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A Meta-Analysis of Sensory Modulation Symptoms in Individuals with Autism Spectrum Disorders

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Abstract Sensory modulation symptoms are common in persons with autism spectrum disorders (ASD); however have a heterogeneous presentation. Results from 14 studies indicated a significant high difference between ASD and typical groups in the presence/frequency of sensory symptoms, with the greatest difference in under-responsivity, followed by over-responsivity and sensation seeking. Three moderators that reduced the variability in findings among studies were: chronological age, severity of autism, and type of control group. Sensory differences were highest for studies of children ages 6–9 years, samples with more than 80% with an autism diagnosis, and compared to a CA matched versus a MA or DD matched group. It is important to consider these moderators in the design of studies and interventions addressing sensory symptoms.

Keywords Sensory modulation · Sensory processing · Sensory profile · Autism spectrum disorders · Meta analysis · Pervasive developmental disorders

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Introduction

The description of sensory modulation symptoms in persons with autism spectrum disorders (ASDs) is somewhat baffling as it is described both as a source of distress and anxiety as well as a source of fascination and interest (Jones et al. 2003). The development of standardized norm-referenced sensory parent questionnaires over the past decade has allowed researchers to quantify these behaviors relative to age norms, leading to the accumulation of evidence that was not previously reviewed. Findings from standardized parent questionnaires show that 45–95% of individuals with ASDs present high frequencies of sensory behaviors that are more than 1 *SD* different from norms (Baker et al. 2007; Baranek et al. 2006; Kay 2001; Tomcheck and Dunn 2007). In addition, sensory responses are qualitatively different in this population (e.g. visual and hearing distortions: Jones et al.). Although sensory modulation symptoms have been associated with ASDs from the time autism has been defined as a diagnosis (Kanner 1943) there is a long lasting debate whether sensory symptoms are a component of core ASDs deficits or a co-morbid phenomenon. Sensory symptoms are often evaluated in the diagnosis of autism (i.e. unusual sensory interests are scored in gold-standard autism diagnosis measures); however, there is disagreement as to whether they should be considered as core features of ASDs (i.e. deficits in social interaction, communication and stereotyped and restrictive behaviors). To qualify as a core symptom there needs to be indication for the universal (present in almost all individuals with that syndrome), unique (differs from individuals with other clinical diagnoses), and specific (differs from other core symptoms) nature of the symptom (Sigman 1994). Sensory symptoms in persons with ASDs demonstrate these criteria in some studies while not in others.

Inconsistent evidence of an association between sample characteristics and sensory symptoms limits our understanding of the unique nature, cause, and prognosis of these symptoms in persons with ASDs. Small sample sizes further limit conclusions from single studies supporting the need for a systematic aggregation of evidence.

Ayres (1985) described the human brain as a "sensory processing machine", as over 80% of the nervous system is involved in processing or organizing sensory input. Individuals differ in their way of processing information from the auditory, tactile, vestibular, proprioceptive, gustatory, and olfactory senses (Huebner and Dunn 2001). Sensory processing disorders (SPDs), are a group of disorders that involve challenges in modulation, integration, organization, and discrimination of sensory input to the extent that the person does not respond appropriately to the input and experiences disruptions in daily activities and emotional-behavioral patterns (Interdisciplinary Council on Developmental and Learning Disorders (ICDL) 2005; Miller et al. 2007). Sensory modulation disorders (SMDs) a subtype of SPDs, are defined as difficulties in regulating and organizing the type and intensity of behavioral responses to sensory input to match environmental demands (Miller et al.). SMDs are classified into three types: (a) *over-responsivity*, which describes exaggerated, rapid onset and/or prolonged reactions to sensory stimulation (e.g. distress from loud noises), (b) *under-responsivity*, which describes unawareness or slow response to sensory input (e.g. tends to walk into things), and (c) *seeking*, which describes craving of, and interest in sensory experiences that are prolonged or intense (e.g. engaging in rhythmical movements) (ICDL; Miller et al.). This classification is based on previously proposed models such as Dunn's (1997) model. Recent research has shown that persons with ASDs tend to show more than one type of SMD and have been classified into subtypes that differ in their severity and/or types of SMD (Liss et al. 2006; Ben-Sasson et al. in press). We examined different types of SMD to determine whether a particular reactivity pattern is associated with ASD.

Sensory Modulation Symptoms in Relation to Chronological Age, Mental Age, and Severity of ASD

The literature suggests three factors that may contribute to the nature of sensory modulation symptoms in persons with ASDs: chronological age (CA), mental age (MA), and severity of ASD. There is contrasting evidence regarding the direction of the association between sensory symptoms and CA of individuals with ASDs (Kern et al. 2006, Saulnier 2003 vs. Talay-Ongan and Wood 2000 vs. Adamson et al. 2006; Baranek et al. 2006), as well as with MA (Baranek et al. 2006; Gal 2006; Kay; 2001; Liss et al. 2006 vs. Pfeiffer et al. 2005, Rogers et al. 2003, Sagarin 1998) and severity of ASD symptoms (Baranek et al. 2006; Saulnier 2003 vs. Kientz and Dunn 1997). We do not know whether discrepancies in findings reflect differences in age, in classification of ASD and/or whether they pertain to a certain type of SMD. Knowledge of the characteristic sensory symptoms of persons with different levels of ASD severity at different ages, and at different levels of functioning can assist in planning allocation of services and in estimating prognosis of symptoms.

The rationale for conducting this meta-analysis related to the (a) accumulation of studies on sensory modulation and ASD; (b) lack of a quantitative review on SMD and ASD; (c) the fact that previous literature reviews in this area (Iarocci and McDonald 2006; O'Neill and Jones 1997; Rogers and Ozonoff 2005) described evidence based upon different definitions of SMD (e.g. including unusual sensory interests, sensory stereotypes, perceptual distortions), different types of measures (e.g. parent report, observation, and physiological measures), included peer reviewed studies together with qualitative and autobiographical accounts, and did not include most of the studies we analyzed. This meta-analysis sought to summarize results across studies of sensory modulation symptoms in individuals with ASDs with the intent of identifying significant relationships between study features and sensory differences between groups. The questions addressed in this project were: (a) Are differences in the sensory profiles between ASD and typical groups consistent across studies? (b) Does the magnitude of these differences between groups change among the three types of sensory symptoms (i.e. over-responsivity, under-responsivity, and seeking)? (c) Are differences in sensory scores related with participant characteristics (i.e. CA, percent of autism in sample, type of control group)? (d) Are differences in sensory symptoms between ASD and DD groups consistent across studies?

Methods

Literature Search

A literature search was performed to identify studies reporting sensory modulation symptoms of individuals with ASDs conducted up to May, 2007. The search used the electronic databases PsychInfo and Web of Science with search terms combinations including a population term (autism/asperger/pervasive developmental disorder), a sensory term (sensory/reactivity/response/auditory/tactile/vestibular/oral), and a descriptor term (processing/integration/modulation/regulation/profile/symptom/unusual/hypo/hyper). Reference lists of the papers obtained through the methods above were manually searched including literature

reviews. Attempts were made to search for unpublished studies such as dissertations, theses, poster and conference presentations. Figure 1 presents the process of study selection.

The criteria for study inclusion were: (a) The study used a parent-report measure designed for assessing sensory processing across several sensory modalities as opposed to sensory items dispersed within a broader measure or in one sensory modality; (b) The study included individuals with ASDs as a distinct group rather than within a general developmental disorder (DD) group; (c) The findings were reported in English; (d) The study included a comparison group with typical development or with a non-ASD DD; (e) There was enough data for calculating effect sizes in publication or as provided by authors once contacted. Fourteen studies met these criteria. Following the development of coding guidelines, 29% of studies were coded by two authors. Any disagreements in coding were discussed and if consensus was not achieved a third author was consulted. The remaining studies were coded by one of the three authors involved in the above reliable coding process. The selection of variables to code was based on the evidence cited in the literature review and on previous meta-analytic studies with persons with ASDs (Yirmiya and Shaked 2005).

Moderator Categories

The three potential moderators that we examined were CA, percent of autism diagnosis, and type of control group and were defined as follows.

Chronological Age

Studies were divided into four age groups based on their mid-age range: (a) 0–3.4 years; (b) 3.5–6.4 years; (c) 6.5–9.4 years; and (d) above 9.5 years. Mid-range was used as four studies did not report means but reported age range. Kern et al.'s (2007) study included individuals within a wide developmental age range (40 years) thus was excluded from age related analyses.

Percent of Autism Diagnosis

In absence of consistent information about the mental level of participants and/or their severity of ASD symptoms we looked at the percent of individuals with an autism diagnosis as an estimate of the severity and functioning level of the ASD sample studied. Since the distribution of percent of autism diagnosis was skewed with six out of 11 studies having more than 80% with an autism diagnosis, this variable was categorized into: (a) studies with more than 80%

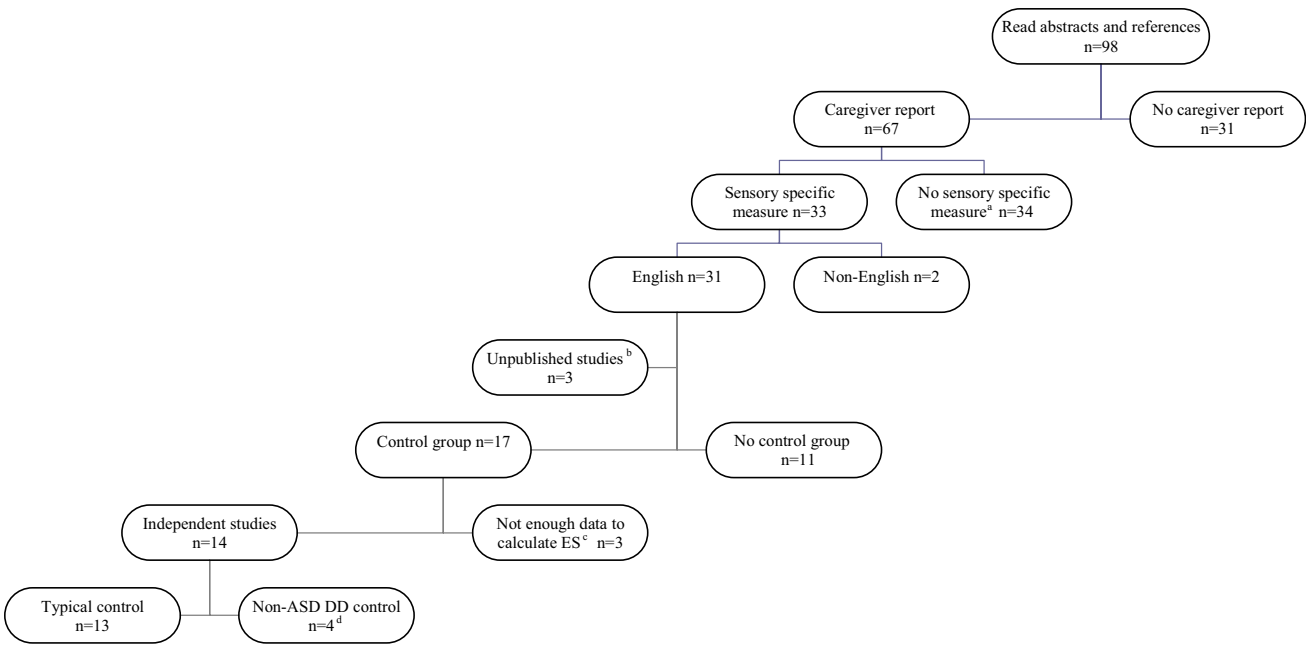

Fig. 1 Article selection process. *Note*. The number of reviewed articles does not include studies that were retrieved but used a different definition of sensory processing, case studies, auto-biographical accounts, and literature reviews. Independent studies were defined as studies that did not overlap in their ASD sample. [a]Studies that included one or a few sensory items within a broader measure. [b]Authors of unpublished studies were contacted but not all responded and/or sent data. All other studies were published in journals, in preparation for journal publication, in book chapters, in dissertations or thesis, or presented at conference talks or posters. [c]Authors of these studies were contacted to request additional data. [d]Three of these studies also had a typical control group

of participants having autism, versus (b) studies with fewer than 80%.

Type of Control Group

This moderator included (a) studies that matched ASD and typical groups on CA, versus (b) studies that matched ASD and typical groups on MA. Type of control group was determined by the CA and/or MA ranges reported or based on the researchers' description of type of matching. Only for the purposes of testing this moderator, Ben-Sasson et al.'s study (2007) was included in both categories, once compared to a typical group matched on CA, and the other compared to a non-overlapping typical group matched on MA. Given the small number of studies within category we were willing to compromise category independence.

Data Management and Analysis

Effect sizes (*ES*) of type *d* (Cohen 1988) was computed to measure the differences in sensory symptoms between groups. *ES*s were calculated for each of the four types of scores (i.e. Total, Over-responsivity, Under-responsivity, and Seeking) depending on the measure employed in the study. Different sensory measures included different items and/or factor scores. In order to create composite scores that were conceptually comparable across measures a team of researchers with expertise in sensory processing determined which sensory scores within a measure should be aggregated. Scores within sensory measures that represented multiple types of SMDs were included only in total score analysis. In most studies lower scores indicated higher frequency of sensory symptoms, however in four studies (Baranek et al. 2006; Rogers et al. 2003; Saulnier 2003; Talay-Ongan and Wood 2000) higher scores indicated higher frequency/presence and therefore were transformed. Aggregation over studies was done using weighted means accounting for differences in sample sizes. The pooled *SD* over the two groups was used for *ES* calculation (Hedges and Olkin 1985). *ES*s were averaged across scores in cases for which raw means and *SD*s were not reported but *ES*s were.

To test the role of moderators we obtained the statistic Q_B—weighted mean sum of squares between categories. If the moderator accounted for variability between studies, it would show a significantly high Q_B indicating a significant difference in *ES* between studies in the moderator categories. For measuring the fit of a model we used the homogeneity statistic—Q_w, which is a chi-square statistic that evaluates homogeneity of residuals between studies. A low and non-significant Q_w indicates a good fit. When categorizing moderating variables we ensured that for the total sensory score there were at least two studies within a category to allow for analysis of within category homogeneity. See Yirmiya and Shaked (2005, pp. 72–73) for a detailed explanation of meta-analytic statistical procedures. Moderator testing was not possible for sensory difference between ASD and a non-ASD clinical control group as there were only four such studies.

Results

Characteristics of Studies

The electronic and manual search yielded 98 studies potentially suited for analysis. Of these, 14 studies met inclusion criteria (these studies appear in the reference list with an asterisk), 13 of which included a typically developing comparison group, and four that included a DD comparison group. Table 1 presents study characteristics. The 14 studies were published or completed between 1998 and May 2007. Participant CA ranged from 7 months to 56 years. Of the studies reporting the following demographic information, 75–93% were boys, and 77–100% were of Caucasian ethnicity. Mental level of ASD group described in five studies (Baranek et al. 2006; Ben-Sasson et al. 2007; Gabriels et al. 2005; Rogers et al. 2003; Saulnier 2003) ranged between 2.53 and 1.16 *SD*s below average. There was variability in inclusion criteria applied across studies. Five studies included only individuals with an autism diagnosis, one study included individuals with Asperger's syndrome, and eight studies included children with different types of ASD. Of the eight studies that described their method of ASD diagnosis, four used a gold-standard diagnostic test (i.e. ADI, ADOS), two studies required individuals to meet diagnostic criteria on both measures, while the other two relied on one of these measures in conjunction with DSM-IV, ICD–10, CARS, or clinical information; and four studies did not rely on a formal diagnostic test. Six studies stated that a medical and/or a psychology professional were involved in the diagnosis.

Seventy-nine percent of the studies used different versions of the Sensory Profile including the Sensory Profile (Dunn 1999), the Infant/Toddler Sensory Profile (Dunn 2002), and the Short Sensory Profile (Dunn 1999). The Sensory Profile is a norm-referenced questionnaire, in which the caregiver rates the frequency in which the person engages in the described response to sensory input. This measure yields factor scores that correspond to the three types of SMDs. Two studies (Baranek et al. 2006; Saulnier 2003) used other questionnaires that provide reactivity level scores (e.g. over-responsivity). For one study (Talay-Ongan and Wood 2000) that used the Sensory Sensitivity Questionnaire only a total score was analyzed as the measure does not provide scores comparable to the three types of SMDs.

Table 1 Characteristics of studies

Study	Year	Na (Nt, Ndd)	CA Mean (*SD*) Range	CA midrange	Age group[a]	Percent autism	Measure
Ermer et al.	1998	38 (1075, 0)	– 36–180	108	3	–	Sensory Profile
Talay-Ongan et al.	2000	30 (30, 0)	– 48–168	108	3	100	Sensory Sensitivity Questionnaire
Watling et al.	2001	40 (40, 0)	– 36–72	54	2	–	Sensory Profile
Dunn	2002	24 (24, 0)	– 7–36	21.5	1	–	Infant Toddler Sensory Profile
Smith-Myles et al. [b]	2002	42 (42, 0)	135.96 96–168	132	4	0	Sensory Profile
Saulnier [c]	2003	222 (195, 0)	98 (48.2) 18–280	149	4	69	Sensory Questionnaire
Rogers et al.	2003	26 (24, 32)	36.67 (3.6) 26–41	33.5	1	100	Short Sensory Profile
Gabriels et al.	2005	63 (0, 18)	124.56 (47.74) 39–216	89	3	75	Short Sensory Profile
Baranek et al.	2006	80 (110, 68)	39.81 (11.79) 23–80	51.5	2	70	Sensory Experience Questionnaire
Gal	2006	56 (30, 29)	116.52 (21.48) 72–156	114	3	100	Short Sensory Profile
Schaaf et al.	2006	14 (12, 0)	102 (30) 60–144	102	3	100	Short Sensory Profile
Tomcheck et al.	2007	281 (281, 0)	51.58 (10.30) 36–72	54	2	91	Short Sensory Profile
Kern et al.	2007	104 (104, 0)	239.04 (137.04) 36–672	354	4	100	Sensory Profile
Ben-Sasson et al. [d]	2007	170 (100, 99)	28.35 (3.93) 18–33	27.57	1	48	Infant Toddler Sensory Profile

Note. Na- sample size of ASD group, Nt- sample size of typical group, Ndd- sample size of group with DD or matched on MA, CA- chronological age of the ASD group in months

[a] Age group was based on mid range: '1' = 0–3 years, '2' = 3–6 years, '3' = 6–9 years and '4' = above 9 years

[b] This study is by Dunn, Smith-Myles, & Orr and was labeled differently to distinguish from Dunn (2002)

[c] Some of the evidence in Saulnier's thesis was reported in Liss et al.'s paper from 2007

[d] Data of the typical group were from the 2007 paper and data for the ASD group was from a paper in press

Comparison of ASD and Typical Groups

Mean *ESs* across studies was high and significant for all types of sensory scores (0.82–2.01; see Table 2). The majority of the 42 individual *ES*s between ASD and typical groups were high ($d > .81$), positive, and significant, indicating that individuals with ASDs had lower sensory scores (i.e. higher frequency or presence) than typically developing individuals. Only for Dunn (2002), *ES* of seeking, was not significant as the 95% CI included '0'. For Ben-Sasson et al. (2007) *ES* of seeking was negative but significant, indicating that toddlers with ASDs had lower frequencies of seeking than the typical group. Note that both Dunn and Ben-Sasson et al. included children under the age of 36 months and overlapped in some of their typically developing children but not in their ASD group.

To determine whether a certain type of SMD is more characteristic of persons with ASDs than another we estimated the difference in *ES* between scores. This estimate was obtained by the simple mean over the differences of the corresponding *ESs* in studies which had both *ESs* measured (Shadish and Haddock 1994). Since most studies did not report correlations between measures we used the mean correlations over studies which did report them, assuming similarity of correlations in all studies and in both typical and ASD participants. The estimated difference between *ES* of

Table 2 Effect sizes (*d*) and 95% CI for sensory differences between ASD and control groups

Study	Total		Over		Under		Seek	
	d	95% CI	*d*	95% CI	*d*	95% CI	*d*	95% CI
Ermer et al.	2.11	1.78–2.45	1.84	1.51–2.17	3.26	2.91–3.61	1.53	1.20–1.86
Talay-Ongan et al.	1.67	1.08–2.25						
Watling et al.	1.44	0.95–1.93	0.85	0.39–1.30	1.77	1.26–2.29	1.47	0.98–1.96
Dunn	1.4	0.77–2.02	1.84	1.17–2.52	1.87	1.19–2.54	0.03	−0.53–0.59
Smith-Myles et al.	1.57	1.09–2.06	1.23	0.77–1.70	1.78	1.28–2.29	1.44	0.97–1.93
Saulnier	1.21	1.00–1.41	0.9	0.70–1.11	1.8	1.57–2.02	0.91	0.71–1.12
Rogers et al.	1.62	0.98– 2.25	0.81	0.24–1.38	–	–		
	(0.55)[a]	(0.02–1.06)[b]	(0.32)	(−0.20–0.83)	(−0.06) [c]	(−0.57–0.46)		
Gabriels et al.	–	–	–	–	–	–		
	−0.11	(−0.40–0.63)	−0.24	(−0.28–0.76)	−0.32	(−0.21–0.84)		
Baranek et al.	1.31	1.00–1.62	0.86	0.56–1.16	–	–		
	(0.63)	(0.30–0.96)	(0.30)	(–0.03–0.62)	−0.69	(0.35–1.02)		
Gal	1.61	1.10–2.11	1.60	1.09–2.10	–	–		
	(1.80)	(1.26–2.30)	(1.09)		(0.72)	(0.25–1.17)		
Schaaf et al.	1.77	0.87– 2.67	1.18	0.36– 2.00				
Tomcheck et al.	1.71	1.52–1.90	1.68	1.49– 1.87				
Kern et al.	1.63	1.31–1.94	1.54	1.23–1.85	1.67	1.35–1.98	1.4	1.10–1.70
Ben-Sasson et al. Matched on CA	1.19	0.92–1.45	1.08	0.82–1.34	2.03	1.73–2.33	−0.25	−0.50 to −0.004
Ben-Sasson et al. matched on MA	0.98	0.72–1.24	1.02	0.76–1.28	2	1.70–2.30	−0.58	−0.83 to −0.32
Average effect size	1.50	1.41–1.59	1.28	1.19–1.37	2.02	1.90–2.14	0.83	0.71–0.95
	(0.73)	(0.50–0.95)	(0.45)	(0.24–0.67)	(0.49)	(0.28–0.71)		

Note. Empty cells indicate that scores could not be computed based on the measures used in the study. Average *ES* for Total was based on 13 independent studies with 3,192 participants. Average *ES* for Over-responsivity was based on 12 studies with 3,132 participants. Average *ESs* for Under-responsivity and Seeking were based on 7 studies with 2,218 participants

[a] *d* values in parentheses are *ESs* of ASD versus DD. [b] CI values in parentheses correspond to the *ESs* between ASD and DD groups. [c] For under-responsivity *d* in parentheses represents high threshold scores, a sum of seeking and under-responsivity

Under-responsivity and Seeking was 1.29, between Under- and Over-responsivity 0.74, and between Over-responsivity and Seeking 0.55 ($p < .001$ for all). This suggests that of the types of SMDs Under-responsivity had the greatest magnitude in ASD relative to typical groups.

Although aggregated average *ESs* were significant they were not homogeneous as indicated by the significance of Q_w (Total Q_w = 33.78; Over-responsivity Q_w = 63.64; Under-responsivity Q_w = 58.36; Seeking Q_w = 125.43, $P <$ .00 for all). This suggests that studies varied in the magnitude of difference between groups, thus we explored potential moderators that can account for such variability.

Moderator Model Testing

Chronological Age

For the Total, Over-responsivity, and Seeking scores there was an increase in *ES* from studies of individuals, ages 0–3 years, to studies of 3- to 6-year-olds, to 6- to 9-year-olds, and a decrease in *ES* in studies of individuals above 9 years. No consistent pattern was found for Under-responsivity (see Table 3). The highest *ES* was for studies with 6- to 9-year-olds. For all sensory scores *ES* was significantly different between age groups. For the Total score there was homogeneity among studies within each age group as indicated by their non-significant Q_w. For Over-responsivity there was homogeneity within studies of participants, ages 0–3 years, 6–9 years, and above 9 years. For Under-responsivity there was homogeneity within studies of children between ages 0–3 years, and among those with individuals above 9 years. Seeking was homogeneous among studies with children ages 0–3 (Q_w for Under-responsivity and Seeking could not be calculated for studies of 3–6 and 6- to 9-year-olds as there were not enough studies). The remaining heterogeneity may indicate other sources of variance other than CA or that there were not enough studies within a category.

Percent of Individuals with an Autism Diagnosis

Studies with more than 80% autism in their sample had significantly higher differences in Total, Over-responsivity,

Table 3 Comparison of sensory effect sizes between age groups

Moderator	0–3 years	3–6 years	6–9 years	>9 years
Total (Between-class effect, Q_B = 21.12**)				
Mean effect size	1.27	1.58	1.89	1.26
CI for d 95%	1.04–1.50	1.43–1.73	1.65–2.13	1.07–1.45
k studies (n participants)	3 (368)	3 (832)	4 (1285)	2 (501)
Homogeneity within class (Q_w)	1.71	4.97	3.56	1.78
Over-responsivity (Between-class effect, Q_B = 25.08**)				
Mean weighted effect size	1.12	1.38	1.70	0.96
CI for d 95%	0.90–1.35	1.23–1.53	1.44–1.97	0.78–1.14
k studies (n participants)	3 (368)	3 (832)	3 (1225)	2 (501)
Homogeneity within class (Q_w)	5.70	26.08**	2.38	1.58
Under-responsivity (Between-class effect, Q_B = 52.23**)				
Mean effect size	2.01	1.77	3.26	1.79
CI for d 95%	1.73–2.28	1.26–2.28	2.91–3.61	1.58–2.00
k studies (n participants)	2 (318)	1 (80)	1 (1113)	2 (501)
Homogeneity within class (Q_w)	0.19	_	_	0.00
Seeking (Between-class effect, Q_B = 104.72**)				
Mean effect size	–0.20	1.47	1.53	0.99
CI for d 95%	–0.43–0.02	0.98–1.96	1.20–1.86	0.80–1.18
k studies (n participants)	2 (318)	1 (80)	1 (1113)	2 (501)
Homogeneity within class (Q_w)	0.82	_	_	3.90*

Note. * $p < .05$. ** $p < .001$

and Seeking scores between groups than those with less than an 80% rate of autism (see Table 4). For the Total and Over-responsivity scores percent of persons with autism explained heterogeneity in *ES* within both categories of studies. For Under-responsivity *ESs* were homogeneous among studies with an autism rate below 80% but not for Seeking (Q_w could not be calculate among studies with above 80% autism as there was only one study within that category). This suggests that individuals with a non-autism pervasive developmental disorder shared a level of Under- and Over-responsivity but not Seeking.

Type of Control Group

*ES*s were significantly higher for studies that matched on CA than that of studies matched on MA (see Table 5). For the Total, Over- and Under-responsivity scores *ESs* were homogenous among studies that included a MA matched control group but not for Seeking. For all sensory scores *ESs* remained heterogeneous among CA matched studies.

Comparison of ASD and DD Groups

The four studies that compared individuals with ASDs to those with a non-ASD DD, included individuals with ASDs ages 2–20 years. Gal (2006) and Rogers et al. (2003) included only children with an autism diagnosis, while

Table 4 Comparison of sensory effect sizes between studies with fewer than versus more than 80% individuals with autism

Moderator	<80%	>80%
Total (Between-class effect, Q_B = 17.43**)		
Mean effect size	1.25	1.68
CI for d 95%	1.11–1.39	1.53–1.82
k studies (n participants)	4 (961)	6 (990)
Homogeneity within class (Q_w)	2.14	0.37
Over-responsivity (Between-class effect, Q_B = 34.27**)		
Mean weighted effect size	0.97	1.57
CI for d 95%	0.83–1.10	1.42–1.71
k studies (n participants)	4 (961)	5 (930)
Homogeneity within class (Q_w)	2.74	9.03
Under-responsivity (Between-class effect, Q_B = 1.27)		
Mean effect size	1.87	1.66
CI for d 95%	1.70–2.04	1.34–1.98
k studies (n participants)	3 (771)	1 (206)
Homogeneity within class (Q_w)	1.64	_
Seeking (Between-class effect, Q_B = 24.46**)		
Mean effect size	0.54	1.40
CI for d 95%	0.40–0.69	1.09–1.70
k studies (n participants)	3 (771)	1 (206)
Homogeneity within class (Q_w)	66.09**	_

Note. * $p < .05$. ** $p < .001$

Table 5 Comparison of sensory effect sizes between studies with CA versus MA matched control groups

Moderator	CA matched group	MA matched group
Total (Between-class effect, Q_B = 21.74**)		
Mean effect size	1.61	1.17
CI for d 95%	1.50–1.73	1.04–1.32
k studies (n participants)	9 (2449)	4 (926)
Homogeneity within class (Qw)	20.64**	4.76
Over-responsivity (Between-class effect, Q_B = 36.35**)		
Mean effect size	1.47	0.92
CI for d 95%	1.36–1.59	0.79–1.06
k studies (n participants)	8 (2389)	4 (926)
Homogeneity within class (Qw)	28.01**	0.86
Under-responsivity (Between-class effect, Q_B = 4.51**)		
Mean effect size	2.13	1.87
CI for d 95%	1.97–2.29	1.69–2.05
k studies (n participants)	6 (1801)	2 (686)
Homogeneity within class (Q_w)	52.70**	1.17
Seeking (Between-class effect, Q_B = 66.30**)		
Mean effect size	0.78	0.33
CI for d 95%	0.64–0.92	0.17–0.49
k studies (n participants)	6 (1801)	2 (686)
Homogeneity within class (Q_w)	124.31**	81.84**

Note. * $p < .05$. ** $p < .001$

others (Baranek et al. 2006; Gabriels et al. 2005) included other types of ASDs as well. These studies excluded individuals with ASDs from their DD group but differed in their DD criteria. Baranek et al. included in the DD group children with MR or other DDs (i.e. genetic syndromes, and specific developmental delays), Rogers et al. included children with low developmental scores who had a developmental delay with mixed or unknown etiology, while Gal and Gabriels et al.'s criterion was a diagnosis of MR. Gabriels et al.'s DD group was matched on CA to the ASD group, while Rogers et al. and Baranek et al. matched groups on MA.

Table 2 presents the *ESs* of three sensory scores in studies with a DD comparison group: (a) Total, (b) Over-responsivity, and (c) a high threshold score combining under-responsivity and seeking (three of the four studies used the Short Sensory Profile that does not provide separate scores for these constructs). Eleven of the 12 *ESs* were positive, but only six were significant. Average *ES* were 0.73 for the Total score which is considered high, 0.45 for Over-responsivity, and 0.49 for High threshold, which are both considered moderate. Q_w indicated that there was variability among *ESs* of the four studies for the Total (p = .00) and Over-responsivity (p = .04) scores, but not for the High threshold score (p = .07). *ESs* were non-significant in Gabriels et al.'s (2005) study possibly due to the inclusion of older individuals, within a wide age range (17 years) relative to the other studies (1–7 years).

Discussion

This meta-analysis focused on 14 studies that documented the atypical nature of parent reported sensory symptoms in individuals with ASDs. Differences between ASDs and typical groups were greatest for under-responsivity, followed by over-responsivity, and seeking. Most *ESs* were significant and high across different age groups, in studies with low versus high rates of autism diagnosis, and in comparison to different types of control groups. At the same time there were some non-significant differences and lower *ESs* in seeking of young children and in comparisons to DD groups. There was significant variability in the magnitude of difference between studies, which seems to be related to differences in CA, severity of ASD, and type of control group. The paucity of studies in this area requires cautious interpretation of findings.

Sensory Modulation Symptoms and CA

While individual studies examined a linear trajectory in sensory symptoms across age groups of persons with ASDs (Kern et al. 2007; Saulnier 2003; Talay-Ongan and Wood 2000), evidence from this meta-analysis suggests a non-linear course. There was an increase in the frequency of sensory behaviors overall (total score), in over-responsivity, and in seeking up to age 6–9 years, and a decrease there after. For under-responsivity there was no consistent course. The inclusion of children, adolescents, and adults together in single studies may have contributed to the variability in sensory results across studies. During adolescence many individuals with ASDs experience changes in their symptoms (e.g. onset of epilepsy, psychiatric symptoms), and this may occur in sensory modulation symptoms as well (Gal et al. 2007), There are no studies that focus on the sensory profile of adolescents or adults with ASDs relative to control groups. This gap does not necessarily reflect lack of sensory symptoms as autobiographical accounts of adults with ASDs (e.g. Grandin 1995) and evidence that includes this age group indicate ongoing sensory symptoms that interfere with performance of daily living activities (Harrison and Hare 2004; Kern et al. 2007; Pfeiffer et al. 2005).

The highest difference in sensory symptoms between groups was reported for studies that included children ages 6–9 years (Ermer and Dunn 1998; Gal 2006; Schaaf et al. 2006; Talay-Ongan and Wood 2000). These studies were homogeneous in total and over-responsivity scores.

Sensory symptoms may become expressed at this age since children enter the school system, a period in which demand for independence increases, and the social and physical environment is more complex and less controlled. The question is therefore whether sensory symptoms are further expressed because of the change in the child's environmental demands, or whether there is a true increase in these symptoms with age which might indicate a neurological mechanism. Our findings therefore suggest a need for studying narrow age groups longitudinally, in order to test the presented non-linear course of sensory symptoms.

Of all moderators tested, CA was the only one that contributed to the variability in sensory seeking in persons with ASDs. This is based on the finding of homogeneity in *ESs* of Seeking for studies of 0- to 3-year-olds among all the different study categories tested. Seeking in studies with children in this age group was the only finding of a lower frequency of behaviors in ASD relative to typical groups ($d = -.20$). Infants with ASDs may be less likely to actively explore the environment and express interest in sensations compared to the increased tendency to do so in typically developing infants (e.g. mouthing, seeking physical activity). Children with ASDs may seek sensations later on when it is not age appropriate and/or present atypical types of seeking that are not captured by the frequency rating in the Sensory Profile (Ben-Sasson et al. 2007). Since many children with ASDs are delayed, they may not have the motor and cognitive capacity to act on their environments to seek sensation. Comparison with DD groups could not be done because studies with DD comparisons used the Short Sensory Profile which combines seeking and under-responsivity.

Sensory Modulation Symptoms and Severity of ASD

We examined the contribution of the percent of individuals with an autism diagnosis to the variability in sensory findings (i.e. higher percentage may indicate greater ASD severity and/or lower developmental level). This was the best estimate we had in absence of a direct description of these features across studies. Studies that included a higher percent of individuals with autism had higher frequencies of sensory symptoms than those with a small percent. At the same time, studies with either above or below 80% autism diagnosis presented with higher frequencies of all types of sensory symptoms relative to typical groups, in other words severity of ASD was related to the severity of sensory symptoms rather than the type of sensory pattern.

Percent of individuals with an autism diagnosis seems to contribute more to variability in total and over-responsivity scores than in seeking and under-responsivity, as indicated by the significance levels of Q_B and Q_w (Table 4). Differences in under-responsivity among studies were not explained by percent of autism in sample. Under-responsivity may not distinguish individuals with different types of ASD as some items on this scale also describe core ASD symptoms (e.g. delayed or lack of response to name, inattention), which tend to characterize individuals across the spectrum. Under-responsivity was also the most extreme aggregated sensory symptom relative to other types of SMDs, a finding that stands in line with Rogers and Ozonoff's (2005) proposal that of the types of sensory symptoms, under-responsivity is most prominent and unique to persons with ASDs. There is also evidence of a higher rate of under-responsivity scores that differ from age norms relative to over-responsivity rates in ASD (Adamson et al. 2006; Baranek et al. 2006; Ben-Sasson et al. 2007). There is a need to study the presence of non-socially related under-responsivity symptoms (e.g. walks into things, unaware of changes in water temperature) across the spectrum of autism disorders, to determine whether their dominance is a function of the social withdrawal and in-interest inherent to this disorder, or whether these symptoms are more sensory based.

For seeking, the three studies with below 80% individuals with autism (Ben-Sasson et al. 2007; Saulnier 2003; Smith-Myles et al. 2002) differed in their findings (unknown for studies with above 80% autism). This may reflect the wide distribution of percentage of autism among these studies (0–69%), or differences in their age range. Future research can test the interaction between type of ASD and age in relation to sensory symptomotology.

Sensory Modulation Symptoms and Type of Control Group

The type of control group that individuals with ASDs are compared to is critical in the interpretation of results. Overall *ES*s were higher when sensory symptoms of ASD groups were compared to a CA matched group versus a MA matched group. However in both types of comparisons ASD groups differed from controls. As opposed to CA matched studies, studies with MA matched controls were homogeneous in their total, over- and under-responsivity. Examination of two of the studies that compared ASD and DD groups and matched them on MA (Baranek et al. 2006; Rogers et al. 2003), showed that *ES*s of ASD compared to the DD group were 2–3 times lower than the ES of ASD compared to the typical group. The role of DD cannot be separated from CA as these two studies were also close in CA relative to the other two studies that compared ASD and DD groups (Gabriels et al. 2005; Gal 2006). Since there were very few studies that matched on MA, each applying a different method of MA matching, there is need for more research using such a design.

One of the aims of this meta-analysis was to examine the qualification of sensory symptoms as a core ASD

feature. We were able to examine the universality and uniqueness of sensory symptoms in ASD, but did not relate to specificity within the limits of this study. The high *ES*s across age groups and in samples with different proportions of autism diagnosis support its universality across the spectrum of autism and life span. Uniqueness was somewhat supported by the higher frequency of sensory symptoms when compared to MA matched typical groups and in comparison of Total scores to three DD groups matched on MA. However we identified very few studies that used different methods of matching, limiting conclusions regarding the unique nature of sensory symptoms in ASD.

Study Limitations

The current review revealed little consistency among studies in sample selection and diagnosis and lack of clarity in the exact methods employed. First, the small number of comparative studies in the area of sensory modulation and ASD, and even more so within each moderator category limited analytic possibilities (e.g. testing homogeneity within category or interactions between moderators) and conclusions. Second, the role of age was tested using age midrange however studies included persons from different age groups. In order to determine the role of methodological differences in producing variability in sensory evidence there is need for greater clarity and rigor in methodology to allow for comparisons across studies.

Empirical and Clinical Implications

This meta-analysis guides new directions in sensory research of persons with ASDs. In terms of CA there is urgent need for comparative studies of sensory symptoms in adolescents and adults with ASDs, a neglected age group. In addition, there is need for a non-linear longitudinal analysis of the course of sensory symptoms in ASD to determine prognosis, offset, and need for services. Future studies should tighten sample selection criteria (e.g. narrow age range, similar type of ASD), and consider their impact on findings. Differences between CA and MA matched comparisons require studies to provide information on the MA of participants, their matching procedure, as well as include a CA and MA matched control group.

Although parent-report measures are the best standard measures available and are cost and time effective, clinically and empirically there is need for learning about the sensory symptoms of persons with ASDs through different types of measures. Finally, as opposed to the over-responsivity construct that is more consistently defined across studies, seeking and under-responsivity are often measured together and include items that overlap with core ASD symptoms (e.g. spinning objects, avoiding eye contact). There were differences in the contribution of moderators to seeking versus under-responsivity, supporting their distinct assessment. The prominence of under-responsivity of all types of sensory symptoms and its independence of percentage of autism in sample calls for differential assessment of social versus non-social under-responses in order to isolate the role of modulation deficits in this syndrome.

Conclusions

Persons with ASDs show elevated sensory modulation symptoms across ages and spectrum of severity. The variability in the magnitude of these symptoms appears to be moderated by CA, severity of ASD, and the type of control group to which the ASD group is compared. Individuals with ASDs across ages presented with significantly different sensory symptoms compared to age peers and to younger individuals matched mentally. Closer investigation of the elevated risk for sensory symptoms should be evaluated in all children with autism, with particular attention to children ages 6–9 years. The moderators investigated in this meta-analysis must be taken into consideration when designing and analyzing studies in this area as well as in developing and interpreting sensory assessments for individuals with ASDs.

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