J Autism Dev Disord (2010) 40:112–122
DOI 10.1007/s10803-009-0840-2

ORIGINAL PAPER

Sensory Processing Subtypes in Autism: Association with Adaptive Behavior

Alison E. Lane · Robyn L. Young · Amy E. Z. Baker · Manya T. Angley

Published online: 31 July 2009

Abstract Children with autism are frequently observed to experience difficulties in sensory processing. This study examined specific patterns of sensory processing in 54 children with autistic disorder and their association with adaptive behavior. Model-based cluster analysis revealed three distinct sensory processing subtypes in autism. These subtypes were differentiated by taste and smell sensitivity and movement-related sensory behavior. Further, sensory processing subtypes predicted communication competence and maladaptive behavior. The findings of this study lay the foundation for the generation of more specific hypotheses regarding the mechanisms of sensory processing dysfunction in autism, and support the continued use of sensory-based interventions in the remediation of communication and behavioral difficulties in autism.

Keywords Sensory processing · Autism · Subtypes · Adaptive behavior · Communication · Model-based cluster analysis

A. E. Lane (✉)
School of Allied Medical Professions,
The Ohio State University, Columbus, OH 43210, USA
e-mail: lane.350@osu.edu

R. L. Young
Department of Psychology, Flinders University,
Adelaide, SA, Australia

A. E. Z. Baker
School of Nursing and Midwifery, University of South Australia,
Adelaide, SA, Australia

M. T. Angley
Sansom Institute, School of Pharmacy and Medical Sciences,
University of South Australia, Adelaide, SA, Australia

Introduction

Interest in the sensory processing (SP) of children with autism spectrum disorders (ASD) has grown in recent years. Children with autism are frequently reported to exhibit behaviors associated with sensory sensitivity (e.g., covering ears to loud, unexpected sounds; restricted food preferences), sensory under-responsivity (e.g., failure to orient to name or react to pain) or sensory seeking (e.g., rocking, hand flapping, noise-making). Despite the fact that current diagnostic criteria do not consider SP disturbance as a core deficit of an ASD diagnosis, a recent meta-analysis of the sensory modulation literature in autism found support for the universality of these symptoms across the diagnostic spectrum (Ben-Sasson et al. 2009). Unique patterns of SP associated with ASD have not been identified, however, and it is unclear how SP difficulties contribute to the clinical presentation of the disorder. This study describes SP patterns in children with autism and their relationship with adaptive behavior.

Various studies using parent report measures report that SP difficulties associated with ASD are multimodal and variable (Adamson et al. 2006; Kern et al. 2008; Leekam et al. 2007). Kern et al. (2007b) reported that all primary sensory modalities (auditory, visual, tactile and oral) were affected in individuals with autism. Tomchek and Dunn (2007), using the Short Sensory Profile (McIntosh et al. 1999a), reported that children with ASD ($n = 281$) showed differences in 92% of the SP behaviors measured in comparison to typically developing children. Other studies have reported the co-occurrence of increased sensory seeking, avoiding and sensitivity, and low sensory registration behaviors in individuals with autism and other pervasive developmental disorders (Kern et al. 2007a). Tomchek and Dunn (2007) conclude that further systematic exploration of the nature of SP differences in children with ASD is required to understand the role played by SP in its varied clinical presentation.

Using physiologic measures together with the Short Sensory Profile (McIntosh et al. 1999a), Miller et al. (2005) demonstrated the existence of distinct patterns of SP amongst children with high-functioning autism and Asperger's syndrome. When baseline and phasic skin conductance measures were examined, subgroups defined as 'low' or 'high' arousal and sensory 'habituators' or 'non-habituators' emerged. Further, when Miller et al. (2005) examined Short Sensory Profile data, factor analysis revealed three sensory responsivity groupings—'sensory over-responsivity', 'sensory under-responsivity' and 'sensory seeking'. The authors' preliminary analyses of the combined parent report and physiological data indicated that there may be congruence between the physiologic and behavioral sub-groupings. These groups have since been proposed to represent distinct diagnostic subtypes within sensory modulation disorder, a category of sensory processing disorder (Miller et al. 2007).

Rogers and Ozonoff (2005) reviewed laboratory-based studies examining SP in autism and found further support for the existence of distinct SP patterns. They concluded children with autism typically present with 'hypo' or 'under'-responsiveness to sensory stimuli. Similar findings were reported by Baranek et al. (2006, 2007) who found that young children with autism were more likely to show hypo-responsiveness or non-responsiveness to stimuli than developmentally delayed or neurotypical young children. 'Hyper' or 'over'-responsiveness was found by these authors to be negatively associated with developmental age rather than characteristic of autism per se. In a further study, toddlers with ASD were found to display high levels of sensory under-responsiveness and avoiding behaviors but low levels of sensory seeking (Ben-Sasson et al. 2007). The role of age in SP dysfunction in ASD has been examined by a number of authors. In summary, findings from studies to date indicate that: older children with ASD demonstrate more seeking and over-reactive behaviors than young children with ASD (Ben-Sasson et al. 2009; Liss et al. 2006); age is not a significant predictor of overall level of SP dysfunction in ASD (Adamson et al. 2006); SP dysfunction is more highly associated with autism severity in young children with ASD than older children (Kern et al. 2007b) and visual sensitivities tend to improve with age in children with ASDs (Leekam et al. 2007).

An Australian pilot study by our research team (Baker et al. 2008) revealed patterns of marked SP impairment, typical responsiveness and varied responsiveness in children with autistic disorder ($n = 22$) using the Short Sensory Profile (McIntosh et al. 1999a). Specifically, definite differences in Auditory Filtering and a high incidence of sensory seeking behavior were shown. Typical performance, however, was noted in Visual/Auditory and Movement Sensitivity. Further, SP scores for this sample clustered together in a similar manner to that reported by Miller et al. (2005), one cluster indicating sensory over-responsivity and another sensory under-responsivity, with the majority of participants aligning with the under-responsivity group. Replication of this work is required with a larger sample size before definitive conclusions can be drawn.

Few studies have sought to investigate the relationship between SP difficulties and the clinical manifestations of ASD. Miller et al. (2005) found that children with high functioning autism or Asperger syndrome with lower arousal and who habituate to repeated sensory stimuli, tend to have greater communication and social impairment as well as increased repetitive behaviors. Kern et al. (2007b) concluded that multi-sensory disturbance was positively associated with autism severity in children but weakened in adolescents and adults. Similarly, Hilton et al. (2007a) reported that social impairment in school-aged children with high functioning autism was positively associated with SP disturbances. Our earlier study (Baker et al. 2008) found consistent moderate to strong correlations between SP difficulties across domains and the presence of maladaptive behaviors. In particular, significant associations were found between SP dysfunction and parent-reported child anxiety, social relating, communication disturbances, self-absorption and antisocial behaviors. A study by Liss et al. (2006), reported a relationship between sensory over-responsivity in ASD and perseveration and over focusing attention. Further, sensory under-responsivity was associated with lower adaptive functioning and poorer communication and social performance. Similarly, Ashburner et al. (2008), using the Short Sensory Profile (McIntosh et al. 1999a), found that tactile and movement sensitivities and auditory filtering difficulties in children with ASD were associated with inattention, hyperactivity, oppositional behavior and academic underachievement. In contrast, Rogers and Ozonoff (2005) found little laboratory-based evidence for a role for SP difficulties in motor stereotypies which are commonly attributed to sensory-based arousal deficits (Baranek et al. 1997).

Studies examining relationships between SP disturbance and the clinical presentation of ASD have been characterized by variability in investigative approaches (i.e. instrumentation, clinical symptoms examined and diagnostic sub-groupings included) which make interpretation and comparison of studies problematic. A limitation of much of the research is the reliance on imprecise, parent report measures to characterize and operationalise sensory function. The relation of these measures to more specific laboratory assessments of SP is unknown. Direct reports from caregivers and adults with ASD, however, reveal a strong perception that negative behaviors associated with SP difficulties are barriers to achieving competence in social participation and communication (Koenig and Kinnealey 2008). Further, the universality of report of symptoms of SP dysfunction in ASD (Ben-Sasson et al. 2009) suggests that detailed examination of these difficulties may provide insights into common mechanisms underlying the behaviors associated with this disorder. Researchers are obliged, therefore, to continue to investigate and elucidate the role of SP difficulties in the manifestation of symptoms associated with ASD.

The aims of the present study were twofold: (a) to describe the patterns of SP difficulties within autism and (b) to examine the relationship between SP patterns in this group and adaptive behavior. This study extends previously published work by: evaluating SP difficulties with a well-established and psychometrically sound measure of SP; applying state-of-the-art cluster analysis techniques to examine SP patterns; and establishing an empirical foundation for the understanding of the relationship between SP difficulties and adaptive behavior.

Methods

Participants

Fifty-four children with autistic disorder and their caregivers participated in this study. Data from participants ($n = 22$) in our previously published pilot study (Baker et al. 2008) were combined with data from a further 32 participants. Participants were aged between 33 and 115 months (mean = 79.02, standard deviation (SD) = 19.22) with 47 (87%) being male. All participants were registered with the Early Intervention Research Program at Flinders University in South Australia or Headstart Intervention Services offering psychological services for children with an ASD. Diagnostic status for all participants was determined using the Autism Diagnostic Interview-Revised (ADI-R) by the second author (Young). This diagnosis was then supported by a second independent practitioner. All participants met DSM-IV-TR (APA 2000) criteria for an ASD.

Instrumentation

The Short Sensory Profile (SSP) is a 38-item parent questionnaire designed to measure behaviors associated with abnormal SP in children aged 3–10 years (McIntosh et al. 1999a). Scores are derived for seven sensory domains (Tactile, Taste/Smell, Movement and Visual/Auditory Sensitivity, Underresponsive/Seeks Sensation, Auditory Filtering and Low Energy/Weak) and for overall SP function. These are then compared to normative data from 1,200 typically developing children. Higher scores relate to more typical performance whereas lower scores indicate that either a probable or definite difference in SP is likely. Internal consistency of overall and subdomain sections of the SSP has been reported as ranging between $r = .70–.90$ along with acceptable discriminative validity (>95% in differentiating children with and without sensory impairments; McIntosh et al. 1999b). The SSP can be administered in approximately 10 min. Table 1 provides examples of items from each sensory domain of the SSP.

Table 1 Example items from the SSP

SSP domain	Example items
Tactile sensitivity	Item 4: Reacts emotionally or aggressively to touch
	Item 7: Rubs or scratches out a spot that has been touched
Taste/smell sensitivity	Item 8: Avoids certain tastes or food smells that are typically part of children's diets
	Item 10: Will only eat certain tastes
Movement sensitivity	Item 13: Fears falling or heights
	Item 14: Dislikes activities where head is upside down (for example, somersaults, roughhousing)
Underresponsive/seeks sensation	Item 18: Touches people and objects
	Item 19: Doesn't seem to notice when face or hands are messy
Auditory filtering	Item 22: Is distracted or has trouble functioning if there is a lot of noise around
	Item 26: Doesn't respond when name is called but you know the child's hearing is OK
Low energy/weak	Item 29: Tires easily, especially when standing or holding particular body position
	Item 32: Props to support self (even during activity)
Visual/auditory sensitivity	Item 34: Responds negatively to unexpected or loud noises
	Item 38: Is bothered by bright lights after others have adapted to the light

The Vineland Adaptive Behavior Scales (VABS), Interview Edition is a semi-structured interview administered to caregivers to assess adaptive behavior (Sparrow et al. 1984). Adaptive behavior is defined by this instrument as the development and application of abilities required for the attainment of personal independence and social competence. The VABS consists of five domains—communication, daily living, socialization, motor skills and maladaptive behavior. Items in each domain are scored from zero to two, with lower scores indicating skills/behaviors that are sometimes or never performed. Standard scores and an adaptive behavior composite score can be calculated reflecting the overall ability of the participant to live independently. The VABS has demonstrated adequate internal consistency reliability, good test-retest reliability and excellent inter-rater reliability with coefficients ranging between the .80s and high .90s (Sparrow et al. 1984). Evidence of good validity of the VABS was also demonstrated in the areas of construct, content and criterion-related validity (Sparrow et al. 1984).

Procedure

Ethics approval for this study was granted by the Division of Health Sciences Human Research Ethics Committee at the University of South Australia and the Flinders University of South Australia.

The SSP was completed by parents/caregivers of all participants as outlined in the SSP manual (Dunn 1999). VABS data for all participants were obtained from participants' records. As these assessments are administered routinely at several time points during the program, the most recent dataset available for each participant was used. Most VABS data were dated within 12 months of the current study although data for six participants was dated between 1 and 2 years prior and two participants' data was from more than 2 years prior.

Analysis

Descriptive statistics were calculated for the raw scores of the key variables of SP, adaptive behavior and sample demographics. To examine patterns of SP difficulties in this group, SSP z-scores were submitted to correlation and model-based cluster analyses. Cluster analysis seeks to identify groups within data thus establishing if there are patterns or subtypes of SP within autism. Model-based cluster analysis compares the fit to the data of a number of models using the Bayesian Information Criterion (BIC) to determine the best model (Zhong and Ghosh 2003). A high BIC indicates that an optimal trade-off between the fit of the model to the data and the complexity of the model (i.e. numbers of clusters or numbers of parameters) has been achieved. Use of the BIC allows simultaneous comparison of a number of different cluster models that have differing complexity. In general, less complex models are better but not at the expense of poorly fitting the data. By contrast, hierarchical or traditional clustering methods rely on grouping data according to their proximity to each other in order to generate a cluster model. These techniques do not take into account model complexity.

To examine the relationship between SP and adaptive behavior, correlation and multiple regression analyses were performed. These analyses detail the association of SP in autism with various behavioral indices (communication, daily living, motor, socialization, maladaptive behavior). While unproven, a number of authors attribute adaptive behavior difficulties to sensory-based deficits (see for example, Baranek et al. 1997). Therefore, in this study, SP is considered the independent variable and adaptive behavior is the dependent variable. The Statistical Package for the Social Sciences (SPSS) (v. 16.0) and *R* (v. 2.5.1) were used for the analyses.

Results

Participants

Developmental Functioning

The VABS has been widely used with samples of children with Autistic Disorder, and is considered a more appropriate measure of ability and functioning in this group than more traditional psychometric tests such as those measuring IQ (Bölte and Poustka 2002; Freeman et al. 1999; Kraijer 2000; Lord et al. 1997). The Daily Living subdomain of the VABS is the most suitable measure of functioning for children with autism, as it is less confounded with other aspects of autism than are the other subdomains (Kraijer 2000). The Daily Living subdomain is often used as a rudimentary measure of developmental level in low functioning children with autism (e.g., Lord et al. 1997). Therefore, the Daily Living subdomain was deemed appropriate as a measure of developmental level in the current study. Average scores for the Daily Living subdomain for the general population range between 85 and 115 and scores are interpreted according to the following ranges: Low = 69 and below; Moderately low = 70–84; Adequate = 85–115; Moderately High = 116–130; High = 131 and above. Table 2 displays the means and standard deviations for the sample on all VABS domains. As can be seen, Daily Living subdomain scores fell in the low range (mean = 54.94) indicating low developmental level. Developmental functioning ranged from low (minimum = 20) to adequate (maximum = 96.0).

Table 2 Participants' performance on SSP and VABS

Measure	*N*	Mean	SD
SSP (raw scores)			
Tactile sensitivity	54	27.39	4.23
Taste/smell sensitivity	54	11.81	5.73
Movement sensitivity	54	12.81	2.67
Underresponsive/seeks sensation	54	21.24	5.20
Auditory filtering	54	18.44	3.43
Low energy/weak	54	22.28	7.39
Visual/auditory sensitivity	54	18.13	4.63
Overall score	54	132.11	21.18
VABS			
Total	54	62.89	18.91
Daily living	54	54.94	19.87
Communication	54	71.39	24.37
Social	54	71.11	17.29
Motor	32	71.25	21.88
Maladaptive behavior	54	16.31	8.81

Sensory Processing Function

Table 2 shows the means and standard deviations for the sample on the SSP. Figure 1 shows the percentage of study participants exhibiting typical performance, probable differences (1 SD or more from the normative mean) and definite differences (2 SD or more from the normative mean) in SP as measured by the SSP.

The majority (87%) of participants exhibited SP dysfunction overall when compared to the normative data provided with the SSP. Notably, most participants demonstrated differences in Auditory Filtering (92.6%) and Underresponsive/Seeks Sensation (85.2%) domains. Further, 66.7% of the sample exhibited typical performance in movement sensitivity. The sample was split between the extreme high and low range of scores for Taste/Smell Sensitivity with 38.9% demonstrating typical performance and 51.9% demonstrating definite differences.

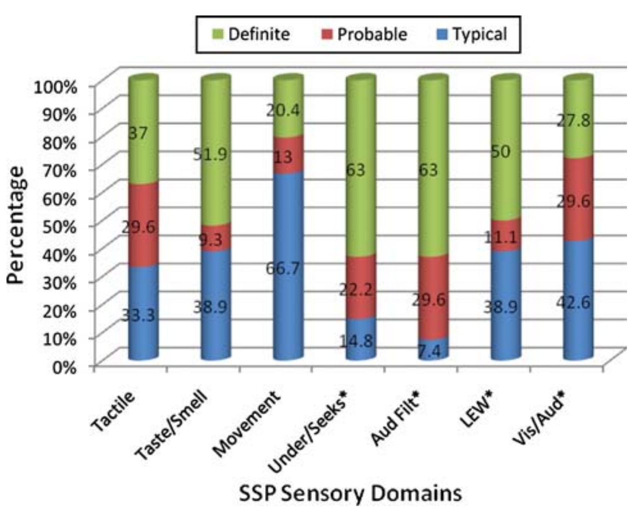

Fig. 1 Percentage of study participants showing typical, probable or definite differences on SSP. * Under/seeks, Underresponsive/seeks sensation; AudFilt, Auditory filtering; LEW, Low energy/weak; Vis/Aud, Visual/auditory sensitivity

Patterns of SP Behaviors

Correlations Table 3 shows the correlations between performance on SSP domains and age for the study participants.

Significant low negative correlations were observed between age and Low Energy/Weak and Visual/Auditory Sensitivity domains (Kielhofner 2006). This result indicates that younger children in the sample tended to receive higher (more typical) scores in these SP domains. Multiple significant low to moderate positive correlations were evident between SSP domains showing a fair degree of interrelatedness in SP performance within this sample.

Cluster Analysis Figure 2 displays the results of the model-based cluster analysis. Participants' SSP scores were submitted to the model-based cluster (mclust) procedure in *R*. A three cluster solution was considered optimal using BIC as the reference criterion. A peak in the BIC was observed at three components or clusters. Visual inspection revealed that the clusters were most clearly distinguishable when Taste/Smell Sensitivity and Low Energy/Weak were used to describe the data (Fig. 2). Figure 2 shows that Cluster 1 ($n = 24$; 44%) is characterized by typical function in both Low Energy/Weak and Taste/Smell sensitivity; Cluster 2 ($n = 17$; 31.5%) is characterized by atypical Low Energy/Weak and atypical Taste/Smell sensitivity; and Cluster 3 ($n = 13$; 24.1%) is characterized by typical Low Energy/Weak and atypical Taste/Smell sensitivity. In this analysis, the BIC was used to identify the three cluster solution. The BIC finds an optimal trade off between data likelihood and model complexity and so traditional power analysis is not needed in this case. The consequence, however, is that the procedure will produce the model of maximal complexity that is warranted by the data. Additional data could lead to more complex models being preferred.

To avoid the possibility of cumulative Type 1 error, one-way ANOVA with post-hoc Tukey analyses for multiple comparisons were conducted to determine the differences between cluster groupings across all SSP domains, age and developmental functioning (Tomita 2006). Age and developmental functioning (VABS Daily Living score) were not significantly different between cluster groupings

Table 3 Correlations: age and SSP (standardized data)

	SSP domains						
	Tactile	Taste/smell	Movement	Under/seeks	AudFil	LEW	Vis/Aud
Age	−.12	−.04	−.19	.08	−.12	−.28*	−.39**
Tactile		.38*	.33*	.23	.33*	.31*	.59**
Taste/smell			−.16	.44*	.34*	.21	.30*
Movement				−.14	.03	.18	.27*
Under/seeks					.42**	.46**	.14
AudFilt						.29*	.45**
LEW							.36**

Under/seeks, Underresponsive seeks sensation; AudFilt, Auditory filtering; LEW, Low energy/weak; Vis/Aud, Visual/auditory sensitivity

* Significant at $p < .05$ level; ** Significant at $p < .001$ level

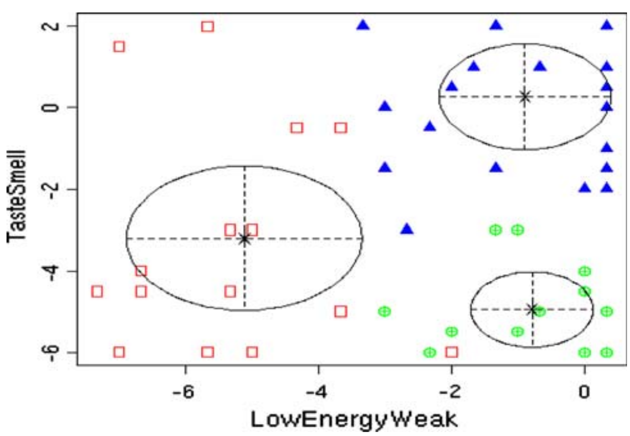

Fig. 2 Cluster representation comparing Taste/smell sensitivity and Low energy/weak scores

(Age: $F_{(2,51)} = 1.32$, $p = .28$; VABS Daily Living: $F_{(2, 51)} = 2.32$, $p = .11$). Table 4 shows the means, F-statistics and significance values for each cluster by SSP domain.

Post-hoc tests revealed significant differences between: Clusters 1 and 2 on Tactile, Taste/Smell, Underresponsive/Seeks Sensation, Auditory Filtering, Low Energy/Weak and Visual/Auditory Sensitivity; Clusters 1 and 3 on Taste/Smell Sensitivity and Underresponsive/Seeks Sensation; and Clusters 2 and 3 on Taste/Smell and Movement Sensitivity and Low Energy/Weak. In summary, Cluster 1 is characterized by typical SP functioning in all domains except Underresponsive/Seeks Sensation and Auditory Filtering which were mildly affected (1 SD below the normative mean). Cluster 2 is characterized by severe SP dysfunction across all domains including Movement Sensitivity which for the remainder of the sample fell within the typical range. Cluster 3 is also characterized by severe SP dysfunction in most sensory domains but is within the typical range for Low Energy/Weak and Movement Sensitivity. Table 5 summarizes the differences in SP dysfunction between clusters.

SP Pattern and Adaptive Behavior

Correlational analyses were performed to determine the association between SSP scores, age and scores on the VABS and is shown in Table 6.

Significant, low to moderate correlations were observed between age and VABS Total, Daily Living and Maladaptive Behavior subscales. In all instances the direction of the correlation indicated lower functioning with younger age. Only one subscale of the VABS consistently correlated significantly with SSP scores. Specifically, higher scores (lower functioning) in Maladaptive Behavior were

Table 4 Means and F-statistics for clusters by SSP domain (standardized data)

Cluster	SSP domains						
	Tactile	Taste/smell	Movement	Under/seeks	AudFilt	LEW	Vis/Aud
1	−.89	.21	−.56	−1.63	−1.76	−.86	−.28
2	−2.37	−3.15	−1.15	−3.51	−2.63	−5.27	−1.80
3	−1.64	−4.96	.08	−3.15	−2.39	−.82	−1.10
F-statistic	6.76	35.33	3.38	8.77	3.38	62.36	5.87
p Value	.002	.0001	.04	.001	.04	.0001	.005

Under/seeks, Underresponsive seeks sensation; AudFilt, Auditory filtering; LEW, Low energy/weak; Vis/Aud, Visual/auditory sensitivity

Table 5 Summary of SP dysfunction differences by cluster

SSP domain	Cluster 1	Cluster 2	Cluster 3
Tactile sensitivity	Typical	Severe	Severe
Taste/smell sensitivity	Typical	Severe	Severe
Movement sensitivity	Typical	Severe	Typical
Underressponsive/seeks sensation	Mild	Severe	Severe
Auditory filtering	Mild	Severe	Severe
Low energy/weak	Typical	Severe	Typical
Visual/auditory sensitivity	Typical	Severe	Severe

associated with lower scores (lower functioning) on Tactile, Taste/Smell, Under-Responsive/Seeks Sensation, Auditory Filtering and Visual/Auditory sensitivity. Coefficients ranged from low to moderate. Further, more typical functioning in the Low Energy/Weak domain was weakly associated with lower functioning in communication.

Further analysis using stepwise multiple regressions revealed significant predictive models for the communication and maladaptive behaviors subscales of the VABS when regressed on SSP scores and age. For the communication subscale, SSP scores explained 24.5% (adjusted $R^2 = .22$) of the variance in communication scores ($F_{(2.51)} = 8.26$, $p = .001$). Two of the SSP subdomain scores were unique predictors of communication performance: Underresponsiveness/Seeks Sensation ($B = 5.90$, $p = .003$), and Low Energy/Weak ($B = -5.11$, $p < .001$).

For the maladaptive behaviors subscale, SSP scores and age explained 52.2% (adjusted $R^2 = .48$) of the variance in maladaptive behavior scores ($F_{(4,49)} = 13.37$, $p < .001$). Unique predictors of maladaptive behaviors included: Taste/Smell Sensitivity ($B = -1.40$, $p = .001$), Auditory Filtering ($B = -2.17$, $p = .01$) and Movement Sensitivity ($B = -1.44$, $p = .04$) and Age ($B = .13$, $p = .01$).

In a final examination of the relationship between SP patterns and adaptive behavior, one-way ANOVA with post-hoc Tukey analyses were conducted on SP cluster grouping and VABS scores. Means, *F*-statistics and *p* values for each SP cluster are shown in Table 7 for each VABS subscale.

Significant differences on the VABS Communication and Maladaptive Behaviors subscales were observed between the clusters. Post-hoc tests revealed that Clusters 2 and 3 differed significantly in the Communication subscale; while Clusters 1 and 2, and 1 and 3 differed significantly on the Maladaptive Behavior subscale. As reported earlier, no significant difference was noted between clusters on the Daily Living subscale, however, suggesting that cluster membership was not dependent on level of developmental functioning.

Table 6 Correlations: SSP, VABS and age

Age/SSP domains	VABS					
	Total	Communication	Daily living	Social	Motor	Maladaptive behavior
Age	−.27*	.05	−.43**	−.15	−.19	.37**
Tactile	−.03	−.20	.14	−.07	−.17	−.45**
Taste/smell	.19	.16	.20	.19	.19	−.53**
Movement	−.01	−.13	.09	−.08	−.21	−.21
Under/seeks	.15	.18	.14	.13	.16	−.35**
AudFilt	.05	–.004	.02	.10	.005	−.48**
LEW	−.19	−.32*	.06	−.11	.17	−.23
Vis/Aud	.10	−.04	.13	.02	.08	−.47**

Under/seeks, Underresponsive seeks sensation; AudFilt, Auditory filtering; LEW, Low energy/weak; Vis/Aud, Visual/auditory sensitivity

* Significant at $p < .05$ level; ** Significant at $p < .001$ level

Table 7 One-way ANOVA of SP cluster by VABS scores

Cluster	VABS					
	Total	Communication	Daily living	Social	Motor	Maladaptive behavior
1	65.04	70.54	59.75	73.21	77.08	10.88
2	67.41	82.94	55.47	75.29	70.90	19.94
3	53.00	57.85	45.38	61.77	64.60	21.62
F-statistic	2.56	4.44	2.32	2.74	.88	11.78
p Value	.09	.02	.11	.07	.43	.0001

Discussion

Patterns of Sensory Processing Behaviors in Autism

This study supports the predominant view in the literature that children with ASD experience significant differences in SP compared with their neurotypical peers. Further, this study has revealed specific characteristics and patterns of SP in a cohort of children with autistic disorder. First, the majority of participants in this study experienced definite differences from typical in the Underresponsiveness/Seeks Sensation and Auditory Filtering domains. The authors of the Sensory Profile, the base measure of the SSP, regard sensory seeking behavior as a manifestation of sensory under-responsivity (Dunn 1999). Underresponsiveness has recently been reported as being characteristic of children with ASD (Ben-Sasson et al. 2009). Underresponsivity, however, is not strongly represented in the items that make up the Auditory Filtering domain of the SSP in which over 92% of the study sample experienced difficulties. Rather, four of the six items on the Auditory Filtering domain describe over-responsive behaviors e.g. 'is distracted or has trouble functioning if there is a lot of noise around', and 'can't work with background noise'. This suggests that sensory under- and over-responsivity may co-exist in children with autism. Ben-Sasson et al. (2007) have also observed the co-occurrence of extreme under- and over-responding (avoiding) behaviors in a group of toddlers with autism and proposed that a mixed pattern of SP in ASD may be indicative of a common etiology underpinning poor sensory modulation.

Second, results of a model-based cluster analysis confirmed the existence of at least three distinct SP subtypes of children with autism. The three subtypes can be described as follows:

1. Sensory-based inattentive seeking (SBIS)—this subtype (Cluster 1) is characterized by mostly typical SP function. Mild difficulties are observed, however, in the domains of Underresponsive/Seeks Sensation and Auditory Filtering. This SP profile has been associated with attentional difficulties (Ermer and Dunn 1998; Watling et al. 2001). Inspection of the items included in these two domains on the SSP confirms that many relate to inattention, distractibility, over focused attention or impulsivity (e.g. jumps from one activity to another so that it interferes with play, touches people and objects, appears to not hear what you say, has difficulty paying attention). Inattentive behaviors may also present as sensory seeking behaviors.
2. Sensory modulation with movement sensitivity (SMMS)—this subtype (Cluster 2) is characterized by SP difficulties across all sensory domains measured by the SSP. Participants in this group presented with symptoms of both under- and over-responsivity (modulation difficulties) and all scores were more than one standard deviation from the normative means. They were also the only group to experience atypical performance in Movement Sensitivity coupled with an extremely low score in Low Energy/Weak. Inspection of the items in the Low Energy/Weak domain revealed that many were associated with movement function (e.g. seems to have weak muscles, has a weak grasp, poor endurance/tires easily).
3. Sensory modulation with taste/smell sensitivity (SMTS)—this subtype (Cluster 3) is characterized by SP difficulties across all sensory domains of the SSP except in Low Energy/Weak and Movement Sensitivity. As for the SMMS subtype, this group experiences symptoms of both under- and over-responsivity (modulation difficulties) but is without impairment in the movement-related sensory domains. Further, this subtype exhibits extreme dysfunction in Taste/Smell Sensitivity.

Support for a broader subtype of modulation difficulties is reported by Ben-Sasson et al. (2007) which aligns somewhat with our SMMS and SMTS subtypes. However, the sensory subtypes revealed through this study cannot be easily explained by the sensory modulation disorder classification of sensory over-responsivity, under-responsivity and sensory seeking (Miller et al. 2007) and commonly referred to in reviews of SP in autism (Baranek et al. 2007; Liss et al. 2006; Rogers and Ozonoff 2005). Instead, the results indicate that consideration of the relative performance of each child across specific sensory domains (i.e. tactile, taste/smell, movement, etc.) rather than in broad patterns of over- and under-responding may be more pertinent. Our findings contrast to cluster analysis results of Liss et al. (2006) who described children with ASD as over- or under-responding. However, these authors used sensory scores already grouped into 'over-reactivity', 'under-reactivity' and 'seeking' categories rather than conducting analyses on individual domain scores. Previous research on the sensory measure used in Liss et al.'s (2006) study supported the over-responsivity/under-responsivity/seeking taxonomy. It is notable that this proposed classification is based on the clustering of measurement items to each other (Miller et al. 2005) rather than the clustering of individual case profiles as was done in the current study. While it appears that there is good rationale to support a theoretical triad of sensory responding behaviors (over-responsive, under-responsive, seeking), it is not clear from the results of this study that our putative clinical clusters align. Instead, evidence from this study suggests that children with autism present with behaviors and difficulties across the spectrum of theoretical responding patterns but differ in the SP domains affected. Future research examining the SP of children with autism should concentrate on specific sensory domains found to be discriminative in this study (i.e. taste/smell, audition and movement) to gain further insights into likely mechanisms of dysfunction in sensory responding patterns.

Third, the results of this study suggest that the sensory domains of Auditory Filtering, Taste/Smell Sensitivity and Low Energy/Weak may be of particular interest in understanding the SP of children with autism. Auditory Filtering dysfunction was evident in 92.6% of participants. Many studies report the presence of auditory processing difficulties in ASD (Ashburner et al. 2008; Dunn et al. 2008; Tecchio et al. 2003). Laboratory-based research has used auditory stimuli to examine overall SP difficulties in autism, and reported a tendency for non-responsiveness or underresponsiveness (Rogers and Ozonoff 2005). Recent electrophysiological evidence suggests children with autism experience a deficit in automatic detection of change in auditory stimulation. Children with autism are observed to respond less to changes in sounds in their environment than their neurotypical counterparts with the exception of when they are actively attending to a stimulus (Dunn et al. 2008). These neurophysiologic findings are consistent with behavioral observations of auditory filtering difficulties, e.g., many children with autism are noted to not respond when their name is called or appear to not to hear what you say.

Literature relating the significance of Taste/Smell Sensitivity and Low Energy/Weak domains to autism is not as prevalent. Hypersensitivity to certain food textures, tastes, smells and/or appearance has been proposed to lead to avoidance and restriction of foods, which is commonly observed in ASD and reported by caregivers (Field et al. 2003; Martins et al. 2008; Schreck and Williams 2006). In a recent chemosensory study examining the olfaction and taste functions of 10–18 year olds, participants with autism were found to be significantly less accurate than their neurotypical peers in discriminating all odors and sour and bitter tastes (Bennetto et al. 2007). Of interest in the current study is the finding that relatively equal groups of children presented with atypical and typical Taste/Smell Sensitivity and this difference discriminated between broader sensory subtypes. Further research examining the role of the taste and smell sensitivity in the manifestation of autism appears warranted.

The Low Energy/Weak domain of the SSP consists of items thought to be indicative of under-responsivity in the vestibular and proprioceptive sensory domains resulting in the appearance of weakness, fatigue and poor core postural stability. Motor coordination delays are one possible outcome of under-responsivity in vestibular and proprioceptive systems (Miller et al. 2007). Dyspraxia and difficulties in imitation and goal-directed actions are commonly reported in children with ASDs (Dziuk et al. 2007; Piek and Dyck 2004) and have been shown to be associated with social communication deficits (Hilton et al. 2007a, b). The current study identifies difficulties in these areas as a key discriminating feature between sensory subtypes which are further distinguished by performance in communication and maladaptive behavior (discussed below).

SP Patterns and Adaptive Behavior

This study revealed mixed results in the association between SP patterns and the clinical presentation of autism. A clear predictive association was evident between SP patterns, communication performance and general maladaptive behavior. Specifically, participants exhibiting the SMTS subtype had significantly greater communication impairment than those in the SMMS subtype. SMTS participants displayed the most dysfunction in Taste/Smell Sensitivity. This result suggests that a common mechanism may underlie difficulties in communication and modulation of olfaction and/or taste sensation in children with autism. A secondary analysis performed by Bennetto et al. (2007) in their investigation of olfaction identification in young people with autism supports this supposition. These authors found that children with the greatest impairment in olfaction identification also scored more poorly in skills relating to social communication. A link between olfaction identification and diminished social drive, lack of spontaneous conversation and impaired volition has also been reported in individuals with schizophrenia (Malaspina and Coleman 2003). It also appears that in children with autism, communication impairment, a core deficit of the disorder, is more likely in those without concomitant praxis and movement processing difficulties (i.e. SBIS and SMTS). Participants in the SMMS subtype exhibiting the greatest degree of dysfunction in movement-related sensory processing, also demonstrated the greatest competence in communication. Our results clearly show that communication impairment and SP difficulties in autism are interrelated and may be useful in defining specific autism phenotypes.

We also observed a strong predictive association between SP dysfunction and the presence of maladaptive behaviors with over 50% of the variance in maladaptive behavior explained by SP function. Taste/Smell Sensitivity, Auditory Filtering and Movement Sensitivity were identified as unique predictors of maladaptive behavior where more typical functioning in these domains was associated with fewer maladaptive behaviors. Further, significant differences between the SBIS subtype and both

SMMS and SMTS subtypes were detected on performance in maladaptive behavior but not between SMMS and SMTS. The SBIS group can be differentiated from SMMS and SMTS by milder overall SP dysfunction (i.e. isolated to Underresponsive/Seeks Sensation and Auditory Filtering only). This indicates that global SP dysfunction is predictive of maladaptive behaviors in autism. Sensory-based intervention strategies, therefore, may counteract the emergence of maladaptive behaviors and be an effective strategy for their management.

A number of limitations of our study need to be acknowledged. First, although the SSP has the best psychometric properties of current sensory profiles and is considered the most appropriate in research contexts, it is still a parent-report measure and therefore, susceptible to the limitations of those tools. Further, the SSP does not allow detailed analysis of sensory threshold data due to the small number of items included. This may have limited the variability of performance in SP in our sample and subsequently limited the sensitivity of the data to associations with some aspects of adaptive behavior.

Second, the SSP and VABS scores for participants were determined at various intervals relative to the point of diagnosis. It is possible that differing intervention i.e. amount and type of intervention already received at the time of SSP and VABS data collection, may have influenced both the adaptive behavior and the SP characteristics exhibited by participants. This factor should be considered in future studies examining SP patterns with attempts made to collect SP and adaptive behavior data at concurrent time points.

Conclusion

This study found that children with autistic disorder exhibit at least three distinct SP subtypes. The differentiation of sensory subtypes and characteristics within the diagnosis and classification of ASD is significant. For the first time, hypotheses regarding the mechanisms of SP dysfunction in autism can be generated based on a more defined and specific description of the associated behaviors. This study also found that patterns of SP dysfunction were strongly associated with some clinical features of autism. A pattern of difficulty in sensory modulation without movement elements was predictive of communication impairment, and general sensory modulation difficulties were predictive of maladaptive behavior. These findings support the continued use of sensory-based interventions in the remediation of communication and behavioral difficulties in autism. Further, the description of distinct sensory subtypes and characteristics in autism provides clinicians with guidelines for the identification of children likely to benefit most from sensory-based intervention techniques.

Acknowledgments We wish to express our gratitude to: the participating children and their parents, Ms Carrie Partington, for her involvement in data collection; Drs Paul Williamson and Simon Dennis for statistical support and advice; and Drs Lucy Miller and Sarah Schoen for their comments on early versions of this paper. This study was supported in part by the Channel 7 Children's Research Foundation, South Australia.

References

Adamson, A., O'Hare, A., & Graham, C. (2006). Impairments in sensory modulation in children with autistic spectrum disorder. *British Journal of Occupational Therapy, 69*, 357–364.

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders (4th ed.) (text revision)*. Arlington, VA: Author.

Ashburner, J., Ziviani, J., & Rodger, S. (2008). Sensory processing and classroom emotional, behavioral, and educational outcomes in children with autism spectrum disorder. *The American Journal of Occupational Therapy, 62*, 564–573.

Baker, A. E. Z., Lane, A., Angley, M. T., & Young, R. L. (2008). The relationship between sensory processing patterns and behavioural responsiveness in autistic disorder: A pilot study. *Journal of Autism and Developmental Disorders, 38*, 867–875.

Baranek, G. T., Boyd, B. A., Poe, M. D., David, F. J., & Watson, L. R. (2007). Hyperresponsive sensory patterns in young children with autism, developmental delay and typical development. *American Journal on Mental Retardation, 112*, 233–245.

Baranek, G. T., David, F. J., Poe, M. D., Stone, W. L., & Watson, L. R. (2006). Sensory experiences questionnaire: Discriminating sensory features in young children with autism, developmental delays, and typical development. *Journal of Child Psychology and Psychiatry, 47*, 591–601.

Baranek, G. T., Foster, L. G., & Berkson, G. (1997). Tactile defensiveness and stereotyped behaviors. *The American Journal of Occupational Therapy, 51*, 91–95.

Bennetto, L., Kuschner, E. S., & Hyman, S. L. (2007). Olfaction and taste processing in autism. *Biological Psychiatry, 62*, 1015–1021.

Ben-Sasson, A., Cermak, S. A., Orsomond, G. I., Tager-Flusberg, H., Carter, A. S., Kadlec, M. B., et al. (2007). Extreme sensory modulation behaviors in toddlers with autism spectrum disorders. *The American Journal of Occupational Therapy, 61*, 584–592.

Ben-Sasson, A., Hen, L., Fluss, R., Cermak, S. A., Engel-Yeger, B., & Gal, E. (2009). A meta-analysis of sensory modulation symptoms in individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 39*, 1–11.

Bölte, S., & Poustka, F. (2002). The relation between general cognitive level and adaptive behavior domains in individuals with autism with and without co-morbid mental retardation. *Child Psychiatry and Human Development, 33*(2), 165–172.

Dunn, W. (1999). *Sensory profile: User's manual San Antonio*. TX: The Psychological Corporation.

Dunn, M. A., Gomes, H., & Gravel, J. (2008). Mismatch negativity in children with autism and typical development. *Journal of Autism and Developmental Disorders, 38*, 52–71.

Dziuk, M. A., Gidley Larson, J. C., Apostu, A., Mahone, E. M., Denclkla, M. B., & Mostofsky, S. H. (2007). Dyspraxia in autism: Association with motor, social, and communicative deficits. *Developmental Medicine & Child Neurology, 49*, 734–739.

Ermer, J., & Dunn, W. (1998). The sensory profile: A discriminant analysis of children with and without disabilities. *The American Journal of Occupational Therapy, 52*, 283–290.

Field, D., Garland, M., & Williams, K. (2003). Correlates of specific childhood feeding problems. *Journal of Paediatric Child Health, 39*, 299–304.

Freeman, B. J., Del'Homme, M., Guthrie, D., & Zhang, F. (1999). Vineland Adaptive Behavior Scale scores as a function of age and initial IQ in 210 autistic children. *Journal of Autism and Developmental Disorders, 29*(5), 379–384.

Hilton, C., Graver, K., & LaVesser, P. (2007a). Relationship between social competence and sensory processing in children with high functioning autism spectrum disorders. *Research in Autism Spectrum Disorders, 1*, 164–173.

Hilton, C., Wente, L., LaVesser, P., Ito, M., Reed, C., & Herzberg, G. (2007b). Relationship between motor skill impairment and severity in children with asperger syndrome. *Research in Autism Spectrum Disorders, 1*, 339–349.

Kern, J. K., Garver, C. R., Carmody, T., Andrews, A. A., Mehta, J. A., & Trivedi, M. H. (2008). Examining sensory modulation in individuals with autism as compared to community controls. *Research in Autism Spectrum Disorders, 2*, 85–94.

Kern, J. K., Garver, C. R., Grannemann, B. D., Trivedi, M. H., Carmody, T., Andrews, A. A., et al. (2007a). Response to vestibular sensory events in autism. *Research in Autism Spectrum Disorders, 1*, 67–74.

Kern, J. K., Trivedi, M. H., Grannemann, B. D., Garver, C. R., Johnson, D. G., Andrews, A. A., et al. (2007b). Sensory correlations in autism. *Autism, 11*, 123–134.

Kielhofner, G. (2006). *Research in occupational therapy: Methods of inquiry for enhancing practice*. Philadelphia: F.A. Davis.

Koenig, K. P., & Kinnealey, M. (2008). Research brief: Sensory, motor, and communication challenges for persons with autism spectrum disorders. *Special Interest Section Quarterly: Sensory Integration, 31*, 3–4.

Kraijer, D. (2000). Review of adaptive behavior studies in mentally retarded persons with autism/pervasive developmental disorder. *Journal of Autism and Developmental Disorders, 30*(1), 39–47.

Leekam, S. R., Nieto, C., Libby, S. J., Wing, L., & Gould, J. (2007). Describing the sensory abnormalities of children and adults with autism. *Journal of Autism and Developmental Disorders, 37*, 894–910.

Liss, M., Saulnier, C., Fein, D., & Kinsbourne, M. (2006). Sensory and attention abnormalities in autistic spectrum disorders. *Autism, 10*, 155–172.

Lord, C., Pickles, A., McLennan, J., Rutter, M., Bregman, J., Folstein, S., et al. (1997). Diagnosing autism: Analyses of data from the Autism Diagnostic Interview. *Journal of Autism and Developmental Disorders, 27*(5), 501–517.

Malaspina, D., & Coleman, E. (2003). Olfaction and social drive in schizophrenia. *Archives of General Psychiatry, 60*, 578–584.

Martins, Y., Young, R. L., & Robson, D. C. (2008). Feeding and eating behaviors in children with autism and typically developing children. *Journal of Autism and Developmental Disorders, 38*, 1878–1887.

McIntosh, D. N., Miller, L. J., Shyu, V., & Dunn, W. (1999a). Overview of the short sensory profile. In W. Dunn (Ed.), *The sensory profile examiner's manual* (pp. 59–73). San Antonio, TX: The Psychological Corporation.

McIntosh, D. N., Miller, L. J., Shyu, V., & Hagerman, R. (1999b). Sensory-modulation disruption, electrodermal responses, and functional behaviors. *Developmental Medicine and Child Neurology, 41*, 608–615.

Miller, L. J., Anzalone, M. E., Lane, S. J., Cermak, S. A., & Osten, E. T. (2007). Concept evolution in sensory integration: A proposed nosology for diagnosis. *The American Journal of Occupational Therapy, 61*, 135–140.

Miller, L. J., Schoen, S., Coll, J., Brett-Green, B., & Reale, M. (2005). *Final report: Quantitative psychophysiologic examination of sensory processing in children with autism spectrum disorders*. Los Angeles, CA: Cure Autism Now.

Piek, J. P., & Dyck, M. J. (2004). Sensory-motor deficits in children with developmental coordination disorder, attention deficit hyperactivity disorder and autistic disorder. *Human Movement Science, 23*, 475–488.

Rogers, S. J., & Ozonoff, S. (2005). Annotation: What do we know about sensory dysfunction in autism? A critical review of the empirical evidence. *Journal of Child Psychology and Psychiatry, 46*, 1255–1268.

Schreck, K. A., & Williams, K. (2006). Food preferences and factors influencing food selectivity for children with autism spectrum disorders. *Research in Developmental Disabilities, 27*, 353–363.

Sparrow, S. S., Balla, D. A., & Cicchetti, D. V. (1984). *Vineland Adaptive Behavior Scales: Interview edition survey form manual*. Minnesota: American Guidance Service.

Tecchio, F., Benassi, R., Zappasodi, F., Gialloreti, L. E., Palermo, M., Seri, S., et al. (2003). Auditory sensory processing in autism: A magnetoencephalographic study. *Biological Psychiatry, 54*, 647–654.

Tomchek, S. D., & Dunn, W. (2007). Sensory processing in children with and without autism: A comparative study using the short sensory profile. *The American Journal of Occupational Therapy, 61*, 190–200.

Tomita, M. R. (2006). Methods of analysis: From univariate to multivariate statistics. In G. Kielhofner (Ed.), *Research in occupational therapy: Methods of inquiry for enhancing practice*. Philadelphia: F.A. Davis Company.

Watling, R. L., Deitz, J., & White, O. (2001). Comparison of sensory profile scores of young children with and without autism spectrum disorders. *The American Journal of Occupational Therapy, 55*, 416–423.

Zhong, S., & Ghosh, J. (2003). A unified framework for model-based clustering. *Journal of Machine Learning Research, 4*, 1001–1037.