International Journal of Developmental Disabilities

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/yjdd20

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To cite this article: Ummugulsum Gundogdu, Ahmet Aksoy & Mehtap Eroglu (2023): Sensory profiles, behavioral problems, and auditory findings in children with autism spectrum disorder, International Journal of Developmental Disabilities, DOI: 10.1080/20473869.2023.2200592

To link to this article: https://doi.org/10.1080/20473869.2023.2200592

Published online: 17 Apr 2023.

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Sensory profiles, behavioral problems, and auditory findings in children with autism spectrum disorder

Ummugulsum Gundogdu[1], Ahmet Aksoy[2] and Mehtap Eroglu[3]

[1]Department of Child and Adolescent Psychiatry, Faculty of Medicine, Marmara University, Istanbul, Turkey;
[2]Department of Otorhinolaryngology, Faculty of Medicine, Nigde Omer Halisdemir University, Nigde, Turkey;
[3]Department of Child and Adolescent Psychiatry, Hatay Training and Research Hospital, Hatay, Turkey

Objective: This study examined the relationship between sensory processing (SP) differences and behavioral problems in children with autism spectrum disorder (ASD). We also investigated whether audiological test results could objectively detect auditory processing differences.
Method: Forty-six children with ASD, ages 3–9 years, were enrolled in the study. Problematic behaviors and sensory processing of children were assessed using scales. The otolaryngologist performed a detailed head and neck examination and a formal audiological examination was performed by an audiologist.
Results: Stereotypy, hyperactivity, and irritability were related to sensation seeking. Stereotypy was also associated with visual processing. Touch processing differences was related to irritability and inappropriate speech. Lethargy was associated with auditory processing. There were no differences in SP and behavior problems in the children whose audiological profiles could be measured between those who passed or failed the test.
Conclusion: There was an association between SP differences and behavioral problems in children with ASD, supporting previous studies. Audiological test results did not reveal the SP differences documented in the parent forms.

Keywords: autism spectrum disorder; sensory profiles; behavioral problems; auditory profiles; children

Introduction

Autism spectrum disorder (ASD) is characterized by impairments in social interaction, communication skills, and repetitive and stereotyped behaviors (American Psychiatric Association 2013). In addition to these symptoms, some children with ASD may also have sensory processing (SP) differences (Wiggins *et al.* 2009). Atypical responses to sensory stimuli are common in children with ASD. They may react inappropriately or excessively to sensory stimuli and respond paradoxically to environmental stimuli (e.g. sounds, touch, smells, tastes, and visual stimuli) (Jamal *et al.* 2021, Leekam *et al.* 2007). These atypical responses can affect arousal levels and contribute to problems with inattention, anxiety, and anger control. Examples of atypical responses observed in children with ASD include looking at objects out of the corner of the eye, interest in rotating objects, and preoccupation with bright lights or smells (Hazen *et al.* 2014, Thye *et al.* 2018).

The effect of SP on children's behavior with ASD has attracted increasing attention recently (Chistol *et al.* 2018, Hazen *et al.* 2014, van den Boogert *et al.* 2021). Poor SP can affect children's social, cognitive, and sensorimotor development, and supporting SP abilities can affect children's functioning (Galiana-Simal *et al.* 2020). Sensory differences in children with ASD may negatively impact their daily lives, such as their diet, sleep routines, bathroom habits, and social activities, and impair their functionality (Thye *et al.* 2018). Sensory processing in children with ASD is important in identifying the sensory and motor characteristics that determine the development of personal autonomy. Children with ASD may have communication difficulties in social settings due to sensory challenges and adjustment difficulties due to their adherence to their routines (Jamal *et al.* 2021, Thye *et al.* 2018). In addition, their sensory sensitivities may negatively impact their physical health and quality of life by affecting

Correspondence to: Ummugulsum Gundogdu, Department of Child and Adolescent Psychiatry, Faculty of Medicine, Marmara University, Istanbul, Turkey. Email: glsmgndgd2@yahoo.com

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DOI 10.1080/20473869.2023.2200592

their participation in social and physical activities (Chen *et al.* 2009, Thye *et al.* 2018).

SP involves acquiring, organizing, and responding to sensory information. The two essential processes of sensory regulation are habituation and sensitization. Habituation refers to a decrease in the response to a stimulus after repeated presentations. It can also be explained as getting used to a situation or a stimulus (Jamal *et al.* 2021). Habituation response is essential for individuals to adapt to their life and focus. Sensitization is defined as a process in which repeated intermittent exposure to a particular stimulus results in an enhanced response to subsequent exposures (Jamal *et al.* 2021). In the central nervous system, systems vary in their patterns of habituation and sensitivity (Thye *et al.* 2018). These changes allow children to modulate sensory knowledge (Jamal *et al.* 2021). When young children have poor modulation capacity between habituation and sensitivity, they may display maladaptive behaviors, such as overstimulation, hyperactivity, or being overly hypoactive and inattentive (Zachor and Ben-Itzchak 2014). Young children with high sensory thresholds (the lowest point at which a particular stimulus causes a response in an organism) respond less or take longer to respond to stimuli. Conversely, when young children's thresholds are low, neurons are more easily triggered and react more frequently to environmental stimuli (Galiana-Simal *et al.* 2020, Thye *et al.* 2018). Previous studies stated that repetitive movements were frequently observed in children in residential care and mentally disabled individuals without autism (Schulz and Stevenson 2020). Stereotypical movements can be observed in individuals who are overstimulated and do not have the opportunity to react (Gabriels *et al.* 2008). Stereotypical behaviors may balance the child's arousal level in monotonous, annoying, or over-stimulating situations and may comfort the child (Schulz and Stevenson 2020).

In studies on auditory processing in individuals with ASD, findings have been obtained regarding the perception of pitch, the perception of a higher voice, the determination of the direction of the voice, the perception of prosody, and the perception of speech sound when there is background noise (O'Connor 2012). Dawson *et al.* (2004) examined orientation to social and nonsocial stimuli in 3–4-year-old children with ASD (Dawson *et al.* 2004). Social stimuli are sounds produced by the human voice (e.g. calling the child's name) or body (finger snapping, humming). In contrast, nonsocial stimuli are mechanical sounds produced by objects, such as the ringing of a telephone. Stimuli were presented to participants behind, in front of, or beside them during play. Compared to controls, children with ASD were significantly less inclined to be attracted to sounds, and the most significant differences between groups were observed for social stimuli (Dawson *et al.* 2004). Symptoms such as hypersensitivity to certain frequencies or types of sounds and insensitivity to nearby sounds or sounds that may startle other children are particularly noteworthy (Chen *et al.* 2009). Khalfa *et al.* (2004) reported in their study that people with autism show symptoms of discomfort against lower tones of voice compared to children with typical development. The children in this study had no hearing problems (Khalfa *et al.* 2004). Likewise, a large-scale study found that 18% of children with ASD showed loud noise disturbance to click stimuli at intensity levels less than 80 dBHL, compared to 0% of child controls (Rosenhall *et al.* 1999). Terms such as hypersensitivity to voices, auditory hypersensitivity, voice sensitivity, phonophobia, hyperacusis, and decreased sound tolerance are used interchangeably in similar contexts (Baguley 2018, Ida-Eto *et al.* 2017). The pathogenesis of auditory processing differences remains unknown (Baguley 2018, Ida-Eto *et al.* 2017).

Some studies have suggested that children with autism exhibit more aggressive behavior than their peers with typical development and other developmental disabilities (Hill *et al.* 2014, Kaat and Lecavalier 2013). Reese showed that children with ASD may act aggressively when performing rituals or engaging in repetitive behaviors (Reese *et al.* 2005). Thus, social relationships may deteriorate. They may face more restrictions at home and school. Thus, they are more likely to become victims (Ochi *et al.* 2020). The stress on caregivers can increase, and financial and family relationships can become more problematic (Fitzpatrick *et al.* 2016, McStay *et al.* 2014). In addition to these adverse consequences, children with autism who exhibit aggressive behavior are more likely to be exposed to physical interventions (Fitzpatrick *et al.* 2016). Therefore, correcting aggression in children with autism is critical for both the children and caregivers (Fitzpatrick *et al.* 2016).

SP differences may increase inappropriate behaviors such as aggressive behaviors, stereotypies, and hyperactivity in children (Joosten and Bundy 2010, van den Boogert *et al.* 2021). In a study by Mazurek *et al.* on children and adolescents with ASD, they found a positive relationship between sensory processing differences and aggressive behavior (Mazurek *et al.* 2013). In another study, Gonthier *et al.* reported a slight positive correlation between excitement-seeking behavior and aggression toward others in a sample of adults with ASD and severe intellectual disability (Gonthier *et al.* 2016). Hilton *et al.* (2007) reported that social impairment was positively associated with SP differences in children with high-functioning autism (Hilton *et al.* 2007). Baker *et al.* (2008) found consistent, moderate to strong correlations between SP differences and the presence of maladaptive behaviors (Baker *et al.* 2008). In particular, significant associations were found between SP differences and parent-reported child anxiety, social interaction, communication disorders, self-focus, and antisocial behaviors (Baker *et al.* 2008). A study by Liss *et al.* (2006) reported a relationship between sensory hypersensitivity, perseveration, and hyperfocus in ASD (Liss *et al.* 2006). Similarly, Ashburner *et al.* (2008) found that touch and movement sensitivities and auditory filtering difficulties were associated with inattention, hyperactivity, oppositional behavior, and academic failure in children with ASD (Ashburner *et al.* 2008). Conversely, Rogers and Ozonoff (2005) found little laboratory-based evidence for the role of SP differences in motor stereotypes often attributed to sensory-based arousal deficits (Rogers and Ozonoff 2005). Sensory problems, including sensory over-responsivity, sensory under-responsivity, and sensory seeking are also common co-occurring problems in children with ASD, and may also be related to the occurrence of aggression (Baranek *et al.* 2013, Leekam *et al.* 2007, Tomchek and Dunn 2007).

Based on the literature, we aimed to investigate the relationship between SP differences and behavioral problems, such as stereotypy, aggression, and hyperactivity, in children with autism. In addition to children's SP differences being assessed using parent questionnaires, we also investigated whether audiological test results could objectively detect SP differences. In this study, we hypothesized that the presence of auditory SP differences can be detected by audiological tests. We also hypothesized that these observed changes would help us objectively reveal auditory SP differences in children with ASD, and we could consider SP differences when dealing with inappropriate behaviors.

Methods

Participants and procedures

The patient group consisted of 46 children aged 3–9 years diagnosed with ASD who applied to the child and adolescent psychiatry outpatient clinic of the hospital in the province where the study was conducted between February 2019 and April 2021. Since the hospital is the only hospital within the provincial borders, children and adolescents with problems such as speech delay and behavioral problems apply to this polyclinic. Therefore, a study was conducted on children diagnosed with ASD according to expert clinician opinion among them. The study started with 51 children diagnosed with ASD between February 2019 and April 2021 who did not use any psychiatric medication, did not show self-harming behavior, and whose parents agreed to the study. In addition, five children who could not comply with detailed head and neck examinations and otoscopic examinations were excluded from the study.

Exclusion criteria were the presence of comorbidities for neurological (cerebral palsy, epilepsy, migraine), psychiatric (anxiety, depression, and psychosis) and other related medical conditions. All participants whose age under 6 underwent Denver-II Developmental Screening Test. Wechsler Intelligence Scales were tried to be applied to 18 children aged 6–9 years. The test could be completed with 3 children. The availability of standard intelligence measurement methods in children with ASD is limited (Ameis *et al.* 2022). In children with ASD, behavioral adaptation levels gain importance in functionality instead of standard intelligence scores. The adaptive behaviors of children with ASD can be defined as the evaluation of the skills in the conceptual, social, and practical fields that the individual can show daily with the information received from their families and teachers. Children with significant behavioral adjustment problems such as self-harm were not included in the study, considering they may have severe mental disabilities. Written informed consent were obtained from parents or guardians of children with ASD patients.

Socio-demographic characteristics of the participants were assessed by a detailed form and face-to-face interview, which included information about gender, age of the child, and the age, educational level, and socioeconomic status of the children's parents.

Otologic evaluation

Detailed head and neck examination and otoscopic examination of both ears of the children were included in the study were performed by the otolaryngologist. In addition, a formal audiologic assessment was performed by an audiologist in a soundproof environment and provided detailed information about hearing ability. Children were examined by an otolaryngologist. In the interview with the parents of the children, it was asked whether there was a family history of hearing loss, whether there was trauma, accident, illness, drug use that could cause hearing loss.

Testing in cooperative children

Pure tone audiometry

Pure tone audiometry determines the minimum loudness that both ears can hear at different frequencies. In a soundproof cabin, the sounds were listened to the patient by means of special headphones. With the help of the button, it is possible to know whether the patient hears these sounds. Sensorineural sensitivity, or sensorineural hearing loss, can be defined as difficulty understanding speech, even when the speaker's volume is loud enough.

Tests for young and uncooperative children

Young children and some children with developmental disabilities may not be able to cooperate with pure tone or speech audiometry testing as described above. Their hearing is assessed using behavioral methods in conjunction with other tests, such as acoustic impedance testing, OAEs.

Tympanometry

In the tympanometry test, which measures the pressure of the middle ear, air pressure is applied to the outer ear canal to measure the mobility of the middle ear and eardrum. By measuring the mobility in the middle ear and eardrum, information about the function of these structures can be obtained. During the tympanometry test, the eardrum should not be perforated (Demopoulos and Lewine 2016, Helenius *et al.* 2012, Shanks and Shohet 2009). Five types of tympanogram can be seen Type A – Normal middle ear pressure, Type B – Little or no mobility, suggestive of fluid behind the tympanic membrane or perforation, Type C – Negative pressure in the middle ear, suggestive of a retracted tympanic membrane, Type As – A very stiff middle ear system that can be caused by myringosclerosis or otosclerosis, Type Ad – The highly compliant tympanic membrane seen in ossicular chain discontinuity

Stapedial reflex

The response of the stapedius muscle in the middle ear to acoustic stimuli is called the acoustic reflex. It gives information about the auditory pathways up to the brain stem level. The acoustic stapedius reflex test assesses the presence or absence of ipsilateral and contralateral stapedial contraction with sound stimulation to each ear. Usually, sound stimulation on one side produces a stapedial contraction on both the ipsilateral and contralateral sides (Demopoulos and Lewine 2016, Lukose *et al.* 2013).

Otoacoustic emissions

The low-intensity acoustic signals produced in the cochlea's outer hair cells (snail) in the human inner ear, independent of the phase sounds, are called otoacoustic emission. These signals, which occur spontaneously in the cochlea, can be measured with the help of a sensitive microphone placed in the external ear canal. The presence of OAE suggests normal cochlear function. Sedation is not necessary for OAE testing. OAE tests are commonly used in newborn hearing screening programs.

Aberrant Behavior Checklist (ABC)

The Aberrant Behavior Checklist (ABC) is a 58-item questionnaire that evaluates behavioral problems in five subgroups. These five domains include irritability, hyperactivity, lethargy, stereotypy, and inappropriate speech. Items are scored between 0 and 3. 0 indicates no problem, and three indicates the degree of the problem is severe (Aman *et al.* 1985). Karabekiroglu *et al.* conducted validity and reliability analysis of Turkish version of ABC. In the Turkish validity and reliability study of ABC, Cronbach's Alpha internal consistency coefficients were between 0.89 and 0.96, excluding inappropriate speech (0.68). For the total score, Cronbach Alpha was 0.96 (Karabekiroglu and Aman 2009). This scale was completed by the parents of the participants.

Childhood Autism Rating Scale (CARS)

CARS is a scale generally used to determine the severity of autism. There are 15 items on the scale. Relationship with people, imitation skills, reactions to change, visual and auditory reactions, perception level, verbal and non-verbal communication skills, fears and anxieties, activity level, general impression, and intellectual relations are questioned. A score between 1 and 4 is given for each item. 1 indicates age-appropriate behavior. In contrast, 4 indicates severe deviation from normal behavior for the age level. The scores of all items are added together, and the total score is obtained. The severity of the disease is calculated according to the score. Between 15-and 29.5 are classified as not autistic, 30–36.5 as mild-moderate, and 37–60 as severe. CARS provides an objective and measurable assessment due to direct observation of behavior rather than clinical judgment (Garfin *et al.* 1988). İncekas *et al* conducted validity and reliability analysis of Turkish version of Childhood Autism Rating Scale. The Cronbach's alpha value of total score of the CARS was determined as 0.95. Test-retest reliability ($r = 0.98$, $p < 0.01$) (Incekas Gassaloglu *et al.* 2016). CARS was administered by a child and adolescent mental health professional.

Dunn Sensory Profile, the Turkish version

Dunn and colleagues developed the Sensory Profile (SP) to assess the sensory responses during various daily sensory experiences in children with and without disabilities. It consists of a total of 125 questions. Parents are asked about their children's responses. These questions and responses are divided into eight categories: Auditory, Visual, Activity Level, Taste/Smell, Body Position, Movement, Touch, and Emotional/Social. The scale covers six areas of sensory processing. There are six areas of sensory processing: auditory processing, visual processing, movement processing, touch processing, oral sensory processing, and body position (Ermer and Dunn 1998). In addition to the sensory processing domains, parents in the study were also asked questions about sensation seeking and activity (Ermer and Dunn 1998). Kayihan *et al* conducted validity and reliability analysis of Turkish version of Dunn Sensory Profile. The Cronbach's as ranged from 0.63 to 0.97 for all subsections. Test-retest reliability over a one-week period was excellent (ICC > 0.90) (Kayihan *et al.* 2015).

Statistical methods

Data were analyzed using the Statistics Program for the Social Sciences (IBM SPSS 21.0). Descriptive statistics (frequency, percentage, mean, standard deviation) were used to analyze the research data. Scale scores were compared between groups using the Student's *t*-test for normal distribution and Mann-Whitney U for non-normal distribution. Correlation analysis between five domains include irritability, hyperactivity, lethargy, stereotypy, and inappropriate speech of the ABC scale and Dunn sensory profile subscales were performed. Variables found to be statistically significant were evaluated with the forward method in linear regression analysis. The model with the highest number of variables from the model obtained is given as an independent variable in the tables. In the regression model, the multicollinearity problem was checked in two ways. All predictor variables were checked for correlation to control using correlation coefficients, and only one of the two variables with coefficients of magnitudes of r is 0.8 or higher was used in the analysis. In addition, VIF values were checked. Those below 5.00 were included in the assessment. For all analyses, the significance level was accepted as $p < 0.05$ and the corresponding 95% confidence intervals.

Results

Children aged 3–9 years with autism were included in the study. Of these children, 8 (17.4%) were girls and 38 (82.6%) were boys. The mean age of the children participating in the study was 5.28 ± 2.17 years. The age, education level, and socioeconomic status of the children's parents are shown in Table 1. Children with autism in the research group consisted of the same race.

Table 2 shows the relationship between scores for irritability, lethargy, hyperactivity, stereotypy, and inappropriate language problems, subscales of the Autistic Behavior Checklist (ABC) scale, and the SP subscales of Dunn's Sensory Profile scale. In addition, the correlation results with the total Childhood Autism Rating Scale score are presented.

Table 1. Sociodemographic properties of children.

			n	%
Gender. *n* (%)	Female		8	17.4
	Male		38	82.6
Socioeconomic status. *n* (%)	Low		14	30.4
	Medium		20	43.5
	High		12	26.1
Maternal education	Low (0–8 years)		22	47.8
	Medium (9–12 years)		17	37.0
	High (University)		5	10.9
	Master's degree		2	4.3
Paternal education	Low (0–8 years)		16	34.8
	Medium (9–12 years)		14	30.4
	High (University)		12	26.1
	Master's degree		4	8.7
	Min/max		M	SD
Age (years)	3	9	5.28	2.17
Maternal age (years)	21.00	48.00	34.02	6.64
Paternal age (years)	26.00	58.00	38.36	7.16

As shown in Table 3, linear regression analysis was performed for the variables that were found to be significant. The SP problem associated with each behavioral problem was identified. ABC irritability showed a significant relationship with sensation-seeking and SP-touch processing ($p < 0.05$) (Table 3). The ABC lethargy was associated with SP auditory processing ($p < 0.05$) (Table 3). ABC hyperactivity was associated with sensation seeking. A significant correlation was found between ABC stereotypy and SP visual processing and sensation seeking ($p < 0.05$) (Table 3). ABC inappropriate speech was positively correlated with SP touch processing ($p < 0.05$) (Table 3).

On physical examination performed by an otolaryngologist, none of the children had problems with the tympanic membrane, such as middle ear fluid, tympanic membrane perforation, tympanic membrane scarring, cholesteatoma, or other middle ear masses. No evidence of spontaneous nystagmus was found in any of the children. The parents of the children included in this study had no history of otosclerosis or hearing loss. Signs of tonsillitis were noted in 3 children. Fourteen children exhibited signs of nasal congestion. Examination findings of the ears, nose, and throat of 29 children were normal. When children with nasal congestion and tonsillitis symptoms in one group and children without symptoms in another group were examined, no difference was found in behavioral problems and sensory sensitivities. Pure-tone audiograms could be performed in only 3 of 46 children. Statistical analysis could not be performed because 3 children were in children with ASD who were performed pure-tone audiograms and 43 children were in the other group.

The Otoacoustic Emission (OAE) test could not be applied to 26 of the 46 children with ASD. Twenty children were able to adapt to the study. Of 20 children, 14 had both ears pass. Four children failed the unilateral test, and 2 patients failed the bilateral test. The ABC irritability subscales of the children who failed the OAE test (6) scored higher on the irritability scale (effect size: 0.47) scale than the children who passed the test (14) ($p < 0.05$) (Table 4). The SP subscale scores of the children who failed the OAE test were similar to those of children who passed the test ($p > 0.05$) (Table 4).

The stapedial reflex test could be applied to 25 of the 46 children with ASD. Bilateral ipsilateral or contralateral reflexes were obtained in 19 of the 25 children whose stapedial reflexes were examined. No reflex was observed in 6 children. There was no difference in the scores obtained on the scales between the children who could adapt to the stapedial reflex examination test and those who passed and failed the test ($p > 0.05$) (Table 4).

Table 2. Correlation analysis of ABC subgroups and Dunn Sensory Profile subgroups and CARS.

	Touch processing	Oral sensory processing	Movement processing	Sensation seeking	Auditory processing	Activity	Visual processing	CARS total
Irritability	0.523**	0.310*	0.180	0.660**	0.504**	0.429**	0.444**	0.375*
Lethargy	0.470**	0.252	0.122	0.509**	0.542**	0.449**	0.468**	0.480**
Stereotypy	0.473**	0.257	0.351*	0.678**	0.629**	0.452**	0.522**	0.439**
Hyperactivity	0.476**	0.434**	0.122	0.841**	0.730**	0.333*	0.455**	0.470**
Inappropriate speech	0.631**	−0.019	0.236	0.328*	0.362*	0.497**	0.355*	−0.040

*. $p < 0.05$. ** $p < 0.01$.
CARS, Childhood Autism Rating Scale.
The Aberrant Behavior Checklist (ABC).

Table 3. Linear Regression Analysis between ABC subgroups and Dunn Sensory Profile subgroups.

Dependent variable	Independent	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients B	*t*	*p*
Irritability	Sensation Seeking	0.857	0.171	0.554	5.006	<0.001**
	Touch processing	0.665	0.266	0.277	2.499	0.017*
Lethargy	Auditory processing	0.841	0.220	0.513	3.828	0.000
Stereotypy	Sensation seeking	0.485	0.104	0.557	4.658	<0.001**
	Visual processing	0.388	0.161	0.288	2.412	0.021
Hyperactivity	Sensation seeking	1.078	0.202	0.563	5.340	<0.001**
Inappropriate speech	Touch processing	0.402	0.076	0.667	5.280	<0.001**

*. $p < 0.05$. ** $p < 0.01$.
The Aberrant Behavior Checklist (ABC).

Table 4. Analysis of Scales of Children according to Auditory Profile Results.

		Otoacoustic emissions (20)					Stapes Reflex (25)				
		Abnormal (6) Unilateral or none		Passed (14)			Abnormal (6)		Bilateral/unilateral (19)		
		M	SD	M	SD	*p*	M	SD	M	SD	*p*
Aberrant Behavior Checklist	Irritability	15.00	9.85	2.33	1.97	0.003**	14.00	10.35	11.84	10.81	0.655
	Lethargy	11.50	5.43	9.54	4.52	0.354	14.50	9.42	8.42	5.81	0.079
	Stereotypy	4.33	3.39	6.62	5.03	0.453	5.83	4.83	6.21	5.42	0.822
	Hyperactivity	12.83	8.98	20.62	13.46	0.203	17.00	12.57	16.00	13.67	0.799
	Inappropriate speech	2.83	4.17	3.00	2.52	0.563	2.17	3.49	2.63	2.06	0.362
Dunn Sensory Profile	Touch processing	6.17	5.78	5.77	3.56	0.895	7.83	5.95	5.00	3.03	0.403
	Oral sensory processing	1.33	0.82	3.38	4.15	0.653	4.33	4.84	4.28	5.23	0.760
	Movement processing	1.17	1.33	1.38	2.33	0.839	1.33	2.42	1.72	2.35	0.655
	Sensation seeking	8.17	6.40	13.08	7.77	0.159	10.17	7.28	11.11	7.61	0.789
	Auditory processing	10.33	5.28	10.46	6.42	0.930	11.83	5.00	8.78	6.29	0.269
	Activity	4.17	4.26	3.38	4.07	0.655	4.33	4.50	3.17	4.31	0.332
	Visual processing	2.33	2.94	2.62	2.10	0.563	5.50	4.46	2.83	3.09	0.106
Childhood Autism Rating Scale		30.33	3.92	29.29	2.89	0.301	32.92	7.21	31.50	6.59	0.611

P-values calculated by Mann–Whitney U test.
*. $p < 0.05$. **. $p < 0.01$.
Effect size of irritability 0.47.

A tympanogram was obtained in 32 of the 46 children with ASD. Twenty-four of the 32 children whose tympanograms were examined had a bilateral type A wave curve. Unilateral A wave curves were found in 5 children (Table 5). Type B and C wave curves were observed in 3 patients. Type B and C tympanograms were obtained in 3 children because of an existing middle ear infection (serous otitis media). Therefore, the tympanogram, OAE, and stapedial reflex results of these 3 children were excluded from the study. There were no differences in the scores obtained from the scales between children with ASD with bilateral or unilateral A wave curves ($p > 0.05$) (Table 5).

Discussion

In this study, we assumed that we could detect problems in audiological test results in the presence of auditory sensory processing differences. We also hypothesized that these observed changes would help us objectively reveal auditory sensory processing differences in children with ASD, and we could consider sensory processing differences when dealing with inappropriate behaviors.

When evaluating children's reactions to stimuli, their SP abilities and environmental stimuli threshold should be evaluated together. For instance, a child with a high threshold may try to apply excessive energy-seeking stimuli to meet high thresholds, or a child with a low threshold may expend energy to avoid triggering low thresholds (Ghanizadeh 2011). Impulsivity, hyperactivity, and inattention can be observed in children with hyposensitivity (Baranek *et al.* 2013). A high need for emotion seeking may be associated with impulsive behavior and poor motor modulation (Ghanizadeh 2011). Herein, sensory seeking was associated with motor hyperactivity, stereotypical behaviors, and irritability in children with ASD. Irritability was also associated with processing the sense of touch. As an example of the relationship between irritability and sense of touch, a child whose sense of touch is overstimulated may not want to wear a piece of clothing (Galiana-Simal *et al.* 2020, McCann *et al.* 1996). He/she may become angry when clothing touches his/her body.

Previous studies have reported that stereotypical movements are frequently observed in children in residential care and in mentally disabled individuals without autism (Moss *et al.* 2009, Schulz and Stevenson 2020). Stereotypical behaviors can be observed in individuals who are overstimulated and do not have the opportunity to react, and they may balance the child's arousal level in monotonous, annoying, or overstimulating situations and may comfort the child (Joosten and Bundy 2010, Schulz and Stevenson 2020). The visual processing section of the sensory profile scale asks, for example, whether children are disturbed by light, whether they close their eyes to protect themselves from light, and whether they look at objects/people intently or attentively (Ermer and Dunn 1998). Visually overstimulated children may exhibit stereotypical behaviors to balance their senses and relax (Joosten and Bundy 2010). In the present study, the relationship between stereotypical behaviors and visual hypersensitivity was significant.

Speech patterns may be unusual in children with ASD due to a fluency disorder called speech dysregulation, which includes excessive talking, repetitive speech, loud landing on oneself, and repeating the same word repeatedly (Aman *et al.* 1985). Clear speech production occurs because of the movement of the tongue muscles in the oral cavity. Receptors in the oral cavity provide feedback on touch, temperature, texture, or sensation. The tactile sensitivity of the tongue and jaw structures can make it difficult to extract the correct letter. The relationship between inappropriate speech symptoms and tactile processing differences may be related to the mouth and its surrounding structures (Kern *et al.* 2007).

Auditory processing is defined by how the brain identifies and understands sound information. For successful auditory processing, children need skills, such as perceiving or discriminating sounds and adapting to a particular sound or tone (Geffner and Ross-Swain 2018). Difficulty processing and understanding auditory stimuli makes it difficult for children to perceive speech. Differences in auditory stimuli may result in difficulty in understanding speech in noisy environments, problems finding the source of the acoustic stimulation, inability to respond to verbal information correctly, frequent repetition of information, and less attention to auditory input (Iliadou and Kiese-Himmel 2018, Linke *et al.* 2018). In our study, lethargy was associated with the changes in processing auditory stimuli and may be related to a decreased response to stimuli, resulting in a hypoactive appearance.

The SP scores were similar in children with ASD who had no problems with the otologic examination or nasal congestion. No increase in behavioral problems was found herein. However, if an increase in behavioral problems is noted in children with ASD, medical problems, including mild upper respiratory disorders such as nasal congestion, should not be ignored (McGonigle *et al.* 2014, Restrepo *et al.* 2020, van den Boogert *et al.* 2021).

OAE is an easily administered, objective test that can be performed quickly. OAEs are basically according to the stimulus type; They are divided into stimulated and spontaneous. Evoked OAEs are of three types: stimulus frequency otoacoustic emissions (SFOAE), transient evoked otoacoustic emissions (TEOAE), and distortion

Table 5. Comparison of the scales with the As wave obtained in the tympanogram and the other waves.

		Bilateral Type As (24)		Unilateral Type As (5)		
		M	SD	M	SD	*p*
Aberrant Behavior Checklist	Irritability	13.04	10.43	11.40	10.95	0.643
	Lethargy	11.21	6.34	10.00	12.31	0.354
	Stereotypy	6.63	5.39	7.00	5.61	0.862
	Hyperactivity	18.67	12.47	15.40	15.66	0.452
	Inappropriate speech	2.50	2.17	2.20	3.49	0.463
Dunn sensory profile	Touch processing	5.17	3.74	7.25	6.85	0.717
	Oral sensory processing	4.21	5.23	7.00	4.24	0.183
	Movement processing	1.54	2.23	2.25	2.63	0.362
	Sensation seeking	11.29	6.87	10.25	9.54	0.532
	Auditory processing	9.63	5.65	13.75	5.44	0.210
	Activity	2.79	3.89	5.75	5.06	0.200
	Visual processing	2.50	2.87	5.25	5.97	0.269
Childhood Autism Rating Scale		31.81	5.32	31.30	9.65	0.665

*. $p < 0.05$. **. $p < 0.01$. *p*-calculated by Mann-Whitney U.

product otoacoustic emissions (DPOAE) (Kemp 2002, Lonsbury-Martin and Martin 2003). In a study conducted in Turkey, 40 ears, including the right and left ears of 20 healthy volunteers aged 6–17 with normal hearing, and 40 ears of right and left ears of 20 individuals diagnosed with ASD between the ages of 6–17 with normal hearing were evaluated using DPOAE (Yüksel 2021). In this study, signal-to-noise ratios (SNR) and amplitude values (λ) at 1 kHz.–1.5 kHz.–2 kHz.–3 kHz–4 kHz and 6 kHz were evaluated. DPOAE values of individuals with autism are at SNR values (3-4-6) kHz compared to the control group and amplitude values (4–6) kHz. It was obtained as high. The authors stated that due to the study findings, children with autism might have hyperacusis originating from the inner ear (Yüksel 2021). In other studies, it has been suggested that central auditory pathways and medial olivocochlear system incompatibilities may also cause hyperacusis (Zanchetta and Furtado 2020). In our study, when comparing those who adapted to and passed the OAE test with those who failed the unilateral and bilateral tests, irritability was more common in individuals who failed the OAE test than in those who passed it. The presence of OAE suggests normal cochlear function (Kemp 2002, Shera 2004). Owing to irritability, some children could not adapt to the test and may have remained unilateral or bilateral during the test.

Lukose *et al.* (2013) performed a detailed quantitative study of the acoustic stapedial reflex (ASR) in children with ASD and typically developing children. Their study found significantly lower hearing thresholds, significantly longer hearing delay, and right-left ear asymmetry in children with autism. They suggested that hearing-related problems in individuals with ASD could be identified with ASR responses (Lukose *et al.* 2013). In this study, there were no differences in behavioral problems and SP between those who passed or failed the test among the children with ASD whose stapedial reflex and tympanometry could be measured. However, we obtained an interesting finding in this study. When tympanograms were examined, 24 of 32 children were found to have a bilateral type A wave curve. Unilateral A wave curves were found in 5 children. The presence of A waves in tympanometry is a finding that favors otosclerosis in adults (Shanks and Shohet 2009). Otosclerosis is characterized by ossification of the ossicular structure in the middle ear and its insufficient movement (Shanks and Shohet 2009). The parents of the children included in this study had no history of otosclerosis or hearing loss. No signs of otosclerosis were found in children with A waves. The stapedial reflex was observed in 22 of the 24 children with bilateral A waves on the tympanogram. Considering that the seventh and eighth nerve structures were preserved with the stapedial reflex, it was thought that the problem might have arisen from the ossicular structures in the middle ear (Lukose *et al.* 2013). The presence of the stapedial reflex in patients with type A waves on tympanograms, absence of otosclerosis, history of hearing loss in all children, and the resulting type A curve in children with autism suggest a different middle ear developmental situation. Evidence has shown that a gene responsible for cell migration may be problematic in some cases of the coexistence of autism and otosclerosis (Mowat *et al.* 2018). Detailed prospective studies on the general function of the middle ear ossicles in children with ASD might provide different information from that in the literature.

Limitations

A limitation of this study is its cross-sectional nature. If audiological findings in children with ASD could change over time and if repeated measures could be used to evaluate whether this is related to sensory and behavioral changes in the process, we might have a chance to obtain more meaningful information. The limited number of participants and absence of adolescents and control groups were also limitations, but the comparison of children with ASD with similar abilities may have increased the power of the study. Electrophysiological tests, such as the auditory brainstem response test, which were included in the study and planned, were not performed in children with autism who could not comply with the tests as per the ethics committee’s decision. However, audiological tests can be performed on conscious, cooperative, and oriented individuals.

Conclusions

In conclusion, this study found an association between behavioral problems and SP abilities in children with ASD, supporting the findings of previous studies. In this study, no differences in behavior and SP were found between children whose audiological profiles could be measured and those who passed or failed the test. The SP differences documents in the parent forms could not be confirmed by audiological testing. Although the small sample size limits the generalizability of the results, differences in SP cannot be objectively demonstrated through audiological testing.

Conflict of interest

The authors have no interests (financial or otherwise) to declare. This research did not involve non-human participants. British Psychological Society (2014) principles were observed throughout the design and execution of this research; participants’ responses were anonymous, participants were informed of their right to withdraw from the study at any time without reason yet without penalty, etc.

Data sharing and declaration

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical approval

Research procedures complied with universal ethical standards and the tenets of the Helsinki Declaration of 1975, as revised in 2000. The Nigde Omer Halisdemir University Research Ethics Committee approved the study by the protocol number 2019/01-12.

Informed consent

A number of measures were taken in order to ensure compliance with ethical standards. Children's legal guardians were informed at institution about the research and gave written consent. Children's legal guardians could withdraw children from participation at any time.

Funding

The study was not supported by funding.

ORCID

Ummugulsum Gundogdu http://orcid.org/0000-0001-6327-4808

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