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Sensory and attention abnormalities in autistic spectrum disorders

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ABSTRACT Individuals with autistic spectrum disorders (ASDs) often experience, describe and exhibit unusual patterns of sensation and attention. These anomalies have been hypothesized to result from overarousal and consequent overfocused attention. Parents of individuals with ASD rated items in three domains, 'sensory overreactivity', 'sensory underreactivity' and 'sensory seeking behaviors', of an expanded version of the Sensory Profile, a 103-item rating scale developed for the present study. Parents also rated symptom severity, overselective attention and exceptional memory, and completed the Vineland Adaptive Behavior Scales. Of 222 rated subjects, 144 had complete data. Cluster analysis showed the predicted overfocused pattern of sensation and attention, comprising overreactivity, perseverative behavior and interests, overfocused attention and exceptional memory in 43 percent of this sample. This pattern was striking in 10 percent. The neurological basis of overreactivity and overfocusing is discussed in relation to the overarousal hypothesis. Attention is drawn to its considerable prevalence in the ASD population.

KEYWORDS *attention; autism; autistic spectrum disorder; cluster analysis; sensory behavior*

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Introduction

Individuals with autistic spectrum disorders (ASDs) often respond in unusual ways to sensory stimuli (see Freeman et al., 1984). Some also describe themselves as being oversensitive to certain stimuli to the point of being impelled to withdraw from them (Grandin, 1996). Yet, conversely, individuals with ASD often underreact to stimuli, for instance ignoring

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painful bumps or bruises (Ornitz, 1988). Although such deviant reactions to sensory stimuli have been repeatedly remarked upon, they are not featured in the extensive symptom list for autistic disorder offered in DSM-IV (American Psychiatric Association, 1994). Also, individuals with autism engage in repetitive behaviors that have been thought to induce sensory self-stimulation. We have termed the three patterns of behavior listed above 'overreactivity', 'underreactivity' and 'seeking' respectively. They may characterize subgroups of individuals with ASD, or alternative states of individuals with ASD.

Impairment in sensory modulation and directing attention featured so prominently among the questionnaire responses of parents of 242 individuals with autism that Ornitz (1988) nominated this difficulty as the cause of autism. On Dunn's (1999) Sensory Profile, an instrument sensitive to anomalous sensorimotor behavior, 32 individuals with autism scored significantly higher than controls on 85 percent of the items, across all factors. Watling et al. (2001) found that eight of 10 Sensory Profile factor scores of 40 children with autism indicated abnormality relative to matched controls. According to Dunn et al. (2002), a group of 42 children with Asperger syndrome scored abnormally relative to controls on 22 of 23 Sensory Profile items. By what means might these pervasive sensory and attentional anomalies arise?

We hypothesize that sensory overreactivity may be explained as a possible response to overarousal. Specifically, overarousal might lead to overselective attention with secondary overreactivity.

Many individuals with autism exhibit overselective attention, typically focusing on a single element in a complex array (Lovaas and Schreibman, 1971; Lovaas et al., 1979). Shifting this focus may be difficult, leading to perseverative behavior. Overarousal leads to a narrowing of the range of cue utilization, rendering attention overselective (Easterbrook, 1959). Waterhouse et al. (1996) in turn related sensory disturbances to exaggerated selective attention. Exaggerated focus on elementary features of objects might amplify the children's experience of sounds, sights, and touches, triggering overreactivity. They also attributed perseverative preoccupations and repetitive movements, classified as seeking behavior, to overselective attention, as when the child is preoccupied with elementary surface features of objects (the spinning of a top, or hands waved in front of the face). Since individuals with autism may concentrate on small details of the environment for an inordinate amount of time, filtering out peripheral stimuli, they may develop savant skills and high-fidelity memory with respect to these details. Kinsbourne (1980) remarked on similarities between repetitive movements, here termed 'sensory seeking', and 'displacement' behavior that is observed in animals when they are in overaroused states of frustration or thwarting. Displacement behaviors appear to serve to moderate arousal levels.

We propose that a subset of individuals with autism will exhibit a pattern of sensory overreactivity in combination with an exaggerated or overfocused selective attention. Thus, we hypothesize that individuals with sensory overreactivity will also exhibit characteristics such as (1) other manifestations of overfocused behavior, such as not being able to shift attentional focus, (2) perseverative preoccupation, and resulting from the latter, (3) exceptional memory for self-selected material.

If such a cluster emerges, its prevalence in the sample population will be of interest. Is it sufficiently prominent to deserve mention in diagnostic symptom lists?

Methods

Procedure

Surveys and return envelopes were distributed at local and national conferences for parents of children with ASD and through the mail via an ASD network newsletter. Parents were told about the survey, and were asked to complete it and to return it either in person or through the mail. They were told that results of the survey would remain anonymous. Participating parents signed an informed consent form to have their data analyzed, and for an hour-long follow-up telephone interview. Parents were not paid for their participation, but were provided with a summary of research results when the investigation was concluded.

Participants

Inclusion criteria were (1) previous diagnosis on the ASD spectrum by a psychologist, psychiatrist or neurologist *and* (2) current diagnosis on the ASD spectrum based on answers given on a DSM-IV checklist included in the package of an initial group of 252. Twenty-nine participants were dropped from the analysis because they did not meet both criteria, and one was dropped on account of exceptionally high scores on the Vineland (e.g. socialization SS = 134). The final sample consisted of 222 parent reports. One hundred and ninety-one parents participated in the follow-up interview and were also administered the Vineland Adaptive Behavior Scales (Sparrow et al., 1984) by telephone. Complete data sets were available on 144 children.

Demographic information and mean scores on all experimental variables are presented in Table 1.

Table 1 **Mean scores on experimental variables (*N* = 144)**

Variable (possible range)	*Mean (SD)*
% male	79.9
Age in months	102.4 (50.1)
Exceptional memory (1–5)	4.1 (1.2)
Overreactivity (1–5)	2.36 (0.54)
Underreactivity (1–5)	2.36 (0.66)
Sensory seeking (1–5)	2.01 (0.53)
DSM-IV social symptoms (1–7)	4.12 (1.8)
DSM-IV communication impairment (1–7)	4.70 (1.4)
DSM-IV perseveration (1–7)	3.57 (1.2)
Kinsbourne Overfocusing Scale (0–75)	44.4 (13.6)
Vineland communication standard score	66.2 (24.6)
Vineland daily living standard score	53.0 (19.4)
Vineland socialization standard score	60.4 (14.2)
Vineland adaptive behavior composite standard score	56.4 (16.7)

Materials

Parents were given a packet that included the following materials.

Sensory Questionnaire This 103-item questionnaire, designed for this investigation (Liss et al., 1998; Saulnier et al., 2002), utilized 60 items from the Sensory Profile (Dunn, 1999) with permission from the author and publisher. These were supplemented with 43 newly developed items that reflected specific sensory behaviors seen in individuals with autism. Items are rated on a 1–5 Likert scale. Higher scores indicate greater impairment. Factor analysis of the standardization sample of 181 children and adolescents with ASD revealed a first factor, termed stimulus seeking, a second factor, termed overreactivity, and a third factor, termed underreactivity. These factors accounted for 34, 14 and 10 percent of the variance respectively, 58 percent accounted for collectively (Saulnier et al., 2002). Ninety-five items clearly fell on one of the three factors (the 43 items we developed, and 52 items from the Sensory Profile). The additional eight items were related to endurance, tone, body position and movement, and did not fall clearly on any of the factors; these items were not used in further analyses. The additional 43 items used, the 52 item numbers from the Sensory Profile, and our coding system, which indicated which items were taken to indicate overreactivity, underreactivity and seeking, respectively, can be seen in Appendix 1.

Parents also rated the extent to which their child had an exceptional memory, on a 1–5 Likert scale.

DSM-IV checklist The wording was kept consistent with the DSM, although for many items (such as impaired gestures, or perseveration on parts of objects) examples were provided to clarify the item. Parents rated their children on a 1–7 Likert scale: (1) symptom is not present, (3) mild impairment, (5) moderate impairment and (7) severe impairment. Mean scores were calculated for social symptoms, communication impairment, and perseveration.

Kinsbourne Overfocusing Scale Kinsbourne (1991) designed this 25-item checklist (see Appendix 2) to assess behaviors of some children referred for attention deficit hyperactivity disorder (ADHD), but whose attention seemed to be overfocused rather than lacking focus (Kinsbourne and Caplan, 1979). Parents rated their children on whether they exhibited the listed behaviors over the past 6 months: (0) never, (1) sometimes, (2) pretty often, and (3) very often. The range of possible scores was 0–75. Factor analysis revealed a first factor, which can be described in terms of perseveration and social withdrawal, in a normative as well as a clinical sample. On the Personality Inventory for Children, the clinical sample was identified with 90 percent accuracy as distinct from mainstream ADHD, in terms of the factors of withdrawal and social incompetence (Kinsbourne, unpublished data).

Vineland Adaptive Behavior Scale At follow-up, the Vineland Adaptive Behavior Scales (Sparrow et al., 1984) were administered over the phone. The Vineland evaluates how well a child functions in his or her day-to-day environment. Standard scores and age equivalents are provided in the communication, socialization, and daily living domains. Standard scores for these domains, as well as the adaptive behavior composite, were used in the analyses.

Results

Data screening

All variables met the assumptions of normality as a precondition for parametric statistics, except exceptional memory, which was highly negatively skewed. A reverse log transformation resulted in an acceptably normal distribution. Lower scores on this transformed variable correspond to higher exceptional memory abilities.

Table 2 **Correlations between Sensory Survey and other variables (*N* = 144)**

	Overreactivity	*Underreactivity*	*Sensory seeking*
Age	0.171*	n.s.	–0.220**
DSM-IV social symptoms	0.269**	0.463**	0.164*
DSM-IV communication impairment	n.s.	0.224**	0.316**
DSM-IV perseveration	0.268**	0.282**	0.332**
Kinsbourne Overfocusing Scale	0.608**	0.293**	0.235**
Vineland communication	n.s.	n.s.	–0.263**
Vineland daily living	n.s.	–0.326**	–0.165*
Vineland socialization	–0.195*	n.s.	n.s.
Vineland adaptive behavior composite	n.s.	–0.221**	–0.235**
log *R* exceptional memory	–0.196*	n.s.	n.s.

* $p < 0.05$; ** $p < 0.01$.

Correlations with experimental measures

Table 2 presents correlations between the experimental measures and the Sensory Questionnaire subscales (overreactivity, underreactivity and sensory seeking).

Overreactivity was significantly positively correlated with age; older individuals tend to have higher overreactivity scores. Overreactivity was also significantly positively correlated with social symptoms and perseveration impairments on the DSM-IV checklist, as well as lower socialization scores on the Vineland. It was highly correlated with the Kinsbourne Overfocusing Scale total score. Overreactivity was unrelated to communication impairment on the DSM-IV checklist or to communication abilities on the Vineland Adaptive Behavior Scales. Overreactivity was negatively correlated with the reverse log of the exceptional memory scale; being overreactive to stimuli is related to having a greater exceptional memory.

Underreactivity was strongly positively related to all dimensions of autistic symptomatology, as well as daily living scores on the Vineland and the adaptive behavior composite (the higher the underreactivity scores, the lower the adaptive functioning scores). It was positively correlated with the Kinsbourne Overfocusing Scale ratings, although less so than overreactivity. There was no relationship between underreactivity and age, or exceptional memory.

Sensory seeking behavior decreased with increasing age. Like underreactivity, it was related to greater symptom severity in all domains. It was also related to lower daily living and communication scores on the Vineland as well as the adaptive behavior composite. It was also positively correlated with overfocusing scores, although not as strongly as overfocusing was correlated with overreactivity.

Subscale intercorrelations

The three subscales of the Sensory Survey were significantly intercorrelated. The bivariate correlation between overreactivity and underreactivity was $r = 0.343$ ($p < 0.001$). The bivariate correlation of sensory seeking to overreactivity was $r = 0.460$ and to underreactivity was $r = 0.545$ (both $p < 0.001$).

Cluster analysis

A hierarchical agglomerative cluster analysis was performed in order to test the theoretical prediction that overreactivity, perseverative behavior, overfocusing, and high-fidelity memory would cluster together in the same individuals. Severity of symptomatology measured by the DSM-IV interview (range 0–7), communication, socialization and daily living standard scores on the Vineland Adaptive Behavior Scales, Kinsbourne Overfocusing Scale total score, Sensory Questionnaire overreactivity, underreactivity and sensory seeking mean scores, DSM-IV interview social symptoms, communication impairment and perseveration scores, and the transformed exceptional memory variable were entered into the analysis. All other variables met the assumptions of normality and linearity.

Clustering was determined by Ward's (1963) method, the procedure that is most frequently used for considering all possible combinations of clusters. Squared Euclidean distance was used as the similarity measure. Variables were standardized to control for unequal scaling that can affect cluster results. To determine the number of clusters, both the hierarchical tree and the agglomeration schedule were examined. Four clusters appeared to differentiate groups of subjects adequately. These four clusters were then subjected to a *K*-means iterative partitioning clustering procedure (Punj and Stewart, 1983). This method lets any misassigned subjects be relocated to a more appropriate cluster and allows for the lowest within-cluster variance and the highest between-cluster variance. Further supporting the four-cluster solution, only 16 of 144 subjects (11 percent) were reassigned to different clusters after the iterative partitioning. Thus, the clusters were relatively stable.

The final cluster centers that used standardized scores for the four groups can be seen in Table 3. One-way ANOVAs using Tukey *post hoc* tests were conducted on the unstandardized variables to examine group differences. Means and standard deviations as well as group differences at the 0.05 level for each cluster on the unstandardized scores can be seen in Table 4. Although the results are identical for the transformed exceptional memory item, the original item is used for ease of interpretation.

Cluster 1 included 17 individuals. It featured overreactivity to sensory stimuli, perseverative behavior on the DSM-IV, high overfocusing scores on

Table 3 Final cluster centers

	Cluster			
	1	*2*	*3*	*4*
Z-score: communication SS	0.98	0.27	–0.65	0.42
Z-score: daily living standard score	0.84	0.51	–0.69	0.11
Z-score: socialization standard score	0.08	0.65	–0.50	0.11
Z-score: Kinsbourne Overfocusing Scale	1.40	–0.89	0.21	0.47
Z-score: overreactivity mean score	1.25	–0.85	0.06	0.19
Z-score: underreactivity mean score	0.30	–0.84	0.83	–0.13
Z-score: seeking mean score	0.74	–0.63	0.54	–0.45
Z-score: DSM social symptoms	0.78	–0.86	0.51	–0.35
Z-score: DSM communication impairment	0.31	–0.33	0.52	–0.68
Z-score: DSM perseveration	1.03	–0.72	0.32	–0.26
Z-score: log *R* exceptional memory	–0.72	0.26	0.65	–0.58

Table 4 Characteristics of four clusters (*N* = 144)

	1 *Overfocused* *n = 17* *Mean (SD)*	*2* *No sensory problems* *n = 36* *Mean (SD)*	*3* *Low functioning* *n = 44* *Mean (SD)*	*4* *Mildly overfocused* *n = 47* *Mean (SD)*
Vineland communication SS	90.7 (20.3)[a]	73.0 (20.7)[a]	49.7 (18.2)[b]	76.6 (22.3)[a]
Vineland daily living SS	68.5 (17.1)[a]	62.0 (12.9)[ac]	38.5 (17.8)[b]	54.2 (17.2)[c]
Vineland socialization SS	60.8 (11.5)[ab]	69.4 (11.2)[b]	52.0 (12.6)[a]	61.2 (14.3)[a]
Kinsbourne Overfocusing Scale total	61.2 (9.5)[a]	30.2 (10.7)[b]	45.0 (10.9)[c]	48.7 (7.9)[c]
Overreactivity	3.0 (0.61)[a]	1.9 (0.35)[b]	2.4 (0.42)[c]	2.5 (0.41)[c]
Underreactivity	2.5 (0.59)[ac]	1.8 (0.42)[b]	2.9 (0.59)[c]	2.2 (0.52)[a]
Sensory seeking	2.4 (0.52)[a]	1.7 (0.39)[b]	2.3 (0.48)[a]	1.8 (0.40)[b]
DSM social symptoms	5.2 (1.1)[a]	3.2 (0.70)[b]	4.8 (0.97)[a]	3.9 (0.98)[c]
DSM communication impairment	5.3 (1.3)[a]	4.4 (1.3)[b]	5.6 (1.2)[a]	3.9 (1.1)[c]
DSM perseveration	4.9 (1.2)[a]	2.7 (0.96)[b]	4.0 (1.1)[c]	3.3 (0.90)[d]
Does your child have an exceptional memory?	4.9 (0.49)[a]	3.8 (1.4)[b]	3.3 (1.3)[b]	4.8 (0.46)[a]
Age in months: mean (SD)	114.2 (46.4)[ab]	80.7 (37.2)[a]	97.5 (50.0)[a]	119.2 (54.1)[b]
% male	88	83	70	83

[a–d] Numbers with different superscripts are significantly different at $p < 0.05$ by Tukey *post hoc*.

the Kinsbourne Overfocusing Scale, and an exceptional memory for selective material. Thus, this group has high scores on all the variables that are highlighted by the theory of overfocused selective attention.

Cluster 2 characterized 36 individuals. It had the lowest scores on the Sensory Survey and was least impaired on the DSM-IV interview. It also included the lowest overfocusing scores. Individuals in cluster 2 are relatively high functioning, are not seriously impaired, and have few sensory problems.

Cluster 3 consisted of 44 individuals. It had the lowest adaptive functioning scores, and high underreactivity and sensory seeking scores. This group is characterized by communication impairments and social symptoms. Their degree of perseveration is second only to that of cluster 1. Overall, this cluster is low functioning, with prominent undersensitivity and sensory seeking.

Cluster 4 had 47 individuals. Their scores were relatively low on autistic symptomatology, and relatively high on adaptive functioning, sensory overreactivity (although not as high as cluster 1), overfocusing, and having an exceptional memory. When a three-cluster solution is forced, this cluster combines with cluster 1. However, including this cluster with cluster 1 obscures the unique overfocusing qualities of cluster 1. Cluster 4 can be considered mildly overfocused.

Group differences on demographic variables can be seen in Table 4. There is a significant group difference for age $F(3, 140) = 4.8$, $p < 0.01$. *Post hoc* analyses indicated that cluster 4 was significantly older than clusters 2 and 3. Cluster 3 had relatively more girls than the other clusters, but this difference failed to reach significance.

Group differences on experimental variables can be seen in Table 4. The significance of the F-statistic for the variables used in the cluster analysis is not useful, as clusters were grouped to create the biggest differences between clusters on these variables. However, *post hoc* testing indicates which of the groups differ from each other. Cluster 1 had significantly higher scores than all other clusters on overreactivity, overfocusing, and DSM-IV perseveration. It had equal impairment in social symptoms and communication impairment on the DSM-IV to cluster 3, the low-functioning cluster. Cluster 2 had lower overreactivity and underreactivity, as well as DSM-IV social symptom and perseveration scores, than all other groups. Clusters 1 and 4 had significantly higher exceptional memory scores than the other two clusters.

Individual DSM-IV items were examined by cluster. Clusters 1 and 3 had the most impaired scores for most of the social symptom items, and were not significantly different from each other. Clusters 2 and 4 had less impaired scores and were not significantly different from each other. The item 'prefers to be alone' was significantly more endorsed in cluster 1 than in any other group, and was significantly less endorsed in cluster 2 than in all other groups. In the communication impairment domain, cluster 3 featured the most 'delay of expressive and receptive language', and cluster 1 the least. Cluster 3 was least able to initiate and sustain a conversation, but cluster 1 used the most idiosyncratic and stereotyped language (although not significantly more than cluster 3). In social and imitative play skills, clusters 1 and 3 were the most impaired, and not different from each other. Cluster 1 has the most impaired scores for all diagnostic criteria in the perseverative category, and cluster 3 has the second most impaired scores. Cluster 1 was significantly more notable for preoccupation with parts of objects, and preoccupation with specific interests, than all other groups.

Discussion

We delineated the nature and extent of sensory disturbances in ASD, and tested the hypothesis that sensory overreactivity is related to overselective or overfocused attention. We hypothesized that a subset of individuals would exhibit both overreactive and overfocused attention. These individuals may disproportionately assign attention to a central focus, thus amplifying the subjective experience of sensory stimuli.

Our hypothesis was confirmed by the results of the cluster analysis. Some 10 percent of the sample had scores indicative of an overreactive, overselective, and overfocused attentional system. They had high scores on overreactivity, exhibited overfocused behaviors (as rated on the Kinsbourne Overfocusing Scale), exhibited perseverative and stereotyped behavior (as measured by the DSM-IV checklist), and had a high-fidelity memory. They were relatively high functioning, and had the highest mean communication scores on the Vineland of the four clusters. Their sensory seeking scores were relatively high, although not significantly higher than those of the low-functioning cluster. A milder form of the same behavioral pattern was seen in a larger group of children.

Although the overfocusing cluster was the highest functioning, it was the most socially impaired. Overfocusing, therefore, appears detrimental to social behavior, but not necessarily detrimental to intellect and behavior in general. Overarousal may specifically impede social interaction (Dawson and Lewy, 1989). Conversely, cluster 3, the lowest-functioning cluster, tended to be underreactive. Underreactivity may be related to mental retardation.

Sensory seeking behaviors were highly prevalent in the overfocused cluster. An overreaction may only occur when an unexpected or otherwise aversive stimulus reaches the attentional focus. But an individual with autism may actively choose a pleasurable stimulus to focus on, finding it fascinating and perhaps soothing (Gillingham, 2000) and an escape from more disturbing input. Repeating the choice would be seen as sensory seeking behavior.

Overfocused attention may be mistaken for the inattention of ADHD, and Kinsbourne (1991) developed the Kinsbourne Overfocusing Scale to differentiate this relatively small subgroup from the mainstream of ADHD individuals. He suggested that the overfocused subgroup represents 'a dimension of personality that extends the continuum of autistic behavior into normality' (1991, p. 32). Although overfocused behavior may be an isolated pattern in an otherwise normally functioning individual, it appears from the present findings that it may also characterize a large subgroup of individuals who have other symptoms of ASD, and in whom the diagnosis of ASD is not in doubt.

Individuals with autism have been thought to have an unstable arousal system, and consequently often to be in a state of overarousal (Dawson and Lewy, 1989; Hutt et al., 1964; Kinsbourne, 1980; 1987). Thus Kinsbourne attributed autistic symptomatology to fluctuatingly exaggerated ascending activation of the cortex from the brainstem. Individuals with ASD have particular difficulty in negotiating social situations, and this may be due to overarousal because a social context is changeable, unpredictable and often emotionally arousing. However, an extensive literature does not reach consensus on whether individuals with ASD are overaroused in a general sense, at least as judged from EEG and autonomic measures. It seems more likely that some individual neurotransmitter pathways are overreactive. The alternative construct of 'noisy' firing of cortical neurons has also been offered (e.g. Hussman, 2001).

Overfocused attention may be related to abnormal neurotransmitter activity. Kinsbourne (1991) linked overfocusing to dopamine overreactivity. Correspondingly, amphetamine augments behaviors that are already common in an animal's repertoire (Robbins, 1975). Furthermore, dopamine agonists induce perseveration in mice (Anisman and Kokkinidis, 1975) and social withdrawal in rats (Gambill and Kornetsky, 1976). Stereotyped activities have been linked to excessive dopamine activity in the nigrostriatal circuitry (Creese and Iversen, 1974). Excessive dopamine activity in the mesolimbic pathway has been implicated in interpersonal-perceptual deficits and in the nigrostriatal pathway in motor stereotypies (Coleman and Gillberg, 1985; Damasio and Maurer, 1978; Maurer and Damasio, 1982). Dopamine antagonists such as neuroleptics and atypical antipsychotics have ameliorated symptoms of ASD, including stereotypies and inattention/hyperactivity, whereas dopamine agonists exacerbated these symptoms (Anderson et al., 1989; McDougle et al., 1998; Mikkelsen, 1982). Thus, excessive dopamine activity in nigrostriatal and/or mesolimbic pathways may play a role in the overreactivity of children with ASD. Deficient dorsolateral prefrontal control may disinhibit nigrostriatal activity (Bannon and Roth, 1983), thereby contributing to the psychopathology.

The overarousal hypothesis has been reformulated in terms of 'noisy' firing of cortical neurons. Hussman (2001) has implicated disinhibition due to release of gabaergic inhibition in ASD, which would result in hyperexcitation of target neurons and therefore difficulty in distinguishing a stimulus from competing 'noise'. Overreactivity would reflect this overexcitement of sensory systems. Overfocus and perseveration would be compensatory behaviors, serving to reduce sensory input into a narrow, controllable scope. Also implicating increased cortical 'noise', Casanova et al. (2002) reported that microcellular columns in the brains of nine individuals with autism who were studied at postmortem were smaller, more numerous and more dispersed in their cellular formation than those of four matched controls. They suggest that this pattern would lead to overconnected and insufficiently inhibited neural networks, with consequent hyperarousal and impaired selection (see also Belmonte and Yurgelun-Todd, 2003).

Difficulty in shifting attention may contribute to overfocusing and exacerbate the difficulties associated with overarousal. If individuals with ASD find it difficult to avert their attention from an aversive stimulus, they might overreact to it. Switching attention involves dorsolateral prefrontal cortex, as evidenced by neuropsychological (Godefroy and Rousseaux, 1996) and functional imaging (Barrett et al., 2003) studies. Difficulty executing rapid shifts of attention may also result from cerebellar dysfunction, and may undermine social development (Courchesne et al., 1994a). The slowing of orienting to visual cues was correlated with the degree of cerebellar hypoplasia in individuals with autism (Harris et al., 1999). Cerebellar abnormalities have been found in postmortem and MRI studies of autism (Courchesne et al., 1994b).

Our findings are consistent with the overarousal hypothesis in any of the above forms. This hypothesis proposes that individuals with ASD suffer from overarousal and that this primary difficulty may lead to overselective attention and repetitive behavior. Overselective attention and repetitive behavior compensate for the hypothesized hyperaroused state by allowing the individual with ASD both to focus on, and to generate, predictable repetitive events to help moderate their arousal level. Our investigation was not designed to determine causality. However, the fact that overreactivity, overfocusing, and sensory seeking behaviors clustered together in a subgroup supports this theoretical position.

Although we did not specifically hypothesize that overeactivity and overfocusing would be related to sensory underreactivity, there was a positive correlation between underreactivity and both of these scales. Thus, it is of theoretical interest to determine whether underreactivity can also be explained by overarousal or an overfocused attention. Underreactivity to sensory stimuli may be caused by the same underlying mechanisms as overreactivity. It may be a matter of the distribution of the individual's attention. If a stimulus is directed outside the focus of attention, and does not elicit orienting or other reaction, then an individual would seem to be underreactive to that stimulus. Alternatively or additionally, underreactivity is the aftermath of overarousal so severe that it precipitates a state of shutdown (Gillingham, 2000), perhaps at the conclusion of a prolonged bout of dearousing repetitive movements (Kinsbourne, 1980).

As predicted, sensory overreactivity clustered with overfocused and perseverative behavior, as well as exceptional memory for material of interest, in subjects who were found to be generally high functioning with disproportionately impaired social skills. In contrast, sensory underreactivity was concentrated in a generally low-functioning subgroup. From an arousal perspective, the high-functioning subgroup would be regarded as generally overaroused, and their underreactivity might suggest that the low-functioning group is in general underaroused. However, being underreactive does not entail being underactive. The repetitive movement patterns here characterized as sensory seeking were common in both subgroups, but more prominent in the low-functioning subgroup. Self-generated and self-referential movements seem to replace this group's reaction to environmental change.

We have suggested that sensory seeking is compensatory, moderating arousal when it rises to uncomfortable heights. However, repetitive movements were prominent also in underreactive low-functioning participants with ASD. Indeed, repetitive movements are frequently observed in intellectually impaired individuals who do not have autism (Alvarez, 1999), in typical children who are in residential care (Troster, 1994), in typical infants confined in cribs, and in caged or isolated animals (Berkson and Mason, 1964). They might be situational, in reaction to an environment that offers few response opportunities to individuals who therefore become overaroused, but whose response capabilities are limited. Baumann remarked that '[stereotypies] seem to stabilize the child's level of arousal in monotonous, frustrating or overstimulating situations' (1999, p. 602). They are perhaps better described as self-soothing than stimulation seeking.

The overreactive/overfocused pattern of behavioral abnormality to some degree characterized nearly half of our study sample, and is therefore a major component of autistic spectrum disorders. Diagnostic criteria typically emphasize deficits and disabilities rather than deviances in behavior. Nonetheless, the overreactivity/overfocusing symptom pattern may merit more than its current low level of prominence among the formal diagnostic criteria for ASD.

Appendix 1: Sensory Questionnaire

The following are the numbers of the 52 items from the Sensory Profile (copyright © 1999 by the Psychological Corporation, all rights reserved). Also shown is the domain in which they were included: O = overreactivity, U = underreactivity, S = stimulus seeking.

1 (O), 2 (O), 4 (O), 5 (O), 6 (U), 7 (U), 8 (S), 9 (O), 10 (O), 15 (O), 18 (O), 19 (O), 20 (O), 21 (O), 25 (S), 26 (S), 27 (S), 28 (S), 29 (O), 30 (O), 32 (O), 33 (O), 35 (O), 36 (O), 38 (O), 39 (O), 40 (S), 41 (S), 42 (U), 43 (U), 44 (S), 45 (S), 46 (U), 50 (U), 53 (S), 54 (O), 55 (O), 56 (O), 57 (O), 58 (O), 59 (S), 60 (S), 64 (S), 65 (S), 77 (O), 78 (O), 81 (S), 83 (S), 87 (O), 89 (O), 96 (O), 99 (U)

The following are the 43 additional items (© by Miriam Liss, Celine A. Saulnier, and Deborah Fein, 1998; University of Connecticut), again with the domains shown:

O Responds negatively to noisy environments (e.g. shopping malls, crowded restaurant).
U Appears not to notice loud and sudden noises (e.g. dishes crashing, sirens).
S Actively seeks loud environments (e.g. prefers noisy cafeteria to quiet classroom).
S Holds hand over ears while vocalizing (e.g. humming, singing).
O Has an adverse reaction to printed words in motion (e.g. credits after a movie).
O Seems to have exceptional peripheral vision (responds to visual cue without looking directly at it).
O Has a negative reaction (covers eyes) to visually complex environments (e.g. colorful classroom).
U Does not react to bright lights when shining in their faces.
U Appears not to see things.
S Waves fingers in front of eyes.
S Touches or presses eyeballs.
S Presses face to television.
S Has fixation on moving words (e.g. movie credits).
S Stares at spinning objects for long periods of time.
O Dislikes spinning.
U No reaction to being moved suddenly (being turned upside down, being swung around in a circle).
U Does not appear to get dizzy when spinning.
S Seeks out swinging.
S Jumps excessively (on bed, floor, etc.).
O Hates cold weather or cold water.
O Has a negative reaction to tags on clothing.
O Has an adverse reaction to light/gentle touch (e.g. tickles).
O Has an adverse reaction to deep pressure (hugs, someone grabbing arm).
U Unresponsive to extreme heat.
U Unresponsive to extreme cold.
U Doesn't seem to notice light touch.
U Doesn't seem to notice deep pressure.
U Unresponsive to aversive textures (e.g. sand or rocks in shoes).
S Hits body.
S Bangs head.

S Throws body.
S Bites self.
S Sucks on fingers.
S Picks skin.
S Pulls own hair out.
S Flaps hands.
S Other similar behaviors (list: ______________________________).
O Gags or vomits in response to non-preferred food items.
U Appears unresponsive to strong or spicy foods.
S Shows preference for strong or spicy foods.
O Overreactive to strong odors.
O Can detect/is aversive to faint odors (e.g. body lotion, faint perfume).
S Seeks out certain smells (list: ______________________).

Appendix 2: Kinsbourne Overfocusing Scale

Please rate the child's behavior on each item listed below over the last 6 months. Please circle only one of the following ratings:

0 = behavior occurs not at all; 1 = it occurs sometimes; 2 = it occurs pretty often; 3 = it occurs very often

1 Prefers sameness, upset by sudden changes in routine.
2 Socially withdrawn and unskilled, especially with strangers.
3 Works slowly and may be compulsive.
4 Resists being hurried or told to do more than one thing at a time.
5 Organization is difficult (for instance, organizing schoolwork, keeping up with assignments, cleaning up room), especially at the beginning of tasks.
6 Often seems preoccupied with his/her own thoughts.
7 Is bothered by loud noises.
8 Unusually sensitive hearing.
9 Has a narrow scope of interest.
10 Prefers to focus on one thing at a time.
11 Explores topics of own choosing in depth.
12 Resists shifting attention or changing activities on someone else's timetable.
13 Worrier, anxious.
14 Overly sensitive to negative feedback.
15 May interpret a parent's frown as indicating anger or a teacher's scolding directed specifically at him/her.
16 Has trouble 'remembering' (for instance, remembering more than one instruction at a time, classroom assignments, chores).
17 Is quietly oppositional, stubborn.
18 May have explosive outbursts, and takes a considerable time to cool off.
19 Performs better on tasks and in situations after getting used to them (for instance, at the end of the school year than at the beginning, or after trying a task one or more times).
20 May keep the same posture of facial expression for unusually long periods of time.
21 Is frightened of anticipated new or intense experiences (for instance, meeting new people or undertaking new activities).
22 Becomes preoccupied with impending, anticipated events.

23 Engages in repetitive movements (for instance, tapping, self-touching).
24 Often sits 'hunched over' when working.
25 Is shy.

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