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REVIEW PAPER

A Systematic Review of Assessments for Sensory Processing Abnormalities in Autism Spectrum Disorder

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Abstract Sensory processing abnormalities are frequently reported in individuals with autism spectrum disorder (ASD), but few studies have evaluated the utility of the measures used to evaluate sensory responses. A systematic literature review was conducted to identify current trends in sensory processing assessments. Across the 93 studies included in this review, 16 measures were identified. The results of this review indicate that the majority of assessment measures are based on informant-report rather than behavioral observation, and that the most commonly used measure is the Sensory Profile (Dunn 1999, 2014). Some of these measures lacked well-established psychometric properties, which highlights the need for further validation of these measures. The authors also suggest a more multi-method approach to sensory processing assessment.

Keywords Autism spectrum disorder · Developmental disabilities · Sensory · Assessment

Autism spectrum disorder (ASD) is a heterogeneous neurodevelopmental disorder, and symptom presentation and severity differ significantly from individual to individual (Geschwind and Levitt 2007). Children with ASD have a high rate of co-occurring psychiatric disorders (Konst and Matson 2014; Leyfer et al. 2006; Simonoff et al. 2008; Tsai 2014) and medical conditions (Kielinen et al. 2004; Zafeiriou et al. 2007). This variability makes it a complex disorder that requires individualized treatment to address the specific needs of each person. One variable that can impact symptom presentation is the presence of abnormal sensory issues (Rinner 2002).

While not a universal feature of the disorder, abnormal sensory issues are reported in many individuals with ASD (Cheung and Siu 2009; Kern et al. 2008; Matsushima and Kato 2013; O'Brien et al. 2009; Tomchek and Dunn 2007). Indeed, one diagnostic criteria of ASD is restricted, repetitive patterns of behavior, interests, and activities, and these can manifest as unusual interests in sensory features of the environment or hyper- or hyporeactivity to sensory input (American Psychiatric Association 2013). These sensory abnormalities are often present in multiple modalities (e.g., auditory, visual, tactile; Kern et al. 2006; Leekam et al. 2007) and include both oversensitivity and undersensitivity to stimuli (Ben-Sasson et al. 2009; O'Neill and Jones 1997). When contrasted to typically developing (TD) children or those with other developmental disorders, children with ASD are reported to show different patterns of behavioral responses to sensory processing (Baranek et al. 2006; Schoen et al. 2009; Tomchek and Dunn 2007).

Overall, reports of sensory abnormalities characteristic of ASD fall into three primary domains: hypersensitivity, hyposensitivity, and sensory-seeking behaviors. Many children with ASD display a pattern of exaggerated behavioral responses to sensory stimuli (Baranek et al. 2007), also known as overresponsivity or hyperresponsivity, which is thought to be due to hypersensitivity to sensory input. Behavioral examples of hyperresponsivity include covering their ears to avoid loud sounds, a negative reaction to lights, and avoidance of certain textures (Baranek et al. 2013).

Conversely, a lack or insufficiency of response to sensory stimuli is known as underresponsiveness, hyporesponsiveness,

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or hyposensitivity (Baranek et al. 2013). An example of hyporesponsiveness in persons with developmental disabilities (DD) is reduced responsiveness to pain (Gilbert-MacLeod et al. 2000; Militerni et al. 2000). Both hypo- and hyperresponsive patterns have been shown to occur at high rates in individuals with ASD (Boyd et al. 2010; Greenspan and Wieder 1997), and individuals frequently present with a combination of these symptoms (Ashburner et al. 2008). Additionally, the same behavior can serve both a hyper- and hypo-sensitive function (e.g., body rocking to either stimulate the individual to counteract hyposensitivity or calm the individual to counteract hypersensitivity). It has been suggested that this co-occurrence is due to hypersensitivity and aversion to sudden or abrupt sensory input coupled with a preference for predictable and repetitive sensory input (Ashburner et al. 2008). While the presence of sensory symptoms in this population is well documented, little is known about the etiology of these abnormalities.

Another major feature of sensory abnormality in ASD is engaging in sensory-seeking behaviors. These behaviors involve unusual actions that intensify or reinforce a sensory experience (e.g., making vocalizations continuously, chewing or clenching the jaw, seeking out tactile sensations). Sensory-seeking behaviors are reported to be more common among children with ASD than other groups (Kirby et al. 2015). Further, a study by Gabriels et al. (2008) found evidence that sensory-seeking behaviors are related to the stereotyped, repetitive behaviors and interests that are characteristic of the disorder. Self-stimulatory behaviors are thought to provide sensory stimulation to the individual and are often automatically reinforced, which means that the behavior itself is reinforcing to the individuals and is not contingent upon external reinforcement (Rapp and Vollmer 2005). The reports that these behaviors are usually automatically maintained make it likely that these behaviors fulfill a sensory-seeking function. However, there is also evidence that some of these behaviors may be reinforced by attention, escape, or tangibles rather than or in addition to a sensory function (Cunningham and Schreibman 2008; Kennedy et al. 2000); therefore, function rather than just topography should be considered.

The pattern of atypical sensory responsiveness across individuals with ASD has been widely studied, with varied results. Numerous studies have investigated the relationship between sensory processing differences and age and autism symptom severity. Most studies have identified that sensory abnormalities diminish with age (Kern et al. 2006, 2008); however, others have found that these difficulties persist into adulthood (Leekam et al. 2007). It has been suggested that children with more severe ASD demonstrate higher levels of impaired sensory processing (Sanz-Cervera et al. 2015; Tavassoli et al. 2013). However, there is also evidence that autism symptom severity is only significantly related to sensory processing in childhood, and becomes less significant in older individuals with ASD (Kern et al. 2007c). In reference to observations that sensory problems diminish with age, this may be due to neurological maturation (Baranek et al. 2013) or more sophisticated coping strategies in older populations (Baranek et al. 2006).

Another challenge is that sensory sensations are private, internal events and by definition are unobservable. Therefore, any assessment will rely upon either observation of behavioral responses or self-report of internal experiences. While we can make inferences about the sensory source of certain behaviors, the cause of many of these behaviors could equally be due to over- or undersensitivity. Given that we can only infer the cause of these behaviors, measures of neurophysiological response to sensory stimuli may yield more informative results regarding internal sensory experiences. Previous studies have attempted to use physiological means to investigate certain aspects of sensory processing such as pitch sensitivity (Bonnel et al. 2003), visual acuity (Ashwin et al. 2009; Bölte et al. 2011), and taste identification (Bennetto et al. 2007). Sensory abnormalities have also been explored through neuroimaging (Gomot et al. 2008; Green et al. 2013). While these studies contribute to a better understanding of sensory abnormalities in the scientific community, clinical assessment of ASD often relies on behavioral observation and informant-report measures (Ozonoff et al. 2005). The scarcity of clinical application of physiological and neuroimaging measures (e.g., magnetic resonance imaging [MRI] machines, electroencephalogram [EEG]) may be due to the fact that these measures tend to be more expensive, less accessible, and more difficult to administer.

Several measures have been designed to evaluate atypical patterns of sensory processing and are often used in research as well as clinical settings (e.g., the Sensory Profile, Dunn 1999, 2014; the Sensory Experiences Questionnaire, Baranek et al. 2006), but further research is needed to investigate the accuracy and utility of these measures. Given that children with ASD exhibit such varied patterns of sensory difficulties, and these abnormalities are now considered a diagnostic feature of ASD, effective assessment of sensory symptoms is necessary in order to understand how sensory abnormalities affect the child's functioning (Rinner 2002). Any attempts to further our understanding of sensory abnormalities in ASD and use that knowledge to improve treatment outcomes will be limited by our assessment tools. That is to say, the validity and reliability of our conclusions about sensory issues in ASD are dependent upon the validity and reliability of the tools used to draw those conclusions. The purpose of the current review is to describe the extant literature over the last 20 years on measures of sensory abnormalities in individuals with ASD in order to identify trends in sensory assessment. Unusual sensory processing in this population may be related to restricted, repetitive interests and behaviors. It is possible that some of these behaviors develop in response to sensory processing difficulties, and serve to help the

individual either behaviorally cope with an overload of sensory information or to stimulate the individual. These sensory deficits have potential implications for the developmental performance of individuals with ASD across social, communication, motor, and adaptive domains.

Methods

The following databases were searched for peer-reviewed papers published between 1995 and December 2015: PsychInfo and GoogleScholar using the terms "sensory" AND "autism" OR "pervasive developmental disabilit*" OR "asperger's."

The abstracts and method sections of the articles were then reviewed by the first author and included if the study (a) was published in a peer-reviewed journal, (b) included a group of individuals with ASD, Asperger syndrome (AS), or pervasive developmental disorder (PDD-NOS), and (c) an assessment measure of sensory symptoms was a variable within the study. Studies that used physiological or neurological techniques (e.g., EEG, fMRI) to assess reaction to sensory stimuli without also implementing a behavioral or informant-report measure were not included in this review. The reason for this exclusion was that these techniques typically require advanced training and access to necessary equipment, and the purpose of this review was to focus on standardized measures that could be conducted by allied professionals or clinicians during routine psychological or medical evaluations. Studies were also excluded if the measure was not used as an independent or dependent variable in the study (i.e., if the measure was used only for participant screening or inclusion criteria). Reviews and meta-analyses were also excluded (Fig. 1).

It is unlikely that this produced an exhaustive review; however, it should be representative of the current trends of measures used in research to evaluate sensory symptoms in individuals with DD and ASD.

Results

The literature search produced 426 publications from GoogleScholar and 158 from PsychInfo. After review of the abstracts, 88 articles were included from the GoogleScholar search and an additional 5 from PsychInfo for a total of 93 studies. Across these 93 studies, a total of 16 measures were identified in the literature search and are included in this review. These measures are described in order of frequency of use. Table 1 shows the measures used for each study.

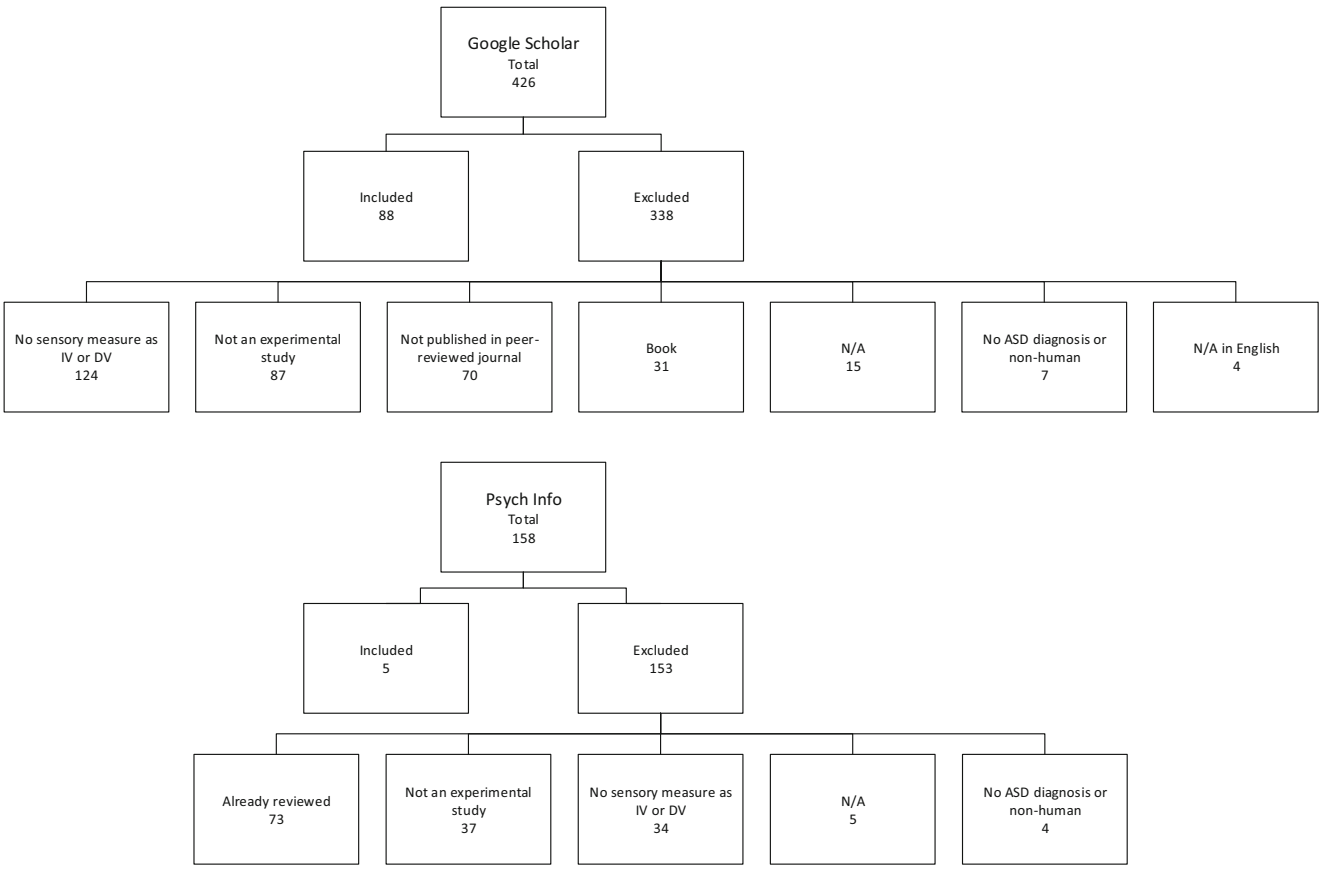

Fig. 1 Outcomes of systematic literature search

Table 1 Studies of sensory abnormalities in individuals with ASD

Authors	Sensory assessment measure	Type of measure
Ashburner et al. (2013)	AASP	Self-report
Crane et al. (2009)	AASP	Self-report
De la Marche et al. (2012)	AASP	Self-report
Fuentes et al. (2011)	AASP	Self-report
Jones et al. (2009)	AASP	Self-report
Ludlow et al. (2014)	AASP	Self-report
Milosavljevic et al. (2015)	AASP	Self-report
Stewart et al. (2016)	AASP	Self-report
Green et al. (2012)	ITSEA	Caregiver-report
Mulligan and White (2012)	ITSP	Caregiver-report
Woodard et al. (2012)	ITSP	Caregiver-report
Ben-Sasson et al. (2008)	ITSP and ITSEA	Caregiver-report
Ben-Sasson et al. (2007)	ITSP and ITSEA	Caregiver-report
Ben-Sasson et al. (2013)	ITSP and ITSEA	Caregiver-report
Matsushima and Kato (2013)	JSI-R	Caregiver-report
Ausderau et al. (2013)	SEQ	Caregiver-report
Baranek et al. (2006)	SEQ	Caregiver-report
Little et al. (2015)	SEQ	Caregiver-report
Schaaf et al. (2012a, b)	SEQ	Caregiver-report
Boyd et al. (2010)	SEQ, SP, SPA, and TDDT-R	Both informant and behavioral/performance
Watson et al. (2011)	SEQ, SP, SPA, and TDDT-R	Both informant and behavioral/performance
Bitsika et al. (2015)	SP	Caregiver-report
Daluwatte et al. (2015)	SP	Caregiver-report
Dunn et al. (2002)	SP	Caregiver-report
El Batrawi et al. (2014)	SP	Caregiver-report
Ermer and Dunn (1998)	SP	Caregiver-report
Gabriels et al. (2008)	SP	Caregiver-report
Hilton et al. (2010)	SP	Caregiver-report
Hilton et al. (2007)	SP	Caregiver-report
Joosten and Bundy (2010)	SP	Caregiver-report
Kern et al. (2006)	SP	Caregiver-report
Kern et al. (2008)	SP	Caregiver-report
Kern et al. (2007a)	SP	Caregiver-report
Kern et al. (2007b)	SP	Caregiver-report
Kern et al. (2007c)	SP	Caregiver-report
Kientz and Dunn (1997)	SP	Caregiver-report
Lidstone et al. (2014)	SP	Caregiver-report
Martínez-Sanchis et al. (2014)	SP	Caregiver-report
Mattard-Labrecque et al. (2013)	SP	Caregiver-report
Myles et al. (2004)	SP	Caregiver-report
Reese et al. (2003)	SP	Caregiver-report
Reynolds et al. (2011)	SP	Caregiver-report
Reynolds et al. (2012)	SP	Caregiver-report
Watling et al. (2001)	SP	Caregiver-report
Leekam et al. (2007)	SP	Caregiver-report
Cheung and Siu (2009)	SP (Chinese translation)	Caregiver-report
Chuang et al. (2012)	SP (Chinese translation)	Caregiver-report
Tseng et al. (2011)	SP (Chinese translation)	Caregiver-report

Table 1 (continued)

Authors	Sensory assessment measure	Type of measure
Ward et al. (2013)	SP-SC	Teacher-report
Schaaf et al. (2012a, b)	SP and SEQ	Caregiver-report
Lane et al. (2012)	SP and SPS (SensOR Inventory)	Caregiver-report
Brown and Dunn (2010)	SP and SP-SC	Caregiver/teacher-report
Brock et al. (2012)	SP, SEQ, TDDT-R, and SPA	Both informant and behavioral/performance
Baranek et al. (2007)	SPA	Performance measure
Baranek et al. (2013)	SPA, SEQ	Both informant and behavioral/performance
Pfeiffer et al. (2011)	SPM	Caregiver/teacher-report
Roley et al. (2014)	SPM	Caregiver/teacher-report
Sanz-Cervera et al. (2015)	SPM	Caregiver/teacher-report
Miller-Kuhaneck and Britner (2013)	SPM and SPM-P	Caregiver/teacher-report
Gee et al. (2014)	SPM and SPS (SenSOR scales)	Both informant and behavioral/performance
Tavassoli et al. (2014)	SPQ and SensOR Inventory	Self-report
Sullivan et al. (2014)	SPS (SensOR Inventory)	Caregiver-report
Tavassoli et al. (2014)	SPS (SensOR Scale)	Self-report
Boyd et al. (2009)	SQ	Caregiver-report
Ashburner et al. (2008)	SSP	Caregiver-report
Chen et al. (2009)	SSP	Caregiver-report
Corbett et al. (2009)	SSP	Caregiver-report
Hochhauser and Engel-Yeger (2010)	SSP	Caregiver-report
Lane et al. (2010a, b)	SSP	Caregiver-report
Lane et al. (2014)	SSP	Caregiver-report
Lane et al. (2010a, b)	SSP	Caregiver-report
Liu (2013)	SSP	Caregiver-report
Mazurek and Petroski (2015)	SSP	Caregiver-report
Mazurek et al. (2014)	SSP	Caregiver-report
McCormick et al. (2015)	SSP	Caregiver-report
Nadon et al. (2011)	SSP	Caregiver-report
O'Donnell et al. (2012)	SSP	Caregiver-report
Provost et al. (2009)	SSP	Caregiver-report
Rogers et al. (2003)	SSP	Caregiver-report
Schoen et al. (2009)	SSP	Caregiver-report
Tomchek and Dunn (2007)	SSP	Caregiver-report
Tomchek, Huebner, and Dunn (2014)	SSP	Caregiver-report
Tomchek et al. (2015)	SSP	Caregiver-report
Wiggins et al. (2009)	SSP	Caregiver-report
Wigham et al. (2015)	SSP	Caregiver-report
Zeina et al. (2014)	SSP	Caregiver-report
Gal et al. (2010)	SSP	Caregiver-report
Mazurek et al. (2013)	SSP	Caregiver-report
O'Brien et al. (2009)	SSP (adapted)	Caregiver-report
Orekhova et al. (2012)	SSP (Russian translation)	Caregiver-report
Minshew and Hobson (2008)	SSQ	Self-report and caregiver-report
Talay-Ongan and Wood (2000)	SSQ-R	Caregiver-report
Donkers et al. (2015)	TDDT-R, SPA, SEQ, and SP	Both informant and behavioral/performance

Assessment Measures

Sensory Profile (SP, SP-2)

Seventy-four studies used a version of the Sensory Profile (SP; Dunn 1999, 2014). Thirty-four of these studies used the original SP, and three of these used a Chinese translation. The SP contains 125 items that describe various behavioral responses to sensory stimuli and is based on caregiver report (Dunn 1997). The measure is divided into three sections: sensory processing, modulation, and behavioral and emotional responses. The authors report that the SP is most appropriate for children 5–10 years of age (Dunn 1999). Cronbach's coefficient alphas were used to examine internal consistency and ranged from .47 to .91 (Pearson Education 2008b). Ohl et al. (2012) found that intraclass correlation coefficients (ICCs) for test-retest reliability were in the good range for the four quadrants (.80–.90) and the moderate to good range for the factor scores (.69–.88) and section scores (.50–87). They also found that the SP had high internal consistency across quadrants (a = .89–.95) and factor scores (a = .82–.93), and moderate to high internal consistency across section scores (a = .67–.93). The SP has been shown to demonstrate good discriminant validity between certain groups of children with disabilities (Ermer and Dunn 1998) and between children with and without ASD (Kientz and Dunn 1997).

Additional versions of the SP include the following: the Infant/Toddler Sensory Profile (ITSP; Dunn 2002) for birth to 36 months, the Adolescent/Adult Sensory Profile (AASP; Brown and Dunn 2002) for children 11 years and older, and the Sensory Profile School Companion (SP-SC; Dunn 2006) for children 3 to 11 years old. The Short Sensory Profile (SSP; McIntosh et al. 1999) is a 38-item caregiver questionnaire for use in screening and research protocols. Eight studies used the AASP, five used the ITSP, two used the SP-SC, and 26 used the SSP (one of these used a Russian translation). One study used both the SP and SP-SC.

The subscales of the AASP had varying levels of item reliability. The Sensory Sensitivity subscale yielded a coefficient alpha value of .81, .66 for the Sensation Avoiding subscale, .82 for the Low Registration subscale, and .79 for the Sensation Seeking subscale (Brown et al. 2001). Dunn and Daniels (2002) found that for the ITSP, the internal consistency alpha coefficient was .85 for Sensory Seeking, .60 for Low Registration, .67 for Sensory Avoiding, and .65 for Sensitivity/high responding. Test-retest coefficients were .86 for the sensory processing sections and .74 for the quadrants (Pearson Education 2008a).

The revised Sensory Profile-2 was recently published (SP-2; Dunn 2014) and the age range was expanded to birth to 14 years 11 months. It includes the following: Infant Sensory Profile 2 (birth to 6 months), Toddler Sensory Profile 2 (7 to 35 months), Child Sensory Profile 2 (3 to 14 years), Short Sensory Profile 2 (3 to 14 years), and the School Companion Sensory Profile 2 (3 to 14 years), as well as Spanish translations. The updated version has revised content and greater consistency between forms. To date, little research has been conducted on the psychometrics of the SP-2 measures.

Sensory Experiences Questionnaire (SEQ, Versions 1.0, 2.0, 2.1, and 3.0)

The Sensory Experiences Questionnaire (SEQ) was used in 10 studies and is a brief caregiver-report measure that evaluates behavioral responses to sensory experiences (Baranek 1999a; Baranek et al. 2006). The original 21-item questionnaire was designed for children 5 months to 6 years of age with ASD, developmental delay, or typical development. It has been shown to be a reliable measure with good test-retest reliability (ICC = .92) and acceptable internal consistency (α = .80; Little et al. 2011). Baranek et al. (2006) also found that the SEQ is useful in characterizing sensory features in children with ASD and can differentiate TD individuals from those with ASD, which provides evidence for construct validity.

The recently expanded 105-item version (SEQ-3.0) is meant for children 2–12 years old with ASD or DD, though it is currently not available for distribution. This measure is meant to assess the frequency of behaviors across four sensory patterns (hypo- and hyperresponsiveness), five sensory modalities (tactile, auditory, visual, gustatory/olfactory, and vestibular/proprioceptive), and both social and nonsocial contexts. Ausderau, Sideris, and colleagues (2013) found that the SEQ-3.0 has an empirically valid factor structure for individuals with ASD. Additional psychometric analyses are reported as currently in progress (Ausderau and Baranek 2013).

Sensory Processing Assessment for Young Children (SPA)

The Sensory Processing Assessment (SPA) was used in six studies. It is a semi-structured, play-based observational assessment for children 9 months to 6 years old, and was intended for use identifying patterns of sensory processing in children with ASD or DD (Baranek 1999b). The authors report that the SPA is designed to be used with the SEQ, so as to give a comprehensive view of the child's behavioral responses based both on caregiver report and direct observation. The sections of the SPA include approach/avoidance, orienting to unexpected sensory stimuli, habituation to repeated stimuli, and unusual sensory-seeking behaviors. Baranek (1999b), cited from Baranek et al. (2013), reported that the SPA has high test-retest reliability between two raters (ICC = .92 for the six orienting items, .92 for the three social items, and .87 for the three nonsocial items).

Sensory Processing Measure (SPM)

The Sensory Processing Measure (SPM) was used in five studies. It is a parent and/or teacher rating scale to evaluate social participation, praxis, and sensory processing issues in children (Miller-Kuhaneck et al. 2007a; Parham and Ecker 2007). This measure is intended for children 5 to 12 years of age and consists of a Home Form (75 items; Parham and Ecker 2007), a Main Classroom Form (62 items; Miller-Kuhaneck et al. 2007a), and a School Environments Form (10–15 items for each of six settings; Miller-Kuhaneck et al. 2007a). The authors report that these forms are designed to be used together to give a comprehensive measure of the child's sensory functioning across contexts. However, these forms can also be administered individually as screening tools. Scores for each scale fall into three categories: typical, some problems, or definite dysfunction. The internal consistency for the Home Form scale ranged from α = .77 to .95 and test-retest reliability coefficients ranged from .94 to .98 (Pearson Education Limited n.d.). The Main Classroom Form had internal consistency estimates ranging from .75 to .95, and test-retest reliability coefficients of .95–.98. The School Environments Form had internal consistency estimates ranging from .82 to .91 (Pearson Education Limited n.d.). Brown et al. (2010) further reported that the SPM is significantly correlated with the SP.

The SPM-School (originally the School Assessment of Sensory Integration) has been found to have high internal consistency for TD children for sensory processing environment and social participation items (α > .9). For sensory processing items, Cronbach's alpha for children with sensory issues ranged from .87 to .99 and from .70 to .99 for TD children. For social participation, Cronbach's alpha ranged from .91 to .97 for children with sensory issues and .98–.99 for TD children. The SPM-School discriminated between 82.4% of cases of TD children and children with sensory issues (i.e., correctly classified TD children 92.3% of the time and children with sensory issues 72% of the time; Miller-Kuhaneck et al. 2007b).

There is also a Sensory Processing Measure-Preschool (SPM-P) for children 2–5 years old who have not yet entered kindergarten. This rating scale includes a Home Form (Ecker and Parham 2010) and a School Form (Miller-Kuhaneck et al. 2010), which each have 75 items for the parent/caregiver and teacher/daycare provider to complete. Both the Home and School forms demonstrated adequate internal consistency (α > .7) and excellent test-retest stability (α > .9; Glennon et al. 2011).

Sensory Processing Scale Assessment (SPS)

The Sensory Processing Scale (SPS) was used in five studies (Schoen et al. 2008). It measures multiple domains of sensory functioning using dichotomous ("yes/no") behavioral response options. Most of the research on these scales has focused on the SOR, or SensOR scales, which measure sensory overresponsivity in seven sensory domains. These scales include the SOR Assessment, which is an examiner-administered performance evaluation, and the SOR Inventory, which is a self- or caregiver-rating scale. The SensOR scales have been shown to have moderate to high internal consistency reliability (i.e., SensOR assessment r = .60–.89 for domains and r = .92 for total tests; SenSOR inventory r = .65–.89 for domains and r = .97 for total tests). The SensOR assessment has also been shown to have moderate to high inter-rater reliability (r = .75 for total test and r = .63–.89 for domains). Additionally, the scales have been shown to differentiate between overresponsive and typically responsive groups, as well as have significant concurrent validity with the SSP (Schoen et al. 2008).

The SPS Assessment Version 2.0 was expanded to include activities that elicit behaviors for the seven sensory domains. The expanded version of the SPS includes all three subtypes of sensory modulation: Sensory overresponsivity (SOR), sensory underresponsivity (SUR), and sensory seeking (or sensory craving). The SPS Assessment Version 2.0 has been shown to have good internal consistency (a = .94), domain reliabilities (.79–.93), and discriminant validity (p < .002), which supports the construct validity of the measure (Schoen et al. 2014).

Tactile Defensiveness and Discrimination Test-Revised (TDDT-R)

The Tactile Defensiveness and Discrimination Test-Revised (TDDT-R) was used in four studies (Baranek 2010; Baranek and Berkson 1994). It is a 15–20-min structured behavioral observation assessment of tactile processing for children with ASD or other DD ages 2 to 14 years old. It evaluates hyperresponsiveness and tactile discrimination through presentation of play-based tactile tasks and coding observations of responses. Inter-rater reliability for this measure has been reported to be good (ICC >.9) for both defensive and seeking behaviors (Foss-Feig et al. 2012). It is not currently commercially available (Watling 2013).

The Infant Toddler Social and Emotional Assessment (ITSEA)

The Infant Toddler Social and Emotional Assessment (ITSEA) was used in four studies (Carter and Briggs-Gowan 1993, 2000, 2006). It is a parental report measure of social-emotional and behavioral problems in infants and toddlers 12 to 36 months of age. The ITSEA consists of 166 items and uses a three-point likert response to assess four domains: externalizing, internalizing, dysregulation, and competence. While this measure does not focus solely on sensory

responses, the dysregulation domain includes a sensory sensitivity subscale. The ITSEA has been found to have good test-retest reliability (r = .82–.9 for domains and .69 = .85 for scales) and moderate to good inter-rater agreement between mothers and fathers (ICC from .58 to .79 for domains and .43–.78 for scales). The ITSEA has also been shown to have good internal consistency for all but the additional indices (r = .80–.90 for domains and .59–.84 for scales; Carter et al. 2003).

Japanese Sensory Inventory-Revised (JSI-R)

The Japanese Sensory Inventory-Revised (JSI-R) was used in one study (Ota et al. 2002; Ota 2004). It is a standardized caregiver-report assessment that consists of 147 items grouped into eight subcategories in the Japanese language. It is used to describe the behavioral responses to sensory stimuli of children 4–6 years old. JSI-R items were based on a review of research on atypical sensory processing, and show adequate test-retest reliability (r = .34–1.0; Ota 2004, cited from Matsushima and Kato 2013).

Sensory Perception Quotient (SPQ)

The Sensory Perception Quotient (SPQ) was used in one study (Tavassoli et al. 2014). It is a self-report questionnaire for adults with ASD that assesses sensory hyper- and hyposensitivity across the five sensory modalities. Items included main sensory receptors for each modality and relevant characteristics of the environment. The full 92-item version and reduced 35-item version were both found to have high internal consistency (α = .92–.93). The full SPQ is moderately correlated with the SensOR across groups ($r = -.5$, $p < .001$) and within the ASD ($r = -.49$, $p = .007$) group, though the correlation was lower for the control group ($r = -.23$, $p = .004$). Concurrent validity was also lower for the reduced version ($r = .20$, $p = .0001$). The ASD group and control group different signfiicantly on total SPQ scores ($F(6339) = 13.44$, $p < .005$). The SPQ was also somewhat correlated with autistic traits (measured by the Autism Quotient; AQ) across groups ($r = -.39$, $p = .0001$) and marginally within the ASD group ($r = -.18$, $p = .009$) and the control group ($r = -.15$, $p = .06$). The reduced SPQ also correlated with the AQ ($r = -.14$, $p = .007$; Tavassoli et al. 2014).

Sensory Questionnaire (SQ)

The Sensory Questionnaire (SQ) was used in one study (Boyd and Baranek 2005). It is an informant-based questionnaire used to evaluate sensory processing issues in children with ASD. The measure consists of six items that evaluate whether the child currently (within the last 3 months) or ever (demonstrated in the past but not in the last 3 months) displayed sensory processing difficulties. A study by Boyd et al. (2009) found that factor loading on items 1 to 5 ranged from .71 to .89. Item 6 did not load on the same factor as the other items and so was excluded. A confirmatory factor analysis revealed that a single factor model fit for items 1 through 5 ($\chi^2(5) = 4.33$, $p = .503$, CFI = 1.00, RMSEA < .001; (Boyd et al. 2009).

Sensory Sensitivity Questionnaire (SSQ)

The Sensory Sensitivity Questionnaire (SSQ) was used in one study (Minshew and Hobson 2008). The SSQ includes both self-report and caregiver-report measure. Clinical reports and behavioral descriptions by individuals with ASD were also considered in the development of the measure. The self-report and parent-report forms consist of 13 yes/no items. The authors reported that this was not a standardized measure with established reliability and validity (Minshew and Hobson 2008).

Sensory Sensitivity Questionnaire-Revised (SSQ-R)

The Sensory Sensitivity Questionnaire-Revised (SSQ-R) was used in one study (Talay-Ongan and Wood 2000). It is a caregiver-report measure that was developed to probe sensory sensitivities in all sensory domains by presenting nine closed (yes/no) items for each domain (i.e., auditory, tactile, visual, gustatory, vestibular, and olfactory). Discriminative ability has been shown for 45 out of the 54 total items. The authors of the measure state that content and concurrent validity are assumed since all items are statements that represent hypo- or hypersensitivity to sensory stimuli and there is significant overlap with other measures of sensory processing (Talay-Ongan and Wood 2000).

Trends in Sensory Research

Through a 20-year review of research on sensory abnormalities in ASD, it is clear that informant ratings dominate the literature, in particular the SP. Across the 93 studies, a total of 16 sensory measures were identified. Eleven of these are caregiver- or teacher-report measures, four of which were versions of the SP (i.e., SP, SSP, ITSP, SP-SC). The additional seven were the SEQ, SPM, SPS (SensOR inventory), ITSEA, JSI-R, SSQ, SSQ-R, and SQ. We found three self-report measures, AASP, SSQ, and SPS (SensOR inventory), which is consistent with the fact that the majority of studies focused on children with ASD and that caregiver- or teacher-report measures are often used for younger individuals. Three performance and behavioral observation measures were identified in this review (i.e., the TDDT-R, SPS [SensOR assessment], and SPA). Some of these measures, such as SPS, included more than one type of response format.

Of the 93 studies reviewed, 74 (79.6%) used a form of the SP, including the SSP, ITSP, AASP, and the SP-SC. Three of those used the SP Chinese version (SP-C), and one used a Russian translation of the SSP. The SEQ was used in 10 studies (10.8%) and the SPA was used in 6 (6.5%). Both the SPM and SPS (including the SenSOR scales, inventory, and assessment) were used in five studies (5.4%) and the TDDT-R and ITSEA were used in four (4.3%). SPQ, SQ, SSQ, SSQ-R, and JSI-R were each only used in one of the identified studies (1.1%). Overall, the SP was by far the most commonly used measure in this sample, while the SSQ, SSQ-R, SPQ, SQ, and JSI-R were the least commonly used. Figure 2 shows the frequency of use of each measure across the 93 studies.

From the review of the included studies, it is clear that most of the measures used in research to investigate sensory abnormalities in individuals with ASD are informant-report measures. Of the 93 studies, 75 (80.7%) used only a caregiver- and/or teacher-report measure, while 10 (10.8%) used only self-report measure and 1 (1.1%) used both self- and caregiver report. One (1.1%) of the studies identified used only a behavior/performance measure and six (6.5%) of the studies used a behavior/performance measure and either a caregiver/teacher or self-report measure. This suggests that the majority of research studies rely on caregiver- and/or teacher-report measures to evaluate atypical sensory processing in individuals with ASD.

We also examined whether trends in sensory assessment have changed over the last 20 years. We found that all of the studies that used both informant and behavioral/performance measures were published in the last 6 years (i.e., 2010 or later). Additionally, prior to 2010, only one study had used a performance measure and the rest of the studies all used self- or caregiver report. However, this does not represent a clear progression in the field, as nearly two thirds of the studies included in this review were published after 2010, and the majority of those were based on caregiver report. This indicates that there has been a lack of progress in the field in recent years to move toward including behavioral observation methods in addition to informant-report measures.

Discussion

In view of the inclusion of sensory abnormalities as a diagnostic characteristic of ASD, identification of sensory processing variations is crucial. Sensory difficulties can impact stereotyped interests and behaviors (Boyd et al. 2009; Wiggins et al. 2009), social skills (Ben-Sasson et al. 2007; Matsushima and Kato 2013), behavioral and emotional problems (Baker et al. 2007), and language and communication abilities (Watson et al. 2011). Kern et al. (2008) suggested that differences in sensory modulation in ASD can influence activity level and emotional response. These sensory processing deficits may also impact a child's ability to sustain attention and regulate arousal, and subsequently influence the child's ability to adapt and learn (Tomchek et al. 2014).

The majority of the studies that investigated sensory abnormalities implemented caregiver- or teacher-report measures. Of these assessments, the SP and its additional versions were by far the most commonly used. The SP, while not designed specifically for children with ASD or DD, has been shown to discriminate between TD children and those with disabilities, as well as between groups of children with different disabilities (Ermer and Dunn 1998). A consistent finding across many of the articles reviewed was that individuals with ASD score differently than TD individuals on versions of the SP (Kern et al. 2008; Kern et al. 2007a; Kientz and Dunn 1997; Rogers et al. 2003; Tomchek and Dunn 2007; Watling et al. 2001), which provides evidence that it can reliably identify differences in behavioral symptoms that are commonly

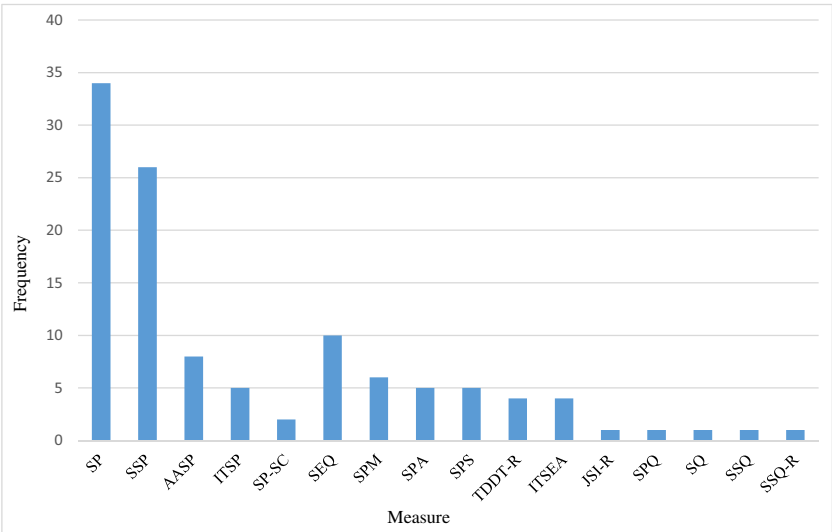

Fig. 2 Frequency of measure use across studies

assumed to reflect sensory processing deficits in individuals with ASD.

In regards to response format, less than 10% of the studies reviewed used behavior observation or a performance measure to evaluate sensory symptoms. Of these measures, the TDDT-R assesses only tactile responses and so is not able to identify trends across sensory modalities. The SensOR scales include both an assessment, which is performance-based, as well as an inventory, which is a self- or parent-report measure. However, researchers did not always use these scales in combination. The third observational assessment identified was the SPA, which is designed to be used in conjunction with the SEQ so as to provide a comprehensive evaluation of sensory abnormalities. The SPA was used alone in one study and alongside the SEQ (as well as additional measures) in four studies. Although the SIPT was used as a behavior performance measure in some of these studies, it was not included in this review because it assesses impairments beyond those directly related to sensory processing (e.g., visual, motor skills). It should be noted that several of the studies did include a behavioral task, but only assessment measures were included in this review. Overall, these results indicate that relatively few behavior observation assessment measures are used in research on sensory processing in ASD. Additionally, measures that are designed to supplement one another by combining both performance and informant-report data are not always used together, which may result in a less accurate representation of the individual's sensory response pattern.

Although caregiver-report measures are commonly used in research, previous studies have shown that there is often low agreement between caregiver report and behavioral observation (Ozonoff et al. 2011). One of the studies reviewed, conducted by Woodard et al. (2012), found that children's scores on the ITSP were not significantly related to behavioral observations of sensory responses or autonomic responsivity. This illustrates the need for additional behavioral and performance measures for sensory responses. The integration of both parent report and behavioral measures administered by trained clinicians in an allied health profession (e.g., psychologist, pediatrician, occupational therapist, speech therapist) is important for gaining a full and unbiased measure of the sensory processing issues of children with ASD.

An important observation from this review is the insufficient amount of research on the psychometric properties of several of these sensory assessments. Some of the measures were not standardized (e.g., SSQ), or the article reported only reliability (i.e., test-retest, inter-rater) and failed to address the validity of the measure. Some authors stated that validity was assumed due to the items asking for specific information. However, establishing validity is more complicated than simply demonstrating the author's intention to measure something well. After test items are written, they still need to undergo evaluation to validate the inferences made from responses to these items (Crocker and Algina 1986). Overall, a lack of well-established psychometric properties for some of the available sensory assessments will in turn limit advancement of understanding of sensory abnormalities in ASD. As such, clinicians and researchers alike are left to wonder if the results of some of these assessments are meaningful.

As previously noted, this review focuses exclusively on assessment measures designed specifically for sensory processing difficulties, such as informant-report or performance measures. Because sensory experiences are an internal phenomenon, both informant-report and behavioral observations can only provide information regarding the behavioral manifestations of sensory abnormalities and require us to make inferences regarding underlying sensory issues. One way that researchers can attempt to supplement this behavioral information is to measure physiological or neurological response to sensory stimuli. This review did not include these outcome variables, as our goal was to investigate assessments that could be used within the context of day-to-day clinical practice. However, some of the studies included in this review did utilize physiological measures, such as electrodermal activity (Schoen et al. 2009), salivary cortisol (Bitsika et al. 2015; Corbett et al. 2009; Reynolds et al. 2011), heart rate (Woodard et al. 2012), and pupillary light reflex (Daluwatte et al. 2015). For example, Woodard et al. (2012) found that both behavioral ratings and parent-report measures were not good indicators of internal, autonomic states, as measured by heart rate. This suggests that validation of the informant-report measures against the physiologically based measures would likely be fruitful.

Other studies have used neuroimaging or neural activation measures (e.g., EEG, MEG, and fMRI; Gomot et al. 2008; Green et al. 2013; Marco et al. 2011) in an attempt to identify brain regions and patterns of activation related to sensory processing difficulties. Marco et al. (2011) highlighted the utility of sensory behavioral phenotyping for both identifying and characterizing sensory abnormalities as well as for monitoring treatment (e.g., behavioral intervention, psychopharmacological) effects. Research on neurological responses to sensory stimuli may provide valuable information on the etiology and biological bases of the processing dysfunctions characteristic of this population. Since studies have implicated an extensive network of brain regions in sensory processing (Gomot et al. 2008; Marco et al. 2011), additional research may serve to more precisely identify areas and elucidate the role of these regions in sensory processing.

In the same way that researchers have attempted to measure other unobservable constructs (e.g., intelligence) through multiple means, this trend is also found in sensory research. Researchers have focused on informant-report, behavioral observation, and physiological measurement to attempt to make inferences regarding sensory experiences. However, only a few of the studies identified in this review integrated these

methods to develop a multi-faceted approach to sensory dysfunction in ASD. Campbell and Fiske (1959) suggest the Multitrait-Mulitmethod model (MTMM) approach to construct validity in which several traits are measured by several different methods. Future research should apply this model to sensory research by focusing on an interdisciplinary approach that compares physiological and behavioral response to sensory input, with the assumption that measures that are well-validated should correspond to physiological markers within individuals. Cascio et al. (2016) recommended that this multi-measure approach (e.g., parent-report, observational measures, and neurophysiological measures) also be utilized in evaluating the effectiveness of treatment. Treatment of sensory abnormalities in ASD has been a highly contentious area and some widely used interventions lack empirical support (e.g., sensory integration therapies or interventions; Case-Smith et al. 2015; Devlin et al. 2009; Lang et al. 2012). Effective treatment is contingent on a comprehensive understanding of the issues at hand and a valid way of evaluating the efficacy of treatment. Future research should utilize methodology that demonstrates high internal validity to investigate the effects of intervention on behaviors with a hypothesized sensory function (Cascio et al. 2016).

Multiple behavior assessments, such as informant-report and behavioral observation, combined with the practitioner's clinical judgment should also be considered. Further investigation of the associations between these measures would contribute to better construct, convergent, and divergent validity of behavioral sensory measures. The effectiveness of these measures is of even greater importance now that identification of these symptoms can impact the diagnosis of ASD. Further evaluation and development of appropriate sensory assessments is crucial since in sensory processing, as in the assessment of other features of ASD, measures are not meant to replace the clinician's judgment, but serve as tools to make the assessment process more efficient, reliable, and valid.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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