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Toward a Best-Practice Protocol for Assessment of Sensory Features in ASD

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Abstract Sensory difficulties are a commonly occurring feature of autism spectrum disorders and are now included as one manifestation of the 'restricted, repetitive patterns of behavior, interests, or activities' diagnostic criteria of the DSM5 necessitating guidelines for comprehensive assessment of these features. To facilitate the development of such guidelines, this paper provides an overview of the literature on sensory features in autism spectrum disorder. We summarize the literature pertaining to: terminology, current assessment practices, sensory development, and the relationship of sensory features to core symptoms of autism. The paper concludes with recommendations for clinical assessment of sensory features in Autism.

Keywords Autism · Perceptual disorders · Sensory function · Sensory disorders · Symptom assessment · Best practices

Introduction

Reports of behaviors associated with difficulty processing and integrating sensory information—hereafter referred to as sensory features—in individuals with autism spectrum disorder (ASD) are frequently found in the literature (Rogers et al. 2003; Minshew et al. 2002; Williams 1992, 1994; Rogers and Ozonoff 2005). Estimates of the prevalence of sensory features in ASD vary from 45 to 96 %. (Leekam et al. 2007; Tomchek and Dunn 2007; Ben-Sasson et al. 2008). Variations in estimates are likely related to the diversity of assessments utilized and the type of sensory features evaluated. Importantly, some sensory features are now included as one manifestation of the 'restricted, repetitive patterns of behavior, interests, or activities' diagnostic criteria (Criteria B) of the DSM5 (APA 2013) while others are not. Specifically, "hyper- or hypo-reactivity to sensory input or unusual interest in sensory aspects of the environment" qualifies as one of four sub-criteria (two sub-criteria are required) on this diagnostic dimension (APA 2013). Given the increased emphasis on sensory features in diagnostic decision-making in ASD, it is timely to reflect on current understandings of the manifestation of sensory features in ASD, their relation to core features of ASD, and common sensory assessment strategies. Accordingly, this in this paper we provide an overview of the literature in relation to the following key questions:

1. What is the common terminology used for sensory features?
2. What are the common sensory features in ASD?
3. Do sensory features change with age?
4. How do sensory features relate to the core symptoms of ASD?
5. What are the common clinical assessments available to evaluate sensory features in ASD?

On the basis of our summary of the literature relative to these questions, we conclude with suggestions for inclusion in a comprehensive clinical assessment of sensory features in ASD.

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Table 1 Common terms in the literature used to describe sensory features

	Description
Terms used to describe hypo-reactivity	
Poor registration/low registration	Characterized by passive self-regulation strategy with diminished awareness or registration of sensory stimuli and high sensory thresholds (Dunn 1997)
Sensory under-sensitivity; sensory under-responsivity	Diminished awareness of sensory input; may take a lengthened amount of time to respond to sensory stimuli (Ben-Sasson et al. 2009; Oswald 2013)
	Does not respond to sensory input (Miller et al. 2007; Oswald 2013; Zachor and Ben-Itzchak 2014)
Hyporesponsiveness	Slower, diminished, or weakened reactions to sensory input (Ausderau et al. 2014a; Baranek et al. 2006; Oswald 2013; Patten et al. 2013)
	May need several or more intense cues to produce a response (Oswald 2013; Patten et al. 2013)
	Exhibits under-reactivity in response to stimuli (Boyd et al. 2010)
Hypo-reactivity	Does not respond to sensory input or may require increased sensory stimuli to experience the input—may include lack of reaction to temperature (hot/cold) or pain (Elwin et al. 2013; Oswald 2013)
Hypo-sensitivity	Exhibits under-reactivity in response to sensory stimuli (Oswald 2013; Robertson and Simmons 2013)
Terms used to describe hyper-reactivity	
Sensory sensitivity	Characterized by low sensory thresholds and a passive self-regulation strategy, often exhibiting distractibility (Dunn 1997)
Sensory defensiveness	Exhibits over sensitivity that is often negative to sensory stimuli (Ayres 1964; Pfeiffer and Kinnealey 2003)
	May demonstrate aversion or anxiety to gentle touch (Ayres 1964; Pfeiffer and Kinnealey 2003)
Tactile defensiveness	Exhibits intense reactions or anxiety to touch or textures (Ayres 1964; Pfeiffer and Kinnealey 2003)
Oral defensiveness	Has increased sensitivity to particular foods or textures (Wilbarger and Wilbarger 1991)
Visual defensiveness	Characterized by hyper sensitivity to light with feelings of discomfort or pain to light (Wilbarger and Wilbarger 1991)
Auditory defensiveness	Has increased sensitivity to sounds (Wilbarger and Wilbarger 1991)
Hyper-responsiveness	Has over-reactivity that tends to be negative to sensory stimuli (Boyd et al. 2010; Oswald 2013; Patten et al. 2013)
	May avoid stimulation (Oswald 2013; Patten et al. 2013)
Hyper-reactivity	Experiences intense reactions to certain sensory inputs or have increased focus on weak stimuli (Elwin et al. 2013; Oswald 2013)
	May have negative reactions to touch or experience stress from sounds (Elwin et al. 2013; Oswald 2013)
Sensory over-sensitivity/responsivity	Exhibits an automatic and exaggerated response to sensory input (Miller et al. 2007; Oswald 2013; Zachor and Ben-Itzchak 2014)
	Response may be increased in duration, intensity, or reaction time (Ben-Sasson et al. 2013; Miller et al. 2007; Oswald 2013)
	May avoid certain sensory stimuli or exhibit negative emotional responses, withdrawal, moodiness, or aggressiveness (Ben-Sasson et al. 2013; Miller et al. 2007; Oswald 2013; Reynolds and Lane 2008)
Sensory hypersensitivity	Demonstrates increased reaction in response to sensory stimuli such as with input that other people may ignore (Oswald 2013; Panagopoulos et al. 2013)
	Over-reactivity to weakened stimuli (Oswald 2013; Panagopoulos et al. 2013)
	Sensory stimuli may be overly intense such as lights that are overwhelmingly bright (Oswald 2013; Robertson and Simmons 2013)
Enhanced perception	Increased awareness to specific sensory input, especially with certain perceptions like identifying the perfect pitch (Ausderau et al. 2014a; Oswald 2013)
Hypersensitive hearing, oversensitivity to sound, hyperacusis	A subjective increased sensitivity to sounds with normal sounds being perceived as intolerably loud (Lucker 2013; Oswald 2013)
Terms used to describe unusual sensory behaviors	
Sensation avoiding	Characterized by low sensory thresholds and an active self-regulation strategy, often avoiding or withdrawing from activities (Dunn 1997)

Table 1 continued

	Description
Sensation seeking	Characterized by high sensory thresholds and an active self-regulation strategy (Boyd et al. 2010; Dunn 1997)
	Actively engages in activities to acquire sensory stimulation and craves an increased amount of input or a certain kind of stimuli (Boyd et al. 2010; Miller et al. 2007; Robertson and Simmons 2013)
Sensory interests, repetitions and seeking behaviors	Craves or exhibits increased interest in intense and repetitive sensory input such as touching various textures (Ausderau et al. 2014a; Oswald 2013)
Terms for sensory perception	
	The ability to perceive and interpret the qualities of sensory information for use (O'Riordan and Passetti 2006)
	The interpretation of sensation (Schmidt 1985)
	Organization, identification and interpretation of sensory information to understand the environment (AOTA 2008)
Terms for sensory integration or multisensory integration	
Sensory integration	The organization of sensory information for use (Ayres 1979)
	Merging of multiple sources of sensory input (Iarocci and McDonald 2006)
Multisensory integration	The ability to bind sensory information across multiple modalities as a means of assimilating spatially and temporally concurrent information (Donohue et al. 2012; Russo et al. 2010)

What is the Common Terminology for Sensory Features?

One of the barriers to understanding and assessing sensory features associated with ASD relates to the variance in terminology used between and within the multiple disciplines studying this topic. Table 1 presents common terms used to describe sensory features in the clinical literature and the synonyms found in the literature for these terms. Briefly, *hyper-reactivity* as used in the DSM5, is similar to the terms hyper-responsivity, sensory sensitivity, over-responsive, over-reactivity, or low threshold; and *hypo-reactivity* is synonymous with under-responsiveness, under-reactivity, poor registration, or high threshold. The phrase "unusual interest in sensory aspects of the environment" used in the DSM5 is akin to terms such as sensory seeking, sensory craving, sensory interests and repetitions, or sensory preoccupation. Additional sensory features have been identified in the ASD literature but are not named in the DSM5. These include: difficulties with *sensory perception* (Smith Roley et al., in press; Donnellan et al. 2013); and *sensory integration* (Iarocci and McDonald 2006; Stevenson et al. 2014; Donohue et al. 2012). Thus, in this paper we use the DSM5 terminology of hyper-reactivity, hypo-reactivity, and unusual sensory interests; and also include sensory perception, and sensory integration to describe sensory features because these appear in the literature. We intentionally do not use the term "sensory processing" because this term has been used to describe both sensory reactivity and sensory perception and thus adds confusion for interpretation and analysis of the existing literature.

What are the Common Sensory Features in ASD?

Based on the terminology literature above, we broadly classified the studies examining sensory features in ASD into the following categories: (1) sensory reactivity (hyper- or hypo-reactivity) and unusual sensory interests; (2) sensory perception; or (3) sensory integration.

Sensory Reactivity and Unusual Sensory Interests

This literature is mainly based on assessments that utilize proxy or self-report of behaviors although experimental paradigms using objective markers of sensory reactivity are also emerging. In regard to studies using proxy/self-report, a meta-analysis of 14 studies (Ben-Sasson et al. 2009) concluded that: (1) parents of children with ASD report more difficulties in these areas than parents of typically developing controls and other clinical groups; and (2) hypo-reactivity was the most prevalent type. These findings are supported by a number of other studies (Baranek et al. 2006, 2007; Ben-Sasson et al. 2008; Rogers and Ozonoff 2005). More recently, Ausderau et al. (2012, 2013, 2014a, b) reported data from more than 1,200 individuals with ASD aged 2–12 years using the Sensory Experience Questionnaire (Baranek et al. 2006). A confirmatory factor analysis revealed four sensory response patterns: hypo-reactivity, hyper-reactivity, sensory interests and repetitions, and enhanced perception (a newly defined sensory feature). Next, a Latent Profile Analysis was conducted to further characterize these sensory features. Four distinct profiles were found: (1) Mild (29 %)—children who presented with very few sensory features; (2) Extreme-Mixed

(17 %)—children who presented with a high frequency of all types of sensory features; (3) Sensitive-Distressed (28 %)—children who displayed a low frequency of unusual sensory interests and repetitions and hypo-reactivity, but a high frequency of hyper-reactivity and enhanced perception; and (4) Attenuated-Preoccupied (17 %)—children with a high frequency of unusual sensory interests and repetitions and hypo-reactivity but a low frequency of hyper-reactivity and enhanced perception (Ausderau et al. 2014b).

Lane et al. (2010, 2011, 2014) using cluster analysis methodology and the Short Sensory Profile (McIntosh et al. 1999b) reported findings similar to Ausderau's in children with ASD aged 2–10 years. They identified four distinct sensory subtypes characterized as: (1) Sensory Adaptive—sensory features were not clinically significant; (2) Taste/Smell Sensitive—extreme taste/smell sensitivity and moderate levels of hypo-reactivity, seeking and auditory filtering difficulty; (3) Postural Inattentive—extreme low energy weak[1] features and moderate levels of hypo-reactivity, seeking and auditory filtering difficulty; and (4) Generalized Sensory Difference—high levels of features reported in all sensory domains (Lane et al. 2014). Common to all children with ASD were features of hypo-reactivity, sensory seeking behaviors and auditory filtering difficulties. Like Ausderau et al. (2014b), sensory subtypes varied on severity, from low to high, and some children with ASD did not demonstrate any difficulties with sensory reactivity (characterized as "sensory adaptive").

Studies that used objective markers of sensory reactivity such as evoked related potentials, skin conductance, threshold testing or imaging technology, are emerging and provide some insight into the potential mechanisms of sensory hyper or hypo reactivity in ASD. For example, in the auditory domain, mechanisms of hyper-reactivity identified are failure of the normal inhibitory mechanism (Perry et al. 2007), over-activity of the sympathetic nervous system (McAlonan et al. 2002; Chang et al. 2012), and difficulty with selective attention to specific low-level features of stimuli (Jarvinen et al. 2007; Russo et al. 2010). Green (2014) showed that subjects with ASD and parent-rated hyper-reactivity in the visual and auditory systems had greater activation in the primary sensory cortices, the amygdala, hippocampus and orbital-frontal cortex in response to mildly aversive auditory and visual stimuli on fMRI suggesting a fundamental difference in brain response to these sensations in comparison to typically developing controls. Regarding somatosensory reactivity, Cascio et al. (2012) work suggest that adults with ASD showed diminished cortical responses (measured by changes in brain blood oxygenation level-dependent signal—BOLD) to pleasant and neutral textured stimuli, but exaggerated responses to unpleasant stimuli in comparison to a control group. For a full review of the experimental literature on sensory reactivity, the reader is referred to Marco et al. (2011). Of note, many of the participants in these studies presented with more than one type of sensory reactivity (e.g., hypo and hyper-reactivity) and more than one sensory modality was affected (e.g., tactile and auditory).

In summary, descriptions of sensory reactivity and unusual sensory interests based on proxy report of observed behaviors and objective markers consistently report that children with ASD experience greater difficulties in these areas than their typically developing or non-ASD developmentally delayed peers. Although hypo-reactivity is the most consistent feature reported in children with ASD, there is no single characteristic type that is consistently associated with ASD. Of note, initial findings suggest that modalities such as audition, pain, taste–smell, proprioception, and movement may discriminate individuals with ASD from other clinical groups (Klintwall et al. 2011; Lane et al. 2010, 2011; Rogers and Ozonoff 2005); however, more data is needed to support these findings. Further, recent data suggests that some children with ASD (between 25 and 40 %) do not experience any clinically significant differences in sensory reactivity while others are reported as having extreme difficulties in this area (Ausderau et al. 2014a, b; Lane et al. 2014).

Sensory Perception

Studies that measure sensory perception in ASD examine the ability to recognize and interpret sensory stimuli. These include examination of event-related potentials or cortical processing during sensory stimulation and, thus, provide guidance for understanding the mechanisms associated with recognition and interpretation of sensation as well as differences in ASD and other populations. The majority of studies investigate auditory, visual and tactile perception, but there is also emerging data on proprioceptive perception in ASD. We summarize the literature here and direct the reader to the primary sources for more in-depth information.

Auditory Perception

Neurophysiological studies of auditory perception consistently show that individuals with ASD have difficulties with sustained auditory attention (Magnee et al. 2011), orientation to auditory stimuli (Čeponiene et al. 2003), delay in higher order cortical auditory processing (Novick et al. 1980; Boddaert et al. 2004; Kwon et al. 2007),

[1] Low Energy Weak is suggestive of postural (proprioceptive) difficulties.

dysfunction at preconscious stages of cortical auditory discrimination (Tecchio et al. 2003), and/or decreased detection and processing (Courchesne et al. 1984; Jansson-Verkasalo et al. 2003). One of the most frequently examined areas of auditory perception in ASD relates to novelty detection or mismatched negativity (MMN; Jeste and Nelson 2009). In these studies, investigators use event-related potentials or MEG to examine the ability of individuals with ASD to discriminate a novel auditory stimulus in a stream of familiar auditory stimuli. These studies have reported mixed findings but in general, found that individuals with ASD display attenuated responses to novel speech sounds but enhanced responses to non-speech sounds (Kuhl et al. 2005; Lepistö et al. 2005). Of note, studies have been limited to older, higher-functioning individuals with ASD and variations in the findings have been observed in relation to verbal ability (Kuhl et al. 2005). In a recent study by Ludlow et al. (2014), variance in MMN amplitude was observed as a function of auditory sensitivity as measured by the Adult/Adolescent Sensory Profile and thus, additional research is required to elucidate the relationship between sensory reactivity and sensory perception impairments. Thus, while there is consensus regarding the presence of auditory perception difficulties in ASD, there is a lack of clarity regarding the mechanisms underlying these difficulties. Further, it is uncertain whether auditory perception is impaired independently, or in relation to attention (e.g., inability to adequately attend to auditory sensations), or to a core deficit in multisensory integration (e.g., difficulty processing auditory sensations when presented simultaneously with other sensations such as visual). Additional studies that factor out these specific aspects of auditory perception in ASD are needed using innovative protocols that manipulate attention and stimuli salience to inform a clinical assessment protocol.

Visual Perception

Much of the literature relating to the visual system in ASD has focused on visual attention and eye gaze and less on perceptual elements such as acuity and contrast detection. There is now robust evidence suggesting that individuals with ASD show differences in visual tracking, visual attention and eye gaze when compared to their typically developing peers and those with non-ASD developmental disabilities (Behrmann et al. 2006). These differences are particularly pronounced in social situations such as face processing and are hypothesized to be one possible mechanism of social impairment in ASD (McPartland et al. 2011). Further, differences in eye gaze patterns have been shown as a promising early marker of ASD risk in infants and toddlers (Deconinck et al. 2013). In particular, young children with higher risk for ASD show difficulties disengaging visual attention and fixate their eye gaze on one region of the face rather than scanning the whole face (Alie et al. 2011; Elsabbagh et al. 2013; Shic et al. 2008). Additionally, while static visual perception (e.g., embedded figure tasks) and tasks that require attention to details are found to be enhanced in ASD (Shah and Frith 1983; O'Riordan et al. 2001; Plaisted et al. 1998), there are deficits in visual perception of biological motion, particularly in tasks that convey emotion (Blake et al. 2003; Hubert et al. 2006) suggesting their difficulties lie in attending to emotional states. With regard to visual acuity, Ashwin et al. (2009) showed that individuals with ASD had better visual acuity than controls ($n = 30$; ages 19–64 years) but this finding is controversial due to methodological issues. The reader is referred to Simmons et al. (2009) for a comprehensive review of vision in ASD.

Somatosensory Perception

Data on somatosensory processing in ASD includes studies of responses to tactile and vibratory stimulation using electrophysiological markers of sensitivity, perception, and discrimination. In regard to sensitivity, there is some evidence that individuals with ASD are more perceptive of vibratory stimulation (Cascio et al. 2008; Blakemore et al. 2006); but similar to typical controls on measures of tactile sensitivity. Further, Cascio et al. (2008) found no differences in tactile perception in high functioning adults with ASD (ages 25–40) in comparison to controls using nylon filaments that delivered forces from .005 to 448 g. Cortical responses to tactile stimuli, however, have been found to distinguish ASD from control or other clinical populations. For example, Marco et al. (2012) reported that male subjects with ASD (ages 7–11) had smaller cortical response amplitude in the left somatosensory cortex as measured by magneto encephalography (MEG) to slow and deviant tactile stimuli delivered to the right hand during an oddball paradigm. In a clinical study, Smith Roley et al., (in press) showed that children with ASD, aged 4–11 years, showed significant difficulties with somatosensory perception in comparison to normed scores on the Sensory Integration and Praxis Tests (Ayres 1989). They found a relationship between somatosensory perception and social participation and other activities of daily living tasks.

In terms of tactile discrimination (observation of response rates to various textures), O'Riordan and Passetti (2006) found no difference in tactile discrimination between 12 high functioning children with autism and 12 typically developing controls (mean age = 8 years, 7 months). Tannan et al. (2008) found that adults with ASD had significantly poorer ability to discriminate amplitudes of simultaneous tactile stimuli on the dorsum of the hand after adaptation in comparison to controls ($p < .01$). They suggest that this finding provides further support that individuals with ASD have an inhibitory deficit in that they are unable to sufficiently inhibit un-necessary or irrelevant stimuli.

In summary, the literature on somatosensory perception suggests that individuals with ASD are similar to typical controls in terms of response thresholds to tactile stimulation and texture discrimination. However, there is emerging evidence to suggest that processing of tactile information may be diminished at the cortical level (Marco et al. 2012). These data underscore the importance of evaluating somatosensory perception together with reactivity, and behavioral responses to tactile sensations within the context of usual, everyday activities.

Proprioception

Proprioception is the sense of body position and movement (Sherrington 1906) and, as such, contributes to the ability to use the body effectively to act and interact with the environment (Blanche and Schaaf 2001). Early studies of proprioceptive in ASD (Weimer et al. 2001; Molloy et al. 2003) suggested that the motor "clumsiness" in individuals with ASD was related to poor proprioceptive perception and over-reliance on visual information. However, more recent evidence suggests the contrary. Haswell et al. (2009) and Izawa et al. (2012) showed that individuals with ASD have a greater reliance on proprioception to perform skilled motor learning tasks. The researchers suggest that individuals with ASD form stronger than normal representation of internal models of action between self-generated motor commands and proprioception (Izawa et al. 2012). Fuentes et al. (2011) also showed that individuals with ASD have adequate use of proprioceptive cues for motor learning tasks despite their self-report of proprioceptive related difficulties on the Adult Sensory Profile (Brown and Dunn 2002). They suggest that differences in cortical organization and integration of proprioceptive information may account for the difficulties with body awareness reported in the ASD literature. It may be that individuals with ASD rely more on "proximal" or near senses such as proprioception, than distal senses such as vision to direct movements and actions (Fuentes et al. 2011).

The more recent literature on proprioception suggests that individuals with ASD have enhanced proprioceptive perception and that they favor proprioception over visual sensations for motor learning; however, the application of this literature to functional performance is just beginning to emerge. In terms of proprioceptive perception and function, Smith Roley et al., (in press) found that dyspraxia may be related to poor proprioceptive perception in functional motor tasks. Thus, it will be important to include measurement of proprioception as part of a comprehensive clinical assessment of sensory processing in ASD using observational assessment, and to interpret behaviors that may be related to proprioception during skilled motor learning tasks and everyday tasks such as sitting posture, balance responses, and use of body during play (Blanche et al. 2012).

Sensory Integration

Several authors have shown that individuals with ASD have difficulty with sensory integration (also referred to as MSI in the experimental literature) or managing multiple stimuli simultaneously (Ayres 1979; Ayres and Tickle 1980; see Iarocci and McDonald 2006 for review). Donohue et al. (2012) report that adults with autism show abnormal temporal binding of multisensory stimuli and thus demonstrate MSI difficulties. In this study, a simultaneity judgment task was used where an auditory beep and a visual pattern are presented over a broad range of stimulus onset asynchronies. This task evaluated whether multisensory stimuli would be bound together when they are presented in close temporal proximity. Typically, simultaneously perceived stimuli are bound together when they are presented within 150 ms of each other (i.e., temporal window of integration), and when the visual stimulus comes slightly before the auditory stimulus. They found that individuals with ASD had a broader temporal window of integration, suggesting abnormal binding of multisensory stimuli. This finding is consistent with Foss-Feig et al. (2010) and Kwakye et al. (2011). Further, Donohue et al. (2012) found that as autism symptoms increased (measured by the Autism Spectrum Quotient questionnaire; Baron-Cohen et al. 2001), the bias for auditory-first presentations was greater. The finding of auditory preference over visual during multisensory processing in ASD is similar to that of Williams et al. (2004), who found that subjects with ASD had greater dependence on auditory over visual during the McGurk task where concordant and discordant auditory and visual speech sounds are presented.

In terms of integration of multisensory stimuli, Russo et al. (2010) and Brandwein et al. (2013) measured event-related potentials during the combination of auditory and tactile stimuli and found that the typical neural enhancement (larger response with concordant stimuli) present during multisensory stimuli presentation was absent in children with ASD. Similarly, Courchesne et al. (1984) found a reduction in response amplitude in subjects with ASD when concurrent auditory and visual stimuli were presented. In terms of the proposed mechanisms of action, Oberman and Ramachandran (2008) suggest that it may be the inability of the mirror neuron system to utilize information for imitation, action, and higher level cognitive functions that impacts multisensory integration; whereas

Stein and Stanford (2008) suggest that a general impairment in connectivity impacts the brain's ability to rapidly exchange and process information. Similarly, Chang et al. 2014; Marco et al. (2011, 2012) showed that individuals with ASD with sensory impairments show decreased connectivity in areas related to sensory perception and tracts thought to sub serve social-emotional processing. Although they did not study multisensory integration directly, their findings suggest that multisensory integrative skills needed for higher level functioning are impaired in children with ASD and may be related cortical connectivity and impaired white matter microstructure.

Thus, there is evidence suggesting that sensory integration/MSI is both different and inefficient in ASD when compared to typical controls. Further, impairment in MSI impacts the magnitude, latency, and timing of response to sensory stimuli. Clearly, sensory integration/MSI is crucial for many simple and complex activities ranging from focusing on the salient aspects of stimuli for attention to the integration of auditory and visual stimuli for speech comprehension. Hence, it is likely that these differences affect behavior and learning in individuals with ASD and thus, is an important area for assessment.

In total, the literature on common sensory features in ASD shows that individuals with ASD experience a range of sensory features that may limit functional performance. Reports from both clinical and experimental literature are suggestive of core sensory deficits in reactivity, perception and integration across many of the sensory systems. The interaction of these features with specific functional and behavioral profiles is yet to be elucidated and should be the focus of future research.

Do Sensory Features Change with Age?

A key component of the DSM5 criteria for diagnosis of ASD is the presence of symptoms (including sensory features) in early childhood even before the full clinical manifestation of ASD has emerged. Thus, it is pertinent to consider the literature that examines early sensory features associated with ASD and their developmental course to inform a model of best practice assessment.

Studies investigating early sensory features associated with ASD use both retrospective and prospective methodologies. Reports based on retrospective home video analysis suggest that some sensory features are associated with a later diagnosis of autism, for example, lack of response to name and poor visual attention and orientation (Baranek 1999a), excessive mouthing, and social touch aversions (Goldsmith et al. 2006; Brock et al. 2012). In addition, hypo-reactivity was associated with slowness to adapt; sensory defensiveness was associated with fearfulness and anxiety; and increased frequency of sensory features was associated with a more negative mood and withdrawal behaviors.

Regarding the developmental trajectory of sensory features, there is some evidence in the literature that sensory features change and may lessen throughout the course of development in individuals with ASD. In a meta-analytic study, Ben-Sasson et al. (2009) reported that sensory hyper-reactivity and seeking increased from 0 to 6 years; peaked between the ages of 6–9 years; and then decreased after 9 years of age. Kern et al. (2007) reported differences on performance during sensory tasks between younger children with and without ASD but these differences lessened with age and adults with ASD performed more similarly to same-aged typical controls.

While a need for further research remains, studies examining early development in infants at-risk for autism suggest that sensory features may be one factor that discriminates ASD in early development (Baranek 1999b; Garon et al. 2009; Lane and Heathcock 2014). Continued research in this area is required to identify which of these markers are most salient and promising for ASD detection. Given that sensory features change across periods of development when autism diagnosis is likely (2–5 years of age), clinical assessment protocols will need to be sensitive to these age-related differences and provide strategies to capture autism-specific deviations.

Do sensory Features Relate to the Core Symptoms of ASD?

Although atypical sensory features are thought to impact a variety of behaviors including anxiety (Reynolds and Lane 2009), activity level (Hochhauser and Engel-Yeger 2010), daily living skills (Jasmin et al. 2009), arousal regulation and sleep (Goldman et al. 2009), in keeping with our central aims, only the data on sensory features and the core symptoms of ASD will be presented in this paper.

Sensory Features and Restricted and Repetitive Behaviors (RRBs)

A number of researchers show a relationship between RRBs and sensory reactivity. Boyd et al. (2010), using a combination of observational and parent report measures of sensory reactivity, found that greater hyper-reactivity to sensation was related to greater RRBs (stereotypies, compulsions, and rituals/sameness behaviors) in both ASD and developmentally delayed subjects. In an earlier study of individuals with high functioning autism, Boyd et al. (2009) also found that particular types of repetitive behavior (i.e., stereotypies and compulsions) were related to sensory reactivity in autism. Similarly, Gabriels et al. (2008) reported a relationship between high rates of RRBs and abnormal sensory responses in a subgroup of 70 school-aged children with ASD; and Duerden et al. (2012), using hierarchical regression analysis, found that abnormal sensory reactivity was a significant predictor of self-injurious behavior, explaining 12 % of the variance in their sample of 250 children and adolescents with ASD (mean age = 88 months). While multiple studies have reported associations between sensory reactivity and RRBs, none have demonstrated a cause and effect relationship. Elucidation of the specific impact of sensory features on RRBs is required to guide clinical assessment protocols and to better understand the mechanism by which sensory features affect RRBs in autism.

Sensory Features and Social Communication

Difficulties with sensory reactivity have also been linked to impairments in social communication skills in children with ASD. A number of studies report moderate to strong associations between sensory features and various dimensions of social engagement (Hilton et al. 2007, 2010; Baker et al. 2008; Ashburner et al. 2008; Lane et al. 2010; Reynolds et al. 2011; Watson et al. 2011; Hochhauser and Engel-Yeger 2010). For example, Hilton et al. (2007, 2010) reported statistically significant correlations ($r = -.5$ to .8) between measures of sensory hyper-reactivity and social cognition, social communication and social motivation in school-age children with high functioning autism. Further, scores on multi-sensory integration, oral, olfactory and touch processing were the strongest predictors of social impairment. Similarly, Ashburner et al. (2008) and Lane et al. (2010) found a relationship between poor auditory filtering and excessive sensory seeking and social adaptive problems particularly in school settings. Reynolds et al. (2011) reported that children (either with or without autism) demonstrating behaviors associated with hyper-reactivity were less competent in the performance of social activities than their peers without these sensory features; and Hochhauser and Engel-Yeger (2010) found that children with greater levels of sensory sensitivity demonstrated lower quality activity participation in relation to social engagement. Smith Roley et al., (in press) found that low scores on tests of tactile and vestibular perception were significantly related to poor scores on social participation subtest.

In the most rigorous study to date, Watson et al. (2011) examined the differential relationship between sensory features and social-communicative and language competence in children with autism and developmental disability. Hypo-reactivity was positively related to the severity of social-communication difficulties in both autism and developmental disability and negatively associated with language and social-adaptive skills. Sensory seeking was positively related to social-communication difficulties in autism and negatively associated with language skills in both groups. These findings suggest that the relationship of sensory seeking and hypo-reactivity to social-communication may extend across diagnoses. However, contrary to previous studies, hyper-reactivity was not related to any of the social-communication or language dimensions. These differences in relation to hyper-reactivity and social-communication may be related to the approach used for measurement of sensory features as Watson et al. (2011) derived a composite score for each sensory type (hyper-, hypo-reactivity and unusual sensory behaviors/sensory seeking) based on parent report and direct observation measures, whereas other studies used parent report alone.

In summary, a number of studies explored the relationship between social, language and communication competence, RRB's, and sensory features in ASD. Although cause and effect has not been established, it appears that performance in these areas is related; in particular that hypo-reactivity and unusual sensory interests are related to poor social communication. Thus, assessment of sensory features may provide insight into the type and nature of social communicative difficulties in individuals with ASD.

What Are the Common Clinical Assessments Currently Utilized to Evaluate Sensory Features in ASD?

There are a number of clinical tools available to assess sensory features in ASD and these are listed in Table 2. Here we focus on assessments that are solely devoted to assessment of sensory features and again group them by measures of sensory reactivity and unusual sensory interests, measures of sensory perception, and measures of multisensory integration. Although tools such as the Autism Diagnostic Observation Scale (Lord et al. 2000) and the Childhood Autism Rating Scale (Schopler and Van Bourgondien 2010) contain specific items that gather information about sensory features, they are not included here as their focus is not exclusively on sensory features. Similarly, assessments that evaluate only one sensory area such as the Test of Visual Motor Integration (Beery et al. 2010) are not included as we limit our discussion to comprehensive measures of sensory features.

Clinical Assessments of Sensory Reactivity and Unusual Sensory Interests

Most of the published measures of sensory reactivity and unusual sensory interests utilize self or proxy report to assess behavioral responses to sensation during daily activities.

Table 2 Current clinical measures of sensory features in ASD

Assessment	Description	Administration	Age range	ASD norm data?	Focus
Sensory Profile (SP) and Short Sensory Profile (SSP) (Brown and Dunn 2002; Dunn 2002; Dunn and Daniels 2002; Ermer and Dunn 1998; McIntosh et al. 1999a, b; Tomchek and Dunn 2007) Infant/toddler SP (Dunn 2002)	The SP is a 125-item self-administered questionnaire that measures response to sensory events that impact functioning in everyday life. The SP is comprised of multiple versions including a 38-item screening tool (SSP), a 125-item Adolescent/adult SP and a 36- or 48-item Infant/Toddler SP, which allows for the input of caregiver observation, as well as outside evaluations or reports The SP coincides with Dunn's Model of Sensory Processing in that it yields four quadrant scores that help identify which sensory systems may be impacting daily functioning. The four categories include (1) sensory seeking, (2) sensation avoiding, (3) sensory sensitivity, and (4) low registration	Parent/Proxy Report or Self-Report (adult/adolescent) Takes approximately 15–25 min to complete	Sensory Profile and Short Sensory Profile (SSP): 3–14:11 years Adult/ adolescent SP: 11–65+ Infant/toddler SP: Birth—6 months and 7–36 months)	Yes	Sensory reactivity
Sensory Processing Measure (SPM) (Miller-Kuhaneck et al. 2007; Parham et al. 2007)	The SPM is a self-administered parent/proxy questionnaire that assesses behaviors, using a Likert-type scale, as they relate to sensory processing across multiple environments. The SPM uses three separate rating forms including (1) Home, (2) Classroom and (3) School Environments, to assess behaviors related to visual, auditory, tactile, olfactory-gustatory, proprioception and vestibular sensations	Parent/Proxy Report Takes approximately 15–20 min to complete	5–12 years (Grades K-6)	No	Sensory reactivity
Sensory Experiences Questionaire 3.0 (SEQ 3.0) (Ausderau et al. 2014a, b; Baranek et al. 2006; Little et al. 2011, 2014)	The SEQ 3.0 is a 105-item caregiver questionnaire that uses both a Likert-type scale and qualitative data, to measure the frequency and behaviors related to sensory features in children with autism and/or developmental disabilities. These sensory features are addressed across multiple contexts and are characterized into one of four response patterns: hyporesponsiveness, hyperresponsiveness, sensory interests, repetitions, and seeking behaviors, and enhanced perception The SEQ 3.0 is only more recently developed and is not yet available for distribution. The original SEQ is a 43-item caregiver report questionnaire that measures frequencies of the child's unusual sensory reactions across sensory modalities, contexts and response patterns (i.e., hypo/hyperresponsiveness, and sensory seeking)	Parent/proxy report SEquation 3.0—length of time not reported SEQ—15–20 min to complete	SEquation 3.0: 2–12 years SEQ: 6–72 months (6 years)	Yes	Sensory reactivity
The Sensory Processing Scales Sensory Over-Responsivity Scales (SensOR) (Schoen et al. 2008; Schoen 2011)	The Sensory Processing (SP) Scale is a self-report assessment designed to evaluate each individual sensory domain separately in adults and children. The Sensory Overresponsivity Scale (SensOR), is a subscale of the SP that specifically measures over-responsivity in multiple sensory domains. Additionally, the SensOR is correlated with the examiner-administered, observation-based SensOR Assessment, which is frequently used in conjunction with the SensOR scale. These scales are linked to the proposed classifications of sensory overresponsivity, sensory underresponsivity and sensory seeking and were developed to identify subtypes of sensory processing disorder	Parent/proxy report (Sensory Processing Scales) Direct report (SensOR Assessment)		No	Sensory reactivity

Table 2 continued

Assessment	Description	Administration	Age range	ASD norm data?	Focus
The Test of Sensory Functions in Infants (TSFI) (DeGangi and Greenspan 1989a, b)	The TSFI is a criterion-referenced rating scale used to measure sensory processing and reactivity in infants through a series of examiner-administered tests. Reactions to stimuli, involving deep pressure, adaptive motor functions, visual-tactile integration, ocular-motor control and vestibular stimulation, are observed and rated from 0 (adverse) to normal (1–3)	Direct report: criterion-based observational tool Takes approximately 20 min to complete	4–18 months	No	Sensory reactivity Sensory integration
Sensory Integration and Praxis Tests (SIPT) (Ayres 1989)	The SIPT measures a child's ability to integrate sensory input for perception, coordination, motor planning, and visual-spatial actions through a series of 17 performance-based standardized tests which include: 1. Space visualization 2. Figure ground perception 3. Standing/walking balance 4. Design copying 5. Postural praxis 6. Bilateral motor coordination 7. Praxis on verbal command 8. Constructional praxis 9. Postrotary nystagmus 10. Motor accuracy 11. Sequencing praxis 12. Oral praxis 13. Manual form perception 14. Kinesthesia 15. Finger identification 16. Graphesthesia 17. Localization of tactile stimuli	Direct report performance-based standardized tests Takes approximately 2 h to complete Computer scoring can be utilized and any combination of the 17 tests can be scored	4–8:11 years	No	Sensory perception Sensory integration

These include: (1) the Sensory Profile (Dunn 1999) and its various permutations such as The Infant Toddler Sensory Profile (Dunn 2002), The Short Sensory Profile (McIntosh et al. 1999b) and The Adolescent and Adult Sensory Profile (Brown and Dunn 2002), and (2) the Sensory Processing Measure (SPM; Parham et al. 2007) including the SPM Home and School forms and the SPM—Preschool (Miller-Kuhaneck et al. 2010). Collectively, these questionnaires consider similar behaviors to assess sensory reactivity although the SPM includes sections on praxis and social participation; and the SP provides analysis of threshold (high or low) and emotional social responses. In a small study comparing the two instruments in children with ASD ages 4–7 years, found poor to fair agreement between the tools and thus recommend selection of the tool based upon the specific needs of their cohort.

Assessments of sensory reactivity under development include The Sensory Experience Questionnaire (Baranek et al. 2006), the Sensory Processing Assessment (SPA; Baranek 1999b), and the Sensory Processing Scales (SP Scales; Schoen et al. 2008). These tools vary in the choice of respondents; environments assessed; availability to clinicians; and the availability of ASD-specific normative data as described in Table 2. The SPA and the SP Scales are observational assessments of sensory reactivity instruments that have been utilized in research and have not yet been published for general use, however, they hold promise for providing objective data about sensory reactivity to supplement questionnaires in the future.

Clinical Assessments of Sensory Perception and Integration

The most established broad-based clinical assessment of sensory perception and integration is the Sensory Integration and Praxis Test (SIPT—Ayres 1989). The SIPT is standardized on children ages 4.0–8.11 and yields a standardized Z score for each subtest as well as a graphic representation of the child's patterns of scores in relation to others in the normative sample. Although more data is needed, the SIPT holds promise for use as part of a clinical assessment protocol for sensory perception and multisensory integration in ASD. Schaaf et al. (2013) and Smith Roley et al., (in press) utilized the SIPT with subjects with ASD demonstrating its feasibility and utility for this population. Of note, the SIPT also assesses sensory integration via subtests that evaluate visual motor integration, tactile-motor integration, and vestibular-postural integration. The Test of Sensory Functions in Infants (DeGangi and Greenspan 1989b), which assesses tactile, vestibular, visual and proprioceptive perception and integration in children ages 0–18 months, is also currently available but has not been utilized for children with ASD.

Conclusions

This paper provides an overview of our current understanding of sensory features in ASD and makes specific recommendations for clinical assessment. Several key points can be drawn from the literature presented:

- Sensory features in ASD are pervasive and critical to understanding the behavioral and functional profile of individuals with this disorder.
- Evaluation of sensory features in individuals with ASD is an important part of the characterization process and is also important for guiding treatment protocols.
- No single sensory feature is consistently present in ASD and thus, no single clinical instrument that comprehensively the range of sensory features in ASD is currently available.
- There is a range of sensory features in ASD that may be broadly classified as difficulties in sensory reactivity, sensory perception and multisensory integration.
- Sensory features are likely to contribute to specific behavioral and functional profiles in ASD.
- Sensory features may be apparent in early childhood prior to autism diagnosis and therefore, assessment of these features may enhance the sensitivity and specificity of autism screening tools.
- There is a paucity of research that directly relates sensory features to the core clinical symptoms of ASD but researchers hypothesize that they may be related to the RRB's and social communication deficits observed clinically in ASD.
- There is emerging evidence of distinct multisensory integration impairments in ASD that impact the ability to attend to salient stimuli in the environment and adapt responses to suit changes in the environment.
- A range of clinical assessment tools have been or are being developed to assess sensory features in populations such as ASD but there is no single clinical instrument that assesses all aspects of sensory features.
- Current clinical assessment strategies are limited by an over-reliance on parent/proxy-report methodologies that assess sensory reactivity and unusual sensory interests but do not assess sensory perception or sensory integration.

On the basis of these findings, the following recommendations are made for comprehensive assessment of sensory features in ASD:

1. A dual approach
   A dual approach to the clinical assessment of sensory features and their impact on behavior over time in various contexts is needed. It is recommended that this include *both* parent/proxy report of sensory features in

context *and* direct, observational measurement. This dual approach will allow for precise characterization of the sensory features in conjunction with measurement of their impact on daily function.

2. A comprehensive approach
Clinical assessment of sensory features in ASD must adopt a comprehensive approach that includes assessment of sensory reactivity, sensory perception, and sensory integration. Further, data should include information about: (a) the *frequency* of occurrence of sensory features (high to low occurrence), (b) the *type* of sensory features displayed (i.e., hyper-reactivity, hypo-reactivity, poor perception, discrimination and multisensory integration, and unusual sensory interests), and (c) the *specific sensory modalities* affected (i.e., tactile, auditory, etc.).
3. A developmentally sensitive approach
The literature shows that sensory features emerge early and change over time. Thus, clinical assessment protocols should be sensitive to age and developmental trends. Further, sensory features should be re-evaluated at regular intervals after diagnosis to detect changing sensory profiles in association with intervention and development.
4. An inter-professional approach
Given the multi-dimensional nature of sensory features in ASD, it will be useful for an inter-professional team with expertise in ASD, sensory features and their impact on function be utilized for both diagnostic purposes and treatment planning. For treatment planning, this might include professionals from multiple disciplines including psychology, education and occupational therapy. In particular, occupational therapists have a rich history of expertise in sensory features and their impact on daily living skills, play, socialization and other everyday behaviors.

Future Directions

This paper provides an overview of our current understanding of sensory features in ASD and makes specific recommendations for clinical assessment. Several gaps in our knowledge are identified and areas requiring further research are highlighted. Clearly, recommendations for clinical assessment of sensory features in ASD are urgently needed as sensory features inform diagnosis of individuals with ASD and align with the DSM5 diagnostic criteria. Comprehensive assessment data can also be useful to guide the implementation and testing of tailored interventions designed to address sensory features and improve function, behavior, and quality of life for individuals with ASD and their families. Additional research is required to achieve this aim and it is particularly important to incorporate techniques from experimental paradigms assessing sensory functioning into direct assessment protocols to enhance the precision of in identifying salient sensory features. This will require the translation of experimental paradigms into clinic-ready protocols. Also, performance on measures of sensory features should be linked to their impact on autism behaviors, such as RRBs and social communication, as well as other behaviors such as anxiety, sleep, daily living skills, motor learning, and ultimately, participation in life situations. It will be important to conduct research that investigates the relationship of sensory features to these behaviors to guide the interpretation of assessment data, plan targeted therapy, and predict likely outcomes.

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