Somatosensory Discrimination in People With Autism Spectrum Disorder: A Scoping Review

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Importance: Sensory symptoms in people with autism spectrum disorder (ASD) are commonly reported by researchers. However, an often overlooked sensory aspect of ASD is sensory discrimination in general, and somatosensory discrimination in particular.

Objective: To examine what has and what has not yet been learned concerning the somatosensory discrimination abilities of people with ASD and to reveal gaps warranting further research.

Design: Scoping review of clinical studies published 1995–2017 located through searches of PsycNET, PubMed, ERIC, and Google Scholar. Inclusion criteria were English-language peer-reviewed studies with (1) participants diagnosed with ASD, (2) a specific somatosensory discrimination measure, and (3) a comparison group. No age or intellectual exclusion criteria were established; studies were excluded if they were theoretical or descriptive, did not incorporate a control group, focused only on neurology or genetics, or used simple threshold detection measures or somatosensory measures integrated with other measures. The final search yielded 12 comparative articles discussing tactile and proprioceptive discrimination in people with ASD.

Results: Overall, most results showed atypical somatosensory discrimination in people with ASD, especially among young children. The relationship between sensory discrimination abilities and other sensory symptoms and ASD symptoms is briefly discussed.

Conclusions and Relevance: Heterogeneous findings concerning somatosensory discrimination in people with ASD shed light on underlying mechanisms of these disorders and can contribute to improvement of occupational therapy intervention for this population.

What This Article Adds: The occupational therapy evaluation of people with ASD can benefit from addressing somatosensory discrimination and its contribution to other clinical symptoms. This type of assessment can help improve intervention strategies for people with ASD by promoting a focus on the effect of discrimination deficits on daily function.

Autism spectrum disorder (ASD) is typically characterized by deficits in communication and social interaction, restricted and repetitive behaviors, and unusual interests that involve sensory symptoms (American Psychiatric Association, 2013). Atypical sensory symptoms, sometimes referred to as *sensory processing disorders* (SPDs), have long been associated with people with ASD, and prevalence rates reach as high as 90% (Ben-Sasson et al., 2008; Kern et al., 2008). SPDs are complex developmental disorders that affect daily life functioning. The expression and severity of sensory symptoms present differently and uniquely in each person with ASD and differ across contexts (Baranek et al., 2014; Brown & Dunn, 2010). Therefore, occupational therapy practitioners need to use a comprehensive approach in examining sensory symptoms in people with ASD.

Conceptual Model of Sensory Processing Disorders

Miller (2014; Miller et al., 2007) developed a classification system for SPDs that provides a comprehensive view of the symptoms expressed across all sensory modalities and distinguishes among three categories of SPD: sensory modulation disorder (SMD), sensory-based motor disorder (SBMD), and sensory discrimination disorder (SDD). These sensory processing disorders may coexist in people with ASD (Roley et al., 2015) as well as in other clinical populations such as people with attention deficit hyperactivity disorder (Parush et al., 2007). Most sensory research on

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people with ASD has focused on SMD, which reflects difficulties responding to sensory input in a manner appropriate to the degree, nature, or intensity of the sensory information (Baranek et al., 2013). Moreover, accumulating evidence from recent studies reflects a vast array of SBMDs among people with ASD, including dyspraxia, which involves difficulties conceiving of, planning, sequencing, or executing novel motor actions based on spatial or kinesthetic aspects (Roley et al., 2015).

The current review focuses on the third and least studied category of sensory processing disorders, sensory discrimination disorder. SDD involves difficulties in interpreting the temporal and spatial qualities of sensory stimuli and in perceiving similarities and differences between stimuli (e.g., frequency, duration, location, intensity; Baranek et al., 2014). Sensory discrimination processes occur in every sensory modality and contribute to the development of motor skills and higher order perceptual and cognitive processes (Miller, 2014). People with SDD have difficulty telling precisely what or where a stimulus is and may require extra time to process the salient aspects of sensory stimuli, often resulting in sluggish performance that affects daily functioning (Miller et al., 2007).

Somatosensory Discrimination

Most research on the sensory discrimination abilities of people with ASD has focused on neuropsychological studies of visual and auditory discrimination abilities (Baranek et al., 2013). Research concerning somatosensory discrimination remains scarce, reflecting a critical gap because the somatosensory system serves as an important foundation for many aspects of human development, including motor skills and social and communication skills (Cascio, 2011). Somatosensory discrimination relates to the discrimination capacities of the tactile and proprioceptive modalities. Receptors situated in the skin, muscles, joints, and ligaments provide somatosensory information regarding touch, pressure, vibration, temperature, texture, pain, and the location and movement of body parts (Bröring et al., 2008). This review addresses somatosensory discrimination in people with ASD, which is assessed by tasks such as two-point tactile discrimination; stereognosis (i.e., identification of objects through touch); graphesthesia (i.e., recognition of numbers or letters "written" using touch on a person's hand); discrimination among different textures, sizes, and weights of objects; discrimination of body posture; detection of movement; and kinesthesia (i.e., awareness of limb movements in the absence of vision; Bröring et al., 2008).

Somatosensory discrimination abilities are known to have a major impact on the development and performance of gross motor skills, such as walking, and fine motor skills, such as grasping (Cascio, 2011). Infants use somatosensory exploration with the mouth and hands to learn about the weight, texture, size, and form of objects in the environment (Cermak, 2006; Field, 2010). Somatosensory discrimination also plays a crucial role in the complex skill of eating, which involves the interpretation of oral sensory input (e.g., texture discrimination) and affects the motor capacity to suck and swallow (Delaney & Arvedson, 2008).

Moreover, somatosensory discrimination provides the foundation for the development of social and communication skills across the lifespan (Cascio, 2010). For example, touch during early parent–infant interactions contributes not only to growth but also to social, emotional, and communication development and to the ability to self-regulate, adapt to the environment, and establish security through attachment and bonding (Porter, 2004). Throughout the life cycle, nonverbal communication skills such as gestures and facial expressions are dependent on the somatosensory system through proprioceptive feedback from the hands and arms and from stretch receptors in facial skin and muscles (Cascio, 2010). Discrimination among different kinds of touch enables people to accurately identify emotions in others—for example, hitting and squeezing to convey anger and pushing or tapping to convey disgust (Field, 2010; Hertenstein et al., 2009). Thus, considering the crucial role played by somatosensory discrimination and its effect on daily function and social interaction, a review is warranted of the current empirical knowledge regarding the somatosensory discrimination skills of people with ASD.

Method

A scoping review of the literature was deemed appropriate for the purpose of this study to address the question of what empirically based knowledge exists regarding the somatosensory discrimination abilities of people with ASD. In addition, possible connections between somatosensory discrimination skills and other sensory and sensory–motor challenges in people with ASD were explored. This article maps out the extent and nature of peer-reviewed studies on somatosensory discrimination in people with ASD, describes the studies' content, and highlights gaps in the body of knowledge that warrant future research (Armstrong et al., 2011).

We conducted a systematic search for studies published from 1995 to July 2017 using PsycNET, PubMed, ERIC, and Google Scholar. Neta Katz Zetler conducted the initial search, then all authors compared and discussed selected studies. One of the difficulties in reviewing the literature on sensory discrimination abilities in people with ASD is the lack of consistency in terms and definitions used to describe this phenomenon. In addition, most studies on the sensory characteristics of the population with ASD used proxy reports of behavioral responses to sensory stimuli (primarily addressing sensory modulation) intertwined with more refined measures of discrimination abilities. We attempted to focus specifically on somatosensory discrimination in people with ASD. Key words used for the population included *autism spectrum disorder, autism, autistic, PDD–NOS* (i.e., pervasive developmental disorder–not otherwise specified), and *Asperger*. These were combined with terms relating to the sensory modalities: *sensory, somatosensory, tactile, touch, haptic, proprioceptive, weight, form, texture, size, object recognition, limb position and perception, discrimination, integration, reactivity, sensitivity,* and *processing*.

We included all English-language comparative peer-reviewed studies that examined the topic, regardless of the age of participants involved, as long as the studies included participants diagnosed with ASD, a specific somatosensory discrimination measure, and both a clinical (ASD) and a control or comparison group. For studies examining several somatosensory perceptual skills, each of which was tested separately, we considered only the findings related to somatosensory discrimination. No age or intellectual exclusion criteria were established because of the limited amount of research on this topic. Studies were excluded if they were theoretical or descriptive, did not incorporate a control group, focused only on neurology or genetics, or used simple threshold detection measures or somatosensory measures integrated with other measures (i.e., multisensory and visuotactile stimuli). Neta Katz Zetler initially determined article inclusion on the basis of the relevance of the title, followed by a review of the abstract and then the entire article. Reference lists of included articles were also screened for additional studies.

The search yielded 52 articles. Thirty were duplicates, resulting in 22 articles, of which 10 were omitted because they dealt with somatosensory (vibration, light touch, and thermal) thresholds, which are considered a simpler level of stimuli detection than somatosensory discrimination skills (Borstad & Nichols-Larsen, 2014). Thus, the current review includes 12 studies that focused on somatosensory discrimination and that compared the abilities of people with ASD to those of a control group.

Results

The 12 studies included in this scoping review specifically addressed the somatosensory discrimination skills of people with ASD compared with typically developing (TD) control participants; Table 1 provides summaries of the studies. Most studies included samples of high-functioning people with ASD (HFASD) who were rigorously diagnosed using a gold standard ASD assessment: Autism Diagnostic Interview (ADI; Le Couteur et al., 1989), Autism Diagnostic Interview–Revised (ADI–R; Lord et al., 1994), or Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1989). Participants ranged in age from 5 to 45 yr. One study included a second comparison group of children with SPDs.

Table 1. Studies Included in the Scoping Review on Somatosensory Discrimination in People With Autism Spectrum Disorder

Author/Year/Country	Study Purpose	Participants/Diagnosis, Inclusion, Exclusion Criteria	Sensory Discrimination Measures	Results
Abu-Dahab et al. (2013) Jordan	To examine motor and tactile–perceptual skill differences between participants with HFASD and TD participants across age differences	HFASD, *n* = 73 (ages 5–7.99 yr, *n* = 12; ages 8–11.99 yr, *n* = 23; ages 12–21 yr, *n* = 38; 91.7%–95.7% male). TD participants matched on IQ (IQ + verbal IQ ≥ 80), *n* = 75 (ages 5–7.99 yr, *n* = 12; ages 8–11.99 yr, *n* = 26; ages 12–21 yr, *n* = 37; 84.6%–91.7% male). *Diagnosis criteria:* ADI–R, ADOS, and expert clinical opinion *Exclusion criteria:* Associated neurological, genetic, or infectious disorder	▪ Luria–Nebraska tests: simple touch, sharp–dull discrimination, position sense, stereognosis ▪ Halsted–Reitan tests: finger agnosia, fingertip number writing	*Somatosensory Discrimination* Tactile–perceptual skills of the HFASD group were lower than those of the control group in stereognosis (specifically in the older age category) and finger recognition. No differences were found for simple touch, sharp–dull discrimination, or fingertip number writing, although the odds ratios for finger recognition were not clinically meaningful. *Other* Motor outcomes of grip strength, motor speed, and coordination were impaired in the HFASD group compared with the TD group, and the differences between groups varied with age.
Demopoulos et al. (2015) United States	To compare sensory processing in children with ASD, children with SPD in the absence of ASD, and TD children	HFASD, *n* = 20 (*M* age = 9.83 yr ± 1.24). Children with SPD, *n* = 15 (*M* age = 9.56 yr ± 1.20). TD children, *n* = 19 (*M* age = 9.91 yr ± 1.11). All groups, 100% male, age range = 8–12 yr. *Diagnosis criteria:* ADI–R, ADOS, Social Communication Questionnaire, and *DSM–IV* *Exclusion criteria:* Brain malformation or injury, movement disorder, bipolar disorder, psychotic disorder, hearing impairment, IQ < 70	▪ Touch test: two-point discrimination ▪ Tactile form discrimination: plastic domes with several gratings pressed against the left index fingertip in vertical or horizontal orientation ▪ SIPT: graphesthesia	*Somatosensory Discrimination* Mixed results were found; the HFASD and SPD groups were impaired relative to the TD group on right-handed graphesthesia, but they did not differ from each other. No group differences were detected on left-handed graphesthesia, two-point discrimination, or form discrimination. *Other* Only the HFASD group showed significant impairment on an auditory discrimination test. Impaired auditory processing was associated with parent-rated communication skills for both the HFASD group and the combined study sample.
Failla et al. (2017) United States	To compare the structural integrity of white matter pathways for discriminative and affective touch in young children with ASD and TD peers	Children with ASD, *n* = 23 (*M* age = 6.61 yr ± 0.89, 91.3% male). TD children matched on chronological age and gender, *n* = 24 (*M* age = 6.58 yr ± 1.13, 83.3% male). *Diagnosis criteria:* ADI–R, ADOS, and *DSM–IV*	▪ Tactile Defensiveness and Discrimination Test–Revised: active touch (e.g., digging pennies out of a box of sand), experimenter-administered passive touch	*Somatosensory Discrimination* The ASD group exhibited significantly poorer internally controlled haptic (form) discrimination relative to the TD group. *Other* No associations were found between discriminative touch (form perception) and either thalamocortical or intrainsular mean diffusivity measured by MRI. The TD group had higher IQ than the ASD group.

(*Continued*)

Table 1. Studies Included in the Scoping Review on Somatosensory Discrimination in People With Autism Spectrum Disorder (*Cont.*)

Author/Year/Country	Study Purpose	Participants/Diagnosis, Inclusion, Exclusion Criteria	Sensory Discrimination Measures	Results
Fuentes et al. (2011) United States	To examine the accuracy and precision of proprioceptive estimates between adolescents with and without ASD	Adolescents with ASD, *n* = 12 (*M* age = 14.4 yr ± 1.44). Control participants, *n* = 12 (*M* age = 13.8 yr ± 1.2). Both groups, IQ ≥ 80, 91.6% male, age range = 12–16 yr. *Diagnosis criteria:* ADI–R, ADOS, Social Responsiveness Scale, and clinical observations	▪ Kinesthesia tasks using a robotic arm for shoulder–elbow movements: active–passive elbow angle, fingertip matching task	*Somatosensory Discrimination* No group differences were found in proprioceptive accuracy or precision during active or passive tasks. *Other* Adolescents with ASD were impaired on motor tasks and self-reported sensory symptoms. A correlation was found between movement processing sensitivities and lower precision on the active elbow angle task.
Minshew et al. (1997) United States	To examine a detailed characterization of the profile of intact and deficient neuropsychological abilities in participants with ASD	HFASD, *n* = 33 (*M* age = 20.91 yr ± 9.69). Control participants matched on gender (87.9% male), socioeconomic level, IQ (IQ + verbal IQ ≥ 80), and age range (12–40 yr), *n* = 33 (*M* age = 21.21 yr ± 9.99). *Diagnosis criteria:* ADI–R, ADOS, and expert clinical opinion *Exclusion criteria:* Associated neurological, genetic, or infectious disorder	▪ Luria–Nebraska tests: simple touch, sharp–dull discrimination, position sense, and stereognosis ▪ Halsted–Reitan tests: finger agnosia and fingertip number writing	*Somatosensory Discrimination* No impairment was found in sensory perception in the HFASD group, which showed nearly error-free performance on all tests of sensory perception. Two tests passed the tolerance test—fingertip writing and the Luria–Nebraska sharp–dull tactile scale item—both involving higher cortical sensory perception. *Other* The HFASD group was impaired in the skilled motor, complex memory and language, and reasoning domains but was intact or superior in the attention, simple memory and language, and visual–spatial domains.
Minshew & Hobson (2008) United States	To examine sensory differences in participants with HFASD according to both parent- and self-report, as well as elementary and higher cortical sensory perception skills	HFASD, *n* = 60 (*M* age = 17 yr, age range 8–54 yr; 85.0% male). TD participants, *n* = 61 (*M* age = 19 yr, age range = 8–52 yr; 80.3% male). Both groups, IQ > 90, matched on socioeconomic status. *Diagnosis criteria:* ADI–R, ADOS, and expert clinical opinion *Exclusion criteria:* Associated genetic, neurological, or infectious disorder	▪ Luria–Nebraska tests: simple touch, sharp–dull discrimination, position sense, stereognosis ▪ Halsted–Reitan tests: finger agnosia, fingertip number writing	*Somatosensory Discrimination* Both groups made few errors on elementary sensory perception items. The HFASD group showed higher rates of errors on complex sensory skills than the TD group. 30% of the HFASD group made high numbers of errors. No age effect was found. *Other* 32% of the HFASD group endorsed more sensory sensitivity than the TD group on the self- and parent reports. No relationship was found between self- and parent reports and sensory perceptual processing tests in the HFASD group.

(*Continued*)

Table 1. Studies Included in the Scoping Review on Somatosensory Discrimination in People With Autism Spectrum Disorder (*Cont.*)

Author/Year/Country	Study Purpose	Participants/Diagnosis, Inclusion, Exclusion Criteria	Sensory Discrimination Measures	Results
Nakano et al. (2012) Japan	To examine whether participants with ASD have difficulty recognizing object shapes through active touch	Adults with HFASD, *n* = 14 (*M* age = 30.7 yr ± 8.2, 10 male). Adults without ASD, *n* = 20 (*M* age = 27.6 yr ± 8.9, 15 male). Both groups, IQ > 85. *Diagnosis criteria: DSM–IV,* Autism-Spectrum Quotient	▪ Haptic orientation and length task: two different-angled and different-length wooden bars ▪ Stereognosis of familiar symbols, curvilinear shapes, rectilinear shapes	*Somatosensory Discrimination* No difference was found between groups on the haptic orientation and length task and with familiar shapes, but the ASD group showed a higher accuracy rate with the more difficult object shapes. No difference between groups was found in exploration time. *Other* No difference was found in accuracy of discrimination between the right and left hand, and no effect was found for hand laterality. Visuospatial ability did not differ between groups.
O'Riordan & Passetti (2006) United Kingdom	To investigate auditory and tactile discrimination of children with and without ASD	HFASD, *n* = 12 (*M* age = 8.7 yr ± 1.7). TD children matched by IQ, *n* = 12 (*M* age = 8.7 ± 10 mo). *Diagnosis criteria:* ADI–R	▪ Four grades of wet/dry sandpaper ranging from finest to most coarse	*Somatosensory Discrimination* Both groups performed comparably overall and shared similar levels of discrimination ability across all stimulus pairs. *Other* Superior auditory discrimination was found in the HFASD group compared with the TD group.
Riquelme et al. (2016) Spain	To assess somatosensory function in the face and hands and motor function of the upper limbs in children with ASD and TD children	HFASD, *n* = 27 (*M* age = 6.3 yr ± 3.23; 74.1% male). Control participants, *n* = 30 (*M* age = 6.5 yr ± 3.37; 50.0% male). *Diagnosis criteria: DSM–IV*	▪ Stereognosis: 10 common objects, nonstandardized ▪ Proprioceptive tasks: passive joint movements while wearing a sleeping mask	*Somatosensory Discrimination* No group differences were observed for stereognosis. The HFASD group showed lower proprioception skills than the control group. No age effect on stereognosis was found in the HFASD group, whereas the control group showed an age effect. *Other* The HFASD group showed increased pain sensitivity, increased touch sensitivity in C-tactile afferents in innervated areas, and diminished fine motor performance compared with the control group.
Roley et al. (2015) United States	To characterize sensory integration and praxis patterns of children with ASD and discern whether these patterns relate to social participation	Children with ASD, *n* = 89 (*M* age = 7 yr, age range = 4–11 yr; 78% male). Control group, standardization sample of the SIPT (age range = 4–9 yr). *Diagnosis criteria:* 60% diagnosed by physician, psychologist, neurologist, or neuropsychologist; 40% diagnosed by unspecified professional *Exclusion criteria:* Seizure disorder, fragile X syndrome, cerebral palsy, mental retardation	▪ SIPT tasks: manual form perception, kinesthesia, finger identification, graphesthesia, localization of tactile stimuli	*Somatosensory Discrimination* Scores for somatosensory perception were below normal limits for the ASD group. *Other* The ASD group scored relatively well in visual praxis but was impaired in imitation praxis and vestibular bilateral integration and sequencing. A significant correlation was found between somatosensory perception and social participation at school.

(*Continued*)

Table 1. Studies Included in the Scoping Review on Somatosensory Discrimination in People With Autism Spectrum Disorder (*Cont.*)

Author/Year/Country	Study Purpose	Participants/Diagnosis, Inclusion, Exclusion Criteria	Sensory Discrimination Measures	Results
Siaperas et al. (2012) United Kingdom	To examine proprioceptive vestibular and motor functions in children with ASD and TD children, and to examine the relationship between age and sensorimotor performance	Children with ASD, *n* = 50 (*M* age = 10.72 yr ± 2.55, IQ ≥ 80). Control participants, *n* = 50 (*M* age = 10.84 ± 2.21). Both groups, age range 7–14 yr, 100% male. *Diagnosis criteria: DSM–IV, ICD–10,* and ADI–R *Exclusion criteria:* Developmental coordination disorder, intellectual disability, severe sensory disability	▪ SIPT tasks relating to somatosensory discrimination: kinesthesia, graphesthesia, localization tactile stimuli	*Somatosensory Discrimination* The ASD group scored lower than the control group on all SIPT tasks. *Other* The ASD group showed impairment in movement performance. No interaction effects of age and clinical group on level of performance deficit were found.
Williams et al. (2006) United States	To reexamine a characterization of the neuropsychological profile of children with ASD (see Minshew et al., 1997)	Children with ASD, *n* = 56 (*M* age = 11.36 yr ± 2.18, 82.1% male). Control participants, *n* = 56 (*M* age = 11.82 yr ± 2.20, 69.6% male). Both groups, IQ ≥ 80, age range = 8–15 yr. *Diagnosis criteria:* ADI–R, ADOS, and expert clinical opinion *Exclusion criteria:* Associated neurological, genetic, or infectious disorder	▪ Luria–Nebraska tests: simple touch, sharp–dull discrimination, position sense, stereognosis ▪ Halsted–Reitan tests: finger agnosia, fingertip number writing	*Somatosensory Discrimination* Sensory perceptual tasks discriminated between groups; the ASD group performed worse. The more simple discrimination tasks failed the tolerance test; the measures that passed reflected higher cortical tactile functions, such as form recognition. *Other* Group differences were found for the motor and complex language and memory domains, but lower agreement for the reasoning domain was found than previously obtained for adults. No group differences were found for the attention, simple language and memory, and visuospatial domains.

Note. ADI–R = Autism Diagnostic Interview–Revised; ADOS = Autism Diagnostic Observation Schedule; ASD = autism spectrum disorder; *DSM–IV = Diagnostic and Statistical Manual of Mental Disorders,* 4th edition; HFASD = high-functioning autism spectrum disorder; *ICD–10 = International Statistical Classification of Diseases and Related Health Problems, 10th revision; M* = mean; SIPT = Sensory Integration and Praxis Tests; SPD = sensory processing disorder; TD = typically developing.

Somatosensory Discrimination Abilities in People With Autism Spectrum Disorder

The studies revealed an intriguing profile of tactile and proprioceptive discrimination skills. Discrimination tasks included sharp–dull discrimination, two-point discrimination, position sense, kinesthesia, haptic length discrimination, finger touching, fingertip number writing, roughness discrimination, form discrimination, graphesthesia, and stereognosis. Conditions presented included both passive and active touch. The findings were generally mixed; most studies reported significant differences between the ASD and TD groups, but some did not (see Table 1). Further examination of the pattern of these findings revealed that factors such as age and level of tactile task complexity may have contributed to the mixed findings.

Age.

Two studies found that SDD is more pronounced during early childhood than in adolescence and adulthood. Williams and colleagues (2006) found a significant impairment in complex somatosensory discrimination skills (e.g., stereognosis, fingertip writing) in 56 children with HFASD aged 8–15 compared with the control group. In a similar study with adolescents and adults with ASD aged 12–40, the ASD group exhibited higher error rates on complex discrimination measures than the control group; however, these differences were not significant (Minshew et al., 1997).

In another study, an age effect was found for a finger recognition task in participants aged 5–21 in which the greatest between-group difference was found in the middle age group (aged 8–11.99; Abu-Dahab et al., 2013). In contrast, Riquelme and colleagues (2016) found no age effect on stereognosis in the ASD group compared with the control group, and both groups showed improvement with age; participants in this study had a relatively narrow age range (4–15 yr) and did not include older adolescents and adults.

Stimulus Complexity.

Some investigators discussed their findings in terms of the complexity of the stimuli provided, ranging from simple to complex. The literature is, however, somewhat inconsistent regarding which tasks are defined as simple and which are considered complex (i.e., involving higher function and more cortical integration). Borstad and Nichols-Larsen (2014) presented a hierarchical model of somatosensory measures, ranging from simple stimuli detection (somatosensory thresholds) to discrimination between stimuli, in which they ranked stimuli in a graduated manner with stereognosis being the most complex.

Several studies suggested that simple somatosensory discrimination skills may be preserved in children with ASD, whereas discrimination of more complex stimuli may be impaired. In a study involving low-level tactile discrimination between the roughness of different grades of sandpaper, intact skills were found in 12 children with HFASD (mean [*M*] age = 8.7 yr; O'Riordan & Passetti, 2006). Similarly, Fuentes and coworkers (2011) compared 12 adolescents with HFASD (*M* age = 14.4 yr) to TD adolescents matched for IQ and age on simple discrimination skill tasks involving sharp–dull discrimination, position sense, and kinesthesia. No group differences were found, and both groups showed consistent intact abilities on those tests. In another interesting study, 14 adults with ASD (*M* age = 30.7 yr) demonstrated intact tactile length and orientation discrimination abilities compared with a control group on a low-level task comparing pairs of wooden bars at different angles and of different lengths (Nakano et al., 2012). Although the findings of these studies might be limited because of their relatively small sample sizes, they consistently showed that low-level discrimination skills such as sharp–dull discrimination, position sense, and simple touch were intact in people with ASD of all ages.

Three similarly structured studies examined complex discrimination skills in a total of 189 children, adolescents, and adults with ASD (aged 8–54) and TD control participants matched by age and IQ (Abu-Dahab et al., 2013; Minshew & Hobson, 2008; Williams et al., 2006). These studies found significant differences between groups in complex discrimination skills, yet the ASD participants' skill in performing simple discrimination tasks was intact. The researchers measured somatosensory abilities using the Luria–Nebraska Tactile Scale (Golden et al., 1980) and the finger agnosia and fingertip number writing tasks from the Halstead–Reitan Neuropsychological Test Battery (Reitan & Wolfson, 1993). The Halstead–Reitan battery includes both complex (e.g., stereognosis) and simple (e.g., sharp–dull discrimination, simple touch) discrimination tasks.

In a similar study comparing 33 adolescents and adults with ASD to TD control participants, no significant between-group differences were found. However, ASD participants exhibited nearly error-free performance on all simple discrimination tasks, whereas only more complex tasks passed the tolerance test, suggesting that complex discrimination skills were more impaired (Minshew et al., 1997). Failla et al. (2017) also found significant deficits in complex form discrimination in 29 children with ASD aged 5–8 yr compared with TD children; however, simple discrimination tasks were not included in this study.

The findings of four studies differed from those of the studies described thus far. Two studies (Roley et al., 2015; Siaperas et al., 2012) compared the performance of 139 children with and without ASD on the Sensory Integration and Praxis Tests (SIPT; Ayres, 1989). Children with ASD demonstrated poorer performance than TD children in both simple and complex somatosensory discrimination tasks. In a third study, Demopoulos et al. (2015) found no differences for either simple or more complex somatosensory discrimination tasks among groups of 20 children with ASD

(aged 8–12), TD children, and children with SPDs, with the exception of one task (right-hand form discrimination), in which the ASD group performed less successfully than the TD group. The researchers suggested that a reduced cortical somatosensory response in the left somatosensory cortex in ASD, as shown by Marco and colleagues (2012), might explain this laterality effect. In a fourth study comparing children aged 4–15 with ASD to TD children, the ASD group performed more poorly in a simple upper limb kinesthesia task and better in a stereognosis task, representing a higher level of discrimination ability (Riquelme et al., 2016).

Whereas most of the literature on this topic relates to intact or impaired somatosensory discrimination in people with ASD, Nakano et al. (2012) presented a unique finding suggesting enhanced somatosensory discrimination ability in ASD. In this study, adults with ASD performed a stereognosis task with unfamiliar items (curvilinear and rectilinear test objects) with higher accuracy than the control group. The study further found no somatosensory discrimination differences between dominant versus nondominant hands.

Relation of Somatosensory Discrimination Skills to Other Symptoms of Autism Spectrum Disorder

Several of the studies described in this review also addressed the possible relationship between somatosensory discrimination and other SPD subtypes, such as SMD and SBMD. For example, Minshew and Hobson (2008) did not find significant correlations between parent- and self-reported sensory sensitivities and somatosensory discrimination deficits for 60 people with HFASD. However, in their study of proprioceptive discrimination skills in people with ASD, Fuentes et al. (2011) found that those with self-reported sensory hypersensitivity scored significantly lower on proprioceptive discrimination measures, such as less precise movements on the active elbow angle task.

Several studies found that children with ASD exhibited both somatosensory discrimination deficits and motor deficits. Riquelme et al. (2016) found diminished fine motor performance and somatosensory discrimination skills in children with ASD compared with TD children. In addition, a study examining people with HFASD found deficits in coordination, motor speed, and grip strength, as well as in stereognosis ability (Abu-Dahab et al., 2013). Similarly, Siaperas et al. (2012) found congruent deficits among children with HFASD in both somatosensory discrimination and movement skills. Although these studies identified both motor and somatosensory impairments in children with ASD, they did not examine the relationship between these factors. However, in a unique study examining children with ASD aged 4–9, Roley et al. (2015) identified significant correlations between difficulties in imitation praxis, vestibular bilateral integration, and somatosensory discrimination as measured by the SIPT.

In addition to examining the relationship of somatosensory discrimination to sensory modulation and motor concerns, two studies examined its relationship to characteristics of social interaction and cognitive abilities. Minshew and Hobson (2008) examined the correlation between discrimination skills and cognitive ability. They found that participants with ASD who made more errors on complex somatosensory discrimination tasks tended to have lower verbal and full-scale IQ scores. Roley et al. (2015) reported a significant correlation between somatosensory discrimination and social participation at school as measured by proxy report.

Discussion

The current review addresses the lesser studied topic of somatosensory discrimination, an area critically important to motor, social, and daily function, in people with ASD. The clinical studies reviewed reveal heterogeneous somatosensory discrimination abilities of people with ASD, including intact, impaired, and even enhanced somatosensory discrimination skills in both simple and complex tasks. The differences among findings led the researchers to suggest different causative explanations ranging from the nature of the task to the postulated cortical or peripheral mechanisms. The heterogeneous results regarding SDD in people with ASD are not surprising given the heterogeneity of this population (Lord & Jones, 2012) and the wide range of sensory subtypes (Ausderau et al., 2014; Lane et al., 2014).

Taken together, however, the reviewed studies provided relatively consistent results regarding the development of somatosensory discrimination across age. As in typically developing children, somatosensory discrimination skills such as kinesthesia and form recognition tend to improve with age from preschool to early and middle childhood in people with ASD (Riquelme et al., 2016). Indeed, SDD was found to be more pronounced during early childhood than in adolescence and adulthood (Minshew et al., 1997; Williams et al., 2006). This improvement over time may result from the maturing of cortical integration, which may affect discrimination skills, during childhood (Abu-Dahab et al., 2013; Marco et al., 2012). By adolescence and adulthood, somatosensory discrimination impairments in ASD become more attenuated, perhaps because of improved sensory integration at the cortical level during the second decade of life (Abu-Dahab et al., 2013).

However, studies suggest that in the fourth decade of life, somatosensory discrimination skills begin to deteriorate, possibly because of neural changes (Dunn et al., 2015; Humes et al., 2009). The majority of the reviewed studies used samples composed of children and adolescents with ASD, and less is known concerning adults and older adults with ASD. Moreover, most of the studies reviewed were cross-sectional in design, which limited their ability to examine developmental changes. Therefore, this review highlights the need for longitudinal research examining somatosensory discrimination skills in people with ASD from childhood through adulthood to expand current knowledge and promote age-appropriate methods of sensory evaluation and treatment.

Regarding the impact of complexity of somatosensory stimuli on discrimination skills in people with ASD, the majority of studies revealed intact somatosensory discrimination skills for simple tasks (Fuentes et al., 2011; Nakano et al., 2012; O'Riordan & Passetti, 2006) but deficient performance in tasks requiring more complex cortical somatosensory ability (Abu-Dahab et al., 2013; Failla et al., 2017; Minshew et al., 1997; Minshew & Hobson, 2008; Williams et al., 2006). The researchers suggested that the cause may be diminished primary somatosensory cortical responses attributable to reduced inhibitory neurons and gamma-aminobutyric acid receptors (Failla et al., 2017). This lack of inhibition or imbalance between inhibition and excitation may lead to a "noisy" somatosensory cortex that "overlooks" salient somatosensory stimuli. Thus, low-level peripheral discrimination abilities remain intact, whereas discrimination skills involving higher cortical mechanisms are more impaired. However, this explanation has been challenged by contradictory findings from other studies, such as general deficits in both low and complex discrimination abilities (Roley et al., 2015; Siaperas et al., 2012), generally comparable skills (Demopoulos et al., 2015), or even enhanced complex discrimination capacities (Nakano et al., 2012). Regarding the latter, Nakano et al. (2012) postulated that long-range intracortical connectivity may be overexpressed in the brains of people with ASD, especially the posterior regions, resulting in superior form recognition abilities.

Several researchers have suggested that rather than cortical mechanisms, peripheral mechanisms might explain the variability in discrimination abilities in people with ASD. Cascio and colleagues (2008) suggested that special unmyelinated mechanoceptors known as C-tactile afferents located in the dorsal forearm respond more to affective social tactile stimuli than stimuli placed on other body sites, such as the palmar surface of the hand. Therefore, it is possible that the reason for the mixed findings across studies is that the tasks performed differed with respect to the body part involved in performing the tasks (e.g., touch to the dorsal surface of the finger vs. stereognosis involving the palmar surface of the hand).

Moreover, special attention must be given to the human versus nonhuman context of discrimination stimuli, which is known to affect people with ASD (Baranek et al., 2013; Brown & Dunn, 2010). For example, Deschrijver et al. (2016) found that touching the fingertip of a person with ASD with a human versus a nonhuman agent (wooden hand) produced different results. Thus, somatosensory discrimination tasks involving the touch or movement of one's hand (e.g., kinesthesia task in Roley et al., 2015) might yield different results than discrimination tasks involving nonhuman touch, such as that of a robotic arm (e.g., Fuentes et al., 2011). Additional studies including a variety of types of somatosensory discrimination stimuli could provide a better understanding the origin of these conflicting results.

Moreover, the effect of hand dominance and laterality on discrimination abilities in people with ASD should be explored, as indicated by Demopoulos et al.'s (2015) results.

The current review also presented studies indicating that somatosensory discrimination skills seem to correlate with several other sensory–motor symptoms characteristic of ASD, including motor deficits and sensory reactivity symptoms. Motor deficits in ASD might stem from sensory processing deficits in general, and somatosensory impairments in particular (Molloy et al., 2003), perhaps within the higher cortical somatosensory integration process (Fuentes et al., 2011).

Concerning the most reasonable relationship between SMD and SSD in people with ASD, Miller and colleagues (2007) stated that both under- and overresponsivity are types of SMD that can be related to atypical discrimination abilities. However, studies providing evidence supporting this assumption are scarce (Fuentes et al., 2011) and may be influenced by the low level of correspondence between different aspects of sensory functioning targeted by each of the sensory measures; SMD studies tend to rely on caregiver questionnaires, whereas somatosensory discrimination skills are usually measured by laboratory-based assessments. In addition, considering the fact that SPDs (e.g., SMD) in children with ASD have context-specific qualities that express themselves differently across settings such as school and home (Brown & Dunn, 2010), an examination of the more functional outcomes of sensory discrimination in the daily lives of people with ASD is needed. Therefore, further investigation is recommended that includes performance-based measures of possible causative connections between performance-based discrimination abilities in people with ASD and other SPD types.

During the past decade, research regarding SMD in children with ASD has moved toward finding sensory subtypes. Specifically, Lane and colleagues (2014) identified four distinct sensory subtypes among children with ASD characterized by both sensory modality involved and reactivity pattern. Similarly, Ausderau and colleagues (2014) reported four distinct profiles in people with ASD, including a sensitive–distressed profile in children who displayed a high frequency of hyperreactivity and enhanced perception, thus relating both to modulation and discrimination symptoms. Research on SDD in people with ASD could follow this direction of sensory subtypes, examining the interrelation of different types of somatosensory disorder (discrimination and modulation) that may be integrated into subtypes together. Such an investigation would provide insight concerning somatosensory profiles in people with ASD. The identification of subtypes can enhance our understanding of phenotypes, with implications for diagnosis, prognosis, and intervention.

Finally, the current review emphasizes the paucity of knowledge concerning the possible relationship between somatosensory discrimination and other clinical symptoms in people with ASD, including social communication skills and repetitive and restrictive behaviors. Such information might shed light on the underlying neurofunctional mechanisms of ASD and help determine whether somatosensory discrimination is secondary to other core symptoms in ASD, or whether it coexists with the other symptoms and they contribute to one another.

Results of the studies included in this review must be considered with caution. Some are limited by methodological issues, including small clinical samples and narrow participant age ranges (Fuentes et al., 2011; O'Riordan & Passetti, 2006). Some studies included only participants with HFASD, and it is reasonable to speculate that people with ASD who perform at a lower functioning level might present a different clinical picture of somatosensory abilities. In fact, some of the findings concerning complex somatosensory discrimination abilities in people with ASD might have been influenced by cognitive operations (e.g., language, comprehension, attention). Another methodological challenge in interpreting these studies is the use of a broad variety of somatosensory stimuli (e.g., proprioceptive discrimination for the estimation of body position; texture, shape, or tactile form recognition), making it difficult to compare findings. Moreover, the measures used in several studies had age-norm limitations that precluded the investigation of a possible age effect on somatosensory discrimination abilities (Abu-Dahab et al., 2013; Minshew et al., 1997; Williams et al., 2006).

Implications for Occupational Therapy Practice

The results of this study have the following implications for occupational therapy practice:

- The occupational therapy evaluation of people with ASD of all ages, especially younger children, can benefit from the use of performance-based somatosensory discrimination measures in addition to sensory modulation and sensory-based motor skill measures. This addition to the occupational therapy evaluation process would result in a more comprehensive understanding of the sensory profiles of people with ASD and their contribution to social and communication skills and other clinical symptoms.
- Occupational therapy practitioners should use well-validated and sensitive somatosensory discrimination measures as well as both simple and complex tasks in assessing people with ASD to enable the detection of subtle variations in discrimination skills.
- The assessment of somatosensory discrimination skills can help practitioners develop more efficient intervention strategies for people with ASD that include a focus on the effects of discrimination deficits on daily function.

Conclusion

Somatosensory discrimination skills of people with ASD are an essential component of the sensory evaluation and treatment process in occupational therapy, especially because they contribute to other clinical symptoms of ASD and to daily function. Further studies are recommended to develop reliable and valid somatosensory discrimination measures for this population.

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