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The Development of Sensory Over-responsivity From Infancy to Elementary School

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Abstract Some infants experience atypical levels of over-responsivity to sensations, which limit their ability to interact and explore their environment. Yet, little is known about typical development of over-responsivity during infancy or whether the presence of extreme over-responsivity in infancy is a predictor of clinically significant sensory over-responsivity (SOR) at school-age. This study followed a representative sample of children (n=521, 47% boys) at four time points from infancy (mean ages in months Year 1=18.23, Year 2=30.39, Year 3=39.40) to elementary school-age (mean age=7.97 years). SOR was measured via parent report. A latent growth curve model predicting SOR at school age from the intercept and slope of Sensory Sensitivity between Years 1–3 showed excellent fit with the data. Both early sensory sensitivities and change in early sensitivities were associated with SOR status at school-age.

Keywords Sensory over-responsivity · Sensitivity · Sensory modulation · Growth curve model · Developmental trajectories · Infancy · School-age

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The ability to modulate sensory responses to the environment emerges early in life as a protective and discriminative mechanism (Dunn 1997). As children grow they typically become better at tolerating uncomfortable sensory stimuli, applying self-regulation strategies, and engaging with novel sensory experiences (Baranek et al. 2007). Sensory over-responsivity (SOR) reflects a failure in achieving a balance between sensitization (i.e., noticing novel or threatening stimuli) and habituation (i.e., adapting to familiar stimuli). Although individuals are known to differ in their normative level of responsiveness to sensations in terms of frequency, type, and/or intensity of response (Dunn 1997), there is no empirical data about the normal developmental course of sensory responsiveness in typically developing children. Drawing from the more general emotion regulation literature, one may expect increases in the self-regulation of sensory responsiveness with maturation. However, it is currently unclear whether there are developmental shifts in sensory over-responsiveness in early childhood (i.e., normative increases or decreases) or whether there is individual continuity in a child's level of sensory over-responsiveness from infancy to elementary school.

Understanding normative developmental patterns of reactivity to sensations in early childhood may inform the early identification of those children who do not habituate at a typical rate to the sensations around them and are overly sensitive to input to a degree that is impairing and warrants intervention. Specifically, if the frequency and/or

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intensity of responsivity to sensation are relatively stable in the general population across infancy then acceleration or changes in level of responsivity within infancy could serve as a 'red flag' for SOR risk. Children who show persisting extreme levels of SOR may have related impairments in functioning that merit services to address this condition. The term SOR throughout the paper will refer to the clinical/impairing state of elevated reactivity to sensations as opposed to the normative trait of sensory responsiveness.

Definition

At the extreme, SOR is considered a type of sensory modulation disorder (SMD) in which an individual presents with exaggerated, intense, and/or prolonged responses towards certain sensations relative to same-age peers (Miller et al. 2007). SOR, as a primary condition/disorder, has been described in children (Stagnitti et al. 1999) as well as adults (Kinnealey and Fuiek 1999). Rates of SOR in young children have been reported between 2.8% to 6.5% (Goldsmith et al. 2006; Schoen et al. 2008). Although SOR can occur in any sensory modality (Miller et al. 2007) it has been primarily described in the tactile and auditory modalities (e.g., Royeen and Fortune 1990). SOR can compromise participation in daily occupations such as self-care, learning, and social interaction (Dunn 1997), may be characterized by avoidance, anxiety, aggression and/or defiance, and may reduce psychological well-being (Kinneally and Fuiek 1999). SOR is included as a clinical entity in the diagnostic classification of children 0–3 years (ICDL 2005) but has not been integrated into diagnostic classifications of older individuals (e.g., DSM-IV-TR 2000).

Underlying Mechanisms

There is a growing body of literature supporting the physiological, neurological, and genetic substrates of SOR. As a group, children with SMD including SOR have been shown to present with unique physiological features (Davies and Gavin 2007; McIntosh et al. 1999), and differ in their parasympathetic responses (Schaaf et al. 2003) compared to children without SOR. In addition, studies of twins indicate stronger heritability for over-responsivity in the tactile than in the auditory modality (Goldsmith et al. 2006) as well as moderate heritability estimates for the ITSEA Sensory Sensitivity subscale (Saudino et al. 2008). Given these biological substrates (especially heritability) patterns of reactivity are likely evident in early childhood, yet we know very little about their developmental course and pathways, which the present study aims to unfold.

Developmental Patterns

Cross-sectional evidence documents consistency in the range of parental ratings of the frequency of their child's negative responses such as avoidance, resistance, and distress towards daily sensations across typically developing individuals at different ages. No significant age differences were obtained in parent reported over-responsivity across seven age groups of typically developing individuals between ages 3 to 43 years (Kern et al. 2007) or between 2 to 10 years, with the mean frequency of over-responsivity across all age groups remaining consistently low (Saulnier 2003). Normative data from studies designed to standardize SOR parent-report scales have shown similar frequencies or rates at different ages (Dunn 1999, 2002; Dunn and Westman 1997). In addition, the ITSEA normative data from a birth-cohort sample of toddlers demonstrated longitudinal stability in Sensory Sensitivity scores across a one-year period (Carter et al. 2003). Although the pattern of findings across studies shows that levels of SOR are comparable for groups of children at different ages, additional longitudinal data is needed to address the issue of individual stability.

Several studies have addressed the issue of individual stability of the broader domain of "dysregulation." A few studies support the moderate stability of dysregulation problems (including SOR) in young children with elevated levels of dysregulation. In a longitudinal study, 50% of children with moderate to severe regulatory disorders at 7 months continued to show such problems at 36 months (Degangi et al. 2000). In an earlier study with the sample described here after, 39% of one- and two-year-olds with an elevated ITSEA Dysregulation scale (includes but is not limited to Sensory Sensitivity) continued to show elevated scores approximately one year later (Briggs-Gowan et al. 2006). Goldsmith and colleagues (2007), who focused on sensory defensiveness, (which is comparable to SOR), reported higher levels of persistence in sensitivity with 50% of twins who were reported as auditory defensive at age 2 presenting as auditory defensive at age 4 to 5; and 48% of the twins who were reported as tactile defensive at age 2 still tactile defensive at age 4 to 5. Evidence regarding the persistence of these symptoms beyond 36 months is needed, because gains in coping skills and cognitive abilities may differentially improve self-regulation and diminish correlations over time. Similarly, the sensory modulation challenges associated with formal schooling may be quite different from those present in the preschool years. Determining continuity in SOR from early childhood to school age in a representative sample would support the need for early intervention for these types of behaviors even in absence of other developmental challenges. In addition, most children with SOR are referred to services when they are school-aged when in many cases secondary emotional, social, and academic consequences have developed and are noticeable to the teacher and/or caregiver (Stagnitti et al. 1999). Therefore there is need for enhancing our ability to identify these children early on to provide a preventative early intervention approach.

Although developmental trajectories of over-responsiveness have not been examined in the general population of young children, developmental patterns have been examined in samples of individuals with other developmental disorders that are accompanied with high rates of SOR. For instance cross sectional analysis showed an increase in rates of SOR with age in individuals with autism spectrum disorders (ASD) (e.g., Ben-Sasson et al. 2008; Saulnier 2003; Talay-Ongan and Wood 2000). The only longitudinal study of SOR in clinical populations we are aware of is of boys with Fragile X Syndrome ($n=13$) (Baranek et al. 2008) that showed an increase in rates of deficient SOR scores from infancy to late preschool age, relative to typically-developing comparison. Since lower mental age in clinical populations has shown to mediate the association between chronological age and SOR (e.g., Baranek et al. 2007) there is need for studying the course of SOR in children with no other developmental problems.

Finally, the development and manifestations of typical and atypical levels of over-responsiveness are likely influenced by both biology and environmental experience. Earlier work including previous findings from the sample described in this paper has shown that school-aged children with versus without SOR above a clinical cutoff are more likely to be at sociodemographic risk including poverty, single parent, and teen parent status [withheld for blind review], supporting the role of environment in the development of SOR.

The current study addressed the following research questions: (1) Is the initial level of sensitivity and/or the rate of change in sensitivity in early childhood associated with SOR level in elementary school? (2) Do school-aged children with elevated SOR show a unique early developmental pattern of sensory sensitivity behaviors? and (3) Does the child's SES risk status influence SOR growth? We hypothesize that children with versus without elevated SOR in elementary school would show a unique developmental trajectory.

Method

Participants

Participants included parents followed longitudinally, initially selected randomly from birth records at the State of Connecticut Department of Public Health for births at Yale New Haven Hospital from July, 1995 to September, 1997 (see details in Briggs-Gowan et al. 2001) for children living in the 15 towns comprising the regional Standard Metropolitan Statistical Area of the 1990 Census at the time of their birth. Children were ineligible if they: (1) were likely to have developmental delays (e.g., due to birth weight below 2,200 grams, gestational age less than 36 weeks, APGAR score less than or equal to 5, birth complications such as hypoxia) $n=675$; (2) had a sibling who was sampled, $n=277$; (3) were identified as deceased through death record review, $n=4$; (4) had adoption reported on record, $n=14$; or (5) were the child of an investigator, $n=1$. After excluding these birth records, a random probability sample of 1,788 was drawn from a total eligible sample of 7,433 eligible children. The sample was selected to have equal proportions of boys and girls and to be equally distributed between 11 and 35 months of age at recruitment. After initial sampling, the following inclusion criteria were applied: (1) at least one parent able to participate in English (excluded $n=50$); (2) child still in the custody of biological parent (excluded $n=17$); and (3) 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 it was not possible to locate the family to verify eligibility. Compared with the post-sampling ineligible sample ($n=297$), the final eligible sample of 1,491 was significantly higher in birthweight, paternal and maternal age, maternal education, and years at the birth address, and less likely to be of minority ethnicity (*t-values* range 2.84–6.26, $p<0.01$); but these differences were all of small effect size (Cohen's d range 0.18–0.41). There were no significant differences in gestational age, paternal education, or child gender.

After exclusions, 1,329 families participated in one or more of surveys of three annual surveys in the Early Childhood portion of the study, when children were between the ages of 12 and 48 months. The response rate for the Early Childhood portion of the study was 89%. Participants ($n=1,329$) and non-participants ($n=162$) were similar in child age, child gender, minority status, birth weight, gestational age, paternal age, maternal age paternal education, maternal education, and length of time at the birth address. The sample was sociodemographically comparable to the Census region from which it was drawn (Briggs-Gowan et al. 2001).

All participants in the Early Childhood surveys were followed to School-age. Families were contacted for the School-age survey 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 next school year, resulting in a Second Grade/ Third Grade survey. At the time of the School-age survey, 17 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, $p<0.01$, *phi* ranged from −0.08 to −0.19). The effect sizes for these differences were small (*phi*=0.08 to 0.19). There were no significant differences in child gender. The SOR inventory (SensOR: Schoen et al. 2008) was added to the School-age survey after data collection had begun thus was obtained for 925 families (71% of the School-age sample). This sub-sample did not differ significantly from the full school-age sample in demographic features.

The sample described in the current paper included 521 children who were below 24 months in Year 1 as these children were sampled at each of the four time points of interest to the current investigation. This sample was between 11–24 months (mean=18.23, SD=3.85) in Year 1, between 23–42 months (mean=30.39, SD=4.10) in Year 2, between 31–51 months (mean 39.4, SD=3.87) in Year 3, and between 7 and 10 years (mean=7.97, SD=0.52) at School age. Of this sample 47% were boys and 68% were of Caucasian ethnicity. Most informants had a partner, were working, and had an education level that was greater than high school.

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 that targeted the full sample in the first three years of data collection (at ages 1- to 3-years) and at elementary school. Among other measures, the first three surveys included the ITSEA questionnaire and demographic information, while the fifth survey included the SensOR inventory. Data collection for the fifth survey began in the 2002/2003 academic year and continued through the 2005/2006 academic year with families first contacted to identify whether or not their children had entered second grade. Because a significant period of time was often required to locate families and obtain participation some surveys were gathered while the child was in third grade and a small number of surveys were not collected until the summer months after the child had completed third grade. Parents received $25 for each of the first three surveys and $30 for the fifth survey.

Measures

The Infant Toddler Social and Emotional Assessment (ITSEA Carter and Briggs-Gowan 2006). The ITSEA is a parent report measure of social-emotional and behavioral problems and competencies in infants and toddlers. 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. The Dysregulation domain comprises of Negative Emotionality, Sleep Problems, Eating Problems, and Sensory Sensitivities scales. In this study the Sensory Sensitivity scale is described as it includes 6 items that measure sensory over-responsivity across sensory modalities. 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 inter-rater reliability (Carter and Briggs-Gowan 2006).

Sensory Over-Responsivity Scales (SensOR: Schoen et al. 2008). This inventory includes 76 items that describe sensations in all sensory domains that may bother an individual ages 3–55. In the present study 41 items from the auditory and tactile modalities of the pilot research version of the SensOR were included. 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 subset 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 and Dunn 2002) (see Schoen et al. 2008). Schoen et al. also had occupational therapists with expertise in sensory modulation identify children with SOR. Their inclusion criteria for SOR were: (1) presence of over-responsivity in at least one sensory domain with significant impairment in daily life activities, and (2) endorsing a majority of sensory over-responsive items on the Short

Sensory Profile or the Adult Sensory Profile. Schoen and colleagues found that the sensitivity and specificity of the SensOR inventory in differentiating children with SOR ($n=101$) from typically developing children ($n=120$) was highest (sensitivity=69, specificity=84) when at least four tactile *or* auditory items were present. In the current study 18.2% ($n=95$) of the sample had SOR based on this cutoff. Analysis of scale properties was conducted for the full school-age sample of the current study and indicated internal consistency between all auditory and tactile items on the SensOR was good (Ben-Sasson et al. 2009).

Data Analysis

Latent Growth Curve modeling was applied using AMOS 7.0 program to measure change over time and to examine the impact of initial levels of, as well as change in, ITSEA sensory sensitivity during infancy upon level of SOR in elementary school co-varying for SES risk status at Year 1. This method of modeling is advantageous as it: (1) considers the dependence introduced by repeated measurements by estimating random effects, (2) includes all children even if not all of them have all four data points by giving more weight to individuals with the most time points, (3) takes into account factor means and variances allowing for a description of group change and individual differences in change, and (4) can incorporate covariates that may moderate change (Duncan and Duncan 2004). The overall fit of a growth curve model is determined by the chi-square statistic that compares between the proposed model and the independence model in which variables are assumed to be uncorrelated with the dependent variables. However, because the chi-square statistic can be influenced by large sample size, as is the case in the present study, three additional goodness-of-fit indices were used to provide information on the adequacy of fit of the proposed model. These indices were: comparative fit index [CFI], normed fit index [NFI], root-mean-square error of approximation [RMSEA]. Models are considered a good fit if CFIs and NFIs are greater than 0.90 and RMSEAs are less than 0.05 (McDonald and Ho 2002). Given the skewed distribution of the SOR scores in School-age, this variable was entered as a dichotomized variable in the growth curve model. SOR was dichotomized into ‘1’ when the parent reported that they child was bothered by at least 4 tactile *or* auditory items, and ‘0’ otherwise. This cutoff was based on previous sensitivity and specificity evidence using this measure (Schoen et al. 2008). Figure 1 presents the latent growth curve model employed. The two latent factors are the Intercept (ICEPT) and Slope of the three repeated measurements of ITSEA Sensory Sensitivity scores in infancy (i.e., ITSENS Y1, ITSENS Y2, ITSENS Y3). Paths from Intercept and Slope to SOR at school-age aimed to examine the role of initial status and of change in Sensory Sensitivity in predicting later SOR. A covariate of SES risk in Year 1 was included based on its association with SOR (Ben-Sasson et al. 2009). The SES risk variable measured parent education, minority ethnicity, poverty and parent employment status, single, and teen parenting. The distribution of SES risk scores supported the categorization of SES risk into: ‘0’ showing no more than 3 risk factors (91% of the sample) and ‘1’ showing above 3 risk factors.

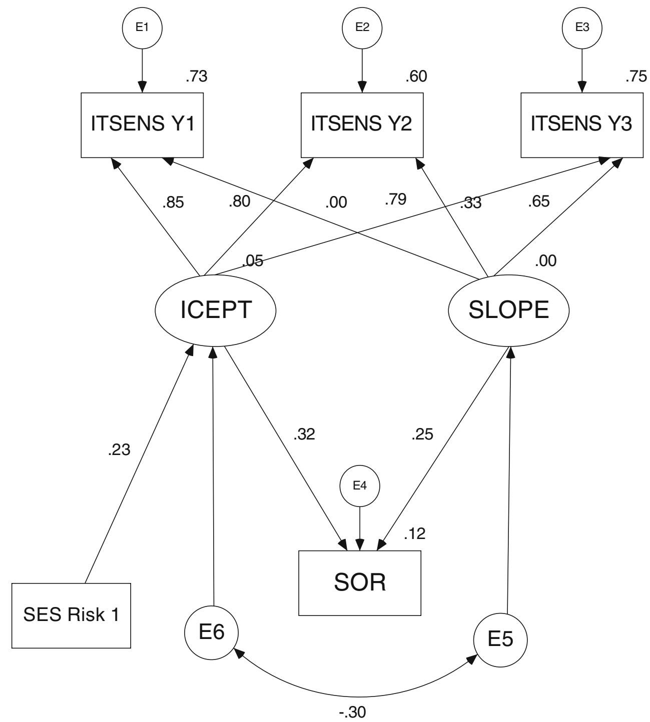

Fig. 1 A two-factor latent growth curve model of sensitivity predicting to SOR with an SES risk covariate (standardized model)

Results

Latent Growth Curve Analysis

The latent growth curve model predicting School-age SOR from the intercept and slope of ITSEA Sensitivity scores in Years 1-3 co-varying for Year 1 SES risk status showed an excellent fit with the data. Values of selected fit indices were *Chi Square*=11.52, *df*=6, $p<0.074$; *CFI*=0.99, *NFI*=0.98, and *RMSEA*=0.04 with the 90% CI 0.00–0.08 (see Fig. 1). Initially this model included direct paths between SES risk at year 1 and School-age SOR as well as with the Slope. Since these were non-significant (only the path to the intercept was significant) and did not change model fit they were trimmed from the final model. Table 1 presents

Table 1 Parameter Estimates From the Latent Growth Curve Model for SOR

Parameter	Unstandardized	SE	Standardized
	Mean structure		
Intercept	0.36**	0.01	0
Slope	0.01†	0.01	0
SES Risk Y1	0.15**	0.02	0
	Variance and Covariance structure		
Intercept→SOR	0.45**	0.04	0.32
Slope→SOR	0.83**	0.24	0.25
SES Risk Y1→Intercept	0.17**	0.03	0.23

† $p<0.06$. * $p<0.05$. ** $p<0.001$

the estimated mean regression weights for the slope, intercept, and covariate. The slope (i.e., change in Sensitivity between Years 1–3) approached but did not attain significance, suggesting that on average, across the sample there was little change in these scores over the first years of life. However, there was significant individual variability ($p<0.001$) in both the intercept (the variance estimate was 0.071, which is 8.70 SEs above zero) and the slope (the variance estimate is 0.013, which was 3.53 SEs above zero) of sensitivity behaviors in early childhood. Further, individual variations in both the intercept and slope of the ITSEA Sensitivity scores in early childhood were significantly associated with school-aged SOR scores. This suggests that children who start with higher levels of SOR at Year 1 and/or show more significant increases in Sensitivity between Years 1–3 have higher levels of SOR in School-age. As is common in these models, there was a significant negative correlation between the slope and intercept ($r=-0.30$), which suggests that children who start higher show smaller increases in early childhood, which may, in part, reflect a ceiling effect. SES risk at Year 1 was significantly associated with the intercept (i.e., initial level of ITSEA Sensitivity, $r=0.23$) but not with changes in sensory sensitivity (i.e., slope) or school-age SOR scores.

Following the characterization of average group and individual changes in SOR and predictors of later SOR we were interested in determining whether the pattern of early childhood sensory sensitivity change differentiates children with versus without SOR in school-age. For this purpose we conducted a Repeated Measures MANOVA to examine differences in mean ITSEA Sensitivity scores in Years 1–3 between School-age SOR groups controlling for SES risk status in Year 1. The Wilk's Lambda multivariate test indicated a significant effect of time ($F(2, 439)=5.35$, $p=0.005$, *partial eta square*=0.02) and a significant main effect for SOR group ($F(1,440)=43.81$, $p<0.001$, *partial eta square*=0.09). The interaction between SOR group and time was not significant ($F(1,440)=2.60$, $p=0.08$, *partial eta square*=0.01), indicating that the two groups did not differ in their mean pattern of change over time. There was no interaction between time and SES risk ($F(2, 439)=0.31$, $p=0.74$, *partial eta square*=0.001). Post-hoc comparisons between years showed that the mean Sensitivity score at Year 1 (*Mean*=0.38, *SE*=0.01) was significantly different from mean Sensitivity scores at Years 2 and 3 (*Means*=0.43, 0.41 respectively, *SE*=0.02 for both) ($p<0.01$). Figure 2 shows that children with versus without SOR in School-age have a higher mean Year 1 Sensitivity in early childhood however the pattern of change is similar supporting the growth curve model results.

Finally, we examined the likelihood of children with SOR at school-age being rated with ITSEA Sensitivity scores above clinical cutoff (90th percentile) during infancy. Fisher's exact tests indicated that a significantly higher percentage of children with versus without SOR at school-age were identified with ITSEA Sensitivity scores above the 90th percentile cutoff at Years 1–3. Children with SOR in school age had a 3–7 times higher likelihood of showing elevated ITSEA Sensitivity scores in infancy than those without SOR (see Table 2). In addition, 33.3%–53.8% of those with ITSEA scores above clinical cutoff in years 1, 2 and/or 3, had elevated SOR at school-age (i.e., persistent in problem SOR).

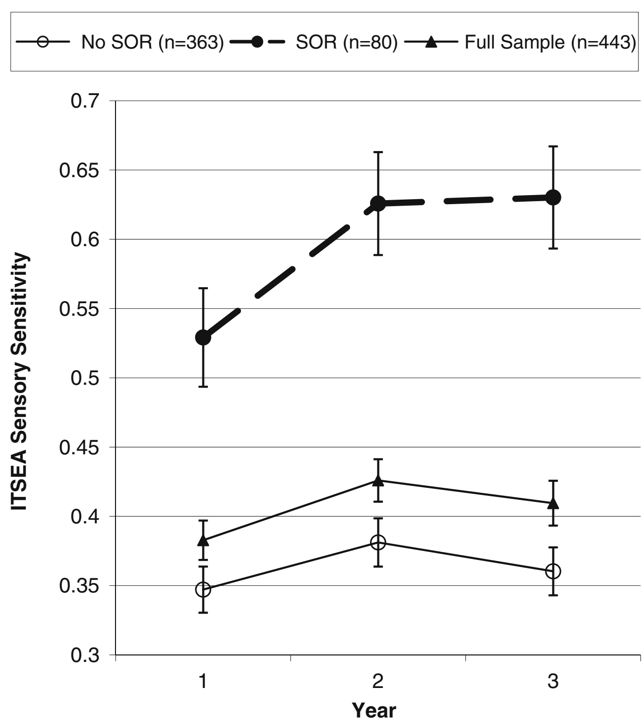

Fig. 2 Estimated marginal means and SE of sensory sensitivity of children with and without SOR at school-age

Table 2 Comparison of the Number of Children with Elevated Early Sensitivity Scores between School-age Children with Versus without Elevated SOR

	School-age SOR groups		OR (95% CI)
	No SOR (n=420)	SOR (n=93)	
ITSEA Sensitivity Year 1 (n=57)	38	19	
Within SOR Groups	(9.0%)	(20.4%)	2.58 (1.41–4.72)
Within ITSEA Groups	(66.7%)	(33.3%)	
ITSEA Sensitivity Year 2 (n=69)	39	30	4.82 (2.79–8.34)
Within SOR Groups	(9.4%)	(33.3%)	
Within ITSEA Groups	(56.5%)	(43.5%)	
ITSEA Sensitivity Year 3 (n=52)	24	28	7.14 (3.87–13.19)
Within SOR Groups	(6.4%)	(32.9%)	
Within ITSEA Groups	(46.2%)	(53.8%)	

All comparisons were significant at a *p-level* <0.001 based on Fisher's exact tests. ITSEA Sensitivity scores above the 90th percentile were considered elevated

Discussion

The present study is the first to investigate the development of indicators of SOR from infancy through early childhood to early elementary school. Findings from this study, conducted in a diverse, representative sample, demonstrate overall stability in ITSEA Sensitivity scores over the first three years of life. At the same time, findings revealed significant individual variation in sensitivity scores and change in sensitivity scores, indicating that some children did change significantly over this time period. Importantly, these early childhood patterns of sensitivity significantly predicted SOR status in elementary school. Specifically, both the initial level of sensory sensitivity in infancy and the change in sensory sensitivity through the toddler and early preschool years predicted SOR status in elementary school, supporting the continuity of SOR level in the general population. These findings highlight the importance of elucidating developmental pathways of sensory sensitivities beginning early in life.

The presented evidence of early-emergent, stable elevations in over-responsivity, underscore the clinical relevance of identifying children with clinically-significant SOR in early childhood. One of the indications for the early emergence of SOR is the finding that children with elevated over-responsivity scores in elementary school had higher initial levels of sensitivity in infancy as well as a unique early trajectory of sensory sensitivity behaviors. Although approximately one third of children who had elevated SOR at one and two years of age were also reported to have elevated SOR in school age, over half of children with elevated SOR at age 3 persisted with elevated SOR in school age. It is also notable that 20–33% of those with elevated SOR in school age already showed elevated SOR in early childhood. It is possible that some children are born vulnerable and stay vulnerable; or that those who fall behind the developmental curve on mastery of sensory input by age 3 are more likely to develop SOR. The fact that a large percentage with later problems were not identified early could mean that (1) some children have a later onset (e.g., after serious adverse experiences or some biologic maturation) or (2) the later assessment was broader than the ITSEA so naturally some children were not detected early on.

Early manifestation of sensitivity may reflect a genetic disposition (Goldsmith et al. 2006) and underlying biological mechanisms (McIntosh et al. 1999), which have been associated with SOR in previous studies. One's genetic composition dictates neural connectivity growth (i.e., synaptogenesis) and neuron elimination resulting in a certain level of behavioral tolerance and response (Hensch 2004). Thus, although the behavioral manifestation of SOR may reflect multiple underlying substrates, or equifinality, it is reasonable to hypothesize that children with SOR will show a unique developmental pattern guided by their common baseline substrates.

Furthermore children who are genetically vulnerable for SOR may be more likely to evidence relative elevations in SOR over-time, with potentially cascading effects on development by limiting exposure to and exploration of environmental input and/or shaping the caregiver's interaction with the child, which further compromises learning and adaptation. The child's actions to deal with overwhelming sensations have developmental consequences directly through their avoidance or indirectly through caregivers' preventative adaptations to the child's SOR (e.g., the child may become distressed by touching messy materials and therefore caregiver will provide non-messy foods for self-feeding). From the other side, environmental experiences and expectations of a child play an important role in providing exposure to certain types and intensities of sensations. The environment shapes the way the child learns to self-regulate and develop coping strategies (Dawson et al. 2000). Thus the combination or co-action of environmental factors, genetic factors, neural activity, and behavior, and probably timing of their co-action, may explain certain outcomes (Schneider et al. 2008).

The idea that SOR indicators may be consolidating very early in life is somewhat addressed in this study. In the full sample, over-responsivity appeared to stabilize after Year 2, when children were 24 months of age or older. This suggests that there may be a period in which it is normal for infants and toddlers to be figuring out ways to regulate their response to sensations of various intensities both at a behavioral and physiological/neurological level (although not measured directly in this study). Developmental transitions such as the onset of walking and expectations such as enjoyment of a greater range of foods and activities involving new or messy materials that occur at this age expose the infant to an increasing range and intensity of sensations (Kraemer 2001). It is also around 24 months that children are more able to communicate the sources of their distress through both verbal and non-verbal means (e.g., joint attention behaviors). Perhaps during these developmental transitions some children develop more control over the types and levels of sensations that they are exposed to or at least express own needs. This can also assist parents in linking their child's negative emotions with particular sensory input possibly leading to an increase (1) in accuracy of parent report of these behaviors, and (2) in parent attempts to adapt and accommodate to these behaviors. These developmental transitions may explain why all children in our sample underwent change from Year 1 relative to Years 2 and 3. These findings raise further questions as to whether there is an early critical period during infancy for the development of sensory modulation via experience as proposed by Hensch (2004).

Early SES risk significantly contributed to the first time SOR was measured (intercept) but did not contribute to change in SOR or to SOR at school-age indicating that this contribution occurs early in the life span. In previous work we demonstrated that SES risk was associated with SOR in school-age (Ben-Sasson et al. 2009) suggesting that associations between SES risk and SOR in school-age are mediated by their influence on early sensitivity. Other environmental factors that need further inquiry, such as life events and parenting patterns, may have a stronger contribution to the child's sensory development, and to individual variation that is apparent in early sensory development. As there is evidence of heritability from twin studies (Goldsmith et al. 2006; Saudino et al. 2008), there is also a need for studies that are designed to examine the co-contribution of both genetic and environmental factors that may differentiate children who show impairing SOR early on that persists versus those for whom early manifestations of SOR remit over time.

The moderate correlations presented in the growth model between early sensitivity and later SOR suggest that there are additional child-related factors that mold its development. Social-emotional problems and skills may effect the development of SOR behaviors by determining the coping strategies that a child will adopt to regulate responsivity. Briggs-Gowan and colleagues (2006) showed that the persistence of Dysregulation problems in this sample was moderated by co-morbidity with other emotional problems. In an earlier paper we report evidence of a relation between early and concurrent sensitivity and internalizing symptoms and social adaptive behaviors in school age (Ben-Sasson et al. 2009). In addition to the potential impact of social-emotional abilities upon sensory modulation development, other factors such as cognitive abilities may determine a child's coping strategies and self-regulation abilities. Development is a complex and dynamic process to quantify and explain within one dimension, in our case over-responsivity. It is important to advance our understanding of constitutional and environmental factors that underlie the development of over-responsivity in order to reveal potential moderators and mediators in the case of extreme SOR.

Limitations

This study provides preliminary evidence based on parent report of sensitivity and SOR indicators. A more thorough multi-method evaluation of SOR is needed. The lack of a SOR measure that is based on both parent and clinical information and one that includes the same items and/or modalities across different ages challenges practice and science in this area. Such a measure would enable us to document development on one scale to ensure that the same construct is measured over time. The fact that other types of SMDs were not evaluated does not allow us to understand the full sensory profile of the child.

The relatively low percentage of school-aged children with SOR who earlier were reported to have clinically significant ITSEA Sensitivity scores (i.e., up to a third) may also reflect the lenient cutoff for SOR applied at school age in this study. We assume that children with clinical SOR that is based on a direct assessment by a trained clinician would present with much higher risk rates of clinical ITSEA Sensitivity scores early on.

Conclusions

Study findings document the continuity of over-responsivity behaviors from infancy to early elementary school in the general population, providing valuable evidence for clinical practice in this area. Findings suggest that an early acceleration in over-responsivity may serve as a 'red flag' for monitoring a child and referring to early intervention. Development goes beyond elementary school, thus studying the continuity of typical and atypical levels of over-responsivity into adulthood, is crucial for understanding the presentation and persistence of SOR across the life span. There may be multiple personal and environmental factors that impact the course of SOR including neurological maturation, acquisition of efficient coping mechanisms, cognitive abilities, and contextual family factors. The stability of SOR and its relative independence from SES risk strengthens its construct validity and can guide future study of the etiology, diagnosis, and prognosis of SOR.

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