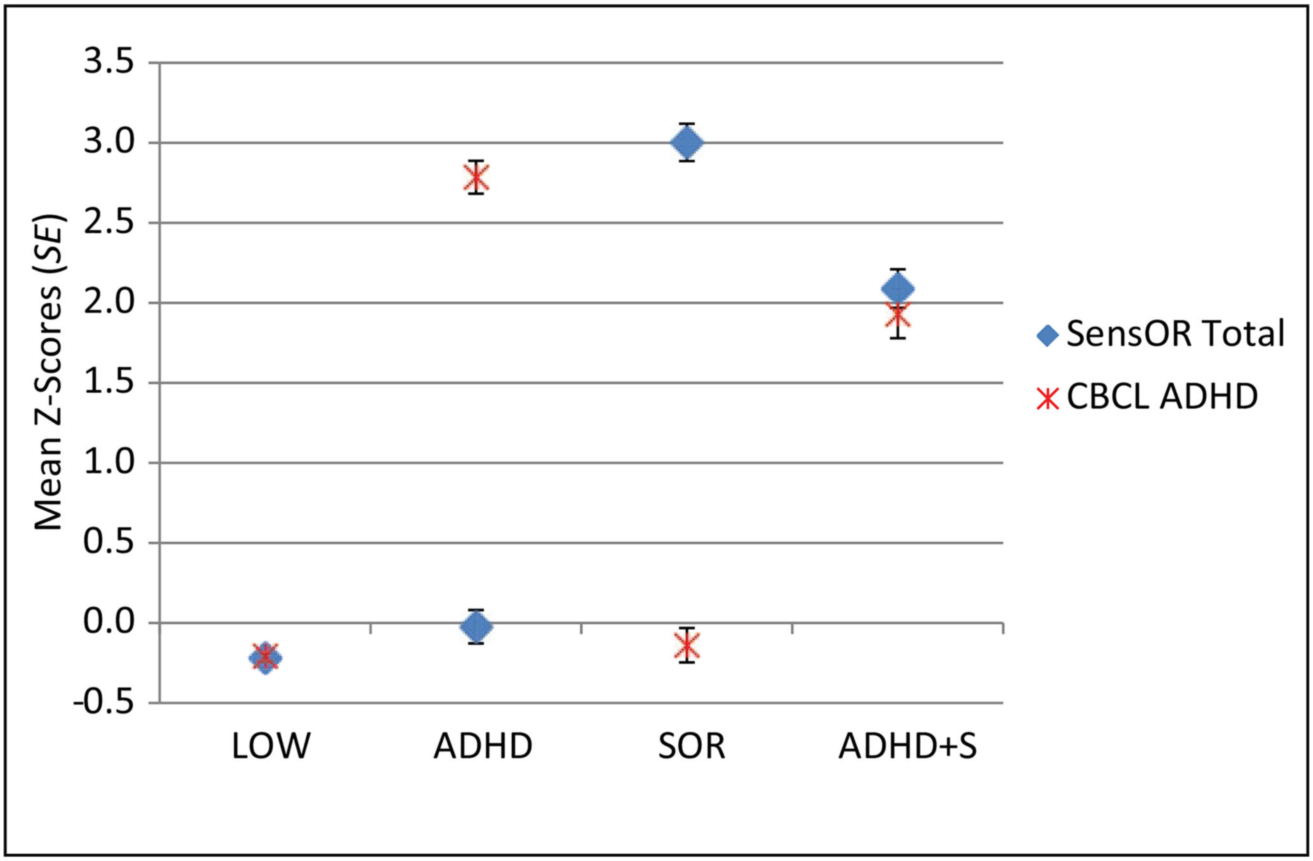
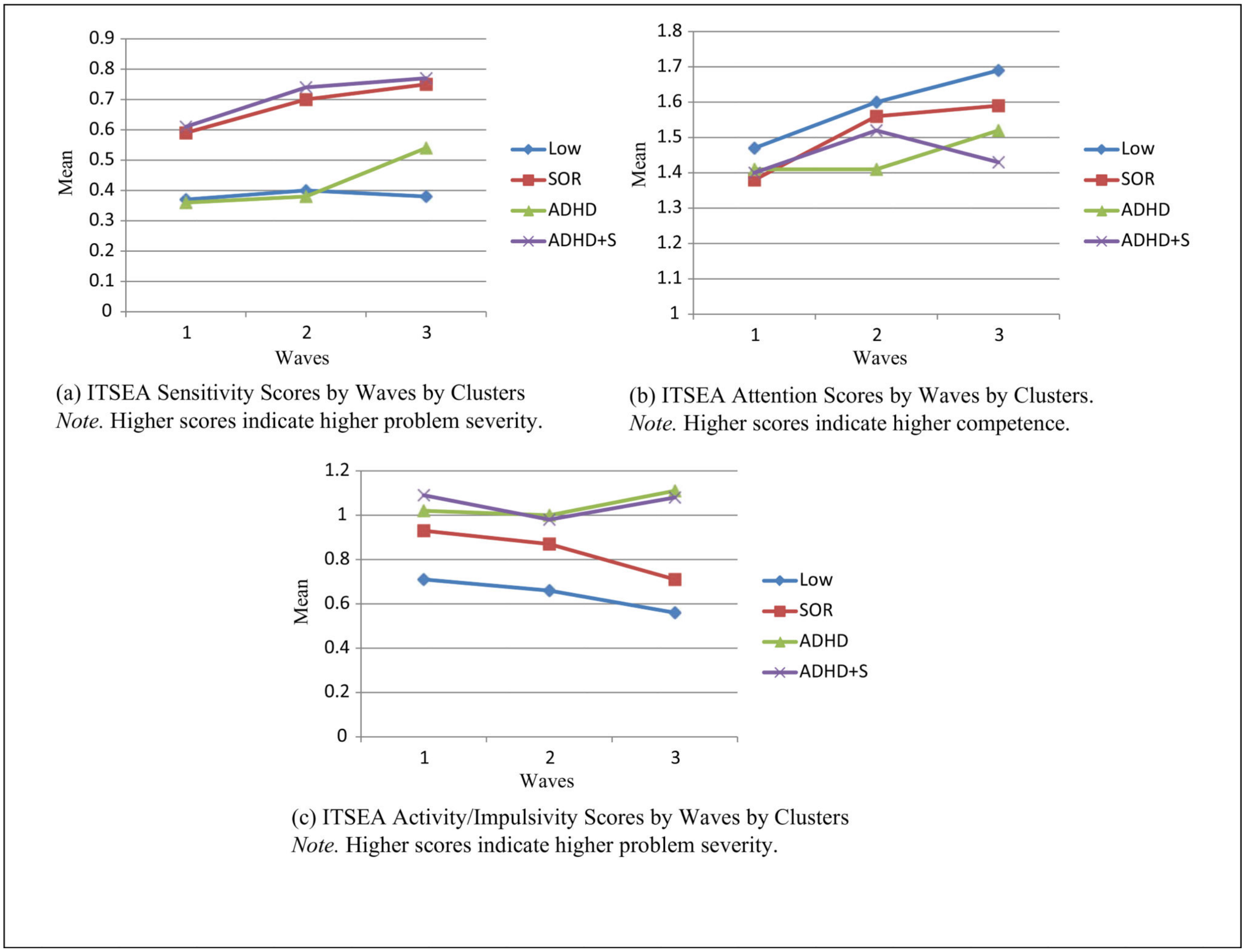


Figure 1.
Cluster centers.
Note. CBCL = Child Behavior Checklist.



(a) ITSEA Sensitivity Scores by Waves by Clusters
Note. Higher scores indicate higher problem severity.

(b) ITSEA Attention Scores by Waves by Clusters.
Note. Higher scores indicate higher competence.

(c) ITSEA Activity/Impulsivity Scores by Waves by Clusters
Note. Higher scores indicate higher problem severity.

Figure 2.

ITSEA Scores by Wave by Cluster (pooled imputed datasets).

Note. SOR = sensory over-responsivity; ITSEA = Infant-Toddlers Social and Emotional Assessment.

Table 1

Means (*SDs*) of SensOR Inventory and CBCL ADHD Scores by Cluster and Sex.

	Low symptoms			Elevated SOR			Elevated ADHD			Elevated ADHD + SOR		
	Boys *n* = 374	**Girls *n* = 440**	**Full *N* = 814**	**Boys *n* = 18**	**Girls *n* = 17**	**Full *N* = 35**	**Boys *n* = 30**	**Girls *n* = 8**	**Full *N* = 38**	**Boys *n* = 19**	**Girls *n* = 16**	**Full *N* = 35**
CBCL ADHD	**2.08** (2.09)	**1.49** (1.68)	1.76_a (1.90)	1.94 (1.89)	1.94 (1.56)	1.94_a (1.71)	9.83 (1.74)	9.75 (1.70)	9.82_b (1.71)	6.95 (2.25)	8.19 (2.48)	7.51_c (2.41)
SensOR Inventory												
Total SOR	1.77 (1.69)	1.80 (1.78)	1.78_a (1.74)	10.33 (1.91)	9.94 (1.68)	10.14_b (1.78)	2.53 (1.59)	1.38 (1.77)	2.29_a (1.68)	7.32 (1.57)	8.31 (2.06)	7.77_c (1.85)
Tactile	1.41 (1.33)	1.35 (1.34)	1.38_a (1.34)	6.94 (1.63)	7.18 (1.67)	$7.06_{a,b}$ (1.63)	1.90 (1.27)	1.00 (1.41)	1.71_a (1.33)	4.42 (1.57)	5.69 (2.27)	5.00_c (2.00)
Auditory	0.36 (0.76)	0.45 (0.88)	0.41_a (0.83)	3.39 (2.03)	2.76 (1.30)	3.09_b (1.72)	0.63 (1.07)	0.38 (1.06)	0.58_a (1.06)	2.89 (1.66)	2.63 (1.82)	2.77_b (1.72)

Note. Significant results from pairwise comparisons within cluster are presented by the bolded numbers showing that boys and girls within that cluster differed at $p < .05$. Clusters with different subscript letters are significantly different at $p < .05$.

CBCL = Child Behavior Checklist; SOR = sensory over-responsivity.

Table 2

Differences in Clusters' Means (*SDs*) in ITSEA Scores Within and Over Time in Early Childhood.

	Low symptoms ***n*** **= 814**	**Elevated SOR** ***n*** **= 35**	**Elevated ADHD** ***n*** **= 38**	**Elevated ADHD + SOR** ***n*** **= 35**
ITSEA sensitivity				
Year 1	0.37 (0.29)$_{a,1}$	0.59 (0.45)$_{a,2}$	0.36 (0.30)$_{a,1,2}$	0.61 (0.34)$_{a,2}$
Year 2	0.40 (0.31)$_{b,1}$	0.70 (0.46)$_{b,2}$	0.38 (0.33)$_{a,1}$	0.74 (0.38)$_{b,2}$
Year 3	0.38 (0.32)$_{b,1}$	0.75 (0.42)$_{b,2}$	0.54 (0.37)$_{b,1}$	0.77 (0.42)$_{b,2}$
ITSEA attention				
Year 1	1.47 (0.41)$_{a,1}$	1.38 (0.39)$_{a,1}$	1.41 (0.45)$_{a,1}$	1.40 (0.51)$_{a,1}$
Year 2	1.60 (0.33)$_{b,1}$	1.56 (0.29)$_{b,1,2}$	1.41 (0.37)$_{a,2}$	1.52 (0.41)$_{a,1,2}$
Year 3	1.69 (0.31)$_{c,1}$	1.59 (0.26)$_{b,1,2}$	1.52 (0.35)$_{a,2}$	1.43 (0.41)$_{a,2}$
ITSEA activity/impulsivity				
Year 1	0.71 (0.43)$_{a,1}$	0.93 (0.38)$_{a,2}$	1.02 (0.45)$_{a,2}$	1.09 (0.50)$_{a,2}$
Year 2	0.66 (0.40)$_{b,1}$	0.87 (0.40)$_{a,2}$	1.00 (0.47)$_{a,2}$	0.98 (0.46)$_{a,2}$
Year 3	0.56 (0.44)$_{c,1}$	0.71 (0.43)$_{b,1}$	1.11 (0.45)$_{a,2}$	1.08 (0.49)$_{a,2}$

Note. Pooled means and *SD*s are presented across imputed data sets. Higher Sensitivity and Activity/Impulsivity scores indicate more problems whereas higher attention scores indicate higher competencies. Years with different subscript letters are significantly different within cluster at $p < .05$. Clusters with different subscript numbers are significantly different within year at $p < .05$.

ITSEA = Infant–Toddler Social and Emotional Assessment; SOR = sensory over-responsivity.