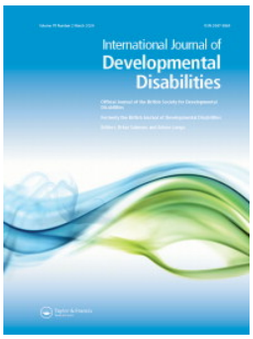

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Cross-disorder comparison of sensory reactivity, pain, gastro-intestinal symptoms and obsessive-compulsive symptoms in adolescents and young adults with autism and other neurodevelopmental disorders

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There is considerable evidence of the relationship among sensory reactivity, abdominal pain, and gastrointestinal symptoms in individuals with Autism Spectrum Disorder (ASD). Furthermore, these events are linked to the gut-microbiota-brain axis *via* the enteric nervous system. However, few studies have compared autism with other neurodevelopmental disorders in terms of sensory reactivity, pain, or gastrointestinal symptoms. Consequently, this study aimed to analyze the differences in sensory reactivity, pain, and gastrointestinal symptoms between adolescents and young adults with ASD and other neurodevelopmental and neurotypical disorders. Differences in sensory reactivity, pain, gastrointestinal symptoms, and obsessive-compulsive symptoms between a group of individuals with ASD level I ($n = 37$), Attention Deficit Hyperactivity Disorder or ADHD ($n = 15$), Learning Difficulties or LD ($n = 23$), and a control or neurotypical group ($n = 76$) were analyzed. Higher levels of sensory hyperreactivity were found in individuals with ASD than in the other clinical (ADHD and LD) and neurotypical groups. Sensory hyporeactivity was greater in individuals with ASD as well as in individuals with ADHD than that in the neurotypical group. Higher levels of pain were found in the ADHD group than in the ASD or neurotypical group. Gastrointestinal symptoms of the abdominal type were more severe in the ASD group than in the ADHD, and LD groups, whereas dyspepsia was more severe in the ADHD group. The results indicate a sensory and gastrointestinal profile in individuals with ASD and ADHD. Future studies should increase the number of participants for each neurodevelopmental disorder and perform a more comprehensive analysis of the gut microbiota-brain axis.

Keywords: Autism; attention deficit hyperactivity disorder; learning difficulties; sensitivity reactivity; pain; gastro-intestinal symptoms

Introduction

Altered sensory responsiveness refers to impairment in the modulation of output to several forms of sensory stimuli, including visual, auditory, tactile, odour, taste, and proprioceptive stimuli. Consequently, affected individuals may exhibit altered behaviour that manifests as sensory hyperreactivity/Sensory Over-Responsivity (SOR), sensory hyporeactivity/Sensory Under-Responsivity (SUR), and sensation seeking (Miller *et al.* 2007).

Altered sensory responsiveness is included in the Diagnostic and Statistical Manual of Mental Disorders

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(DSM-5) as a component of restricted and repetitive behaviors (RRBs) in autism spectrum disorder (ASD) (APA 2013, 2022). RRBs are common transdiagnostic symptoms that can appear in both ASD and Obsessive-Compulsive Disorder (OCD). Thus, meta-analysis studies have indicated a prevalence of approximately 20% for OCD symptoms in ASD. Specifically, the rates of OCD with a current prevalence estimate of 24% and a lifetime prevalence of 22% in adults with ASD (Hollocks *et al.* 2019), and 17.4% in children with ASD (Van Steensel *et al.* 2011). Furthermore, there is a relationship between sensory alterations and RRBs in ASD (Fetta *et al.* 2021).

Sensory responses are impaired in 45–95% of individuals with ASD (Baranek 2009, Tomchek and Dunn 2007). In this respect, a recent meta-analysis found that individuals with ASD have significantly higher (large effect) scores on SOR, SUR, and sensation seeking than neurotypical controls (Ben-Sasson *et al.* 2019). Moreover, many studies have shown a relationship between RRBs and emotional states among individuals with ASD, as RRBs have been linked to anxiety and stress (for example, Glod *et al.* 2019, Renna *et al.* 2018, Russell *et al.* 2019). However, altered sensory responsivity has also been found in other disorders such as Attention-Deficit/Hyperactivity Disorder (ADHD), learning disabilities (LD), intellectual disability, anxiety disorders, and trichotillomania (for example, Armstrong 2019, Conelea *et al.* 2014, Crow *et al.* 2020, Falkenstein *et al.* 2018, Panagiotidi *et al.* 2018). Other meta-analyses have indicated that olfactory dysfunction is evident in individuals with ASD and Obsessive-Compulsive Disorder (OCD), with small to insignificant effects on ADHD (Crow *et al.* 2020). These findings suggest that olfactory dysfunction is associated with the clinical phenotypes of ASD and OCD but not ADHD. There are differences in the connections of neural networks between individuals with and without ASD during sensory perception (Jassim *et al.* 2021). A recent study indicated that children and adolescents with LD have altered auditory processing and show a specific cognitive profile, including lower verbal and spatial reasoning performances (Cunha *et al.* 2019). Furthermore, visuomotor impairment is greater in individuals with LD than in neurotypical or healthy individuals (Mekki *et al.* 2022, Mirzakhani and Shahriarpour 2021). In addition, SOR-related difficulties are more severe in individuals with OCD than in healthy individuals, further supporting the causal relationship between neurological disorders and SOR and suggesting its transdiagnostic nature (Isaacs *et al.* 2022). Research on sensory reactivity in the general population has also found a strong association between SOR and OCD symptoms (Ben-Sasson and Podoly 2017, Taylor *et al.* 2014).

Recent findings indicate that SOR, abdominal pain, and anxiety are related to both clinical and non-clinical populations (Dufton *et al.* 2010, Mazefsky *et al.* 2021, Mazurek *et al.* 2014, 2013, Thapar *et al.* 2020). In this respect, functional abdominal pain disorders are common, accounting for 3–16% of the general population (Thapar *et al.* 2020). An incidence of 40–70% of gastrointestinal symptoms (GS) in ASD has been reported (Leader *et al.* 2022). Furthermore, GS may exacerbate repetitive behaviors, or vice versa, independent of other associated behavioral symptoms (Chakraborty *et al.* 2021). Selective or restrictive dietary patterns (e.g. picky eaters) are related to GS in individuals with ASD (for example, Berding and Donovan 2018, Leader *et al.* 2022). Thus, GS, such as constipation, are more severe in individuals with ASD than in neurotypical controls (Leader *et al.* 2022). Furthermore, children with ASD and GS have significantly higher rates of anxiety and SOR (Kurokawa, *et al.* 2021, Mazurek *et al.* 2013). Similarly, associations have been found between anxiety, SOR, and chronic abdominal pain, with SOR being a significant predictor of pain onset (Mazurek *et al.* 2014). Therefore, abdominal pain appears to be more common in children with ASD. These findings suggest that anxiety, SOR, GS, and abdominal pain are possibly interrelated phenomena that may share common underlying mechanisms (Mazurek *et al.* 2013, 2014). Furthermore, several studies have pointed out the relationship between abdominal pain, selective dietary patterns, emotional instability, and gut dysbiosis in neurodevelopmental disorders such as ASD, all of which seem to be related to the gut–microbiota–brain axis (Leader *et al.* 2022, Plaza-Diaz *et al.* 2021, Rose *et al.* 2018). The 'gut–microbiota–brain axis' refers to the network of connections involving multiple biological systems (central nervous system, digestive system, immune system, etc.) that allows bidirectional communication between gut bacteria and the brain (Morais *et al.* 2021). Thus, studies indicate between 40 and 70% GI symptoms in individuals with ASD. Among the studies that found differences, correlations have been found between GI symptoms and gut microbe abundance (Gan *et al.* 2023). However, it is still too early to draw conclusions regarding the gut microbes involved in the GI symptoms of ASD (Coe *et al.* 2023).

In summary, previous scientific literature has pointed out at high incidence of GI symptoms in ASD. However, no comparative studies have been conducted on GI symptoms and pain in neurodevelopmental disorders. In this study, we expect to find differences in these variables between the neurotypical group and each of the clinical groups (ASD, ADHD, and LD). On the other hand, ASD is fundamentally characterized by sensory reactivity and repetitive behaviors (APA 2022). Therefore, higher scores in obsessive-compulsive symptoms and sensory hyper-reactivity are expected in individuals with ASD than in those with ADHD and LD.

Sensory hyporeactivity has been little explored in ADHD and information that could help understand the etiology of ADHD is expected to be found. Thus, the present study aimed to examine differences in sensory reactivity, pain, and GS between individuals with ASD and those with other neurodevelopmental disorders (ADHD and LD).

Methods

Participants

The present study used a clinical sample of 75 adults, of whom 37 were individuals with ASD, 15 with ADHD, and 23 with LD, and a neurotypical sample of 76. The participants were from the south of Spain: from the Valencian Community, Region of Murcia, and Andalusia. Individuals with ASD, ADHD, and LD were recruited from different university centers. The DSM-5 diagnostic criteria (APA 2013) were the referent for the inclusion criteria of the clinical sample. All individuals with ASD, ADHD, and LD had previously been diagnosed by mental health services or institutions responsible for determining their level of disability and dependency. Participants with ASD have a level 1 ASD and no intellectual disability. Table 1 presents the socio-demographic characteristics of the participants.

Measures

Sensory Over-Responsivity Scales (SOR-Scales)

The SORS measure assesses sensory hyperreactivity to auditory, tactile, visual, olfactory, and taste stimuli, and was adapted from a measure used with a general community sample in a survey study (Taylor *et al.* 2014). It consists of rating scales for distress and impairment of both auditory and tactile over reactivity (Falkenstein *et al.* 2018). Each SORs contains four questions rated on a scale of 0 to 4, with overall scores ranging from 0 to 80. Total scores for each subscale were separated and ranged from 0 to 16, with the highest scores indicating high severity. Cronbach's alpha to evaluate the internal consistency of the SOR scales and their subscales show strong internal consistency in the United States sample (SOR-Total = 0.93; SOR-Hearing = 0.89; SOR-Touch = 0.88; SOR-Smell = 0.90, SOR-Sight = 0.94, and SOR-Taste = 0.88) and in the Spanish sample (hearing = 0.89; touch = 0.86; smell = 0.91; sight = 0.90; and taste = 0.86) (Moreno-Amador *et al.* 2023).

Pain and Sensitivity Reactivity Scale (PSRS)

The PSRS is a 50-item scale that evaluates reactivity to pain and sensory reactivity. It comprises of three dimensions: pain, sensory hyporeactivity, and sensory hyperreactivity. Items are rated on a four-point Likert scale ranging from 0 (behavior does not occur) to 3 (behavior occurs and is a severe problem). The dimensions of hyposensitivity and hypersensitivity include tactile, olfactory, visual, gustatory, and auditory items. In addition, the PSRS includes a pain reactivity domain with seven items. The PSRS contains two versions: a version for caregivers-professionals and another self-reported version. The self-report version was used in this study. Cronbach's alpha to evaluate the internal consistency of the total scale and its subscales showed strong internal consistency in the Spanish sample (PSRS-Total = 0.92; Pain = 0.79: Sensory hyporeactivity Total = 0.88; Sensory hyperreactivity Total = 0.90).

Severity Scale of Gastrointestinal Symptoms Gastrointestinal Symptom Severity Scale (GSSS)

The instrument was based on the Rome IV criteria (Drossman and Hasler, 2016), and consisted of seven items of the main GS (constipation, diarrhoea, average stool consistency, stool odour, flatulence, gas, and abdominal pain). Items are rated on a four-point Likert scale ranging from 0 (None/nothing or this symptom does not occur) to 3 (very frequent and bothersome symptoms). The instrument has an abdominal subscale (abdominal pain, gas, and constipation) and a vomiting and defecation subscale (vomiting, defecation in inappropriate places, diarrhoea, and rumination). The instrument developed by the GINTA group contains two versions: a version for caregivers-professionals and a self-reported version. The GSSS presents a single factor and has adequate psychometric properties in a neurotypical young adult population ($\alpha = 0.68$; $\omega = 0.70$).

Clinical questionnaire on gastro-intestinal disorders

An *ad hoc* questionnaire developed for gastrointestinal disorders according to the Rome criteria (Rasquin *et al.* 2006, Drossman and Hasler, 2016). It consists of a

Table 1. Sociodemographic characteristics of the total sample.

Variables	NT	ASD	ADHD	LD	TCS
n	76	37	15	23	75
Years old	19.18 (4.44)	21.46 (6.01)	18.87 (2.41)	21.30 (9.40)	21.89 (6.78)
Gender					
Female	47 (61.8%)	13 (35.1%)	8 (53.3%)	19 (82.6%)	40 (53.3%)
Male	29 (38.2%)	24 (64.9)	7 (46.7%)	4 (17.4%)	35 (46.7%)

Note. Neurotypical participants = NT. Autism Spectrum Disorder = ASD. Attention-Deficit/Hyperactivity Disorder = ADHD. Learning Disabilities = LD. Total clinical sample = TCS.

series of questions about gastrointestinal disorders (e.g. diarrhea, abdominal pain, dyspepsia, and gastroesophageal reflux). The presence or absence of a digestive disorder is indicated according to the experiences of the previous month. In addition, the questionnaire includes information on the continued presence of digestive of disorders among the family members.

Obsessive-Compulsive inventory – revised (OCI-R)

The OCI-R is an 18 item self-report questionnaire assessing obsessive-compulsive symptom severity with a 5-point Likert scale ranging from 0 (not at all) to 4 (very much). The OCI-R is composed of six factors that represent the following symptom domains: checking, ordering, neutralizing, washing, obsessing, and hoarding (Foa *et al.* 2002). Each factor is composed of three items (possible range = 0–12). Overall, the measure shows good internal consistency in different countries (Cronbach's α range 0.81- 0.95) (Hon *et al.*2019).

Procedures

All the participants were residents of Spain. Young adults from different universities and educational centres in Spain participated in this study. The survey was carried out using online data collection. The reporting assessment protocol was applied individually using the online survey tool LimeSurvey (LimeSurvey GmbH). Appropriate instructions were provided on each scale. The total time required to complete all scales was approximately 20 min. The survey was conducted between November 2020 and December 2021. Participants completed the protocol in their classrooms. The researcher remained in the classroom during the administration to assist students who experienced difficulties. The tests were administered by experienced psychologists who provided instructions and individual assistance to students who needed it.

Neurotypical participants (NT) were randomly chosen from a sample of 1,122 Spanish young adults who completed the online protocol. Participants with neurodevelopmental disorders were previously identified through the orientation service of each educational center and the diversity attention service of the universities. Participants had a recognised clinical diagnosis by a mental health centre and a recognised degree of disability. This information was verified by the diversity service of the participating universities. Participants with ASD had a level 1 autism severity and no intellectual disability. Participants with ASD received emails and phone calls requesting their participation. The individuals with ASD were more reluctant to go to the usual classes and did not seem to read the notification emails about taking the online survey. For this reason, the diversity services of the universities made phone calls to explain the reason for the online survey. Thus, some participants with ASD carried out the tests in the diversity service office of the universities, while others carried out the online protocol at their homes. Individual with borderline intellectual capacity and disabilities (physical, visual, etc.) were excluded from the neurotypical sample. Furthermore, people who had several diagnosed mental disorders were excluded because it was not possible to create a well-defined mixed group (e.g. ADHD and ASD, ADHD and dyslexia, and anxiety). This information was collected from the administered questionnaires. The present study was approved by the Ethics Committee of the University of Alicante, Spain (reference: UA-2019-10-04). The adult participants signed an informed consent form, whereas the minors provided informed consent from their caregivers.

Data analyses

Statistical analyses were performed using IBM SPSS Statistics v 25.0 for Windows (IBM 2017). Means and standard deviations of each sample were obtained from the direct scores provided by the participants for each item corresponding to each test. Cronbach's alpha was calculated for each subscale of the SOR-Scales, PSRS, SSGS, OCI-R and the total scale in each group (ASD, ADHD, LD, and NT). To prepare for the main analysis, the sociodemographic variables of the four groups were compared to examine possible confounding factors. Chi-square analyses were conducted for the categorical variables of sex and age. For the comparison of mean values, the normality assumption of parametric tests was checked by applying the Kolmogorov-Smirnov test to the groups. The assumption was not met, therefore the non-parametric Mann-Whitney U test was used to determine whether ASD, ADHD, LD, and NT differed in the SOR-Scales, PSRS, GSSS, and OCI-R subscales and the total of the scales, with differences $p < 0.05$ considered significant. The corresponding effect size was calculated to determine if there were statistically significant differences between the proportions found: $0.20 \leq d \leq 0.50$, being a low-effect size, whereas $0.51 \leq d \leq 0.79$, moderate-effect size, and $d \geq 0.80$ high-effect size (Cohen 1988).

Results

Differences in pain and sensory reactivity

Table 2 shows the means and standard deviations of the different pain and sensory reactivity scores obtained from the ASD, ADHD, LD, and control groups. The ADHD group, when compared to the control group and individuals with ASD, presented significantly higher mean scores on the pain subscale of the PSRS, with a difference in magnitude between low (ADHD-NT; $p = 0.03$, $d = 0.45$) and high (ASD-ADHD; $p = 0.00$, $d = 0.83$).

Table 2. Differences in pain and sensory reactivity between sample types.

PSRS	NT *M(DT)*	ASD *M(DT)*	ADHD *M(DT)*	L *M(DT)*	TCS *M(DT)*	*U*	*p*	*d* [95% CI]	Group contrasts
Pain	5.88 (3.60)	4.92 (3.13)	7.47 (2.88)	6.17 (4.02)	5.81 (3.48)	2805.50	.87		NT-TCS
						1192.00	.19		ASD-NT
						361.50	.03	0.45 [-0.11; 1.01]	ADHD-NT
						824.00	.68		LD-NT
						134.00	.00	0.83 [0.21; 1.45]	ASD-ADHD
						339.50	.19		ASD-LD
						130.00	.20		ADHD-LD
Broad sensory hyporeactivity	11.96 (8.27)	19.46 (13.70)	20.93 (9.64)	15.09 (9.65)	18.41 (11.91)	1835.50	.00**	0.62 [0.30; 0.95]	NT-TCS
						927.50	.00	0.72 [0.31; 1.12]	ASD-NT
						233.00	.00**	1.05 [0.47; 1.62]	ADHD-NT
						675.00	.10		LD-NT
						254.50	.64		ASD-ADHD
						355.50	.29		ASD-LD
						110.50	.06		ADHD-LD
Hypo tactile	3.84 (2.50)	6.00 (4.13)	7.00 (2.78)	5.17 (4.02)	5.95 (3.87)	1914.50	.00**	0.64 [0.32; 0.97]	NT-TCS
						950.50	.01	0.69 [0.28; 1.09]	ASD-NT
						231.50	.00**	1.23 [0.65; 1.81]	ADHD-NT
						732.50	.24		LD-NT
						225.50	.29		ASD-ADHD
						370.50	.40		ASD-LD
						112.00	.07		ADHD-LD
Hypo olfactory	2.46 (1.72)	2.78 (2.93)	3.40 (2.20)	3.26 (2.40)	3.05 (2.62)	2641.00	.43		NT-TCS
						1315.00	.57		ASD-NT
						425.00	.11		ADHD-NT
						719.00	.19		LD-NT
						207.00	.15		ASD-ADHD
						341.00	.19		ASD-LD
						163.50	.79		ADHD-LD
Hypo visual	1.86 (2.18)	3.35 (2.91)	3.20 (3.21)	2.26 (2.38)	2.99 (2.83)	2162.50	.01	0.44 [0.12; 0.77]	NT-TCS
						935.50	.00	0.61 [0.20; 1.01]	ASD-NT
						389.50	.05		ADHD-NT
						837.50	.76		LD-NT
						255.00	.65		ASD-ADHD
						329.00	.14		ASD-LD
						131.50	.21		ADHD-LD
Hypo taste	1.66 (2.02)	3.43 (3.19)	3.00 (2.39)	1.74 (1.84)	2.83 (2.75)	2112.50	.01	0.48 [0.16; 0.80]	NT-TCS
						948.00	.00	0.71 [0.31; 1.12]	ASD-NT
						324.00	.01	0.64 [0.08; 1.20]	ADHD-NT
						840.50	.77		LD-NT
						271.50	.90		ASD-ADHD
						297.50	.05		ASD-LD
						109.50	.06		ADHD-LD
Hypo auditory	2.14 (1.61)	3.89 (3.16)	4.33 (1.84)	2.65 (2.17)	3.60 (2.71)	1977.50	.001	0.65 [0.32; 0.98]	NT-TCS
						986.00	.01	0.78 [0.37; 1.18]	ASD-NT
						209.50	.00**	1.32 [0.73; 1.90]	ADHD-NT
						782.00	.44		LD-NT
						226.00	.29		ASD-ADHD
						330.00	.14		ASD-LD
						96.50	.02	0.81 [0.14; 1.49]	ADHD-LD
Broad sensory hyperreactivity	10.08 (6.89)	24.11 (16.72)	15.07 (12.37)	17.35 (12.03)	20.23 (14.95)	1584.50	.00**	0.87 [0.53; 1.20]	NT-TCS
						619.00	.00**	1.26 [0.83; 1.68]	ASD-NT
						443.00	.17		ADHD-NT
						522.50	.00	0.86 [0.38; 1.35]	LD-NT
						173.50	.04	0.57 [-0.04; 1.18]	ASD-ADHD
						313.00	.09		ASD-LD
						142.50	.37		ADHD-LD
Hyper tactile	2.59 (2.25)	5.97 (4.64)	3.93 (3.54)	3.70 (2.93)	4.87 (4.08)	1858.00	.00**	0.69 [0.36; 1.02]	NT-TCS
						763.00	.00**	1.04 [0.62; 1.45]	ASD-NT
						413.50	.09		ADHD-NT
						681.50	.11		LD-NT
						198.50	.11		ASD-ADHD
						302.50	.06		ASD-LD
						168.50	.90		ADHD-LD
Hyper olfactory	2.18 (1.66)	4.46 (4.05)	3.27 (3.22)	5.09 (3.64)	4.41 (3.78)	1900.00	.00**	0.76 [0.43; 1.09]	NT-TCS
						983.00	.01	0.84 [0.44; 1.25]	ASD-NT
						488.50	.38		ADHD-NT
						428.50	.00**	1.27 [0.77; 1.77]	LD-NT
						234.50	.38		ASD-ADHD
						369.00	.39		ASD-LD
						113.00	.07		ADHD-LD

(*Continued*)

Table 2. (*Continued*).

PSRS	NT M(DT)	ASD M(DT)	ADHD M(DT)	L M(DT)	TCS M(DT)	U	p	d [95% CI]	Group contrasts
Hyper visual	0.91 (1.05)	3.32 (3.06)	1.60 (2.61)	1.70 (2.00)	2.48 (2.78)	1838.00	.00**	0.74 [0.41; 1.07]	NT-TCS
						662.00	.00**	1.23 [0.80; 1.65]	ASD-NT
						526.50	.62		ADHD-NT
						649.50	.05		LD-NT
						161.00	.02	0.58 [-0.03; 1.19]	ASD-ADHD
						297.00	.05		ASD-LD
						147.50	.44		ADHD-LD
Hyper taste	1.55 (1.78)	3.84 (3.70)	2.33 (2.77)	2.83 (2.81)	3.23 (3.29)	2048.50	.00	0.63 [0.30; 0.96]	NT-TCS
						890.50	.00	0.89 [0.48; 1.29]	ASD-NT
						516.00	.55		ADHD-NT
						642.00	.05		LD-NT
						208.50	.16		ASD-ADHD
						371.50	.41		ASD-LD
						151.00	.51		ADHD-LD
Hyper auditory	2.84 (2.44)	6.51 (3.47)	3.93 (2.94)	4.04 (3.28)	5.24 (3.51)	1665.00	.00**	0.79 [0.46; 1.12]	NT-TCS
						547.50	.00**	1.29 [0.87; 1.72]	ASD-NT
						435.00	.14		ADHD-NT
						682.50	.11		LD-NT
						154.00	.01	0.77 [0.15; 1.39]	ASD-ADHD
						255.00	.01	0.72 [0.18; 1.26]	ASD-LD
						172.00	.99		ADHD-LD

Note. Neurotypical participants = NT. Autism Spectrum Disorder = ASD. Attention-Deficit/Hyperactivity Disorder = ADHD. Learning Disabilities = LD. Total clinical sample = TCS. Pain and Sensitivity Reactivity Scale = PSRS. Sensory hyporeactivity = Hypo. Sensory hyperreactivity = Hyper. $^{**}p < 0.001$.

Regarding sensory reactivity measured with the PSRS, both individuals with ASD and ADHD had significantly higher scores on the PSRS broad sensory hyporeactivity than the control group, and the magnitude of the differences was high (ASD-NT; $p = 0.00$, $d = 0.72$ and ADHD-NT; $p < 0.00$, $d = 1.05$). Specifically, differences were found between the control group and the ASD and ADHD groups in terms of tactile, visual, taste, and auditory hyporeactivity (see Table 2). On the other hand, individuals with ASD had significantly higher scores on the PSRS broad sensory hyperreactivity compared to the control group and the group of individuals with ADHD, with a difference in magnitude between moderate (ASD-ADHD; $p = 0.04$, $d = 0.57$) and high (ASD-NT; $p < 0.00$, $d = 1.26$). Specifically, differences were found in tactile, olfactory, visual, taste, and auditory sensory hyperreactivity between the control and ASD groups, which were higher in individuals with ASD (see Table 2). In addition, significantly higher scores for visual ($p = 0.02$; $d = 0.58$) and auditory ($p = 0.01$; $d = 0.77$) sensory hyperreactivity were found in individuals with ASD than in those with ADHD, with a moderate difference.

Similarly, individuals with ASD had significantly higher scores on sensory hyperresponsiveness touch ($p < 0.00$), hearing ($p < 0.00$), sight ($p = 0.00$), taste ($p = 0.00$), and SOR-Total ($p < 0.00$) compared with the control group, with a high magnitude of differences (see Table 3). Furthermore, individuals with ASD had significantly higher scores on the SOR-Touch subscale than the group of individuals with ADHD ($p = 0.01$; $d = 0.81$) and LD ($p = 0.00$; $d = 0.80$), with a moderate magnitude of difference.

Differences in gastrointestinal symptoms

A higher prevalence of gastrointestinal diseases was observed in the clinical population in comparison to the neurotypical population. Specifically, gastroesophageal reflux, dyspepsia (early satiety, significant fullness, stomach pain, or heartburn), nonspecific abdominal pain, and infectious diarrhea (viruses and bacteria) (see Table 4). The highest levels of nonspecific abdominal pain prevalence are found in the sample of individuals with ASD and LD. However, gastroesophageal reflux and dyspepsia occur more frequently in individuals with ADHD and LD. Regarding the family history of gastrointestinal diseases, both clinical and non-clinical samples coincide with a higher frequency in parents (see Supplementary Table S1).

Differences in GS between the sample types were analyzed using GSSS (Table 5). The results show that individuals with ASD have higher scores than the neurotypical sample on the abdominal subscale, with a moderate magnitude of differences ($p = 0.02$; $d = 0.59$). However, significantly higher scores were found in the vomiting and defecation subscale in individuals with ADHD compared to individuals with ASD ($p = 0.00$; $d = 0.82$) and the neurotypical sample ($p = 0.00$; $d = 0.77$), with magnitude of the differences being high. Similarly, higher scores were found on this scale in the LD group than in the sample of individuals with ASD ($p = 0.04$; $d = 0.48$). Finally, the total clinical sample seems to have higher levels of severity of GS compared to the neurotypical sample, although the magnitude of the differences was small ($p = 0.04$; $d = 0.41$).

Table 3. Sensory over-responsivity differences according to the type of sample.

SOR-scales	NT M(DT)	ASD M(DT)	ADHD M(DT)	LD M(DT)	TCS M(DT)	U	p	d [95% CI]	Group contrasts
SOR-Touch	2.55 (2.24)	5.95 (4.20)	2.80 (2.78)	2.96 (2.01)	4.40 (3.69)	1995.00	.00	0.60 [0.28; 0.93]	NT-TCS
						667.00	.00**	1.12 [0.70; 1.54]	ASD-NT
						569.00	.99		ADHD-NT
						759.00	.33		LD-NT
						149.50	.01	0.81 [0.19; 1.43]	ASD-ADHD
						236.50	.00	0.80 [0.18; 1.42]	ASD-LD
						149.50	.49		ADHD-LD
SOR-Hearing	3.76 (3.27)	8.05 (4.18)	5.87 (3.72)	4.48 (3.03)	6.52 (4.05)	1676.50	.00**	0.74 [0.41; 1.07]	NT-TCS
						584.00	.00**	1.18 [0.76; 1.61]	ASD-NT
						370.00	.03	0.63 [0.06; 1.19]	ADHD-NT
						722.50	.21		LD-NT
						188.50	.07		ASD-ADHD
						210.00	.00	0.94 [0.39; 1.48]	ASD-LD
						133.00	.23		ADHD-LD
SOR-Smell	1.88 (2.03)	3.84 (4.37)	2.53 (2.30)	4.61 (4.37)	3.81 (4.06)	2114.00	.01	0.60 [0.27; 0.92]	NT-TCS
						1092.00	.05		ASD-NT
						466.50	.26		ADHD-NT
						555.50	.01	0.99 [0.50; 1.47]	LD-NT
						258.00	.69		ASD-ADHD
						373.50	.42		ASD-LD
						133.00	.23		ADHD-LD
SOR-Sight	1.96 (2.18)	4.57 (4.42)	2.47 (2.39)	2.91 (2.78)	3.64 (3.71)	2075.00	.00	0.55 [0.22; 0.87]	NT-TCS
						905.50	.00	0.84 [0.43; 1.25]	ASD-NT
						491.50	.39		ADHD-NT
						678.00	.10		LD-NT
						207.00	.15		ASD-ADHD
						347.00	.23		ASD-LD
						156.00	.62		ADHD-LD
SOR-Taste	2.05 (2.00)	4.62 (3.95)	2.53 (1.85)	3.00 (3.21)	3.71 (3.49)	2112.50	.01	0.58 [0.25; 0.91]	NT-TCS
						890.00	.00	0.91 [0.50; 1.33]	ASD-NT
						476.50	.31		ADHD-NT
						746.00	.28		LD-NT
						201.50	.12		ASD-ADHD
						324.00	.12		ASD-LD
						169.00	.92		ADHD-LD
SOR-Total	12.21 (8.40)	27.03 (18.35)	16.20 (9.31)	17.96 (10.65)	22.08 (15.44)	1646.50	.00**	0.79 [0.46; 1.12]	NT-TCS
						650.00	.00**	1.17 [0.75; 1.60]	ASD-NT
						422.50	.11		ADHD-NT
						574.00	.01	0.64 [0.16; 1.11]	LD-NT
						186.50	.07		ASD-ADHD
						279.50	.03	0.57 [0.04; 1.10]	ASD-LD
						160.00	.71		ADHD-LD

Note. Neurotypical participants = NT. Autism Spectrum Disorder = ASD. Attention-Deficit/Hyperactivity Disorder = ADHD. Learning Disabilities = LD. Total clinical sample = TCS. Sensory Over-Responsivity = SOR. Sensory Over-Responsivity Scales = SOR-Scales. $^{**}p < 0.001$.

Table 4. Prevalence of gastro-intestinal diseases in each sample.

	NT	ASD	ADHD	LD	TCS
Gastroesophageal reflux	9.2	8.1	13.3	26.1	14.7
Dyspepsia (early satiety, significant fullness, stomach pain or heartburn)	5.3	8.1	13.3	17.4	12
Nonspecific abdominal pain	10.5	18.9	13.3	43.5	25.3
Infectious diarrhea (viruses, bacteria)	15.8	8.1	13.3	43.5	20
Peptic ulcer disease	0	0	0	0	0
Irritable bowel syndrome	1.3	2.7	6.7	0	2.7
Inflammatory bowel disease	0	0	6.7	0	1.3
Crohn's disease	0	0	0	0	0
Ulcerative colitis	2.6	0	0	0	0
Celiac disease	0	2.7	0	0	1.3
Infantile dyschezia (defecation failure)	2.6	5.4	6.7	0	4
Significant flatulence	3.9	10.8	13.3	0	8

Note. Neurotypical participants = NT. Autism Spectrum Disorder = ASD. Attention-Deficit/Hyperactivity Disorder = ADHD. Learning Disabilities = LD. Total clinical sample = TCS.

Differences in OCD symptoms

Finally, individuals with ADHD and LD had significantly higher scores on the hoarding ($p = 0.00$; $d = 0.87$), obsessing ($p = 0.01$; $d = 0.83$), and total subscales of the OCI-R ($p = 0.00$; $d = 0.76$) compared with the control group, with a moderate magnitude of differences. On the other hand, individuals with ASD had significantly higher scores on the ordering ($p = 0.01$; $d = 0.63$), neutralizing ($p = 0.01$; $d = 0.59$), washing ($p = 0.04$; $d = 0.57$), obsessing ($p < 0.00$; $d = 0.98$), and total subscales of the OCI-R ($p = 0.00$; $d = 0.85$) compared to the control group, with a moderate magnitude of differences. Differences were found between the clinical groups (Table 6).

Discussion

ASD is a neurodevelopmental disorder that affects individuals in a variety of ways, including their

Table 5. Differences in the severity of gastrointestinal symptoms between sample types.

GSSS	NT *M(DT)*	ASD *M(DT)*	ADHD *M(DT)*	LD *M(DT)*	TCS *M(DT)*	*U*	*p*	*d* [95% CI]	Group contrasts
Abdominal (Factor 1)	1.30 (1.37)	2.27 (2.10)	1.80 (2.18)	2.09 (2.37)	2.12 (2.18)	2331.00	.05		NT-TCS
						1047.50	.02	0.59 [0.19; 0.99]	ASD-NT
						533.00	.68		ADHD-NT
						750.50	.29		LD-NT
						233.50	.36		ASD-ADHD
						391.00	.59		ASD-LD
						160.50	.71		ADHD-LD
Vomiting and defecation (Factor 2)	0.74 (1.22)	0.62 (1.16)	1.80 (1.97)	1.35 (1.97)	1.08 (1.67)	2559.00	.23		NT-TCS
						1285.00	.40		ASD-NT
						327.00	.00	0.77 [0.20; 1.33]	ADHD-NT
						705.00	.12		LD-NT
						149.00	.00	0.82 [0.20; 1.44]	ASD-ADHD
						306.50	.04	0.48 [−0.05; 1]	ASD-LD
						124.00	.13		ADHD-LD
GSSS-Total	2.04 (2.11)	2.89 (2.82)	3.60 (3.81)	3.43 (4.00)	3.20 (3.39)	2314.00	.04	0.41 [0.09; 0.73]	NT-TCS
						1190.00	.18		ASD-NT
						411.00	.08		ADHD-NT
						713.00	.17		LD-NT
						247.00	.53		ASD-ADHD
						405.50	.76		ASD-LD
						156.50	.63		ADHD-LD

Note. Neurotypical participants = NT. Autism Spectrum Disorder = ASD. Attention-Deficit/Hyperactivity Disorder = ADHD. Learning Disabilities = LD. Total clinical sample = TCS. Gastrointestinal Symptom Severity Scale = GSSS.

Table 6. OCD symptoms differences according to the type of sample.

OCI-R	NT *M(DT)*	ASD *M(DT)*	ADHD *M(DT)*	LD *M(DT)*	TCS *M(DT)*	*U*	*p*	*d* [95% CI]	Group contrasts
Hoarding	3.09 (2.47)	4.43 (3.52)	5.27 (2.49)	4.57 (2.59)	4.64 (3.05)	2017.00	.00	0.55 [0.23; 0.88]	NT-TCS
						1138.50	.10		ASD-NT
						300.00	.00	0.87 [0.31; 1.44]	ADHD-NT
						578.50	.01	0.59 [0.11; 1.06]	LD-NT
						221.50	.26		ASD-ADHD
						391.50	.60		ASD-LD
						149.00	.48		ADHD-LD
Checking	2.49 (1.93)	4.14 (3.79)	3.40 (1.84)	3.43 (2.57)	3.77 (3.12)	2222.00	.02	0.49 [0.17; 0.81]	NT-TCS
						1140.50	.10		ASD-NT
						394.00	.06		ADHD-NT
						687.50	.12		LD-NT
						273.50	.94		ASD-ADHD
						411.50	.83		ASD-LD
						160.00	.71		ADHD-LD
Ordering	3.34 (2.61)	5.27 (3.72)	4.47 (2.72)	4.22 (3.62)	4.79 (3.50)	2186.00	.01	0.47 [0.14; 0.79]	NT-TCS
						976.00	.01	0.63 [0.23; 1.04]	ASD-NT
						426.00	.12		ADHD-NT
						784.00	.45		LD-NT
						249.50	.57		ASD-ADHD
						357.00	.30		ASD-LD
						153.50	.57		ADHD-LD
Neutralizing	0.88 (1.67)	2.16 (2.91)	1.47 (2.26)	2.91 (3.16)	2.25 (2.89)	1994.00	.00	0.58 [0.25; 0.90]	NT-TCS
						998.00	.01	0.59 [0.19; 0.99]	ASD-NT
						492.00	.34		ADHD-NT
						504.00	.00	0.96 [0.47; 1.44]	LD-NT
						236.00	.38		ASD-ADHD
						362.50	.32		ASD-LD
						122.00	.12		ADHD-LD
Washing	1.79 (1.95)	3.24 (3.39)	1.87 (2.20)	3.00 (2.91)	2.89 (3.05)	2264.00	.03	0.43 [0.10; 0.75]	NT-TCS
						1081.00	.04	0.57 [0.17; 0.97]	ASD-NT
						549.50	.82		ADHD-NT
						633.50	.04	0.54 [0.07; 1.02]	LD-NT
						212.50	.18		ASD-ADHD
						424.00	.98		ASD-LD
						121.50	.12		ADHD-LD
Obsessing	2.46 (2.95)	5.86 (4.30)	5.07 (3.85)	4.39 (3.58)	5.25 (4.00)	1656.50	.00**	0.79 [0.46; 1.12]	NT-TCS
						767.00	.00**	0.98 [0.57; 1.39]	ASD-NT
						321.50	.01	0.83 [0.27; 1.40]	ADHD-NT
						568.00	.01	0.62 [0.14; 1.09]	LD-NT
						250.50	.58		ASD-ADHD
						343.50	.21		ASD-LD
						155.00	.60		ADHD-LD
OCI-R Total	14.11 (10.31)	25.30 (17.33)	22.00 (10.23)	22.52 (13.93)	23.79 (15.03)	1758.00	.00**	0.75 [0.42; 1.08]	NT-TCS
						885.00	.00	0.85 [0.44; 1.26]	ASD-NT
						303.50	.00	0.76 [0.20; 1.32]	ADHD-NT
						569.50	.01	0.74 [0.26; 1.22]	LD-NT
						247.00	.54		ASD-ADHD
						394.00	.63		ASD-LD
						168.00	.89		ADHD-LD

Note. Neurotypical participants = NT. Autism Spectrum Disorder = ASD. Attention-Deficit/Hyperactivity Disorder = ADHD. Learning Disabilities = LD. Total clinical sample = TCS. Obsessive-Compulsive Inventory – Revised = OCI-R. $^{**}p < 0.001$.

sensory processing and reactivity, pain perception and gastrointestinal function (Berding and Donovan 2018, Leader *et al.* 2022). Furthermore, several studies have analysed the relationships between sensory reactivity, pain, and GS in both the general and clinical populations (e.g. Dufton *et al.* 2010, Mazefsky *et al.* 2021, Mazurek *et al.* 2013, 2014, Thapar *et al.* 2020). While studies have examined sensory reactivity, pain and GS in individuals with ASD, less is known about how these symptoms differ among adolescents and young adults with ASD compared to those with other neurodevelopmental and neurotypical disorders. Therefore, the aim of this study was to analyse differences in sensory reactivity, pain and GS between these groups.

The results for sensory hyporeactivity on the PSRS reflect atypical sensory processing, being more frequent in ASD and/or ADHD than in the neurotypical group, with no significant difference between ASD and ADHD. These results are in line with those of previous studies, suggesting that there may be common sensory processing between ASD and ADHD (Dellapiazza *et al.* 2021). Very interesting results were found for sensory hyporeactivity in individuals with ADHD. Specifically, higher levels of tactile, taste, and auditory hyporeactivity are found compared to those in the control or neurotypical groups. Therefore, individuals with ADHD show an increase in their approach behavior when faced with tactile, gustatory, and auditory stimuli. These results are consistent with the symptomatology of ADHD (APA 2013, 2022). These results have important clinical and educational implications because they inform us of the sensory profile of ADHD.

In our study, we found increased levels of sensory hyperreactivity on most sensory dimensions in individuals with ASD compared to the control group, using the PSRS and SOR-Scales. These findings are consistent with those of previous studies (Ben-Sasson *et al.* 2019, Crow *et al.* 2020, Dellapiazza *et al.* 2021). The SOR is a fundamental characteristic of ASD (APA 2013, 2022). Similarly, the high levels of hypo- and hyperreactivity found in the ASD group are compatible with the clinician's diagnosis according to DSM-5 (APA 2022). ASD presents great heterogeneity not only in severity, but also in the sensory profile. Thus, a person with ASD may show a continuous preference for a type of song or sound (sensory hyporeactivity) but may also be very sensitive to certain sudden and unexpected sounds (sensory hyperactivity). Therefore, it is not strange to find these results.

In the SOR's comparison between clinical groups, individuals with ASD show significant differences with respect to individuals with ADHD, with more sensitive visual, auditory and tactile processing. These results coincide with those found in previous studies that indicate more sensitive or atypical sensory processing in ASD (Dellapiazza *et al.* 2021, Schulz *et al.* 2023). Therefore, the sensory profiles differ between neurodevelopmental disorders. These results suggest that ASD and ADHD may not be associated with unique patterns in sensory processing abilities (Scheerer *et al.* 2022). Sensory processing behaves differently, which may be an important diagnostic criterion for future revisions to diagnostic manuals. In the LD group, differences were found only in the total score of the sensory hyperreactivity subscale, with the olfactory dimension being the most prominent compared to the control group. These results partially support the possible sensory alterations in individuals with LD (Cunha *et al.* 2019, Mekki *et al.* 2022, Mirzakhani and Shahriarpour 2021). This possible sensorial alteration could influence the process of information acquisition and be related to poor academic performance. In conclusion, understanding the sensory profile of each neurodevelopmental disorder will allow professional designs to be more specific and effective in improving mental health. In the same way, it will allow more appropriate curricular adaptations to be made within the educational field.

GS has been studied both in the general population and in individuals with neurodevelopmental disorders (Thapar *et al.* 2020). Abdominal pain is one of the most frequently studied types of GS. The prevalence results of our study are consistent with research carried out in a neurotypical population and with ASD. There is a higher percentage of GS, such as abdominal pain, in ASD (Leader *et al.* 2022). However, we found a similar percentage of non-specific abdominal pain among individuals with ADHD. In addition, the results found for the pain subscale of the PSRS suggest higher levels of pain among individuals with ADHD. These results are consistent of those of other studies that have shown a higher prevalence of ADHD in adolescents with chronic pain and a higher prevalence of chronic pain in samples of youth with ADHD (Battison *et al.* 2023). Thus, these results support a possible association or comorbidity between pain and individuals with ADHD. High levels of pain sensation in ADHD are a very relevant finding for understanding the etiology of ADHD. Future studies will have to investigate whether there is a relationship between high pain sensitivity and high levels of tactile, auditory, and taste sensory hyporeactivity. Likewise, analyze whether there are neurobiological alterations in pain processing (e.g. the anterior cingulate cortex and dopaminergic system) in ADHD (Kerekes *et al.* 2021).

The results obtained with the GSSS indicate that individuals with ASD have a greater severity of abdominal symptoms than the neurotypical group. However, there are no differences between the clinical groups. These results support the idea that in ASD there are more GS associated with abdominal pain and

constipation than those associated with abdominal pain disorders according to the Rome IV criteria (Rose *et al.* 2018). On the other hand, ADHD has a greater severity of symptoms related to functional nausea and vomiting disorders according to the Rome IV criteria. These findings suggest that individuals with ADHD have more symptoms of dyspepsia, such as, indigestion, gas, early satiety, postprandial fullness, burning, or burning pain (Kedem *et al.* 2020). Constipation is the most common GS associated with a possible dysbiosis or alteration of the gut microbiota in ASD (Coe *et al.* 2023). Therefore, constipation and abdominal pain are indicators of possible impairment of the interaction between the intestine and the brain. These findings should be considered when implementing prebiotic- and probiotic-based treatments to reduce GS (Song *et al.* 2022).

In this study, higher levels of ordering, neutralizing thoughts, cleaning behaviors, and obsessions were found in individuals with ASD compared to the neurotypical sample. These results are compatible with previous studies that indicate comorbidity and a high incidence of OCD symptoms in ASD (Mutluer *et al.* 2022, Postorino *et al.* 2017). Therefore, it would have to be considered that both OCD and ASD have transdiagnostic symptoms. Psychological treatment for OCD (Exposure and response prevention therapy) should be analyzed as an alternative treatment for repetitive behavior in individuals with Level 1 ASD severity (Eilers and Hayes 2015).

In conclusion, the results of our study point to possible profiles of sensory reactivity and GS between clinical groups, particularly in individuals with ASD and ADHD. The ASD group has a more complex and heterogeneous sensory profile than individuals with ADHD. Furthermore, GS (Nonspecific abdominal pain and constipation) in the ASD group is more related to a possible alteration of the gut-microbiota, although this cannot be verified without a study of the gut-microbiota. This contribution is in line with recent studies (Scheerer *et al.* 2022) and can be considered when implementing assessment and intervention protocols for neurodevelopmental disorders. Understanding these differences may potentially provide valuable insight into the unique challenges faced by individuals with ASD and ADHD, as well as possible avenues for intervention and support. However, this study has certain limitations that reduce the scope of the conclusions obtained. For example, the ADHD sample number is smaller than the other clinical samples. In general, a larger clinical sample would have been desirable. However, similar studies with similar sample sizes have been published (Dellapiazza *et al.* 2021). Future studies should expand the autism sample to better understand the different sensory profiles and identify possible sensory subtypes associated with autism severity. Additionally, there are discrepancies between sexes, especially for NT (61.8% female), ASD (64.9% male), and LD (82.6% female). This should be considered a limitation, as it is possible that the findings may generalize between sexes. Future studies should analyze the relationships between sensory reactivity, pain, GS, diet, RBBs, and gut microbiota. This will allow us to obtain a more comprehensive view of the gut microbiota-brain axis. Finally, a larger sample of clinical subgroups would allow for a better psychometric analysis.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Research data associated with this article is not available.

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