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Sensory processing in toddlers with autism spectrum disorders

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ABSTRACT

Sensory symptoms are common in individuals with autism spectrum disorders (ASD) but the patterns of these symptoms vary. Early assessment of sensory processing is therefore crucial for diagnosis and early intervention. However, studies in this area are conducted almost exclusively in English-speaking populations. In our study, we examined sensory processing in 380 toddlers: 96 with ASD, 42 with other developmental disabilities (DD), and 242 typically developing (TD) controls. Caregivers completed a Polish version of the Infant/Toddler Sensory Profile (ITSP). Results showed that children with ASD and those with DD were more hypo- and hypersensitive and showed more avoidance of stimulation than TD controls. Children with DD had less severe symptoms than those with ASD and showed higher levels of sensation seeking than the ASD and TD groups. Furthermore, we identified four sensory subtypes with different sensory thresholds and regulatory strategies. Two of them reflected healthy patterns of sensory processing: a healthy-active and a healthy-passive subtype. The third subtype was characterized by mild sensory symptoms. The fourth pattern was specific to toddlers with ASD and included severe sensory symptoms and avoidance of stimulation. The Polish ITSP may be a useful instrument in early diagnosis of ASD, as well as in future research.

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KEYWORDS Sensory processing; sensory sensitivity; sensory subtypes; autism spectrum disorders; ASD; developmental disorders; Infant/Toddler Sensory Profile; ITSP

1. Sensory processing in young children with ASD

Atypical responses to sensory stimulation are a common feature of children with autism spectrum disorders (ASD), occurring in as many as 80–95% of cases (Tavassoli et al., 2016; Tomchek & Dunn, 2007),

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reflected by the diagnostic criteria in the latest edition of DSM-5 (APA, 2013). These symptoms persist into adolescence (La Marche, Steyaert, & Noens, 2012) and adulthood (Crane, Goddard, & Pring, 2009; Tavassoli, Miller, Schoen, Nielsen, & Baron-Cohen, 2014) and continue to affect everyday functioning. Sensory symptoms are also frequently present in other neurodevelopmental disorders, such as Down or Williams syndromes and idiopathic developmental delay (Baranek et al., 2013), attention deficit hyperactivity disorder (ADHD) (Bijlenga, Tjon-Ka-Jie, Schuijers, & Kooij, 2017), mental disorders (for a review see: Harrison, Kats, Williams, & Aziz-Zadeh, 2019), and in some typically developing individuals without any neurological or psychiatric abnormalities (Little, Dean, Tomchek, & Dunn, 2017).

Patterns of sensory symptoms (profiles) differ across disorders. Compared to children with developmental delay, children with ASD show more severe symptoms, they are more often hyporesponsive, and more frequently display a pattern of hyporesponsiveness to certain stimuli concurrent with hyperresponsiveness to other kinds of stimuli (Baranek, David, Poe, Stone, & Watson, 2006). On the other hand, young adults with ADHD are more prone to seek sensory stimulation (Clince, Connolly, & Nolan, 2016) than their peers with ASD. Furthermore, studies have shown that within groups of participants with a specific disorder, such as ASD, subtypes exist which differ with regard to sensory features and symptom severity (see reviews in Davies & Tucker, 2010; DeBoth & Reynolds, 2017). In one study with children with ASD aged 2–12 years, four subtypes were identified based on scores in four factors: hyperresponsiveness (HYPER), hyporesponsiveness (HYPO), sensory interests, repetitions, and seeking (SIRS), and enhanced perception (EP) (Ausderau, Furlong, et al., 2014). The four subtypes were: 1. Mild (with low scores in all factors), 2. Extreme-mixed (with high scores in all factors), 3. Sensitive-distressed (with lower scores on HYPO and SIRS and higher on HYPER and EP), and 4. Attenuated-preoccupied (with higher scores on HYPO and SIRS and lower on HYPER and EP). Another study with toddlers with ASD (Ben-Sasson, Cermak, Orsmond, Tager-Flusberg, Kadlec, & Carter, 2008) demonstrated the existence of three subtypes: 1. with a low frequency of sensory symptoms, i.e., low hypo- and hypersensitivity and low sensation seeking, 2. with a high frequency of sensory symptoms (high hypo- and hypersensitivity and seeking), and 3. a mixed pattern with high hypo- and hypersensitivity and low seeking. Finally, in a community sample of children and young teenagers aged 3 to 14 years with and without developmental disabilities, five subtypes were identified: 1. Balanced (with scores in the normal range), 2. Interested (with relatively high sensation seeking), 3. Intense (with high hypo- and hypersensitivity, high seeking and avoiding), 4. Mellow until (hyposensitive and avoiding sensation), and 5. Vigilant (hypersensitive and avoiding) (Little et al., 2017). Clearly, some of the subtypes identified in different studies overlap, but others vary, as do the samples and instruments used.

A prevalent pattern of sensory processing in ASD consists of the co-occurrence of hyposensitivity and hypersensitivity. Pellicano (2013) proposed that such symptoms can be explained by attenuated top-down modulation of sensory input. While previous experience guides the interpretation of sensory stimuli in typical individuals, individuals with ASD may use these 'priors' to a lesser degree. Moreover, as a result of reduced reliance on previous experience, sensations may seem unexpected and uncontrollable. This may account for the insistence on sameness, the need for routine, and the focus on repetitive behaviours (Pellicano, 2013).

Dunn's Model for Sensory Processing (Dunn, 1997) provides a promising theoretical framework for research on sensory abnormalities in ASD and other developmental disabilities. The model includes two dimensions: neurological thresholds (low to high) and strategies of self-regulation (passive to active). The thresholds continuum stands for the amount of input to the nervous system required to trigger a response. Individuals with high thresholds (low reactivity) need greater sensory input to elicit a response, while individuals with low thresholds (highly reactive) need very little input to respond. The self-regulation continuum represents the ability to cope actively with tasks and environmental demands that carry varying levels of stimulation. A person with a passive strategy shows a tendency to refrain from acting, while a person with an active strategy attempts to control the input. From those two continuums, Dunn derived four basic patterns (quadrants, Q) of sensory processing: Low registration (Q1), Sensation seeking (Q2), Sensory sensitivity (Q3), and Sensation avoiding (Q4). Low registration is characterized by the combination of high neurological thresholds with a passive self-regulation strategy. Sensation seeking results from the combination of high thresholds with an active self-regulation strategy. Sensory sensitivity is the combination of low neurological thresholds with a passive self-regulation strategy. Finally, Sensation avoiding is considered an outcome of the combination of low neurological thresholds with an active self-regulation strategy. Dunn (2002, 2014)) developed parent-report questionnaires for the evaluation of children's behavioural responses to sensory input. One of them, the Infant/Toddler Sensory Profile (ITSP), covers several modalities (e.g., auditory processing, visual processing, tactile processing, etc.) and the four quadrants of sensory responses.

The ITSP has proven itself a useful tool in research with infants and young children raised in English-speaking families. Our study is one of very few projects that provide data on the ITSP from a non-English speaking European sample (however, see Beranova et al., 2017, who used a different instrument). There are reasons to expect inconsistent results, as in a multinational study Matson et al. (2017) found that parents in different countries noticed different developmental difficulties in infants and toddlers with ASD. In this study a Polish version of ITSP was used, giving new insight into the universality of this instrument's diagnostic usefulness.

We examined sensory processing in three groups of young children: children with a diagnosis of ASD, with other developmental disabilities (DD), and typically developing (TD) controls. We expected that children with ASD would show higher levels of sensory hypo- and hypersensitivity, as well as more sensation seeking and avoiding than controls. We also predicted that children with developmental disabilities would differ from controls in terms of sensory processing; however, we expected their symptoms to be less severe than those observed in children with ASD. The examination of sensory profiles in children with developmental disabilities without ASD was not, however, the focus of the study. Rather, the DD group was used as an additional comparison group for children with ASD.

To complement the examination of the overall sensory patterns, we compared modality-specific patterns, which included visual, auditory, vestibular, tactile, and oral processing. We also searched for subtypes, that is subgroups of participants that would differ in sensory thresholds (high/low) and regulatory strategies (active/passive). In the final set of analyses, we aimed to establish preliminary cut-off points for the Polish version of the ITSP that could be used in early stages of clinical assessment.

2. Method

2.1. Design and procedures

Questionnaires were completed by the primary caregiver at home or day care centres, early intervention centres, and clinics across Poland. Participants were recruited by professionals providing day care or early diagnosis and intervention, through flyers and posters in health-care centres and nurseries, and through media ads. All parents gave written informed consent. The studies were approved by the local institution's ethics committee and conformed to the Declaration of Helsinki.

2.2. Participants

Altogether, 473 participants took part. Participants were qualified for the final analysis based on four criteria: 1. the child was born full term; 2. the child did not have any significant uncorrected vision or hearing impairment (per parent report); 3. the child was between 16 and 36 months of age; 4. the child could be assigned to one of the following three groups: diagnosis of childhood autism or other ASD (pervasive developmental disorders, unspecified; the ASD group), diagnosis of developmental disabilities or disorders, without autism or other ASD (Down syndrome, developmental delay, language disorder, without any comorbid disorders or medical problems; the DD group), typical development (healthy, without any first-degree relatives with autism or other ASD; the control group). Fifty-three participants born preterm (gestational age < 37 weeks, including 18 children with ASD and 1 with DD) were excluded. We also excluded 18 participants with significant uncorrected vision or hearing impairment reported by the caregiver. Finally, 12 children were excluded because they had siblings with autism or other ASD.

The final sample included 380 participants (*M* age = 24.98 months, *SD* = 4.85, range 16–36 months; 225 boys; ASD n = 96, DD n = 42, and TD n = 242). Demographic data is presented in Table 1. Participants with missing values in the ITSP form were excluded on an analysis-per-analysis basis (*Low registration*: n = 14, *Sensation seeking*: n = 15, *Sensory sensitivity*: n = 9, *Sensation avoiding*: n = 7).

All children in the ASD group had a community-based diagnosis of ASD, provided by a child psychiatrist and a psychologist on the basis of ICD-10 criteria (WHO, 1992). The diagnostic process included clinical interviews with parents and extended observations of a child's behaviour. Participants in the ASD group did not have epilepsy or any other serious medical conditions likely to affect the clinical picture. Children from the DD group had a medical and psychological diagnosis based on ICD-10 criteria (World Health Organisation, 1992).

Table 1. Study 1: demographic data for groups (SD in brackets).

Group	N	Sex Boys/Girls	Age [months]	Gestational age at birth [weeks]	Birth weight [grams]	Mother's education PV/HSB/MA	Father's education PV/HSB/MA
ASD	96	71/25	26.75 (5.21)	39.17 (1.2) Missing data: n = 4	3,417 (452) Missing data: n = 4	9/33/53 Missing data: n = 1	14/35/44 Missing data: n = 3
DD	42	30/12	25.26 (4.96)	39.17 (1.43)	3,318 (453)	6/12/24	7/12/22 Missing data: n = 1
Control	242	124/118	24.23 (4.50)	39.31 (1.16) Missing data: n = 2	3,451 (487) Missing data: n = 2	13/49/180	26/77/136 Missing data: n = 3
Total	380	225/155	24.98 (4.85)	39.26 (1.2) Missing data: n = 6	3,428 (475) Missing data: n = 6	28/94/257 Missing data: n = 1	47/124/202 Missing data: n = 7

Abbreviations: ASD, autism spectrum disorders; DD, developmental disabilities, without ASD; PV, Primary or vocational education; HSB, high school or bachelor's degree; MA, master's degree

Controls were typically developing infants without any parent-reported developmental or ASD-specific concerns.

The groups differed by age, $F[2, 377] = 9.80$, $p < .001$, $\eta_p^2 = .049$, with the controls ($M = 24.23$ months, $SD = 4.50$) being on average younger than participants in the ASD group ($M = 26.75$ months, $SD = 5.21$; $t = 2.52$, $p < .001$). There were no significant age differences between the DD and control group ($p = .58$) or between the ASD and DD group ($p = .27$).

There were some differences in the number of boys and girls in the ASD and DD groups. Boys outnumbered girls in the ASD group ($\chi^2[1, N = 96] = 22.04$, $p < .001$; 71 boys) and in the DD group ($\chi^2[1, N = 42] = 7.71$, $p = .005$; 30 boys). The higher ratio of boys in the ASD group reflects the gender disproportion in the ASD population (Baio et al., 2018) and in the DD population (Hawke, Olson, Willcut, Wadsworth, & DeFries, 2009). There were no significant differences between the number of boys and girls in the control group ($p = .70$).

2.3. Infant/Toddler Sensory Profile – polish version

The Infant/Toddler Sensory Profile (Dunn, 2002) is a widely used questionnaire for the assessment of sensory patterns in infants and toddlers. There are two versions of the scale: for young infants from birth to 6 months of age, which contains 36 items, and for children aged 7 to 36 months, which contains 48 items. In this study, the former was used. The items are grouped by quadrants (Low registration, Q1; Sensation seeking, Q2; Sensory sensitivity, Q3; and Sensation avoiding, Q4) and by specific modalities (auditory, visual, vestibular, tactile, and oral). There is also one general subscale with items assessing reactions to changes in daily schedule, avoidance of playing with other children, and withdrawing from situations. Thus, ITSP scores reflect both overall responsiveness to stimuli (Q1 and Q3) and regulatory strategies (Q2 and Q4), as well as symptoms within specific modalities (subscales) and more general responses to stimuli (the general subscale).

Caregivers respond on a Likert-like scale (*almost always, frequently, occasionally, seldom, almost never*), with *almost always* scoring 1 point and *almost never* scoring 5 points. Consequently, higher scores reflect typical functioning or less significant symptoms, while lower scores reflect more severe symptoms.

ITSP was translated from English into Polish with the publisher's consent by psychologists-researchers fluent in English. Next, a professional translator translated the Polish version of the questionnaire back into English. A native English speaker compared the original and back-translated versions and some minor edits were made.

Cronbach's alphas were computed to estimate the reliability of the Polish version of the instrument. The analyses showed satisfactory reliability for all four quadrants: Q1 α = .88, Q2 α = .88, Q3 α = .81, and Q4 α = .84. These coefficients are similar or higher than those reported for the original ITSP (Q1 α = .70, Q2 α = .86, Q3 α = .72, and Q4 α = .70) (Dunn, 2002, p. 60). Also for subscale scores: general α = .69, auditory α = .85, visual α = .67, tactile α = .82, vestibular α = .60, and oral α = .71, the coefficients in our study are similar or higher than those reported in the ITSP manual (general α = .63, auditory α = .70, visual α = .55, tactile α = .72, vestibular α = .42, and oral α = .55) (Dunn, 2002, p. 60). Altogether, our data indicated that the Polish version of ITSP had high internal consistency when used to assess sensory processing in toddlers aged 16–36 months.

2.4. Statistical analyses

The first set of analyses concerned the differences between the ASD, DD, and control groups with regard to quadrant and subscale scores. The scores were entered into one-way ANOVAs with group (ASD, DD, control) as a factor and age as a covariate. Planned comparisons were used to compare the ASD and DD groups with controls and the ASD with the DD group.

Second, a hierarchical cluster analysis followed by a k-means cluster analysis was conducted to identify possible subtypes (subprofiles), i.e., distinct subgroups of participants with specific sensory profiles. As this analysis required all four quadrant scores, only participants who did not have any missing data were included ($n = 343$). A chi^2 test with subsequent Bonferroni-corrected *post hoc* comparisons was run to determine whether the numbers of participants from each group (ASD, DD, control) differed between clusters. For the method we used to apply Bonferroni corrections to *post-hoc* tests in the analyses of contingency tables, see Beasley and Schumacker (1995). ANOVAs and Bonferroni-corrected pair-wise comparisons were then used to characterize the four clusters.

Finally, we used ROC analyses to establish preliminary cut-off points for quadrant scores, which could be used for screening and diagnostic purposes.

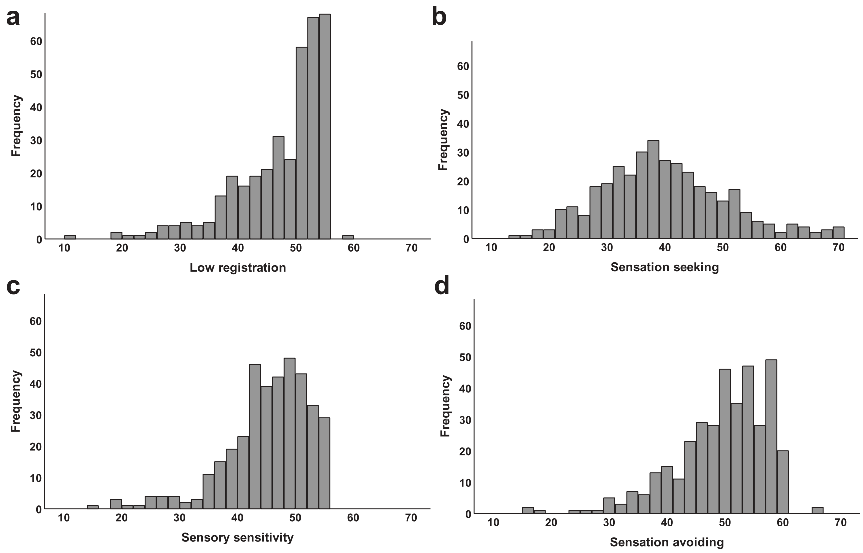

Figure 1. (a) Distributions of low registration scores in the whole sample. (b) Distributions of sensation seeking scores in the whole sample. (c) Distributions of sensory sensitivity scores in the whole sample. (d) Distributions of sensation avoiding scores in the whole sample.

3. Results

3.1. Sensory processing in toddlers with ASD, DD, and controls

Figure 1 presents the distributions of ITSP quadrant scores in the whole sample. This result was to be expected, as higher scores reflect normal functioning. Table 2 presents mean raw summary scores in quadrants and subscales, the results of the ANOVAs with planed comparisons for quadrant scores, and Bonferroni-corrected pairwise comparisons for subscale scores (see also Figure 2).

3.1.1. Low registration

A significant main effect of group was found for the *Low registration* quadrant. A planned comparison revealed a significant difference between children with ASD and controls. The ASD group scored lower than controls, indicating that they were more hyposensitive. Similarly, children with DD were more hyposensitive than controls. There was also a significant difference between the ASD and DD groups, with the children from the ASD group being more hyposensitive than children with DD.

Table 2. Descriptives and results of ANOVAs and planned comparisons for raw scores in quadrants and subscales by group.

	ASD		DD		Control			Age			Group			ASD-Control		DD-Control		ASD-DD	
	M	*SD*	*M*	*SD*	*M*	*SD*	n	*F*	η_p^2	*p*	*F*	η_p^2	*p*	*t*	*p*	*t*	*p*	*t*	*p*
Low registration	39.09	8.96	45.50	6.90	50.45	4.42	366	.06	.00	.81	108.60	.38	<.001	−11.40	< .001	−4.97	< .001	6.43	< .001
Sensation seeking	40.95	7.97	35.83	7.56	39.44	12.16	365	14.21	.04	< .001	2.84	.02	.06	.28	.84	−4.05	.02	−4.33	.03
Sensory sensitivity	40.04	9.28	42.34	6.28	47.10	5.13	365	.12	.00	.73	39.41	.18	< .001	−7.00	< .001	−4.75	< .001	2.25	.07
Sensation avoiding	41.75	9.14	46.71	6.72	52.36	5.36	373	.00	.00	.98	83.71	.31	< .001	−10.60	< .001	−5.64	< .001	−4.96	< .001
General	9.99	2.96	11.64	2.55	12.94	1.81	377	1.70	.01	.19	54.15	.23	< .001	−2.87	< .001	−1.26	.37	−1.61	< .001
Auditory	31.44	8.18	37.00	5.66	41.23	5.21	372	.46	.00	.50	84.35	.31	< .001	−9.94	< .001	−4.2	< .001	−5.62	< .001
Visual	22.49	4.92	22.36	3.53	24.78	4.88	369	.50	.00	.48	10.4	.05	< .001	−2.40	< .001	−2.4	.002	−.07	.94
Tactile	53.75	11.37	54.90	7.09	60.03	7.50	372	1.48	.00	.22	21.37	.10	< .001	−6.57	< .001	−5.24	< .001	1.34	.41
Vestibular	18.59	3.77	17.95	3.27	20.63	3.58	374	20.16	.05	< .001	22.97	.11	< .001	−2.51	< .001	−2.83	< .001	−.32	.62
Oral	25.52	5.79	26.20	5.50	29.65	4.08	374	2.68	.01	.10	31.6	.15	< .001	−4.34	< .001	−3.54	< .001	.79	.37

Abbreviations: ASD, autism spectrum disorders; DD, developmental disabilities

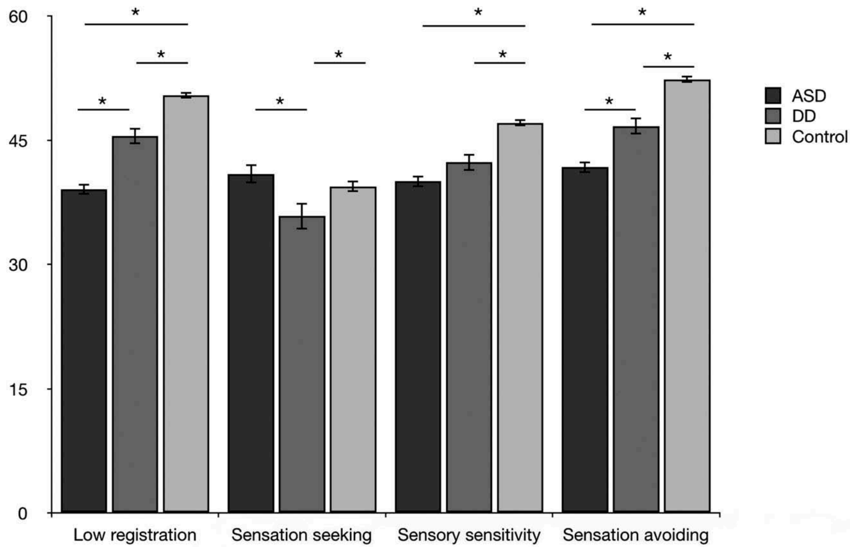

Figure 2. Mean raw quadrant scores by group (error bars represent SEM).

3.1.2. Sensation seeking

There was no significant main effect of group in sensation seeking; however, there was a trend approaching significance. A planned comparison did not reveal any significant differences between children with ASD and controls. There was, however, a significant difference between the DD and the control group. Children with DD scored lower than controls. They also scored lower than children with ASD. These results indicate that children with DD showed higher levels of sensation seeking than children with ASD and controls.

As the main effect of age was significant, we performed a correlation analysis to establish the relation between participant age and sensation seeking scores. There was a very weak but significant positive correlation ($r_\tau = .14$, $p < 001$).

3.1.3. Sensory sensitivity

A significant main effect of group was found for sensory sensitivity. A planned comparison revealed a significant difference between children with ASD and controls. Children with ASD scored lower than controls, indicating that they were more sensitive to sensory stimulation. Children with DD also were more sensitive than controls. With regard to the ASD and DD groups, a planned comparison did not reveal any significant difference.

3.1.4. Sensation avoiding

A significant main effect of group was found for sensation avoiding. A planned comparison revealed a significant difference between children with ASD and controls. Children with ASD scored lower than controls, indicating a greater tendency to avoid stimulation. Similarly, children with DD showed greater avoidance of sensory stimulation than controls. Finally, children with ASD scored lower than children with DD, which indicated that they were more prone to avoid sensory stimulation.

To sum up, the results revealed significant differences in sensory processing among children with ASD, DD, and TD controls. Results in three quadrants differentiated the ASD from the TD group. Toddlers with ASD were more hypo- and hypersensitive and displayed more sensation avoiding than TD children. Toddlers with DD differed from controls in all four quadrants, as they were more hypo- and hypersensitive and displayed more sensation seeking and avoiding. In comparison with the ASD group, children with DD were less hypo- and hypersensitive and showed more sensation seeking.

3.1.5. Subscale scores

The three groups of participants differed with regard to sensory symptoms in all modalities: auditory, visual, tactile, vestibular, and oral, as well as general difficulties (reactions to changes in routine, avoidance of playing with other children, and withdrawing from situations). In particular, the ASD group showed more severe symptoms than the control

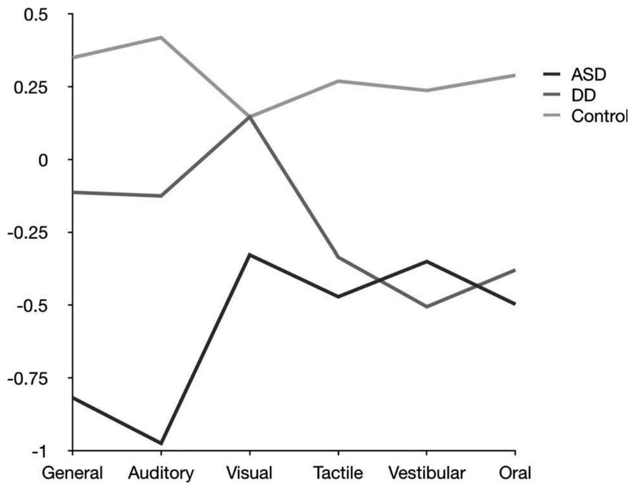

Figure 3. Mean z-scores in subscales by group.

Table 3. Sensory subtypes: descriptives and results of ANOVAs for quadrant scores and subscales.

	HA		HP		MS		EA		Age			Subtype		
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	η_p^2	*p*	*F*	η_p^2	*p*
Low registration	50.65	3.32	51.80	3.43	41.68	7.92	30.07	8.47	.37	.00	.54	228.33	.67	< .001
Sensation seeking	31.16	6.42	52.01	7.50	38.51	6.53	35.04	6.94	2.23	.01	.14	172.82	.61	< .001
Sensory sensitivity	46.46	4.20	49.95	4.07	41.23	5.01	29.79	8.57	2.06	.01	.15	144.42	.56	< .001
Sensation avoiding	52.08	4.04	54.72	4.38	43.91	4.58	31.07	6.47	1.11	.00	.29	251.60	.69	< .001
General	12.85	1.62	10.72	2.19	13.51	1.69	7.50	2.76	4.88	.01	.03	91.28	.45	< .001
Auditory	40.12	3.69	33.44	7.56	44.55	4.02	22.79	7.52	.51	.00	.48	227.18	.67	< .001
Visual	21.97	3.06	22.60	3.67	28.98	3.50	17.75	4.25	4.00	.01	.05	122.26	.52	< .001
Tactile	57.26	4.94	54.72	6.42	66.38	5.19	41.75	11.05	.81	.00	.78	138.5	.55	< .001
Vestibular	19.42	2.67	18.54	3.12	22.81	3.51	15.07	3.15	12.36	.04	< .001	61.60	.35	< .001
Oral	28.74	3.49	25.34	4.36	32.25	3.00	21.11	5.46	.06	.00	.81	87.71	.44	< .001

Abbreviations: HA, Healthy-active; HP, Healthy-passive; MS, Mild symptoms; EA, Extreme-active group, as did the DD group. Furthermore, the ASD group showed more severe symptoms regarding auditory processing and general behaviour than the DD group. The main effect of age was non-significant for all but the vestibular modality. A correlation analysis revealed that the scores in the vestibular processing subscale were significantly and positively correlated with age (r_τ = .13, p < 001); however, the correlation was very weak.

The number of items varied among subscales of the ITSP, therefore the subscale scores presented in Figure 3 have been standardized.

3.2 Sensory subtypes

We conducted k-means cluster analysis in the search for sensory subtypes among toddlers with ASD, DD and controls. Here we report the results of ANOVAs with cluster, i.e., subtype, as a factor and age as a covariate. Statistically significant differences between clusters are unsurprising, but a closer look at the differences in quadrant and subscale scores between clusters provides an outlook on the specificity of sensory subtypes (see Table 3–4 and Figure 4). The number of clusters was set *a priori* at four for three theoretical reasons: 1. according to Dunn's model (2002), four subtypes should be observed (low/high thresholds x active/passive); 2. previous studies have reported from three to five sensory subtypes (see a review in DeBoth & Reynolds, 2017); 3. In a study with a method closely resembling ours in which ITSP was used to assess sensory symptoms and the mean age of participants equalled 28 months (Ben-Sasson et al., 2008), but only toddlers with ASD were included, three subtypes emerged. As our sample also included typical controls, an additional subtype was expected. Furthermore, we conducted a hierarchical cluster analysis based on Ward's algorithm with squared Euclidean distances used as a distance measure. Ward's clustering was used in order to acquire clusters with minimum internal variance, internally cohesive and externally isolated. Figure S1 presents the dendrogram acquired, which indicates that a four-cluster solution is possible.

chi^2 test revealed that the number of participants from each of the three groups (ASD, DD, control) significantly differed between clusters, χ^2 (6, N = 343) = 152,55, p < .001 (see Table 5). Cluster 1 included fewer ASD and DD participants and more controls than expected. Cluster 2 included fewer ASD and DD participants and more controls than expected. Cluster 3 grouped more ASD and DD children and fewer controls than expected. Finally, cluster 4 grouped more ASD and fewer control participants than

Table 4. Sensory subtypes: bonferroni-corrected pairwise comparisons for quadrant scores and subscales.

	HA-HP		HA-MS		HA-EA		HP-MS		HP-EA		MS-EA	
	MD	*p*	MD	*p*	MD	*p*	MD	*p*	MD	*p*	MD	*p*
Low registration	−1.23	.28	8.89	< .001	20.47	< .001	10.12	< .001	21.70	< .001	11.58	< .001
Sensation seeking	−20.56	< .001	−7.06	< .001	−3.48	.10	13.49	< .001	17.07	< .001	3.58	.10
Sensory sensitivity	−3.69	< .001	5.01	< .001	16.4	< .001	8.70	< .001	20.10	< .001	11.39	< .001
Sensation avoiding	−2.78	< .001	8.04	< .001	20.82	< .001	10.82	< .001	23.61	< .001	12.79	< .001
General	−.79	.01	2.01	< .001	2.01	< .001	2.80	< .001	5.97	< .001	3.18	< .001
Auditory	−4.53	< .001	6.59	< .001	17.21	< .001	11.12	< .001	21.74	< .001	10.62	< .001
Visual	−7.21	< .001	−.83	.55	3.96	< .001	6.38	< .001	11.16	< .001	4.78	< .001
Tactile	−9.16	< .001	2.50	.03	15.48	< .001	11.66	< .001	24.61	< .001	12.95	< .001
Vestibular	−3.09	< .001	1.18	.04	4.7	< .001	4.27	< .001	7.84	< .001	3.57	< .001
Oral	−3.34	< .001	3.42	< .001	7.66	< .001	6.91	< .001	11.15	< .001	4.24	< .001

Abbreviations: HA, Healthy-active; HP, Healthy-passive; MS, Mild symptoms; EA, Extreme-active

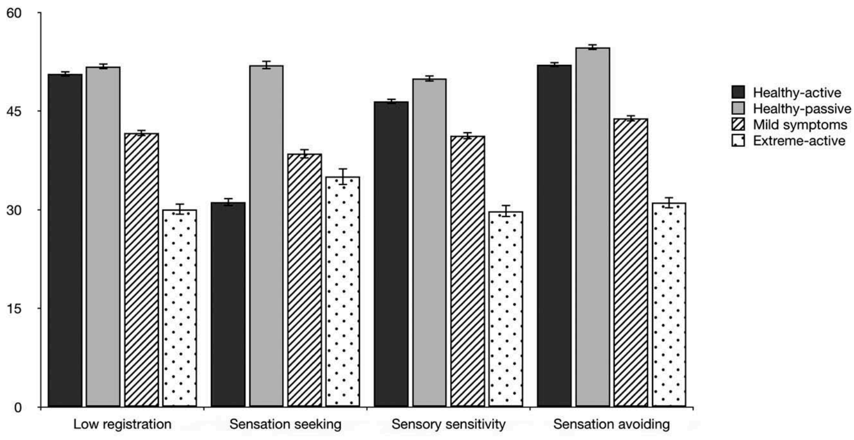

Figure 4. Mean raw quadrant scores by subtype (error bars represent SEM).

Table 5. Number of participants in the four clusters.

	Group			
Subtype	ASD	DD	Control	n
HA	5	13	111	129
z-score	−6.96*	−5.85	6.64	
p	< .001	< .001	< .001	
HP	14	4	83	101
z-score	−3.02*	−2.79	4.56	
p	.003	.005	< .001	
MS	42	19	24	85
z-score	6.06	3.67	−7.90	
p	< .001	< .001	< .001	
EA	24	3	1	28
z-score	7.79*	−.11	−6.93*	
p	< .001	.91	< .001	

Abbreviations: ASD, autism spectrum disorders; DD, developmental disability; HA, Healthy-active; HP, Healthy-passive; MS, Mild symptoms; EA, Extreme-active

expected. The number of DD children was not significantly different from the expected number in cluster 4.

There were no significant age differences between clusters ($p > .05$).

Based on the number of participants from each group (ASD, DD, control) who fell into each cluster and their sensory features (as indicated by the quadrant scores), we assigned the following names to the subtypes: Healthy-active (HA, cluster 1), Healthy-passive (HP, cluster 2), Mild symptoms (MS, cluster 3), and Extreme-active (EA, cluster 4).

We first present the results regarding the quadrant scores. The HA and HP subtypes differed with regard to the amount of sensation seeking. While the children with the HA subtype tended to seek sensation, children with HP did so to a lesser extent. The HA group was also somewhat more prone to avoid stimulation than the HP group, although the mean difference was relatively low. Moreover, the HP group was less sensitive than the HA one.

Children with the MS subtype were more sensitive than the HA and HP groups, but they were less sensitive than the EA group. They were also more under-responsive than the HA and HP groups. Finally, they were less active than the HA group but more active than the HP group. In particular, they showed less sensation seeking than HA children and more sensation seeking than the HP ones. Consistent with these results, they were less prone to avoid stimulation than the HA and more prone to avoid stimulation than the HP group.

Children with the EA subtype differed from those with mild symptoms and the HA and HP groups with regard to low registration, sensory sensitivity, and sensation avoiding. They were very hypo-sensitive to certain stimuli and hyper-sensitive to other kinds of stimuli, and they actively avoided stimulation. Notably, while the children with the HA subtype were only active in seeking, the EA group tended to actively seek and avoid stimulation, consistent with their mixed sensitivity levels.

There were no significant main effects of age for any quadrant score.

The differences between participants with different sensory subtypes also manifested in subscale scores for different modalities. As the number of

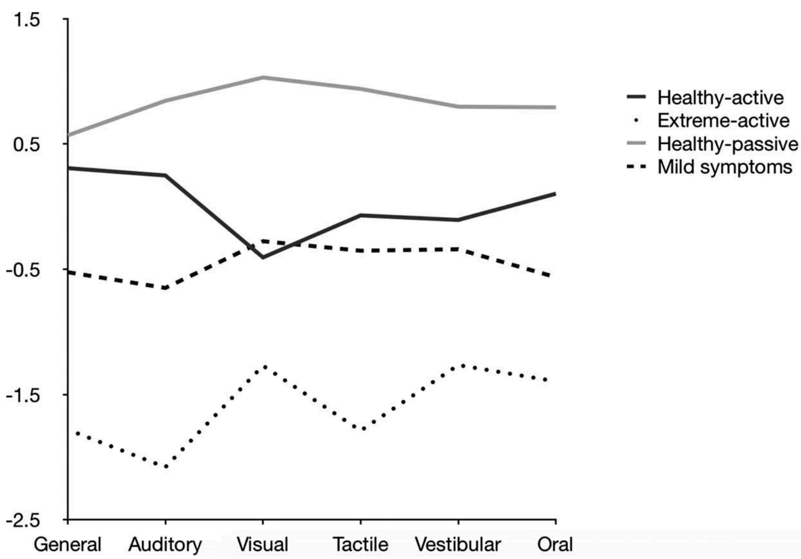

Figure 5. Mean z-scores in subscales by subtype.

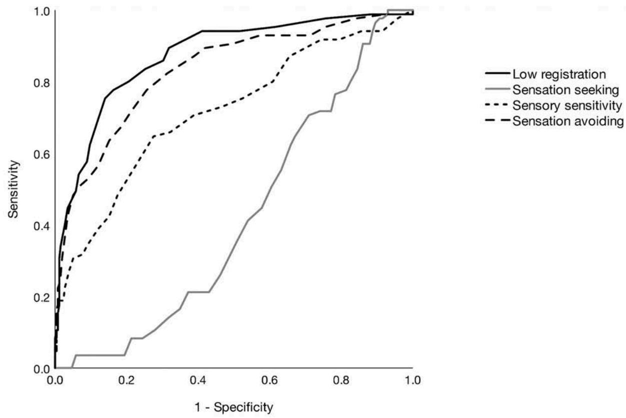

Figure 6. ROC for quadrant scores: ASD versus DD and control groups.

items varied between subscales, Figure 5 represents *z*-scores. Overall, pairwise comparisons revealed significant differences between almost all pairs of subtypes in all subscales, except for visual processing in the HA and MS subtypes. The HP subtype had the lowest symptoms in all modalities, while the EA subtype had the highest symptoms. The EA subtype had the most significant symptoms in the domains of visual and tactile processing. Symptoms in the HA group were somewhat higher than in the MS group. There were significant main effects of age for two subscales: general and vestibular. Correlation analyses revealed significant and positive correlations between age and general processing ($r_\tau = -.08$, $p = .026$) and between age and vestibular processing ($r_\tau = .13$, $p < .001$). The correlations were, however, very weak.

3.3 Quadrant scores as red flags – tentative cutoff points

Following up on the results that showed significant group differences, we examined the potential usefulness of the Polish ITSP as a complementary tool in early screening and diagnosis. We aimed at finding the cut-off scores that would be highly sensitive, to maximize probability of detection (decrease the number of false negatives), but also specific to ASD. Figure 6 presents ROC for all quadrants.

First, we examined whether quadrant scores distinguished the ASD from the other two groups (DD and control). With regard to *Low registration*, the accuracy proved good, AUC = .87, SE = .02, $p < .001$, BCa 95% CI [.83, .92]. Based on the coordinates of the ROC curve, we suggest a cut-off point of 47, with a high sensitivity (.80) and specificity (.80), and a Youden's index $J = .60$. A score of 47 or below would indicate that the child's sensory symptoms, i.e., under-responsiveness, are consistent with ASD.

Scores in the *Sensation seeking* quadrant, poorly differentiated the groups (AUC = .58, SE = .03, p = .016, BCa 95% CI [.52, .65]), therefore they may not be useful in early screening.

Regarding *Sensory sensitivity*, the accuracy was acceptable, AUC = .72, SE = .03, p < .001, BCa 95% CI [.65, .72]. However, the tradeoff between sensitivity and specificity was less favourable than for the *Low registration* quadrant. A score of 49 with the sensitivity of .80 had a specificity of .39, Youden's index $J = .19$. The score of 49 or lower would suggest that a child has sensory symptoms consistent with ASD but would yield a substantial number of false positives.

Finally, with regard to *Sensation avoiding* (AUC = .83, SE = .03, p < .001, BCa 95% CI [.78, .88]), a score of 50 had high sensitivity, .82, and moderate specificity, .69, Youden's index $J = .51$. Thus, scores in this subscale would correctly identify most toddlers with symptoms consistent with ASD, but also many other children.

For screening and initial diagnosis, some descriptive statistics may also be used as points of reference. For the *Low registration* quadrant, the median score was 50 and 37 was the 10th percentile. Lower scores indicate more significant symptoms, therefore scores equal or below the 10th percentile would indicate elevated symptoms. For *Sensation seeking*, the median was 38 and the 10th percentile was 26. However, this quadrant did not differentiate the ASD and control groups, therefore its usefulness in screening and early stages of diagnosis is limited. For *Sensory sensitivity* the median was 46 and 36 was the 10th percentile, and for *Sensation avoiding* the median was 50 and the 10th percentile was 38.

To sum up, scores in three quadrants differentiated the ASD and other groups, namely *Low registration, Sensory sensitivity* and *Sensation avoiding*. We propose that the scores of 47, 49, and 50, respectively be used as cut-off points for this version of the ITSP in as a complementary tool in initial stages of diagnosis to identify children with sensory symptoms consistent with ASD.

4. Discussion

In this study we used the Polish version of the Infant/Toddler Sensory Profile to examine sensory hypo- and hypersensitivity, sensation seeking and avoiding behaviours in toddlers aged 16 to 36 months with ASD, other developmental disabilities and typically developing controls. First, we compared sensory symptoms in the three groups of participants. Results revealed significant differences between the ASD, DD and control groups. Children with ASD scored significantly lower on *Low registration, Sensory sensitivity*, and *Sensation avoiding* than controls, indicating that they were more hypo- and hypersensitive, and showed more active avoidance of stimulation. These children did not differ from controls with regard to *Sensation seeking*. Toddlers with DD also scored significantly lower on *Low registration, Sensory sensitivity*, and *Sensation avoiding* than controls. Their scores in these quadrants were, however, significantly higher than those of children with ASD, indicating that they were less hypo- and hypersensitive and less prone to avoid stimulation than children with ASD. The DD group also differed from controls regarding *Sensation seeking* scores. Children with DD showed more sensation seeking than controls.

Our results are consistent with previous findings on sensory processing in children with ASD obtained mostly from North American samples of similar age (e.g., Baranek et al., 2006; Ben-Sasson et al., 2009).

In terms of Dunn's Model for Sensory Processing (Dunn, 1997), our results demonstrated that young children with ASD had low sensory thresholds for some kinds of stimuli and high thresholds for other kinds of stimuli. Our results are consistent with previous studies, which have also showed that children with ASD were both hypo- and hypersensitive (Ausderau et al., 2014; Ben-Sasson et al., 2007, 2008). The co-occurrence of seemingly contradictory characteristics fits with Pellicano's (2013) conception of attenuated perceptual constraints resulting in atypical processing of stimulation. As a result, children with ASD self-regulate by actively avoiding sensations and controlling sensory input, as evidenced by their *Sensation avoiding* scores. Concurrently, their relatively low sensation seeking indicated that they did not seem to seek stimulation to compensate for their hyposensitivity to certain kinds of stimulation. Active seeking or enhancement of input that falls below sensory thresholds may be beyond the capacities of infants and toddlers.

These specific sensory symptoms observed in toddlers with ASD may hamper everyday interactions with their caregivers. On the one hand, children may frequently and chronically experience discomfort due to over-stimulation and may be over-involved in avoidance behaviours. This may contribute to them being easily irritable, unengaged interaction partners (e.g., Bearss, Johnson, Handen, Smith, & Scahill, 2013). Because of under-sensitivity to certain stimuli, they may miss some social cues (e.g., bids to initiate joint attention), resulting in failures to engage in social exchanges. They may also over-engage in certain stimuli and, as a result, may have difficulties developing some more advanced attention-sharing behaviours that require dynamic changes in the deployment of attention. On the other hand, parents may be challenged by their child's sensory behaviours as the process of identifying the sources of over and under stimulation may be onerous and time-consuming. Moreover, predicting the child's reaction to new stimuli may be particularly difficult. Finally, attempts to encourage children to experience new stimulation may frequently lead to failure. For all these reasons, parents of children with more severe sensory symptoms may report high levels of parenting stress (Ben-Sasson, Soto, Martinez-Pedraza, & Carter, 2013; Schaaf, Toth-Cohen, Johnson, Outten, & Benevides, 2011). To sum up, due to sensory symptoms children with ASD may rarely be in a calm and attentive state, necessary for satisfactory social interactions. Concurrently, parents may struggle to provide optimal settings for these interactions and tune to their child's behaviour. Sensory symptoms may also affect many other, if not all, aspects of a child's everyday life, such as eating, personal hygiene, sleep, play, learning and contact with peers. These difficulties may be addressed by therapeutic approaches focused on improving parent-child interactions.

The DD group in our study included 15 children with Down syndrome and 29 children with general developmental delay and language disorder, all without ASD. It had been included as a complementary comparison group. We predicted that the sensory symptoms in this group would be less severe than in the ASD group but more frequent than in the TD group. Results showed that scores in all four quadrants differentiated these children from controls. In comparison with the ASD group, children with DD showed lower levels of low registration, sensory sensitivity and sensation avoiding, indicating that they were less hypo- and hypersensitive, and less prone to avoid stimulation. These results are partially consistent with findings of previous studies (see Ben-Sasson et al., 2009 for a review) which showed that children with ASD and DD differ with respect to certain sensory symptoms. Our results showed that sensory sensitivity, as well as sensation seeking and avoiding behaviours distinguished children with DD from controls and from children with ASD. It is noteworthy, however, that Rogers, Hepburn, and Wehner (2003) demonstrated that, when matched on mental age, developmentally delayed children did not significantly differ from controls in their sensory reactivity. Furthermore, another study (Baranek et al., 2013) showed a significant relation between mental age and sensory processing, as the symptoms decreased with age.

Children with ASD, as those with DD, exhibited more symptoms in all modalities than controls. However, the only two modalities that differentiated children with ASD from the DD group were general and auditory processing. This reflects the specificity of autistic symptoms, as individuals with ASD react negatively to changes, have difficulties in peer relations, and tend to withdraw from situations (behaviours probed by the general subscale). Impaired auditory processing is also prevalent in ASD (Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011; Rogers et al., 2003; Tomchek & Dunn, 2007). Studies have also shown that tactile processing was atypical in ASD (Baranek, Foster, & Berkson, 1997; Foss-Feig, Heacock, & Cascio, 2012; Rogers et al., 2003; Tomchek & Dunn, 2007); however, in our study, scores in this subscale did not differentiate the ASD and DD groups. These results indicate that the ITSP accurately identified certain – but possibly not all – modality-specific symptoms in the ASD group.

It is worth noting that, despite the young age of the ASD group relative to the average age of diagnosis and the large heterogeneity within the studied groups, ITSP quadrant scores differentiated all three of them. Three quadrants differentiated the ASD group from controls, and all four quadrants differentiated the ASD from the DD group. Furthermore, scores in all four quadrants distinguished children with DD from controls.

The examination of sensory subtypes in children with ASD not only may have important practical implications (Lane, Young, Baker, & Angley, 2010), but it can also inform our understanding of the mechanisms underlying sensory symptoms in ASD. Therefore, the second set of analyses was aimed at finding subgroups of participants characterized by distinct sensory patterns. We identified four subtypes, two of which grouped a majority of typically developing participants, that is the Healthy-active and Healthy-passive subtypes. These groups included 5% and 15% of children with ASD, respectively. Overall, toddlers with the HA or HP subtype did not show any significant difficulties in sensory processing. However, they differed in their regulatory behaviours, as the passive group tended to seek sensation to a lesser extent than the HP group. The HA subtype seems to correspond with the Interested subtype, and the HP corresponds with the Balanced subtype in Little et al. (2017). The Balanced subtype, which was the most prevalent, is graphically represented by a flat line, reflecting similar scores in all ITSP quadrants. In our study, the

HA subtype was the most common (38% of the sample). This subtype is represented graphically by a line with a conspicuous spike, which indicates relatively elevated sensation seeking. Notably, the age range in Little et al. (2016) was broad, from 3 to 14 years, and children with the Interested subtype were on average younger than the other participants in that study. Our participants were toddlers (mean age 24.98 months), and the active pattern was prevalent. This is consistent with a typical developmental trend whereby typically developing young children are prone to seek sensory stimulation. The HA group was also somewhat more sensitive and had a greater tendency to avoid stimulation than the HP one, however the degree of sensation seeking was by far the most significant difference between the two healthy subtypes. Parents of the HP toddlers reported significantly fewer symptoms in all modalities than those of HA toddlers, which further suggests that the HP subtype closely resembles the Balanced subtype in older children.

Forty-nine percent of children with ASD in our sample fell into the MS group. This subtype was characterized by a pattern similar to the HP one, with a greater rate of symptoms. These children displayed some – but not severe – sensory symptoms, hypo- and hypersensitivity, and some degree of sensation seeking, as well as avoiding. This group of children was, however, less prone to seek stimulation than HA children. The subtype seems to correspond with the Mild subtype in Ausderau, Furlong et al. (2014), although in that study the age range was broader, from 2 to 12 years, and a different instrument was used (Sensory Experience Questionnaire 3.0; Baranek, David, Poe, Stone, & Watson, (2006)). The methodology in Ben-Sasson et al. (2008) closely resembled ours, as the ITSP was used and the mean age of participants was 28 months. The MS subtype in our study is to a certain extent similar to the Mixed subtype. While the sample in Ben-Sasson et al. (2008) only included toddlers with ASD, in our sample 7% of healthy controls and almost half of the DD children also fell into the MS category. These children displayed more symptoms in all modalities in comparison with the HP group and in most modalities in comparison with the HA group, except for visual processing. This demonstrated the presence of some sensory processing difficulties in a group of otherwise typically developing toddlers and in many toddlers with DD.

The Extreme-active subtype was characterized by the most severe sensory symptoms and was the least common (8% of participants). This pattern was displayed by 28% of children with ASD, three children with

DD and only one typically developing toddler. It corresponded with the Extreme-mixed pattern in Ausderau, Furlong et al. (2014) and the High frequency of sensory behaviours subtype in Ben-Sasson et al. (2008). EA toddlers showed significant under- and oversensitivity, avoidance of stimuli, and severe symptoms in all modalities. Notably, these children did not differ from the HA group with regard to sensation seeking, as these two groups showed significantly more sensation seeking behaviours than HP and MS toddlers. However, as the EA group was more hypo- and hypersensitive and showed a greater tendency to avoid stimulation than the HA group, it is possible that the seeking of sensory stimulation reflected a different process or had a different function for these two groups of children. While in the HA group the tendency to seek stimulation was *greater* than would be expected in a more balanced pattern, sensation seeking in the EA group was *lower* than expected considering the otherwise severe symptoms. In the case of TD children, sensation seeking may be a curiosity-driven exploratory behaviour. In children with ASD, however, seeking and avoiding may serve as coping strategies they use to deal with under- or over-stimulation. It may be beneficial for therapists to evaluate sensory thresholds for different kinds of stimuli, as well as to assess which seeking or avoidance behaviours are in fact effective strategies, and which are maladaptive and need to be modified. This is particularly important as the extreme pattern is associated with elevated affective symptoms (Ben-Sasson et al., 2008), high maladaptive behaviour, and parenting stress (Ausderau et al., 2014). The other two dysfunctional patterns found by Ausderau and colleagues (2016), namely the Attenuated-preoccupied and Sensitive-distressed subtypes, did not find matches in our sample. This may be partially explained by differences in the age range of participants, as well as the use of different instruments. Furthermore, as mentioned earlier, parental perceptions of sensory symptoms in young children vary across countries (Matson et al., 2017), which may account for the discrepancies between results. More studies are needed to examine these differences, as conclusions drawn from studies conducted in English-speaking countries may not be fully pertinent to other populations.

Overall, of the four subtypes identified in our study, the Extreme subtype, prevalent in children with ASD, seemed to be the most universal insofar as similar patterns were also described in Ausderau, Furlong et al. (2014) and Ben-Sasson et al. (2008), despite differences between samples. The Mild symptoms subtype was consistent with the subtype of the same name in Ausderau, Furlong et al. (2014). The Healthy-active and Healthy-passive subtypes in our study corresponded with the Interested and Balanced subtypes, respectively, in Little et al. (2016), but their prevalence differed. In our sample the Healthy-active subtype prevailed, while the Balanced subtype was most common in Little et al. (2016). This may be partially explained by differences in sample characteristics, as the mean age in our study was lower than in Little et al. (2016).

As the ITSP is a parent-report measure with a relatively short administration time and items that directly relate to everyday activities and easily observable behaviours, it seems to be a good complementary measure for early screening and initial stages of diagnosis. Although further studies are needed in order to establish the psychometric properties of the Polish version of the ITSP, the tentative cut-off points presented in this paper may serve as a point of reference in clinical practice. ROC analyses indicated that scores in the Low registration quadrant had the most favourable sensitivity to specificity ratio, hence they may be the most efficient as a red flag. Scores in the Sensory sensitivity and Sensation avoiding quadrants may be useful in identifying children with elevated symptoms in those domains; however, cut-off scores with high sensitivity (potentially useful in screening) are rather non-specific. Scores in the Sensation seeking quadrant did not effectively differentiate children with ASD and controls. Despite that, the results indicate that the Polish version of the ITSP may be a useful complementary tool in early diagnosis of young children exhibiting symptoms of various developmental disorders.

Some limitations of our study should be noted. First, we only used one tool, the ITSP, whereas assessments of autistic symptoms, overall functioning, or mental age of participants could provide a more in-depth understanding of the results. Assessment of internalizing symptoms, sleep problems, and externalizing behaviour would be especially valuable, as previous studies have established certain relations between those symptoms and atypical patterns of sensory processing (e.g., Ben-Sasson et al., 2008; Carter, Ben-Sasson, & Briggs-Gowan, 2011; Gourley, Wind, Henninger, & Chinitz, 2013; Mazurek & Petroski, 2015). This constitutes an important area for future research. Second, children from the control group were significantly younger than children in the ASD group. As certain sensory symptoms may only manifest at a later age, had the children from the ASD group been assessed at a younger age, perhaps the group differences would have been less pronounced.

Third, few socio-demographic characteristics of the sample were available for analysis. Finally, the DD group was heterogeneous, relatively small, and not matched on mental age with the ASD group or controls. However, this group was used primarily as a comparison group, and an examination of sensory processing in children with DD without autism was beyond the scope of this study.

5. Conclusions

This study replicated to a large extent existing findings on sensory symptoms in toddlers with ASD, who showed symptoms of hypo- and hypersensitivity and actively avoided stimulation. Nevertheless, subtypes characterized by distinct sensory features were found. Although the most dysfunctional pattern of sensory processing identified in our study was almost exclusive to children with ASD, approximately one in two toddlers with ASD displayed relatively mild symptoms. The results of this study indicate that the Polish version of the ITSP could be used in early diagnosis as well as in future research. More studies are needed to establish the diagnostic usefulness of other language versions of the instrument.

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