

# Sensory Sensitivities and Performance on Sensory Perceptual Tasks in High-functioning Individuals with Autism

Nancy J. Minshew · Jessica A. Hobson

Published online: 27 February 2008  
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**Abstract** Most reports of sensory symptoms in autism are second hand or observational, and there is little evidence of a neurological basis. Sixty individuals with high-functioning autism and 61 matched typical participants were administered a sensory questionnaire and neuropsychological tests of elementary and higher cortical sensory perception. Thirty-two percent of autism participants endorsed more sensory sensitivity items than any control participants. Both groups made few errors on elementary sensory perception items. Controls made few errors on higher cortical sensory perception items, but 30% of the autism participants made high numbers of errors. These findings support the common occurrence of sensory symptoms in high functioning autism based on first person report, and the presence of neurological abnormalities in higher cortical sensory perception.

**Keywords** Autism · Sensory sensitivities · Sensory perception · Sensory neglect

## Introduction

The nerve endings on my skin were supersensitive. Stimuli that were insignificant to most people were like Chinese water torture. (Grandin 1992)

When Kanner (1943) and Asperger (1944/1991) first described the condition of autism, each reported inappropriate responses to sensory stimulation among the children they observed. Early clinical accounts described sensory dysfunction as central to the condition (Bergman and Escalona 1949), and some clinicians continue to hold this view (Talay-Ongan and Wood 2000). Further, sensory sensitivities and peculiarities have been incorporated as diagnostic features of the syndrome (DeMyer 1976; Hermelin and O'Connor 1964; Ornitz 1989; Rogers et al. 2003; Wing 1969). In the most recent revisions to the diagnostic system, clinical features associated with autism include “odd responses to sensory stimuli” (e.g., high pain tolerance, over-sensitivity to sound or touch, and excessive reaction to light or odors) (DSM-IV-TR: American Psychiatric Association 2000). DeMyer et al. (1981) described “a solid case for the presence of a significant disturbance in sensory processing” but stated that the underlying mechanism for this disturbance has not been established. In a recently published extensive review of empirical evidence for sensory dysfunction in autism, Rogers and Ozonoff (2005) reported that despite evidence for the prevalence and prominence of sensory symptoms in autism, there is little careful empirical work to support an explanation of the unusual sensory responses often associated with this condition. In addition, empirical information regarding the nature and extent of sensory disturbances within the autism population and potential links between sensory disturbances and neurological profiles in these individuals is lacking.

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N. J. Minshew  
Departments of Psychiatry and Neurology, University  
of Pittsburgh School of Medicine, Pittsburgh, PA, USA

N. J. Minshew (✉)  
NICHD Collaborative Program of Excellence in Autism,  
University of Pittsburgh School of Medicine, 3811 O'Hara  
Street, Suite 300 Webster Hall, Pittsburgh,  
PA 15213-2593, USA  
e-mail: minshewnj@upmc.edu

J. A. Hobson  
Institute of Child Health, University College London, London,  
UK

### First-hand Accounts

Over the past 50 years, sensory sensitivities, sensory overload, and perceptual distortions have been reported extensively in autobiographical accounts by high-functioning individuals with autism (Grandin 1992, 2005; Williams 1994). Such abnormalities include hypersensitivity to stimulation and sensation. Individuals with autism describe auditory experiences “like a hearing aid with the volume control stuck on super loud,” olfactory experiences in which the smell of deodorant and lotion is “so strong to me I can’t stand it,” and tactile experiences in which the feeling of being hugged is like being “overwhelmed by the tidal wave of sensation” (O’Neill and Jones 1997). Grandin (2005) writes, “When people touched me, I experienced an overwhelming, drowning wave of over-stimulation...switching from pants to a dress is difficult because it takes me up to 2 weeks to fully adapt to the feelings of pants against my legs or the absence of pants against my legs.” The above statements underscore a generally accepted but insufficiently understood and documented feature of the syndrome, namely heightened sensitivity across sensory domains (Dawson and Watling 2000; Goldstein 2000; Hill and Frith 2003).

### Clinical Observations

The published literature on sensory-perceptual disturbances in autism is primarily case descriptive. Early clinical descriptions included tactile, auditory, and visual hypersensitivity, and tendencies to ignore pain and cold temperature (Ornitz et al. 1970; Rutter 1966). A recently published developmental case study described “hypersensitivity to approach, loud noise, and tactile contact” as well as “insensitivity to pain” as early as 9–12 months of age in a child later diagnosed with autism (Dawson et al. 2000), and such observations are corroborated by retrospective video analyses (Baranek 1999). Behavior observation scales have yielded confirmatory evidence that sensory disturbance is pervasive in autism (Adrien et al. 1987). DiLalla and Rogers (1994) found that a “Distorted Sensory Response” factor—made up of tactile, visual, and auditory oddities in stimuli responsiveness—represented an essential domain of the Childhood Autism Rating Scale, an observational system frequently used in the diagnosis of autism.

### Parent Report

Parent and caregiver questionnaires have often been used to study sensory reactivity in individuals with autism, and these consistently confirm elevated rates of sensory problems in toddlers (Rogers et al. 2003), preschool children (Ornitz et al. 1977) and children of school age (Kientz and

Dunn 1997), as well as in adults (Harrison and Hare 2004) and across the life-span (Kern et al. 2006).

Rogers et al. (2003) administered a questionnaire—the Short Sensory Profile—to parents of toddlers who either had autism, fragile X syndrome, developmental disorders of mixed etiology, or who were typically developing. Children with autism and children with fragile X syndrome had markedly elevated scores in sensory reactivity and sensory sensitivities in relation to the other groups. When the full version of the Sensory Profile (Dunn 1999), a 125-item questionnaire, was administered to parents of older children with autism, the most frequently endorsed items were “hypersensitivity to touch and to auditory input” (Kientz and Dunn 1997).

These difficulties appear to occur across the ASD spectrum, including in children with Asperger syndrome (Dunn et al. 2002; Dunn et al. 2002; Myles et al. 2004). Using the Dunn (1999) sensory profile across the lifespan, Kern et al. (2006) provide evidence that sensory processing abnormalities involve multiple modalities (e.g., auditory, visual and tactile) and can involve both sensory sensitivities and apparent insensitivity such that sensory seeking and defensiveness occur within the same individuals. These authors also reported that sensory sensitivities may decrease with age (Kern et al. 2006). It should also be noted that rates of sensory symptoms in school-age children with autism range in studies from 42% to 88% and thus are common but not universal to the condition (Baranek et al. 2005).

Structured parent interview data from the Autism Diagnostic Interview-Revised (Lord et al. 1994) suggest high rates of sensory disturbance even in relation to a clinical control group. Harrison and Hare (2004) administered a questionnaire to caregivers of adults with autism living in group homes and found high rates of abnormal sensory-related behavior in their population. Further, community-based questionnaire studies suggest that roughly half of individuals with autism are rated as showing hypersensitivity to touch (Harrison and Hare 2004).

An obvious limitation of observational over patient self-report based interview methods is the inference that the observed behavior is related to a disturbance in sensory perception, when other non-sensory explanations are plausible. In spite of the general acceptance of the presence of sensory symptoms among individuals with autism, no studies, to our knowledge, exist that investigate sensory-perceptual functioning on neurologic tasks and compare this to self-reported sensory sensitivities.

### Sensory-perceptual Studies

In the 1960s, a series of studies conducted by Hermelin and O’Connor (Hermelin 1963; Hermelin and O’Connor 1964;

O'Connor and Hermelin, 1963) demonstrated how—unlike matched children without autism—children with autism respond to signal intensity regardless of modality or meaning. Hermelin (1963) reported how in individuals without autism, “response behavior is structured according to the meaning rather than the modality of the stimulus input...an absence of such a hierarchical structure would lead to behavior which lacks a predictable pattern and appears random...if instead of items of information the input into a system is random noise, the output likewise will be random.” Further studies from this group corroborated these findings in showing how individuals with autism struggle when dealing with complex or patterned stimuli (Frith 1970; Hermelin and Frith 1971).

Other early evidence for unusual sensory-perception has included reports of heightened sensitivity to simple stimulation (Frankel et al. 1976) and improved classroom performance when auditory information was reduced through the use of ear protectors (Fassler and Bryant 1971). A series of studies conducted a number of years ago (Cohen and Johnson 1977; Kootz et al. 1982) demonstrated how cardiovascular indices of sensory reactivity (e.g., heart rate and blood flow) were indicative of what these authors referred to as rejection of sensory stimulation in children with autism as a group. These authors suggested that lower-functioning children with autism (defined as those who had difficulty learning a reaction-time test) may be more sensitive to changes in the environment and thus were even more engaged in sensory avoidance as assessed by cardiovascular measures. These authors speculated that individuals with autism may cope with underlying disturbances in the modulation of stimulation and arousal by actively avoiding stimuli and thereby reducing experiences of novelty. Thus, behavioral features of autism including sensory rejection, self-stereotypical activity, and insistence on sameness may be linked with underlying disturbances in sensory processing at a perceptual level.

Sensory-perceptual function has been investigated with neuropsychologic testing in a few studies. Two studies have evaluated sensory perception but did not find statistical evidence of an overall deficit in this domain (Minshew et al. 1997; Rumsey and Hamburger 1988). However, examination of test performance within this domain in the Minshew et al. (1997) study of 33 adolescents and adults with high functioning autism revealed virtually error-free performance of both autism and control groups on tasks involving elementary sensory abilities (simple touch, sharp-dull discrimination, position sense), but significantly more errors on a sensory-perceptual measure involving complex or higher-cortical processing (Finger-Tip Number Writing) in the autism group compared to controls. In a review of the Rumsey and Hamburger study (1988), the 10 men with autism showed extensive variability on the

finger-tip number writing task, suggesting that some of the members of this group may have been impaired even when the group mean did not reflect overall differences. Recently, Cascio et al. (2008) provided evidence that adults with and without autism were similar in their thresholds for detection of tactile sensation in some respects—detection of light touch and innocuous warmth/cool sensations—but markedly different in others—sensitivity to vibration and thermal pain.

#### Theoretical Accounts

Recent theoretical models have been proposed for considering the role of sensory sensitivities in autism. For example, Waterhouse et al. (1996) have used the term *canalesthesia* to refer to inadequate cross-modal integration, fragmentation, and processing dyscontrol. The model provided by Kootz et al. (1982) focuses on underlying disturbances in attention and modulation of response to stimulation. Theoretical accounts have proposed that individuals with autism show over-arousal (Hutt et al. 1964) as well as under-arousal (DesLauriers and Carlson 1969). Other researchers have considered the children's fluctuating arousal to stimulation (Ornitz 1988) and exaggerated selective attention to minor detail (Kinsbourne 1980, 1991). Dunn and colleagues (Dunn 1999, 2007; Dunn et al. 2002) have proposed and provided empirical evidence for a model of sensory processing based upon high and low neurological thresholds for input. Depending upon an individual's behavioral self-regulation strategies (passive or active), individuals may show features of low sensory registration or sensation seeking behavior, as well as sensory sensitivity or sensation avoiding behavior. Individual differences and variations on these patterns are common among individuals on the autism spectrum.

There is empirical evidence to suggest that individuals with autism may show enhanced perceptual processing for low-level stimuli (Behrmann et al. 2006; Mottron and Burack 2001). Perceptual biases for details and a heightened sensitivity to unique, rather than shared, stimulus features may underlie the autistic “need for sameness” (Happé 1999). Thus, the characteristic cognitive strengths found in autism, such as heightened processing of features and hyper-focus on details, often those that are inconsequential or insignificant, may be linked with or exacerbate sensory processing abnormalities.

Minshew and colleagues have proposed that impairments in higher cortical sensory perception are but one of many manifestations of a more generalized deficit in complex information processing (Minshew et al. 1997) resulting from alterations in the brain connectivity of cortical systems (Just et al. 2004). This dissociation between intact elementary sensory perceptual abilities and impaired

higher order sensory abilities are consistent with the pattern observed across domains in neuropsychological studies (Minshew et al. 1997; Williams et al. 2006) and the widespread disturbances in cortical connectivity shown in fMRI studies (for review: see Minshew and Williams 2007; Williams and Minshew *in press*). The status of elementary and higher cortical perception can be investigated with the sensory perceptual batteries from well-established neuropsychological tests. The relationship between performance on measures of sensory-perceptual function and the presence of sensory symptoms noted by patients or their parents can then be examined.

The neuropsychologic tests commonly used to assess sensory perception are the Luria-Nebraska Battery, Tactile Functions Domain (Golden et al. 1980) and the Reitan-Klove, Sensory Perceptual Exam (Reitan and Wolfson 1993). These tests include items that assess elementary sensory perceptual abilities and higher cortical sensory perceptual abilities. The distinction between elementary sensory abilities and higher cortical sensory perceptual abilities is a standard neurologic convention based on the differences in neuroanatomical representation of these abilities. Elementary somatosensory perceptual abilities are subserved by sensory tracts or pathways in the spinal cord, e.g., the posterior columns for the sensations of position and vibration and the spinothalamic tracts for the sensations of light touch, pain and temperature. The elementary senses of visual, smell, taste, and hearing acuity are subserved by the cranial nerves, which are distinct from but analogous to the somatosensory system. The higher cortical sensory perceptual abilities are supported by specialized circuitry in cerebral cortex and cortico-cortical connections, which result in these more elaborate or specialized sensory abilities. The best known of the higher cortical sensory abilities are the capacity to identify: (1) double simultaneous presentations of stimuli at two corresponding locations on the left and right sides of the body in any sensory domain, e.g., visual (occipital lobe), tactile (parietal lobe), or hearing (parietal) (extinction of the second stimulus, usually on the left is referred to as 'neglect'); (2) numbers written on the skin with a pencil or stylus with eyes closed (graphesthesia); (3) small objects placed in the hand by touch alone (stereognosis); (4) locations touched on the skin by the examiner (touch localization). Successful administration of these batteries requires subjects who comprehend the instructions, are cooperative, and capable of expressing their responses in verbal or motoric format.

As with every cognitive or neuropsychologic test, the task targets a particular ability but invariably relies on multiple abilities for performance. It is therefore necessary to administer a baseline battery to establish that subjects

have the requisite skills to perform the sensori-perceptual tests, thus eliminating other explanations besides the hypothesized sensori-perceptual deficits, if test performance is below norms. For example, when testing position sense, the subject is asked to demonstrate accurate perception of position by imitating the position imposed on his joint *while his eyes are closed*. This is not a traditional imitation task in which the individual sees a motor action and imitates it, but instead his joints and muscles sense the position his elbow or other joint is placed in and replicate it with his other arm. This task also taxes hearing, language comprehension, imitation, movement stability, and muscle strength, in addition to position sense. Deficits in any of these areas could contribute to impaired task performance. To verify that impaired performance on this and other sensory perceptual tasks was related to sensory deficits and not to other skill deficits, all subjects in this study were required to complete in advance a basic battery of attention, memory, language, reading and oral comprehension, verbal fluency, motor speed, motor praxis, motor strength, and rule-learning tests. This test battery was part of the University of Pittsburgh Collaborative Program of Excellence in Autism Subject Core battery administered to all subjects recruited to assure that performance on any project paradigm was not due to a basic skill deficit. The age (8–54 years) and ability range (FS and VIQ 80–125) of the subjects was also compatible with the capability for performing the tests. Thus, any performance difficulty on the sensory perceptual batteries was highly unlikely to be related to inability: to comprehend the tasks, to attend to the tester and the task, to cooperate, to remember instructions, to express a response verbally, or to perform a motor imitation or response. Normative comparisons were provided by the control group selected from the community with the same socioeconomic status as the autism subjects' family of origin, but also by reference to established clinical norms for neuropsychologic parameters (Spreeen and Strauss 1998; Reitan and Wolfson 1993; Golden et al. 1980). The clinical norms are especially useful, as they provide input on the clinical significance of research findings in the study group and also a determination as to whether the findings for the typical control groups reflect those of a larger community population.

The purpose of the present study was to (a) provide descriptive information on the prevalence and nature of sensory sensitivities according to both parent- and self-report in a high-functioning autism sample, (b) compare performance between individuals with and without autism on measures of elementary vis-à-vis higher cortical sensory perception, and (c) examine the relationship between self- or parent-reported sensory symptoms and objective measures of sensory perception among high-functioning individuals with autism.

## Method

### Participants

All participants were recruited and assessed by the Subject Core of the University of Pittsburgh Collaborative Program of Excellence in Autism. Participants in this study included 60 high-functioning individuals with autism (9 female, 51 male;  $M$  age = 17 years, range = 8–54 years,  $SD$  = 10 years) and a closely matched group of 61 normally developing controls (12 female, 49 male;  $M$  age = 19 years, range = 8–52 years,  $SD$  = 9 years). Full scale IQ scores were 90 and above for all participants (autism  $M$  = 111, range = 90–145,  $SD$  = 12; control  $M$  = 112, range = 92–131,  $SD$  = 8), and the groups were closely matched on verbal IQ (autism  $M$  = 110, range = 91–145,  $SD$  = 13; control  $M$  = 110, range = 94–127,  $SD$  = 8,) as well as performance IQ (autism  $M$  = 110, range = 86–137,  $SD$  = 12; control  $M$  = 112, range = 90–129,  $SD$  = 8). Participants with autism were consecutive community referrals over a 4-year period to a research clinic, all of whom met criteria for this study and agreed to participate. Control participants were community volunteers from neighborhoods with the same socioeconomic status (SES) as that of the families of origin of the participants with autism. This study was approved by the University of Pittsburgh Medical Center Institutional Review Board and written informed consent was obtained from participants and/or their guardians.

The diagnosis of autism was established through two structured research diagnostic instruments, the Autism Diagnostic Interview-Revised (ADI-R: Lord et al. 1994) and the Autism Diagnostic Observation Schedule-General (ADOS-G: Lord et al. 1999) and confirmed by expert clinical opinion in accordance with accepted clinical descriptions of high functioning autistic individuals (Minshew 1996; Filipek et al. 1999). All subjects in the autism group met criteria for autism on all three domains of the ADI and the age cut off, and both the social and communication cut offs and the total cut off on the ADOS. Potential participants were excluded if found to have evidence of an associated neurologic, genetic, or infectious disorder, such as tuberous sclerosis, fragile-x syndrome, or fetal cytomegalovirus infection. Exclusions were based on neurologic history, structural imaging, and chromosomal analysis.

Neuropsychiatrically normal, medically healthy control participants were recruited from the community. Potential control participants were screened by questionnaire, telephone, personal interview, and observation during preliminary psychometric evaluations. Exclusionary criteria, evaluated through these procedures, included a history or evidence of: birth or developmental abnormalities;

acquired brain injury; poor school attendance; a learning or language disability; a current or past history of psychiatric or neurologic disorder; a medical disorder with implications for the central nervous system or requiring regular medication usage; or a family history in first degree relatives of developmental cognitive disorder, learning disability, mood disorder, anxiety disorder, alcoholism, or other neuropsychiatric disorder thought to have a genetic or familial component, or of autism in any family member.

### Measures

Participants and their parents each completed a brief questionnaire on sensory sensitivities. We requested that the forms be completed by the participants and parents independently of each other. Although these forms were often not completed in the presence of a staff member, the items were designed to be simple and clear, and we did not ever observe study participants having difficulty with the items. Participants were assessed by trained testers in our lab with standard neurological measures of sensory perception.

#### *Sensory Sensitivity Questionnaire (SSQ)*

In order to ask individuals with autism about their own subjective sensory experiences, we developed a simple self-report SSQ on the basis of (i) items from the highly sensitive person self-report checklist (Aron and Aron 1997) revised to include common reactions to sensory stimuli reported by individuals with autism (e.g., bothered by sounds, overall sensitivity to the environment, and a low tolerance for pain); (ii) classic behavioral descriptions by individuals with autism, for example clothing feeling like sandpaper (Grandin 1992), and (iii) clinical reports (Ayers 1979; McClure and Holtz-Yotz 1991; Zisserman 1992) as well as our own extensive clinical experience. Two versions of this form were created for participants and for their parents. The 13 items assessed are listed in Table 1.

The self-report form consisted of 13 items that were phrased in the form of yes or no questions, and participants were instructed to check corresponding boxes to endorse or deny each symptom. Items included questions regarding auditory and light sensitivity, tactile sensitivities, high and low pain tolerance, temperature sensitivity, awareness of smell or taste, and general questions regarding sensitivity to environmental events or conditions. A priori, we divided the items into categories. Three items assessed for the presence of *Tactile Sensitivities*, two items assessed for the presence of *Low Pain/Temperature Thresholds*, two items assessed for the presence of *High Pain/Temperature Thresholds*, and six further items assessed for *Other Sensitivities*. These four scales for each version were used in

**Table 1** Abbreviated items from Sensory Sensitivity Questionnaire (SSQ)

Domain	Item
Low temperature/ Pain tolerance	(1) Unusually sensitive to heat or cold
	(2) More sensitive to pain than other people
High temperature/ Pain tolerance	(1) Unusually insensitive to heat or cold
	(2) High pain tolerance
Tactile	(1) Made uncomfortable by touch or texture of clothing
	(2) Enjoys light brushing or touch
	(3) Likes or seeks out deep pressure or squeezing
Overall sensory sensitivities	(1) Unusually sensitive to light
	(2) Bothered by sounds
	(3) Unusually responsive to odor or taste
	(4) Covers ears in response to the sound of fire-trucks, crying babies, or other loud noises
	(5) Becomes easily upset or overwhelmed in loud or crowded places
	(6) Overall sensitivity to the environment (e.g., bright lights, strong smells, coarse fabrics, or sirens)

subsequent analyses of sensory sensitivities, rather than conducting analyses according to particular items, where we considered that endorsing more frequent numbers of items would suggest greater numbers of sensory sensitivities. The self-report questionnaire was completed by 87% ( $n = 52$ ) of the participants with autism and by 95% ( $n = 58$ ) of those in the comparison group.

In order to provide an index of reliability, we also administered a parent-report version of this measure. The parent-report version consisted of 13 identical items, which were rephrased to refer to the participant. The same four sub-scales were used as per a priori definition. The parent version of the questionnaire was completed by 82% of parents of participants with autism ( $n = 49$ ) and by 43% of parents of participants in the comparison group ( $n = 26$ ). This is due to the fact that fewer parents of adult comparison participants were involved in the study. For this reason, self-report data are used for analyses involving relations among sensory symptoms and sensory-perceptual processing. However, we confirm the analyses within the participants with autism by considering those who also had parent report to ensure results are similar.

#### Neurologic Sensory-perceptual Measures

All participants in this study completed all of the following sensory-processing items.

#### *Luria-Nebraska Neuropsychological Battery Tactile Functions*

The Tactile Functions domain of the Luria Nebraska was administered to assess tactile sensation (sensitivity to touch), tactile inattention, finger agnosia, stereognosis, and finger-tip writing. The age adjusted norms for these tests are derived by calculations based on equations provided in the manual (Golden et al. 1980) but generally the same low rates of errors are expected as for the Reitan-Klove Examination below.

#### *Reitan-Klove (RK) Sensory Perceptual Examination*

The Reitan-Klove Sensory Perceptual Examination is a common measure used to assess for tactile-perceptual deficits, specifically the Finger-Tip Writing and Tactile Finger Recognition subtests. It also contains stimuli to measure visual and auditory inattention. No errors are typically expected on this examination, however a range of 0–2 errors for the Tactile Finger Recognition subtest and 0–6 errors for the Finger-Tip Writing subtest are considered normal (Reitan and Wolfson 1985; Spreen and Strauss 1998).

#### *Composite Scores*

Composite scores were created to assess the overall hypothesis regarding elementary and higher cortical sensory perception and to facilitate comparison of the sensory sensitivities with sensory perception. A composite of *elementary sensory performance* was created by summing scores on the tactile sensations items of the LN scales. These included: (a) localization of cutaneous sensation (items 64 and 65 on the LN scales, each scored 0, 1, or 2), (b) identification of sharp/dull pressure (items 66 and 67 on the LN scales, each scored 0, 1, or 2), and (c) Muscle and Joint Sensation (items 80 and 81 on the LN scales, each scored 0 or 2). Higher scores reflected greater numbers of errors. The total possible score range for the SSC was from 0 to 12.

A composite of *higher cortical sensory performance* was created by summing scores for (a) Finger-Tip Writing on the RK (items 14 and 16, each ranging from 0 to 20 possible errors), (b) Tactile Finger Recognition on the RK (items 10 and 12, possible score range 0–20 errors for each) (c) Wrist Shape Drawing Perception (items 74 and 75 on the LN scales, each scored 0, 1, or 2) and (d) Stereognosis or tactile form recognition (items 82 and 84 on the LN scales, each scored 0, 1, or 2). The total possible score range for the Complex Sensory Composite (CSC) was 0–88.

Finally, we consider Sensory Neglect by summing errors on each of the left and right sides under conditions of double simultaneous stimulation from the Reitan-Klove

Sensory Perceptual Examination (possible score range 0–12 per side for Tactile, 0–4 per side for Auditory, and 0–12 per side for Visual). Total Neglect Scores could thus range from 0 to 56. The individual sensory domains report on the parietal, temporal, and occipital lobes respectively, and the total neglect score reports as to whether there is any evidence of neglect.

**Results**

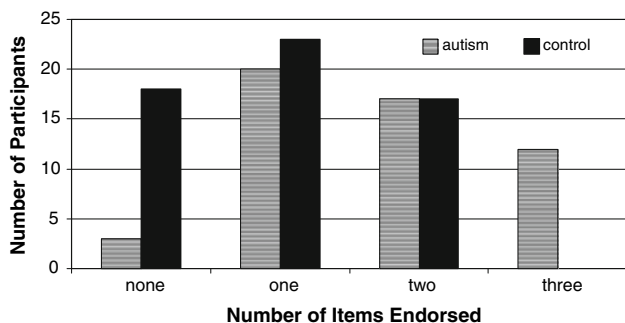
Given the limited range and non-normal distribution of scores, non-parametric statistics were applied to these data.

**Sensory Sensitivity Questionnaire (SSQ)**

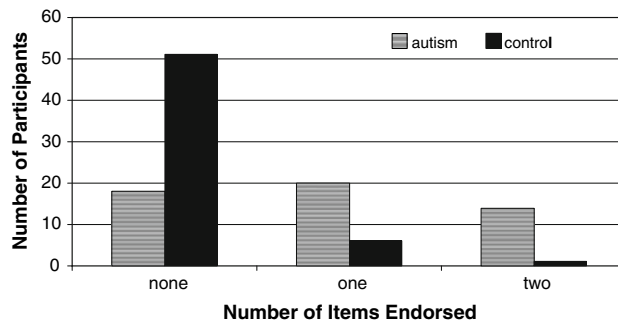
*Self-report Version*

As predicted, there were significant differences between the autism and control groups in self-report of sensory sensitivities. These occurred in the *a priori* established domains of *Tactile Sensitivities* (Mann–Whitney  $U = 861.50$ ,  $z = 4.1$ ,  $p < .001$ ), *Low Pain/Temperature Thresholds* (Mann–Whitney  $U = 672.00$ ,  $z = 5.83$ ,  $p < .001$ ), and *Other Sensitivities* (Mann–Whitney  $U = 468.00$ ,  $z = 6.5$ ,  $p < .001$ ). However, the groups were not different in *High Pain/Temperature Thresholds* (Mann–Whitney  $U = 1325.5$ ,  $z = 1.3$ , *ns*). Figures 1–4 illustrate the numbers of participants endorsing numbers of items in each domain, by group.

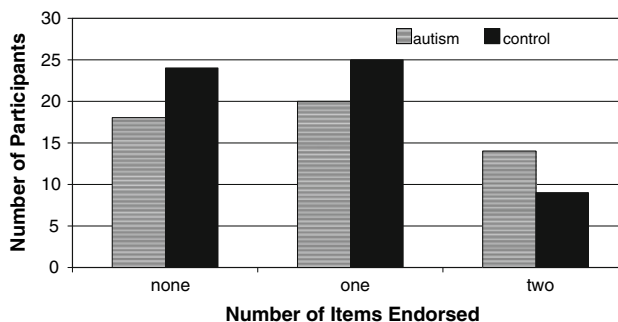
Although there was a highly significant group difference in the number of self-reported sensory sensitivities on the SSQ, it is important to note that there were important individual differences among participants with autism in this sample. By way of illustration, 17 (33%) of the individuals with autism reported eight or more sensory sensitivities. In contrast, not a single participant in the control group reported more than seven. On the other hand, 18 (35%) of the high-functioning individuals with autism received scores of four



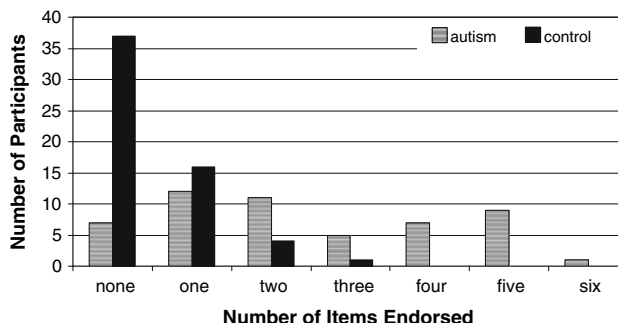
**Fig. 1** Number of tactile sensitivity symptoms endorsed on self-report version of SSQ (0–3)



**Fig. 2** Number of low pain/temperature threshold symptoms endorsed on self-report version of SSQ (0–2)



**Fig. 3** Number of high pain/temperature threshold symptoms endorsed on self-report version of SSQ (0–2)



**Fig. 4** Number of other sensory symptoms endorsed on self-report version of SSQ (0–6)

or less (commensurate with 90% of those in the comparison group), and thus these individuals with autism might be considered to be in the ‘normal range’ of SSQ scores. We will consider these high- and low-sensory symptom groups separately in subsequent analyses.

*Parent-report Version*

As on the self-report version, the mean ranks of participants with autism were higher than those without autism for numbers of sensory sensitivities endorsed by their parents. This was the case for the *a priori* established domains of *Tactile Sensitivities* (Mann–Whitney  $U = 324.0$ ,  $z = 3.7$ ,

$p < .001$ ), *Low Pain/Temperature Thresholds* (Mann–Whitney  $U = 280.5$ ,  $z = 4.6$ ,  $p < .001$ ), and *Other Sensitivities* (Mann–Whitney  $U = 65.5$ ,  $z = 6.6$ ,  $p < .001$ ). Consistent with the self-report version of the SSQ, the groups were not rated by their parents as different in *High Pain/Temperature Thresholds* (Mann–Whitney  $U = 545.0$ ,  $z = 1.1$ , *ns*). Across the entire sample of participants, parents and their sons/daughters were in good agreement on number of items endorsed on the SSQ,  $\rho(65) = .66$ ,  $p < .001$ . Within the group of participants with autism, parents were also in good agreement with their sons and daughters on overall frequencies of items endorsed on the SSQ (13 items),  $\rho(41) = .42$ ,  $p < .001$ .

*Relationship with Age*

The mean total scores on the SSQ for individuals with autism were similar in the group of participants between the ages of eight and 17 years ( $M_s = 6.21$  for parent and 5.71 for self), and scores were very similar for adults of at least age 18 ( $M_s = 6.70$  for parent and 6.67 for self). In addition, age was not correlated with scores on the SSQ,  $\rho(52) = .20$ , *ns*.

Neurologic Sensory Perceptual Examination

The results for the sensory perceptual measures are provided in Fig. 5.

*Elementary Sensory Perception and Simple Sensory Composite (SSC)*

On the SSC, participants in both groups made very few simple sensory perceptual errors. Participants with autism ( $M = 1.57$ ,  $SD = 1.38$ , range = 0–5) and those in the

comparison group ( $M = 1.33$ ,  $SD = 1.22$ , range = 0–6) were similar in their profiles of scores, Mann–Whitney  $U = 1677.5$ ,  $z = .82$ , *ns*. Figure 6 illustrates how the distribution of Elementary Sensory Errors is very similar in the groups.

A closer inspection of the sub-scales comprising the SSC reveals that the groups are similar for errors on localization of cutaneous sensation (autism  $M = .35$ , control  $M = .25$ ) where the total possible score was four and identification of sharp/dull pressure (autism  $M = 1.22$ , control  $M = 1.08$ ) where the total possible score was four. Here, it is clear there were neither ceiling nor floor effects contributing to the group similarity. For muscle and joint sensation items, not a single participant in either group made any errors.

*The Complex Sensory Composite (CSC)*

Participants in the comparison group also made low levels of errors on the CSC items ( $M = 4.87$ ,  $SD = 5.60$ ). However, participants with autism tended to make many

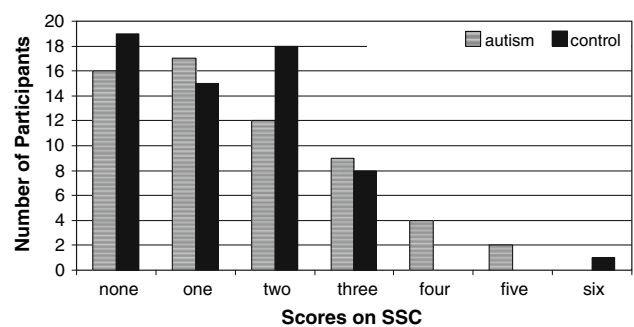
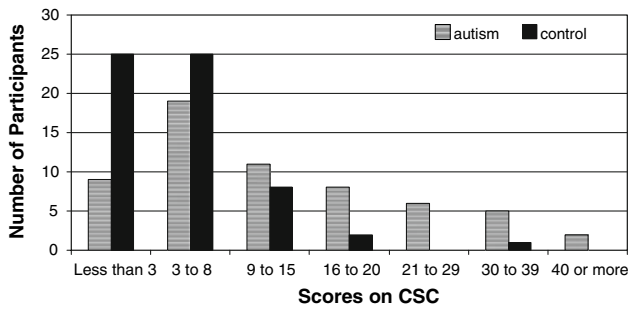


Fig. 6 Distribution of scores on the simple sensory composite

Fig. 5 Mean number of errors for sensory processing domains by diagnosis

	Autism			Comparison			p-value
	M	SD	Range	M	SD	Range	
<b>Simple Sensory Composite</b>	1.57	1.38	0 - 5	1.34	1.21	0 - 6	<i>ns</i>
Localization of Cutaneous Sensation	0.35	0.8	0 - 3	0.25	0.57	0 - 2	<i>ns</i>
Sharp vs. Dull Pressure	1.22	1.19	0 - 4	1.08	1.12	0 - 4	<i>ns</i>
Muscle and Joint Sensation	0.00	0.00	0.00	0.00	0.00	0	<i>ns</i>
<b>Complex Sensory Composite</b>	12.65	11.11	0 - 41	4.87	5.60	0 - 33	$p < .001$
Finger-Tip Writing (RK)	10.77	9.59	0 - 34	4.00	4.68	0 - 26	$p < .001$
Tactile Finger Recognition (RK)	1.15	2.12	0 - 10	0.54	1.42	0 - 8	$p < .10$
Wrist Shape Drawing Perception (LN)	0.55	0.83	0 - 4	0.21	0.61	0 - 3	$p < .05$
Tactile Form Recognition (LN)	0.18	0.54	0 - 2	0.11	0.41	0 - 2	<i>ns</i>
<b>Sensory Neglect</b>							
Auditory Right	0.01	0.13	0 - 1	0.00	0.00	0	<i>ns</i>
Auditory Left	0.05	0.23	0 - 1	0.03	0.18	0 - 1	<i>ns</i>
Visual Right	0.14	0.40	0 - 2	0.01	0.13	0 - 1	$p < .05$
Visual Left	0.07	0.26	0 - 1	0.02	0.13	0 - 1	<i>ns</i>
Auditory plus Visual plus Tactile Right	0.36	0.78	0 - 4	0.17	0.53	0 - 3	<i>ns</i>
Auditory plus Visual plus Tactile Left	0.22	0.54	0 - 2	0.08	0.38	0 - 2	<i>ns</i>





**Fig. 7** Distribution of scores on the complex sensory composite

more errors on the higher cortical sensory perception tasks ( $M = 12.65$ ,  $SD = 11.11$ ). The distribution of scores by numbers of participants per group is shown in Fig. 7.

Participants with autism were more often ranked as higher-scoring (that is showing higher rates of errors) on the CSC than those in the comparison group, Mann–Whitney  $U = 957.5$ ,  $z = 4.54$ ,  $p < .001$ . By way of illustration, one-third ( $n = 20$ ) of the 60 participants with autism showed ‘many’ complex processing errors (i.e., scores higher than 16), whereas only one participant in the comparison group made a high number of errors.

A closer inspection of the sub-domains comprising the CSC reveals that the participants with autism made many more errors than those in the comparison group on Finger-Tip Writing on the RK (autism  $M = 10.77$ ,  $SD = 9.59$ ; control  $M = 4.00$ ,  $SD = 4.68$ )  $p < .001$ , showed a trend toward more errors on Tactile Finger Recognition on the RK (autism  $M = 1.15$ ,  $SD = 2.12$ ; control  $M = .54$ ,  $SD = 1.42$ )  $p < .10$ , and made significantly more errors on Wrist Shape Drawing Perception on the LN (autism  $M = .55$ ,  $SD = .83$ ; control  $M = .21$ ,  $SD = .61$ ),  $p < .01$ . The groups were similar in not making many errors on the Tactile Form Recognition on the LN (autism  $M = .18$ ,  $SD = .54$ ; control  $M = .12$ ,  $SD = .41$ ), ns.

### Neglect

Under conditions of double simultaneous stimulation on the RK, participants in both groups rarely made errors. Of a possible 28 errors on the Right side, four errors were made by one individual with autism, three errors each were made by one individual with autism and by one in the comparison group, two errors each were made by one participant with autism and one without autism, one error was made by eleven individuals with autism and five without, and the remaining 41 participants with autism and 53 participants without autism did not make a single error. Of these errors, there was one individual with autism who made one auditory error, one individual with autism who made two visual errors, and six individuals with autism and one

without autism who made one visual error each. The remaining errors were tactile.

Of a possible 28 errors on the Left side, there were three participants with autism and two without autism who made two errors each, and there were six participants with autism and one without autism who made one error each. The remaining 46 participants with autism and 57 participants without autism did not make a single error. Of the errors made, four individuals with autism and one without autism each made one visual error and three individuals with autism and two without autism each made one auditory error. The remaining errors were tactile.

Thus, although errors were rare in both groups the distribution across the groups was similar and errors did not seem to be associated with any particular sensory domain.

### Relationship to IQ

For participants with autism, errors on simple perceptual items were not associated with Full-Scale IQ, Verbal IQ, or Performance IQ,  $\rho(60) = -.12$ ,  $-.12$ , and  $-.09$ , respectively. However, those participants with autism who made more errors on complex perceptual items tended to have lower Verbal and Full-Scale IQ scores,  $\rho(60) = -.33$  and  $-.27$ ,  $p < .01$  and  $.05$ , respectively, suggesting a relationship to autism severity. Performance IQ was not related to the CSC,  $\rho(60) = -.18$ . For those in the comparison group, there were trends for relations between simple errors and Full-Scale IQ, Verbal IQ, and Performance IQ,  $\rho(60) = -.25$ ,  $-.21$ , and  $-.21$ ,  $p < .10$ ,  $p < .10$  and  $p > .10$ , respectively. However, complex errors were not associated with FSIQ, VIQ, or PIQ,  $\rho(60) = -.07$ ,  $-.19$ , and  $-.02$ , respectively.

### Comparisons of Neurologic Examination & Sensory Symptom Data

There was enough variability among participants with autism to compare their sensory perceptual performance on the neurologic tests with their self-reported sensory sensitivity symptoms. Among participants with autism, there were no relations between reports of sensory abnormality on the SSQ and sensory perceptual processing on the SSC or CSC ( $\rho$  range  $-.06$  to  $-.22$ ). As described previously, one-third ( $n = 20$ ) of the participants with autism made many errors (i.e., scores higher than 16) on the CSC. One-third ( $n = 20$ ) of the participants with autism made five or fewer errors. Therefore, we created two sub-groups of participants with autism based on high (higher than 16) versus low (five or fewer) complex processing errors, and we compared these two subgroups of participants with autism on the number of items they endorsed on the SSQ. When we made this comparison, the groups were very

similar in the frequency of items they endorsed on the SSQ (High CSC  $M = 6.39$ , Low CSC  $M = 5.89$ ).

Hence, about one-third of participants with autism self-report high levels of sensory sensitivities and about one-third of participants with autism have unusually high rates of complex sensory processing errors, but the sensory sensitivities and sensory processing errors do not seem to be associated among individuals with autism. Thus, it appears that those individuals with autism who showed higher cortical sensory impairments may have been in a separate subgroup from those with the highest level of sensory sensitivities. Alternatively, the two sets of measures employed in the study had little overlap in terms of the aspect of sensory function to which they were sensitive thus precluding correlations.

## Discussion

This study investigated the occurrence of sensory symptoms and the status of sensory perception in 60 high functioning children, adolescents and adults with autism and an age, IQ, gender and family of origin SES matched group of 61 typical controls. The study found that a significant proportion of individuals with autism of all ages experience sensory sensitivities. This study is the first one to our knowledge to include self-report questionnaires to quantify what has previously been reported in first hand accounts by anecdote and narrative. This study also demonstrated that a significant proportion of these high functioning individuals with autism have impairments in higher cortical sensory perceptual abilities in the face of intact elementary sensory perception, whereas controls had intact elementary and higher cortical sensory perception. No evidence was found of sensory neglect in any sensory modality (Courchesne et al. 1993) and no relationship was found between the sensory sensitivities and the sensory perceptual deficits.

The prevalence of marked sensory sensitivities in the individuals with autism in this study based on self-report was approximately 32% and was substantiated by the reports of their parents. The individuals with autism in this study had IQ scores from 90 to 145 and ranged in age from 8 to 54 years. There were no differences in the sensory symptoms as a function of age. That is, sensory sensitivities were as common in adults as they were in children and did not differ in character. Secondly, the sensory symptoms were as frequent and prominent in this high functioning group of individuals with autism as has been reported for lower functioning or younger individuals with autism. However, it is possible that the occurrence of sensory symptoms has been under-estimated in non-verbal individuals and is higher than reported for verbal individuals

with autism in this study. Alternatively, a wide variety of behavior based on responsiveness to sensory stimuli is often considered to indicate sensory sensitivity or insensitivity and it is questionable as to whether all these behavioral responses have a sensory basis. In verbal individuals with autism, the assessment advantage is that the questions and responses are more specific to sensory perception.

Thirty percent of the individuals with high-functioning autism exhibited impaired performance on measures of higher cortical sensory perception or complex sensory processing, while performance on measures of elementary sensory perception was intact and similar to individuals without autism. There was also no evidence of extinction or neglect, either in the tactile (parietal lobe), auditory (temporal lobe) or visual (occipital lobe) domains. The most prominent sensory perceptual deficit involved finger tip number writing, followed by wrist shape drawing perception. No deficits were detected in tactile finger recognition or tactile form recognition; these two tests would, on the surface, appear less demanding in terms of sensory and neural processing than the tests demonstrating deficits. In the case of the finger recognition test, the subject identifies which of his/her fingers was touched on the dorsal surface while his eyes were closed. For tactile form recognition, the subject identifies an object (square, circle, triangle) with his eyes closed by manipulating it in his hand; this exposure to the object probably provides more information about the object than occurs when the same shape is traced on the wrist (Wrist Shape Drawing Perception), thus reducing the processing demands. That is, both the Wrist Shape Drawing and Finger Tip Number Writing Tests require the brain and mind to reconstruct in the brain and mind a mental image of the shape drawn on the skin and then associate a name or word to that shape or number. This requires collaboration of multiple brain regions for the necessary integratory processing; these processes have been shown to be specifically deficient in the brain and mind in autism through extensive cognitive and fMRI studies (see: Minshew and Williams 2007, Williams and Minshew *in press* for overview). Similarly, the Shape Drawing tests place higher demands on sensory processing and thus reveal the limitation in higher cortical sensory processing that is present in autism. It is of further note that the deficits in higher cortical sensory perception were bilateral and not unilateral, indicating involvement of both sides of the brain.

As with all deficits reported in autism, one of the first questions raised is why the deficit is not present in all individuals with the disorder. For example, although “absence of” face recognition capacity is thought to be characteristic of autism, only about one-third of testable individuals have very poor face recognition. The deficits

also vary substantially with age, with the typicality of the face, and with the presence of hair and clothing cues. However, more sensitive experimental measures have shown that processing speed is 10–15% slower for faces in individuals with autism who do not have frank face recognition deficits; fMRI studies using face paradigms have shown abnormalities in fusiform face activation and subtle differences in its localization in such individuals. With regard to the current study of sensory perception, the neuropsychologic tests employed are coarse measures, and more refined tests might well reveal abnormalities in a greater proportion of subjects. Alternatively, the intact performance in some individuals with autism might also be related to compensatory mechanisms in the brain that function under relatively undemanding test circumstances but break down under more demanding circumstances; examination of brain activation with fMRI during test performance might reveal abnormal connectivity patterns, as has been documented in the case of verbal working memory (Koshino et al. 2005, 2007). Yet another alternative is that a large number of verbal individuals with autism have sparing of the sensory system because this system develops very early in the brain and the onset of the developmental neurobiologic disturbance responsible for autism occurs later in most individuals.

The findings of this study also showed that some individuals with sensory symptoms or complaints do not display abnormalities on the sensory perceptual examination. In this case, the neurologic measure employed is either not sensitive to or is not related to the symptoms displayed in these individuals. This could be because there is a mixture of symptoms that are collapsed together on the inventory and compared to a perceptual composite. For example, it would not be expected that increased sensitivity to sound or light would be correlated with the perceptual measures assessed. There could be individual items within modalities with significant correspondence to specific items on the perceptual examination. Alternatively, the perceptual items are insufficiently sensitive or unrelated to the disturbance in sensory perception that underlies the distortion in sensory experience described by individuals with autism. Hence, there are major limitations in the sensory perceptual measures in terms of their correspondence with many of the sensory complaints in autism. However, this study was designed to provide some neurologic evidence of the status of sensory perception in cooperative individuals with autism using an established neuropsychologic measure of sensory perception and one that respected the known neurologically based distinctions between elementary and higher cortical sensory perception. In future studies, efforts will need to be made to establish correspondence between sensory perception measures and the sensory symptoms experienced.

This study did not show enhanced elementary sensory perception, which might have been predicted, but rather the same low rate of errors on elementary sensory perception items as in the control population. This link is important in terms of its relevance to the Enhanced Perceptual Functioning (EPF) model of autism described by Mottron and Burack (2001), which argues that the superior performances of individuals with autism in areas involving low-level processing (e.g., absolute pitch, savant drawing abilities) may be associated with enhanced or ‘overfunctioning’ in low-level perceptual processing. It is possible if not likely that there was a floor effect, in that some individuals in the autism group might have had hypersensitive perception but the neurologic measure employed did not allow for that to be detected or for superior performance to be captured as for detection of exceptionally small numbers or numbers written on less sensitive skin areas or perception of unusual shapes or objects. As with memory tests which have failed to document enhanced performance in the face of ample clinical evidence of enhanced recall of details, it may be that the tests are not designed to test the element that is unusual about their memory or in this case what is unusual about their sensory perception. In other words, we may have failed to ask the correct question about sensory perception with our test measures.

The documented pattern of impaired performance on higher cortical but not elementary sensory perceptual measures is consistent with the findings of evoked potential research in autism reporting normal latencies but abnormal P300 and Nc potentials (Novick et al. 1979; Verbaten et al. 1991; Courchesne et al. 1985; Courchesne et al. 1989). These studies found that it was the processing of information that was disturbed but not its conduction. It is also consistent with the recent fMRI study of Hadjikhani et al. (2004) reporting normal retinotopic representation in visual cortex and suggesting that distortions in visual processing are at higher levels of processing, e.g., beyond primary visual cortex. The elementary sensory-higher cortical sensory dichotomy is also consistent with the pattern of dichotomous deficits reported in the motor, memory, language, and abstraction domains in studies of the profile of neuropsychologic functioning in high functioning individuals with autism (Minshew et al. 1997; Williams et al. 2006) and of the impairments in integration of information causing postural instability (Minshew et al. 2004). Functional imaging studies using social, language, and reasoning tasks have provided evidence of a generalized pattern of underdevelopment of the higher-order circuitry necessary for these tasks (Cherkassky et al. 2006; Just et al. 2004, 2007; Kana et al. 2006; 2007; Koshino et al. 2007; Minshew et al. 2002). The presence of the same pattern of elementary ability-higher order ability dissociation in the sensory and motor domains as in the memory,

language and abstraction domains suggests that the sensory and motor impairments are involved by the same neurobiological process as the triad of signs and symptoms on which the diagnosis is based. Extensive structural and functional imaging studies have provided evidence that the neural substrate for these signs and symptoms is intra-hemispheric cortical connectivity (reviewed in: Minshew and Williams 2007; Williams and Minshew *in press*).

Limitations of the present study include that the self-report measure was not a standardized measure with established reliability and validity. Nevertheless, for participants with autism, parental scores were correlated with self-report scores. In addition, the SSQ was not administered in the presence of a clinician and therefore we can not be certain that all the participants did not have assistance from their parents in completion of the items. In addition, the questions did not explore whether or not these symptoms changed or evolved over time in these individuals. Because the subjects had language testing prior to entry to the study to establish that they had the requisite skills to understand questions of this type, lack of understanding of the questionnaire is unlikely to be a limitation. Their IQ scores further support this. The youngest participant in the present study was 8 years of age, and it is possible that children younger than 8 years would have exhibited even higher rates of sensory symptoms and sensory perceptual impairments. Similarly, participants with lower IQ scores who were still verbal (i.e., with IQs between 70 and 90) might have exhibited a higher frequency of impairments, but were not included in this study. However, the reliability of self-report would have declined with decreasing age and IQ and the availability of normal controls to match this group vanishes when IQ drops below 85.

There was some but not a high degree of correspondence between the sensory symptoms and the perceptual impairments. This is likely because the correspondence between sensory modalities was coarse to absent at the instrument level. There have been limited inroads into defining the neurology of the sensory disturbances in autism. This study does support the presence of neurological impairments in higher cortical sensory perception, which is perhaps a first step in finding a neurology for the sensory distortions experienced by individuals with autism. Future studies need to provide better correspondence between sensory complaints and neurological measurements to better clarify the neural basis of the sensory symptoms. fMRI studies might well provide the optimal approach for doing so. This study at least provided a neurologically based assessment using a widely accepted instrument in individuals whose cooperation is sufficient to provide valid and reliable results for the complete test battery.

Sensory sensitivities and perception are very important areas of research in autism. Though not universal in autism,

sensory disturbances can be overwhelming and disabling for the individuals who experience them. Sensory sensitivities may lead to significant behavior problems and may interfere with adaptive functioning across educational and social settings (Dawson and Watling 2000) yet little is known about their neurologic basis or their origin.

**Acknowledgment** We would like to thank all of the volunteers and their families for their enduring patience and for taking their time and making their best effort to complete these questionnaires and participate in this and other research studies for the benefit of all those affected by autism spectrum disorders. We also thank Kimberly Bodner for her assistance in preparation of this manuscript. We acknowledge the support of the NICHD/NIDCD Collaborative Program of Excellence funding without which this work would not have been possible (grant # HD35469).

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