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ORIGINAL PAPER

Sensory Processing Patterns Predict Problem Behaviours in Autism Spectrum Disorder and Attention-Deficit/Hyperactivity Disorder

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Abstract

Objectives Sensory processing is the ability to discern and understand information from one's sensory organs. Understanding sensory processing patterns in different clinical groups could elicit evidence that sensory processing patterns are a transdiagnostic mechanism in neurodevelopmental disorders. Furthermore, there is little evidence of how sensory processing patterns relate to behaviours, such as attention, social, and mood difficulties in autism and ADHD. The goals of this study were to directly compare sensory processing patterns in autism, ADHD, and typical development and to explore the association between sensory processing and behavioural outcomes.

Methods Data were collected through the Province of Ontario Neurodevelopmental Network. The parents of 805 children with typical development, ADHD, or ASD completed measures of sensory processing and behavioural outcomes with the Short Sensory Profile and the Childhood Behaviour Checklist, respectively. Sensory processing was compared across groups and regression analyses were conducted to determine if behavioural patterns could be predicted by sensory processing patterns in the clinical sample.

Results Overall, the results identified significant differences in sensory processing patterns between the diagnosed and undiagnosed participants. Autism and ADHD differed on all Sensory Profile subscales except auditory filtering and under-responsivity/sensory seeking. All behavioural outcomes were predicted by sensory processing patterns over and above the variance accounted for by the diagnostic group, suggesting that understanding sensory processing patterns is an important piece of a comprehensive understanding of the behavioural patterns observed across multiple clinical populations.

Conclusions There is evidence that sensory processing is different in ASD and ADHD but that specific patterns of sensory processing are related to behavioural outcomes in both disorders. Better understanding sensory processing as a mechanism for behaviour can help to identify simple interventions across neurodevelopmental disorders.

Keywords Autism spectrum disorder · Attention-deficit/hyperactivity disorder · Sensory processing patterns · Sensory Profile · Behavioural outcomes · Childhood Behaviour Checklist

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The umbrella term of neurodevelopmental disorders captures a variety of disorders including autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), learning disabilities, intellectual disabilities, and more. Each of these disorders is thought to develop due to unique neural etiologies; however, they often share large areas of overlap in clinical symptomatology (APA, 2013), significant genetic precursors (Satterstrom et al., 2019), hypothesized underlying mechanisms (Rommelse et al., 2017), and the frequent occurrence of comorbidity (Dewey, 2018; Hansen et al., 2018). In particular, the similarities and rates of comorbidity between ADHD and autism are striking. It has been reported that 30% of autistic individuals also meet the diagnostic criteria for ADHD, compared to community estimates ranging from two to eleven percent (Vasiliadis et al., 2017). Likewise, estimates suggest that about 18% of individuals diagnosed with ADHD will have comorbid autism compared to about 1% of the general population (Kotte et al., 2013). Although the overlap in the diagnostic criteria for ADHD and autism is minimal, these two conditions share a number of associated difficulties in areas such as social interactions, attention, and sensory processing patterns (Aduen et al., 2018; Chita-Tegmark, 2016; Little et al., 2011; Murray, 2010).

Sensory processing refers to the way the nervous system receives, organizes, and interprets signals from the sensory organs including the eyes, ears, nose, tongue, and skin (Kilroy et al., 2019). It has been posited that sensory processing serves as a critical building block in cognitive development, and as a result, disruptions in sensory processing cascade into deficits in many processes such as speech perception, language, working memory, attention, social performance, and emotion regulation (Ashburner et al., 2008; Chorna et al., 2014; Ghanizadeh, 2011; Thye et al., 2018). Therefore, a thorough understanding of sensory processing patterns in neurodevelopmental disorders is essential in a complete conceptualization of these disorders.

Sensory processing profiles refer to four common ways sensory processing manifests according to Dunn's theory, namely sensory sensitivity, sensory avoidance, low registration, and sensory seeking (Dunn & Westman, 1997). Sensory processing profiles are identified based on neural thresholds required for the detection of a sensory stimulus and the associated self-regulatory behaviours. Sensory sensitivity and sensory avoidance both result from low neural thresholds or a greater ability to perceive low-intensity sensory information. Of these two profiles, passive regulation results in sensory sensitivity and active regulation results in sensory avoidance of additional sensory input. High neural thresholds for sensory input are indicative of hyposensitivity in which fewer sensory signals are being processed and result in the low registration and sensory-seeking profiles. Low registration is the passive profile of behaviour related to high neural thresholds, whereas sensory seeking is observed when individuals actively seek out additional sensory input (Dunn & Brown, 1997).

Abnormalities related to these four profiles of sensory processing are further divided into seven subscales. Four of these subscales are related to sensitivity or an individual's ability to detect input in different sensory modalities, including tactile sensitivity, taste/smell sensitivity, visual/auditory sensitivity, and movement sensitivity. Movement sensitivity is related to one's vestibular system which is responsible for our spatial understanding which can manifest as a sensitivity to being lifted off the ground or upside-down. Under-responsivity/sensory seeking refers to the lower detection of sensory input and the subsequent search for additional sensory input. Auditory filtering is the ability to unconsciously differentiate between important and irrelevant auditory information. Low energy/weakness assesses the proprioceptive system or one's sense of body awareness in relation to things such as force and pressure. Maladaptive sensory processing patterns are well documented in autism, and hypo- and hyper-sensitivity, specifically, are included in the diagnostic criteria (Marco et al., 2011; O'connor, 2012; Simmons et al., 2009). Atypical sensory processing patterns have also been more recently affiliated with ADHD (Bijlenga et al., 2017; Ghanizadeh, 2011). There is sufficient evidence to support the hypothesis that diagnosed populations, such as autism and ADHD, have atypical sensory processing patterns compared to children without a diagnosis.

While there is a strong evidence base that displays significantly greater differences in sensory processing patterns in diagnosed groups compared to the general population, the research directly comparing autism and ADHD is less substantial and less consistent. One study that used sensory processing patterns to discriminate between autism and ADHD displayed success with up to 90% specificity (Ermer & Dunn, 1998); however, a second study with similar methods failed to identify group differences between autism and ADHD (Cheung & Siu, 2009). Comparisons of means on questionnaires and behavioural measures between autism and ADHD have generally resulted in similar sensory processing patterns across groups (Little et al., 2018); however, where differences were evident, the exact nature of those differences varied between studies. Greater differences in sensory processing patterns have been found in ADHD compared to autism in the domains of body awareness, sensation seeking, and auditory filtering (Clince et al., 2016; Sanz-Cervera et al., 2017; Schafer et al., 2013). In the domain of sensory avoiding, however, greater differences have been observed in autism (Dellapiazza et al., 2021). These idiosyncratic differences between studies may be an issue of sample size, variability (or lack there of) in symptom severity of the participants, differences in ages as sensory processes develop throughout childhood, and various measurements used such as questionnaires, compared to behavioural tasks utilizing discrimination or detection paradigms, or neurological methods, etc. Better understanding how sensory processing patterns are similar or different across diagnoses is essential to early identification of these symptoms resulting in improved intervention outcomes (Dunn, 2007).

While the pursuit of differentiating sensory processing patterns between autism and ADHD is an important question in itself, we are also interested in investigating the role that sensory processing patterns have in the development of behavioural characteristics. Difficulty with cognitive processes arising from early differences in sensory processing patterns may result in the behavioural manifestations and shared features of many neurodevelopmental disorders, including autism and ADHD (Wallace et al., 2020). Understanding the relationships between sensory processing and behaviour in ASD and ADHD may not only help us better provide assessment and intervention in these two disorders, but across neurodevelopmental disorders more broadly.

Overall, we aimed to assess sensory processing patterns as a trans-diagnostic mechanism in autism and ADHD. Our first aim was to examine whether sensory processing patterns differ between autism, ADHD, and typical development. Our hypothesis was that significant differences would be found between both diagnosed samples and our control group on all aspects of sensory processing. Specifically, we hypothesized differences in sensory seeking, movement sensitivity, and auditory filtering such that the ADHD group would have more severe and frequent behaviours related to these specific sensory processing patterns compared to the ASD group. Our second aim was to explore the relations between sensory processing patterns and behavioural outcomes, regardless of group membership. Based on the characteristics most prevalent in autism and ADHD, we hypothesized that the strongest associations between sensory processing patterns and behavioural difficulties in the areas of social and attentional problems.

Methods

Participants

Participants were recruited through the Province of Ontario Neurodevelopmental Disorder Network (POND) as part of a large, interdisciplinary, multi-site study comparing characteristics in neurodevelopmental disorders (locations include Kingston, Hamilton, Toronto, and London, ON). Inclusion criteria for the current study were a primary diagnosis of autism or ADHD from a community health care provider or no diagnoses and completion of the measures of interest—the SSP and CBCL. Each participant was assessed by a trained clinician using a cross-disorder checklist and participants were excluded from the ADHD group if any autism DSM-IV or DSM-5 symptoms were present. Likewise, participants were excluded from the autism group if any ADHD characteristics were present according to the cross-disorder checklist. Data were extracted from 867 children including 172 children without diagnoses, 353 autistic participants, and 342 with ADHD (see Table 1).

Procedure

As part of the POND Network data collection, participants underwent an extensive battery of testing across four major testing sites in Ontario, Canada. Depending on the site, participants underwent slight variations of a standard set of testing. Each testing site complied with their corresponding institutes' ethics protocols. Participants were recruited through hospitals, clinics, public advertisements, social media, and existing research databases. Community diagnoses were confirmed through the Autism Diagnostic Observation Schedule, Autism Diagnostic Interview – Revised, and Parent Interview for Child Symptoms.

Measures

Our measures of interest included the SSP and CBCL for school-aged children. The SSP is a broad assessment of sensory processing patterns commonly used in the autistic population. The 38-item parent questionnaire assesses Dunn's four sensory processing profiles in different sensory modalities resulting in seven patterns of sensory processing. Items are rated on a five-point Likert scale in which lower scores indicate greater frequency of behaviours.

The CBCL is a parent questionnaire that is divided into two main components: competence and syndrome assessments (Achenbach & Edelbrock, 1991). The first component assesses competence across a range of areas including socializing, leisure activities, and school performance. The second component examines emotional and behavioural patterns. Our analyses focus on the second component which is

Table 1 Demographic information by group (median and range reported unless stated otherwise)

	TD	ASD	ADHD
n	163	325	317
n Males	91	251	230
n Females	72	74	87
Mean (SD) age	11.29 (3.46)	10.82 (3.43)	9.68 (2.76)
Age range	3–20	2–20	5–18
Mean (SD) IQ	109.56 (12.14)	88.83 (26.98)	93.15 (14.87)

Higher CBCL scores and lower SSP scores indicate greater deviation from scores observed in individuals without a diagnosis further divided into an internalizing scale and an externalizing scale which together comprise a wide range of syndrome scales including anxious/depressed, withdrawn/depressed, somatic complaints, social problems, thought problems, attention problems, rule-breaking behaviour, and aggressive behaviour. Statements are rated on a three-point Likert scale ranging from zero (not true or absent) to two (very true or often true). Greater scores indicate greater severity of the present item. *T*-scores are utilized to compare participants to norms based on sex assigned at birth and age group (6–11 and 12–18 years).

Data Analyses

Outliers were identified and excluded if they fell outside two standard deviations (SD) of the mean of their diagnostic group on the Total CBCL score or the Total SSP score. One-sample Kolmogorov–Smirnov tests were completed for all SSP and CBCL scales within each group to determine the normalcy of the distribution. None of the scores in the ADHD group were normally distributed. The autism data were normally distributed in under-responsivity/sensory seeks. Levene's test suggested that the groups did not have homogenous variances. Because these assumptions were violated, nonparametric Kruskal–Wallis *H* tests were used.

Before completing our primary analyses, we compared ages, intelligence quotients, and sex ratios between groups. Kruskal–Wallis *H* tests are the nonparametric equivalent of a one-way ANOVA. Because data is not normally distributed, comparisons are rank-based as opposed to mean-based. Kruskal–Wallis *H* tests with pairwise comparisons were used to compare ages and intelligence quotients across groups. A chi-square test was used to compare the differences in sex ratios across groups. To address our first aim to compare sensory characteristics between groups, we conducted Kruskal–Wallis tests with pairwise comparisons, comparing autism, ADHD, and TD groups on each of the seven SSP subscales and SSP total score. A Bonferroni correction of 0.05 over 8 tests resulted in a corrected α-value of 0.00625, which all significant results surpassed.

To address our second aim and to relate sensory processing patterns to behavioural outcomes, we conducted multiple hierarchical regressions to determine if the SSP subscales could be used to predict each of the CBCL subscales of interest in our clinical sample. We conducted eight regressions, one for each CBCL subscale, and data from all participants with an autism or ADHD diagnosis were included. Variables such as age, gender, and IQ are related to sensory processing patterns and behavioural outcomes and were thus controlled for in the first step of the regression model. With these analyses, we are taking a dimensional trait (sensory processing patterns) approach to understand maladaptive behaviour in our entire diagnosed sample, which could provide insight into whether sensory processing patterns may be a potential transdiagnostic mechanism. In the second step, diagnosis was included to control for diagnostic grouping and sensory information was included in the third. In the fourth step, we included the sensory processing subscale by diagnostic group interaction terms to determine whether the diagnostic group was differentially affecting the relations between sensory processing and behavioural outcomes.

Results

Out of the total sample, nine TD individuals, 25 individuals with ADHD, and 28 autistic individuals were excluded because their scores on the CBCL or SSP total scores were outside two standard deviations of the mean. After excluding outliers, our final sample consisted of 805 participants (see Table 1 for detailed demographics). Age significantly differed across groups with a small effect size ($H_{(2)} = 33.41$, $p \leq 0.001$, $\eta^2 = 0.04$), such that the ADHD participants were significantly younger on average compared to the two other groups (see Table 1). Intelligence assessments were available for 273 autistic, 73 ADHD, and 162 TD participants and were significantly different between groups ($H_{(2)} = 90.00$, $p < 0.001$, $\eta^2 = 0.17$), such that the diagnosed groups were comparable but both autism and ADHD participants had significantly lower IQs than the TD participants. The ratio of girls to boys also significantly differed between groups, with the TD group having a higher proportion of females than the other two groups ($\chi^2_{(3)} = 24.75$, $p < 0.001$, $\varphi = 0.17$).

Comparing Sensory Processing Patterns

We used Kruskal–Wallis tests to compare sensory processing patterns across groups (see Fig. 1). The groups significantly differed on all SSP subscales, including tactile sensitivity ($H_{(2)} = 236.78$, $p < 0.001$, $\eta^2 = 0.29$); taste and smell sensitivity ($H_{(2)} = 152.93$, $p < 0.001$, $\eta^2 = 0.19$); movement sensitivity ($H_{(2)} = 89.92$, $p < 0.001$, $\eta^2 = 0.11$); under-responsivity/sensory seeking ($H_{(2)} = 300.35$, $p < 0.001$, $\eta^2 = 0.37$); auditory filtering ($H_{(2)} = 312.96$, $p < 0.001$, $\eta^2 = 0.39$); low energy/weakness ($H_{(2)} = 195.55$, $p < 0.001$, $\eta^2 = 0.24$); and auditory and visual sensitivity ($H_{(2)} = 274.11$, $p < 0.001$, $\eta^2 = 0.34$). Pairwise comparisons further analysed individual group differences (see Table 2). Both diagnosed groups were significantly different from the TD group on all measures of sensory processing patterns, such that the TD participants experienced fewer and less severe sensory processing patterns. For under-responsivity/sensory seeking and auditory filtering, no differences were observed between the two diagnosed groups. Autistic participants scored significantly lower, indicating greater severity and frequency, on all other

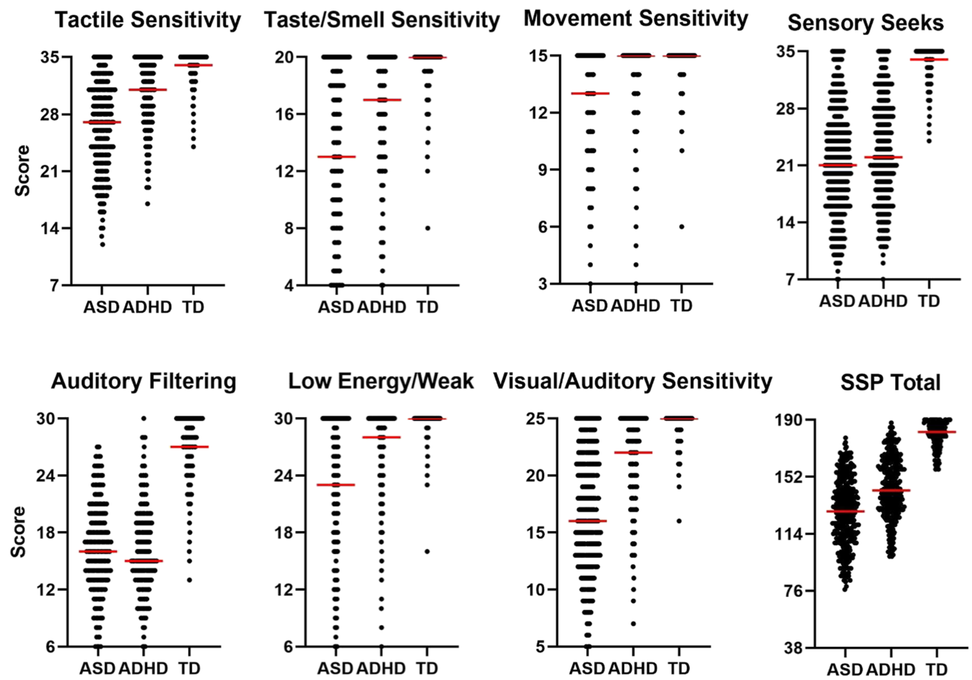

Fig. 1 SSP scores in ASD, ADHD, and TD. Red line indicates group mean

Table 2 Kruskal–Wallis pairwise comparisons of sensory processing patterns across groups

	ADHD vs. ASD			TD vs. ASD			TD vs. ADHD		
	U	*p*	η^2	*U*	*p*	η^2	*U*	*p*	η^2
Tactile sensitivity	**147.31**	< 0.01*	0.74	**338.66**	< 0.01*	0.65	**191.35**	< 0.01*	0.68
Taste/smell sensitivity	**104.70**	< 0.01*	0.75	**271.17**	< 0.01*	0.65	**166.47**	< 0.01*	0.68
Movement sensitivity	**105.63**	< 0.01*	0.75	**190.69**	< 0.01*	0.66	**85.06**	< 0.01*	0.68
Under-responsivity/seeks	28.50	0.12	0.75	**365.56**	< 0.01*	0.65	**337.06**	< 0.01*	0.69
Auditory filtering	16.49	0.37	0.75	**352.84**	< 0.01*	0.65	**369.33**	< 0.01*	0.69
Low energy/weak	**128.00**	< 0.01*	0.75	**298.60**	< 0.01*	0.65	**170.60**	< 0.01*	0.68
Visual/auditory sensitivity	**180.38**	< 0.01*	0.74	**356.76**	< 0.01*	0.65	**176.38**	< 0.01*	0.68
SSP total	**135.01**	< 0.01*	0.75	**445.06**	< 0.01*	0.64	**310.05**	< 0.01*	0.69

U refers to the Kruskal–Wallis test statistic and η^2 is the effect size. Bold values indiciate a *p* level less than 0.05

measures of sensory processing, compared to individuals with ADHD.

Predicting Behavioural Outcomes

A series of regression analyses were run to examine the relations between CBCL scores and SSP subscales (Tables 3, 4, 5, 6, 7, 8, 9, and 10). Across the behavioural outcomes examined from the CBCL, all were significantly predicted by the SSP subscales and only social problems was significantly predicted in the fourth step of the regressions examining the interaction terms. Overall, the effect sizes were quite large for the regressions, suggesting strong predictive power of the sensory processing patterns above and beyond the variance accounted for by diagnosis.

Discussion

The primary goal of this study was to directly compare sensory processing patterns in autism, ADHD, and typical development. Secondly, we explored the relationship

Table 3 Hierarchical regression predicting CBCL anxious/depressive problems

Predictor	β	*t*-value	Partial correlation (pr)	*p*-value
Model 1: $R^2 = 0.03$; F-change(3, 344) = 3.14; $p = 0.03$				
Age	0.05	0.96	0.05	0.34
Gender	−0.04	−0.67	−0.04	0.50
IQ	0.15	2.81	0.15	**0.005***
Model 2: $R^2 = 0.03$; F-change(1, 343) = 1.84; $p = 0.18$				
Age	0.05	0.90	0.05	0.37
Gender	−0.04	−0.82	-0.04	0.41
IQ	0.16	2.90	0.16	**0.004***
Diagnosis	−0.07	−1.35	−0.07	0.18
Model 3: $R^2 = 0.22$; F-change(7, 336) = 11.77; $p < 0.001$				
Age	0.12	2.25	0.12	**0.03***
Gender	−0.02	−0.46	−0.03	0.64
IQ	0.17	3.23	0.17	**< 0.001***
Diagnosis	0.08	1.47	0.08	0.14
Tactile sensitivity	v0.13	−2.08	−0.11	**0.04***
Taste/smell sensitivity	0.14	−2.63	−0.14	**0.01***
Movement sensitivity	−0.15	−2.54	−0.14	**0.01***
Under-responsive/sensory seeking	< −0.01	−0.06	< −0.01	0.95
Auditory filtering	−0.07	−1.13	-0.06	0.26
Low energy/weak	−0.05	−0.81	-0.04	0.42
Visual/auditory sensitivity	−0.14	−2.05	−0.11	**0.04***
Model 4: $R^2 = 0.25$; F-change(7, 329) = 1.62; $p = 0.13$				

The asterisk/bold values indicates significance at an alpha level of 0.05

between sensory processing patterns and behavioural outcomes across the entire clinical sample. Overall, the results identified significant differences in sensory processing patterns between the undiagnosed and diagnosed groups. Autism and ADHD differed on all sensory subscales except auditory filtering and under-responsivity/sensory seeking. In line with our hypotheses, all behavioural outcomes were significantly predicted by sensory processing patterns over and above the variance accounted for by diagnostic group and demographic variables.

Comparing Sensory Processing Patterns

As expected, sensory processing patterns in both diagnosed samples exceeded those observed in undiagnosed participants. Contrary to our hypotheses, the two diagnosed groups did not exhibit similar overall patterns of sensory processing. Instead, the autism group displayed a significantly more severe and frequent pattern of sensory processing than the ADHD group. Our results align with previous literature that has found differences in sensory processing patterns between autism and ADHD participants (Ermer & Dunn, 1998). Because our findings were contrary to some of the literature that has found similar patterns of sensory processing in autism and ADHD (Cheung & Siu, 2009; Clince et al., 2016; Dellapiazza et al., 2021; Sanz-Cervera et al., 2017), a systematic review and meta-analysis has the potential to provide clarity on the inconsistent findings in the existing research in this area.

We hypothesized that the severity in three sensory subscales would be elevated in ADHD relative to ASD, specifically, under-responsivity/sensory seeking, auditory filtering, and movement sensitivity. The first two, under-responsive/sensory seeking and auditory filtering, were exacerbated in ADHD relative to the other subscales within this group. That is, these subscales in ADHD were equivalent to ASD while all other subscales were less severe and less frequent in ADHD than ASD. The fact that under-responsivity/sensory seeking and auditory filtering are exacerbated in ADHD relative to the other subscales aligns with what is known about the characteristics of ADHD. For example, items describing under-responsivity and sensory seeking on the SSP include behaviours such as seeking movement, touching people and objects, and jumping from one activity to the next (Dunn, 1999). Behavioural descriptions of ADHD in the diagnostic criteria include items such as often fidgets or squirms, does not stay seated, and has difficulty sustaining attention or does not complete tasks (APA,

Table 4 Hierarchical regression predicting CBCL withdrawn/depressed problems

Predictor	*β*	*t*-value	Partial correlation (pr)	*p*-value
Model 1: $R^2 = 0.013$; F-change(3, 344) = 1.52; $p = 0.21$				
Age	0.07	1.36	0.07	0.17
Gender	0.08	1.40	0.08	0.16
IQ	0.06	1.04	0.06	0.30
Model 2: $R^2 = 0.09$; F-change(1, 343) = 28.25; $p < 0.001$				
Age	0.06	1.18	0.06	0.24
Gender	0.04	0.84	0.05	0.40
IQ	0.08	1.45	0.08	0.15
Diagnosis	−0.28	−5.32	−0.28	**< 0.001***
Model 3: $R^2 = 0.23$; F-change(7, 336) = 8.65; $p < 0.001$				
Age	0.08	1.62	0.09	0.11
Gender	0.06	1.20	0.07	0.23
IQ	0.06	1.08	0.06	0.28
Diagnosis	−0.14	−2.63	−0.14	**0.009***
Tactile sensitivity	−0.24	−3.85	−0.21	**< 0.001***
Taste/smell sensitivity	−0.09	−1.65	-0.09	0.10
Movement sensitivity	0.03	0.45	0.02	0.66
Under-responsive/sensory seeking	−0.01	−0.22	−0.01	0.83
Auditory filtering	−0.01	−0.12	−0.01	0.91
Low energy/weak	−0.22	−3.91	−0.21	**< 0.001***
Visual/auditory sensitivity	−0.02	−0.23	−0.01	0.82
Model 4: $R^2 = 0.25$; F-change(7, 329) = 1.49; $p = 0.17$				

The asterisk/bold values indicates significance at an alpha level of 0.05

2013). Therefore, there is overlap in behaviours labelled as under-responsivity/sensory seeking and behaviours labelled as ADHD characteristics. The overlap in the measures used to assess sensory processing patterns and symptomatology is a limitation of this study. Future studies should use behavioural measures of sensory processing patterns and more thorough symptom assessments as opposed to symptom checklists, for example, the observation assessment—Achenbach System of Empirically Based Assessments – Test Observation Form.

Likewise, the process of auditory filtering is highly related to attention and thus, ADHD. Auditory filtering refers to our ability to automatically and unconsciously filter out irrelevant auditory information in our environment and attention refers to the active process of extracting salient information from our environment (Gibson & Rader, 1979). Therefore, it follows that if the automatic filtering of auditory stimuli is impaired, the active attentional system has more information to sift through, rendering the process of focusing on the most salient cues in the environment, more difficult. Previous studies examining auditory filtering in ADHD have found no group differences compared to their peers without diagnoses (Conzelmann et al., 2010; Hanlon et al., 2009; Holstein et al., 2013), however, other studies have shown relations between auditory filtering and attention problems (Conzelmann et al., 2015; Hutchison et al., 2017). As a result, the relation between specific auditory filtering processing and attention remains inconclusive. These behaviours associated with the two elevated subscales, Under-responsivity/Sensory Seeking and Auditory Filtering overlap with the diagnostic criteria for ADHD, thus it is understandable that under-responsivity, sensory seeking, and auditory filtering would all be increasingly displayed by individuals with ADHD in comparison to typical development.

While we hypothesized that movement sensitivity in ADHD would exceed ASD movement sensitivity, the opposite was found. One factor that may have affected these results is the differences in ADHD subtypes as we included all ADHD diagnoses without distinguishing between subtypes whereas movement sensitivity might be more prevalent in the inattentive ADHD subtype compared to the impulsive/hyperactive ADHD subtype. These surprising results may also be due to our novel use of the Short Sensory Profile in the ASD/ADHD comparison. Our hypothesis regarding increased movement sensitivity in ADHD was based on the previous finding of increased differences in body awareness from the Sensory Processing Measure and the relations between the

Table 5 Hierarchical regression predicting CBCL somatic complaints

Predictor	β	*t*-value	Partial correlation (pr)	*p*-value
Model 1: $R^2 = 0.01$; *F*-change(3, 344) = 1.54; $p = 0.20$				
Age	0.04	0.73	0.04	0.47
Gender	− 0.09	− 1.72	− 0.09	0.09
IQ	0.05	0.93	0.05	0.35
Model 2: $R^2 = 0.01$; *F*-change(1, 343) = 0.33; $p = 0.57$				
Age	0.04	0.75	0.04	0.45
Gender	− 0.09	− 1.64	− 0.09	0.10
IQ	0.05	0.89	0.05	0.37
Diagnosis	0.03	0.58	0.03	0.57
Model 3: $R^2 = 0.23$; *F*-change(7, 336) = 13.79; $p < 0.001$				
Age	0.09	1.69	0.09	0.09
Gender	− 0.07	− 1.51	− 0.08	0.13
IQ	0.04	0.76	0.04	0.45
Diagnosis	0.21	3.88	0.21	**< 0.001***
Tactile sensitivity	− 0.23	− 3.75	− 0.20	**< 0.001***
Taste/smell sensitivity	− 0.07	− 1.28	− 0.07	0.20
Movement sensitivity	− 0.07	− 1.13	− 0.06	0.26
Under-responsive/sensory seeking	− 0.02	− 0.37	− 0.02	0.71
Auditory filtering	− 0.05	v0.74	− 0.04	0.46
Low energy/weak	− 0.20	− 3.72	− 0.20	**< 0.001***
Visual/auditory sensitivity	− 0.10	− 1.44	− 0.08	0.15
Model 4: $R^2 = 24$; *F*-change(7, 329) = 0.60; $p = 0.75$				

The asterisk/bold values indicates significance at an alpha level of 0.05

Table 6 Hierarchical regression predicting CBCL social problems

Predictor	β	*t*-value	Partial correlation (pr)	*p*-value
Model 1: $R^2 < 0.01$; *F*-change(3, 344) = 0.34; $p = 0.80$				
Age	− 0.04	− 0.82	− 0.04	0.41
Gender	− 0.03	− 0.54	− 0.03	0.59
IQ	0.02	0.34	0.02	0.74
Model 2: $R^2 = 0.01$; *F*-change(1, 343) = 3.71; $p = 0.06$				
Age	− 0.05	− 0.91	− 0.05	0.36
Gender	− 0.04	− 0.76	− 0.04	0.45
IQ	0.03	0.48	0.03	0.64
Diagnosis	− 0.10	− 1.93	− 0.10	0.06
Model 3: $R^2 = 0.25$; *F*-change(7, 336) = 15.09; $p < 0.001$				
Age	0.07	1.37	0.07	0.17
Gender	− 0.07	− 1.36	− 0.07	0.18
IQ	0.09	1.71	0.09	0.09
Diagnosis	0.02	0.43	0.02	0.67
Tactile sensitivity	− 0.08	− 1.36	− 0.07	0.17
Taste/smell sensitivity	− 0.04	− 0.74	− 0.04	0.46
Movement sensitivity	− 0.01	− 0.20	v0.01	0.85
Under-responsive/sensory seeking	− 0.34	− 5.45	− 0.28	**< 0.001***
Auditory filtering	0.00	− 0.08	0.00	0.94
Low energy/weak	− 0.20	− 3.60	− 0.19	**< 0.001***
Visual/auditory sensitivity	− 0.10	− 1.51	− 0.08	0.13
Model 4: $R^2 = 0.29$; *F*-change(7, 329) = 2.86; $p = 0.006$				

The asterisk/bold values indicates significance at an alpha level of 0.05

Table 7 Hierarchical regression predicting CBCL thought problems

Predictor	β	t-value	Partial correlation (pr)	p-value
Model 1: $R^2 = 0.02$; F-change(3, 344) = 2.75; $p = 0.04$				
Age	−0.02	−0.35	−0.02	0.73
Gender	0.08	1.45	0.08	0.15
IQ	−0.13	−2.42	−0.13	**0.02***
Model 2: $R^2 = 0.07$; F-change(1, 343) = 16.64; $p < 0.001$				
Age	−0.03	−0.53	−0.03	0.60
Gender	0.05	1.01	0.05	0.31
IQ	−0.11	−2.18	−0.12	**0.03***
Diagnosis	−0.22	−4.08	−0.22	**< 0.001***
Model 3: $R^2 = 0.32$; F-change(7, 336) = 18.05; $p < 0.001$				
Age	0.14	2.98	0.16	**0.003***
Gender	0.04	0.83	0.05	0.41
IQ	−0.02	−0.37	−0.02	0.71
Diagnosis	−0.11	−2.17	−0.12	**0.03***
Tactile sensitivity	0.01	0.12	0.01	0.91
Taste/smell sensitivity	−0.17	−3.24	−0.17	**0.001***
Movement sensitivity	0.02	0.40	0.02	0.69
Under-responsive/sensory seeking	−0.39	−6.69	−0.34	**< 0.001***
Auditory filtering	−0.01	−0.23	−0.01	0.82
Low energy/weak	−0.01	−0.27	−0.01	0.79
Visual/auditory sensitivity	−0.18	−2.89	−0.16	**0.004***
Model 4: $R^2 = 0.34$; F-change(7, 329) = 0.83; $p = 0.56$				

The asterisk/bold values indicates significance at an alpha level of 0.05

Movement Sensitivity scale and Body Awareness scale (Simard et al., 2011). However, because our results do not align with the previous research, future assessments are required relating these measures to ADHD and the convergent validity of these two assessments of sensory processing patterns.

Predicting Behavioural Outcomes

We analysed the predictive relations between sensory processing and behavioural outcomes. We found that all eight behavioural areas were significantly predicted by sensory processing patterns, even after accounting for diagnostic group differences. Under-responsivity/sensory seeking had the strongest predictive power for a number of behaviours including aggression, rule-breaking behaviour, and thought, attention, and social problems. Sensory-seeking behaviours can include behaviours such as encroaching on someone's personal space, bumping or crashing into things and people, making loud noises, and touching people and objects. These sensory-seeking behaviours may be interpreted as rule-breaking behaviour, aggression, or inattention, which would explain these relations. Additionally, these types of sensory-seeking behaviours have been related to social characteristics in ASD and thus could extrapolate to other diagnosed groups as well (Baranek et al., 2018), suggesting that sensory seeking may be a trans-diagnostic feature related to social problems. Lastly, there is minimal prior evidence linking sensory seeking and thought problems specifically. Further research into this connection is warranted to potentially uncover a shared mechanism.

Two sensory subscales also stand out in terms of their widespread predictive ability in behavioural outcomes: tactile sensitivity and low energy or weakness. Tactile sensitivity was found to be related to somatic complaints. One possible explanation is that individuals with tactile sensitivity are more likely to perceive physical sensations as painful and thus express more somatic complaints. Likewise, low energy or weakness could also be linked to forms of somatic complaints such as tiring quickly or struggling with physical tasks or struggling to support oneself. For similar reasons, low energy or weakness may be related to attention. Individuals who experience low energy and weakness may struggle to sustain their attention for extended periods of time or lack the mental effort to stay focused (Boksem et al., 2005). Lastly, it is understandable that individuals who experience low energy may withdraw and be more depressed and struggle with social situations because they lack the energy

Table 8 Hierarchical regression predicting CBCL attention problems

Predictor	β	t-value	Partial correlation (pr)	p-value
Model 1: $R^2 = 0.05$; F-change(3, 344) = 5.91; $p < 0.001$				
Age	−0.13	−2.40	−0.13	0.02
Gender	−0.09	−1.80	−0.10	0.07
IQ	−0.16	−3.09	−0.16	**0.002***
Model 2: $R^2 = 0.05$; F-change(1, 343) = 0.90; $p = 0.35$				
Age	−0.12	−2.35	−0.13	**0.02***
Gender	−0.09	−1.68	−0.09	0.10
IQ	−0.17	−3.15	−0.17	**0.002***
Diagnosis	0.05	0.95	0.05	0.35
Model 3: $R^2 = 0.39$; F-change(7, 336) = 26.40; $p < 0.001$				
Age	0.04	0.86	0.05	0.39
Gender	−0.15	−3.34	−0.18	**0.001***
IQ	−0.10	−2.28	−0.12	**0.02***
Diagnosis	0.08	1.76	0.10	0.08
Tactile sensitivity	0.14	2.51	0.14	**0.01***
Taste/smell sensitivity	−0.02	−0.50	−0.03	0.62
Movement sensitivity	0.03	0.58	0.03	0.56
Under-responsive/sensory seeking	−0.41	−7.42	−0.38	**< 0.001***
Auditory filtering	−0.30	−5.45	−0.28	**< 0.001***
Low energy/weak	−0.14	−2.87	−0.15	**0.004***
Visual/auditory sensitivity	0.00	0.01	0.00	0.99
Model 4: $R^2 = 0.40$; F-change(7, 329) = 0.74; $p = 0.64$				

The asterisk/bold values indicates significance at an alpha level of 0.05

Table 9 Hierarchical regression predicting CBCL rule-breaking behaviour

Predictor	β	t-value	Partial Correlation (pr)	p-value
Model 1: $R^2 = 0.04$; F-change(3, 344) = 4.34; $p = 0.005$				
Age	−0.18	−3.40	−0.18	**0.001***
Gender	−0.03	−0.46	−0.03	0.64
IQ	0.06	1.19	0.06	0.24
Model 2: $R^2 = 0.04$; F-change(1, 343) = 2.70; $p = 0.10$				
Age	−0.18	−3.33	−0.18	**0.001***
Gender	−0.01	−0.27	−0.01	0.78
IQ	0.06	1.07	0.06	0.28
Diagnosis	0.09	1.64	0.09	0.10
Model 3: $R^2 = 0.14$; F-change(7, 336) = 5.38; $p < 0.001$				
Age	−0.08	−1.48	−0.08	0.14
Gender	−0.04	−0.81	−0.04	0.42
IQ	0.09	1.60	0.09	0.6
Diagnosis	0.08	1.43	0.08	0.16
Tactile sensitivity	−0.04	−0.57	−0.03	0.57
Taste/smell sensitivity	−0.02	−0.33	−0.02	0.74
Movement sensitivity	0.05	0.87	0.05	0.39
Under-responsive/sensory seeking	−0.25	−3.81	−0.20	**< 0.001***
Auditory filtering	−0.14	−2.17	−0.12	**0.03***
Low energy/weak	0.01	0.21	0.01	0.84
Visual/auditory sensitivity	0.08	1.10	0.06	0.27
Model 4: $R^2 = 0.17$; F-change(7, 329) = 1.64; $p = 0.12$				

The asterisk/bold values indicates significance at an alpha level of 0.05

Table 10 Hierarchical regression predicting CBCL aggression problems

Predictor	*β*	*t*-value	Partial Correlation (pr)	*p*-value
Model 1: $R^2=0.05$; F-change(3, 344) = 5.99; $p<0.001$				
Age	−0.21	−3.97	−0.21	**< 0.001***
Gender	0.05	0.87	0.05	0.39
IQ	0.04	0.81	0.04	0.42
Model 2: $R^2=0.06$; F-change(1, 343) = 3.70; $p=0.05$				
Age	−0.21	−3.90	−0.21	**< 0.001***
Gender	0.06	1.09	0.06	0.28
IQ	0.04	0.68	0.04	0.50
Diagnosis	0.10	1.92	0.10	0.06
Model 3: $R^2=0.21$; F-change(7, 336) = 9.33; $p<0.001$				
Age	−0.09	−1.70	−0.09	0.09
Gender	0.04	0.84	0.05	0.40
IQ	0.07	1.39	0.08	0.17
Diagnosis	0.14	2.57	0.14	0.01
Tactile sensitivity	−0.21	−3.34	−0.18	**0.001***
Taste/smell sensitivity	−0.01	−0.23	−0.01	0.82
Movement sensitivity	0.08	1.36	0.07	0.18
Under-responsive/sensory seeking	−0.29	−4.63	−0.24	**< 0.001***
Auditory filtering	−0.05	−0.87	−0.05	0.39
Low energy/weak	0.05	0.95	0.05	0.34
Auditory/visual sensitivity	0.02	0.29	0.02	0.77
Model 4: $R^2=0.22$; F-change(7, 329) = 0.71; $p=0.67$				

The asterisk/bold values indicates significance at an alpha level of 0.05

to engage in enjoyable activities and social interactions (Carter et al., 1995; Ekers et al., 2014).

Individuals who are hypersensitive to sensory stimuli are able to detect stimuli at a lesser intensity, resulting in a greater number of perceivable stimuli in their environments. This may lead an individual to be overloaded by their sensory environment and hypotheses suggest that sensory overload can be related to higher levels of anxiety (Black et al., 2017; Neil et al., 2016). Therefore, because tactile sensitivity can lead to sensory overload from the environment, which in turn increases anxiety and avoidance, this hypothesis could explain the relation between tactile sensitivity and anxious/depressive and depressive/withdrawn behaviours. All in all, tactile sensitivity and low energy or weakness have widespread effects on behaviour. It is important that sensory differences be considered in the treatment of behavioural concerns (see Dunn, 2007 for a thorough guide on practical interventions for sensory processing concerns).

Overall, we aimed to better understand sensory processing as a transdiagnostic mechanism in neurodevelopmental disorders. As of right now, we treat clusters of behaviours, providing a band-aid solution. Elucidating the underlying of specific behaviours allows for more targeted interventions and improved long-term treatment outcomes.

Limitations and Future Directions

There are a few limitations to consider. Firstly, the use of the questionnaires is a limitation because we relied on parent report and the factor structure of the Sensory Profile is under discussion. Evidence dictates that there is often a lack of agreement between children and adolescents and their caregivers when reporting characteristics, behaviours, and experiences (Bitsika et al., 2016; Verhulst & Van der Ende, 1992). The Sensory Profile has shown high validity and reliability, however, recent research has questioned its factor structure, which has implications for our discussion of the relations between the Sensory Profile subscales and behavioural outcomes (Tomchek et al., 2014; Williams et al., 2018).

Secondly, we are unable to speak to the causation of behavioural characteristics because this study is cross-sectional and observational in nature. Future research should include an experimental design in which causation can be inferred. Additionally, we excluded participants who displayed characteristics or traits related to comorbid conditions. While this allowed us to better understand developmental disorders individually, it makes our results less generalizable as the vast majority of this population experience comorbidities. There is a higher prevalence of both ADHD and autism in males compared to females. However, research suggests that the male bias might be due to varying presentations of both autism and ADHD in girls (Young et al., 2018, 2020). Therefore, it is important to note that this male bias may not be representative and may contribute to the disproportionate understanding of these disorders in females.

Lastly, our participants range in age from very young to young adults and there is evidence that sensory processing changes over development. Although we accounted for age in our regressions, it is an important consideration while interpreting our results. Future directions in this line of work include understanding sensory processing differences as a shared underlying mechanism in not only ASD and ADHD, but in other neurodevelopmental disorders as well.

Author Contribution SS designed and executed the study, completed data analysis, and wrote the manuscript. EK, AG, RN, SG, JC, RS, MA, and RAS collaborated on study design, participated in data collection, and edited the final manuscript.

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Declarations

Ethics Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Data collected at each institution obtained ethics approval from that institution. This analysis was approved by the Western University Research Ethics Board.

Consent to Participate Informed consent was obtained for the legal guardians of all participants. Assent was obtained for all individual participants.

Conflict of Interest The authors declare no competing interests.

References

Achenbach, T., & Edelbrock, C. (1991). *The child behavior checklist manual*. The University of Vermont.

Aduen, P. A., Day, T. N., Kofler, M. J., Harmon, S. L., Wells, E. L., & Sarver, D. E. (2018). Social problems in ADHD: Is it a skills acquisition or performance problem? *Journal of Psychopathology and Behavioral Assessment, 40*(3), 440–451.

APA. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). American Psychiatric Association.

Ashburner, J., Ziviani, J., & Rodger, S. (2008). Sensory processing and classroom emotional, behavioral, and educational outcomes in children with autism spectrum disorder. *American Journal of Occupational Therapy, 62*(5), 564–573.

Baranek, G. T., Woynaroski, T. G., Nowell, S., Turner-Brown, L., DuBay, M., Crais, E. R., & Watson, L. R. (2018). Cascading effects of attention disengagement and sensory seeking on social symptoms in a community sample of infants at-risk for a future diagnosis of autism spectrum disorder. *Developmental Cognitive Neuroscience, 29*, 30–40.

Bijlenga, D., Tjon-Ka-Jie, J., Schuijers, F., & Kooij, J. (2017). Atypical sensory profiles as core features of adult ADHD, irrespective of autistic symptoms. *European Psychiatry, 43*, 51–57.

Bitsika, V., Sharpley, C. F., & Mills, R. (2016). Disagreement between mothers' and their sons' with ASD on ratings of Sensory Features. *Research in Autism Spectrum Disorders, 22*, 10–19.

Black, K. R., Stevenson, R. A., Segers, M., Ncube, B. L., Sun, S. Z., Philipp-Muller, A., Bebko, J. M., Barense, D., & Ferber, S. (2017). Linking anxiety and insistence on sameness in autistic children: The role of sensory hypersensitivity. *Journal of Autism and Developmental Disorders, 47*(8), 2459–2470.

Boksem, M. A., Meijman, T. F., & Lorist, M. M. (2005). Effects of mental fatigue on attention: an ERP study. *Cognitive Brain Research, 25*(1), 107–116.

Carter, B. D., Edwards, J. F., Kronenberger, W. G., Michalczyk, L., & Marshall, G. S. (1995). Case control study of chronic fatigue in pediatric patients. *Pediatrics, 95*(2), 179–186.

Cheung, P. P., & Siu, A. M. (2009). A comparison of patterns of sensory processing in children with and without developmental disabilities. *Research in Developmental Disabilities, 30*(6), 1468–1480.

Chita-Tegmark, M. (2016). Social attention in ASD: A review and meta-analysis of eye-tracking studies. *Research in Developmental Disabilities, 48*, 79–93.

Chorna, O., Solomon, J. E., Slaughter, J. C., Stark, A. R., & Maitre, N. L. (2014). Abnormal sensory reactivity in preterm infants during the first year correlates with adverse neurodevelopmental outcomes at 2 years of age. *Archives of Disease in Childhood-Fetal and Neonatal Edition, 99*(6), 475–479.

Clince, M., Connolly, L., & Nolan, C. (2016). Comparing and exploring the sensory processing patterns of higher education students with attention deficit hyperactivity disorder and autism spectrum disorder. *The American Journal of Occupational Therapy, 70*(2), 7002250010p1-7002250010p9. https://doi.org/10.5014/ajot.2016.016816

Conzelmann, A., Pauli, P., Mucha, R. F., Jacob, C. P., Gerdes, A. B. M., Romanos, J., Bahne, C. G., Heine, M., Boreatti-Hummer, A., Alpers, G. W., & Weyers, P. (2010). Early attentional deficits in an attention-to-prepulse paradigm in ADHD adults. *Journal of Abnormal Psychology, 119*(3), 594–603.

Conzelmann, A., Werst, E., Schulz, S., Renner, T., & Pauli, P. (2015). *Emotional-motivational deficits in healthy student with an increase in ADHD symptoms.* Paper presented at the 5th World Congress on ADHD, Würzburg, Germany.

Dellapiazza, F., Michelon, C., Vernhet, C., Muratori, F., Blanc, N., Picot, M.-C., & Baghdadli, A. (2021). Sensory processing related to attention in children with ASD, ADHD, or typical development: Results from the ELENA cohort. *European Child & Adolescent Psychiatry, 30*(2), 283–291.

Dewey, D. (2018). What is comorbidity and why does it matter in neurodevelopmental disorders? *Current Developmental Disorders Reports, 5*(4), 235–242.

Dunn, W. (1999). *Sensory profile: User's manual*. The Psychological Corporation.

Dunn, W. (2007). Supporting children to participate successfully in everyday life by using sensory processing knowledge. *Infants & Young Children, 20*(2), 84–101.

Dunn, W., & Brown, C. (1997). Factor analysis on the Sensory Profile from a national sample of children without disabilities. *American Journal of Occupational Therapy, 51*(7), 490–495.

Dunn, W., & Westman, K. (1997). The sensory profile: The performance of a national sample of children without disabilities. *American Journal of Occupational Therapy, 51*(1), 25–34.

Ekers, D., Webster, L., Van Straten, A., Cuijpers, P., Richards, D., & Gilbody, S. (2014). Behavioural activation for depression; An update of meta-analysis of effectiveness and sub group analysis. *PLoS One, 9*(6), 100100.

Ermer, J., & Dunn, W. (1998). The Sensory Profile: A discriminant analysis of children with and without disabilities. *American Journal of Occupational Therapy, 52*(4), 283–290.

Ghanizadeh, A. (2011). Sensory processing problems in children with ADHD, a systematic review. *Psychiatry Investigation, 8*(2), 89–94.

Gibson, E., & Rader, N. (1979). Attention. In G. A. Hale & M. Lewis (Eds.), *Attention and Cognitive Development* (pp. 1–21). Springer.

Hanlon, M. C., Karayanidis, F., & Schall, U. (2009). Intact sensorimotor gating in adult attention deficit hyperactivity disorder. *International Journal of Neuropsychopharmacology, 12*(5), 701–707.

Hansen, B. H., Oerbeck, B., Skirbekk, B., Petrovski, B. É., & Kristensen, H. (2018). Neurodevelopmental disorders: Prevalence and comorbidity in children referred to mental health services. *Nordic Journal of Psychiatry, 72*(4), 285–291.

Holstein, D. H., Vollenweider, F. X., Geyer, M. A., Csomor, P. A., Belser, N., & Eich, D. (2013). Sensory and sensorimotor gating in adult attention-deficit/hyperactivity disorder (ADHD). *Psychiatry Research, 205*(1–2), 117–126.

Hutchison, A. K., Hunter, S. K., Wagner, B. D., Calvin, E. A., Zerbe, G. O., & Ross, R. G. (2017). Diminished infant P50 sensory gating predicts increased 40-month-old attention, anxiety/depression, and externalizing symptoms. *Journal of Attention Disorders, 21*(3), 209–218.

Kilroy, E., Aziz-Zadeh, L., & Cermak, S. (2019). Ayres theories of autism and sensory integration revisited: What contemporary neuroscience has to say. *Brain Sciences, 9*(3), 68.

Kotte, A., Joshi, G., Fried, R., Uchida, M., Spencer, A., Woodworth, K. Y., Kenworthy, T., Faraone, S. V., & Biederman, J. (2013). Autistic traits in children with and without ADHD. *Pediatrics, 132*(3), e612–e622.

Little, L. M., Dean, E., Tomchek, S., & Dunn, W. (2018). Sensory processing patterns in autism, attention deficit hyperactivity disorder, and typical development. *Physical & Occupational Therapy in Pediatrics, 38*(3), 243–254.

Little, L. M., Freuler, A. C., Houser, M. B., Guckian, L., Carbine, K., David, F. J., & Baranek, G. T. (2011). Psychometric validation of the sensory experiences questionnaire. *American Journal of Occupational Therapy, 65*(2), 207–210.

Marco, E. J., Hinkley, L. B., Hill, S. S., & Nagarajan, S. S. (2011). Sensory processing in autism: A review of neurophysiologic findings. *Pediatric Research, 69*, 48–54.

Murray, M. J. (2010). Attention-deficit/hyperactivity disorder in the context of autism spectrum disorders. *Current Psychiatry Reports, 12*(5), 382–388.

Neil, L., Olsson, N. C., & Pellicano, E. (2016). The relationship between intolerance of uncertainty, sensory sensitivities, and anxiety in autistic and typically developing children. *Journal of Autism and Developmental Disorders, 46*(6), 1962–1973.

O'connor, K. (2012). Auditory processing in autism spectrum disorder: A review. *Neuroscience & Biobehavioral Reviews, 36*(2), 836–854.

Rommelse, N., Buitelaar, J. K., & Hartman, C. A. (2017). Structural brain imaging correlates of ASD and ADHD across the lifespan: A hypothesis-generating review on developmental ASD–ADHD subtypes. *Journal of Neural Transmission, 124*(2), 259–271.

Sanz-Cervera, P., Pastor-Cerezuela, G., González-Sala, F., Tárraga-Mínguez, R., & Fernández-Andrés, M.-I. (2017). Sensory processing in children with autism spectrum disorder and/or attention deficit hyperactivity disorder in the home and classroom contexts. *Frontiers in Psychology, 8*, 1772.

Satterstrom, F. K., Walters, R. K., Singh, T., Wigdor, E. M., Lescai, F., Demontis, D., Kosmicki, J. A., Grover, J., Stevens, C., Bybjerg-Grauholm, J., & Baekvad-Hansen, M. (2019). Autism spectrum disorder and attention deficit hyperactivity disorder have a similar burden of rare protein-truncating variants. *Nature Neuroscience, 22*(12), 1961–1965.

Schafer, E. C., Mathews, L., Mehta, S., Hill, M., Munoz, A., Bishop, R., & Moloney, M. (2013). Personal FM systems for children with autism spectrum disorders (ASD) and/or attention-deficit hyperactivity disorder (ADHD): An initial investigation. *Journal of Communication Disorders, 46*(1), 30–52.

Simard, M. F. E,, Gisel, E. G., & Couture, M. (2011). *Comparison of the Sensory Profile and the Sensory Processing Measure in a cohort of children diagnosed with autism spectrum disorders*. Paper presented at the International Meeting for Autism Research 2011, San Diego, CA.

Simmons, D. R., Robertson, A. E., McKay, L. S., Toal, E., McAleer, P., & Pollick, F. E. (2009). Vision in autism spectrum disorders. *Vision Research, 49*(22), 2705–2739.

Thye, M. D., Bednarz, H. M., Herringshaw, A. J., Sartin, E. B., & Kana, R. K. (2018). The impact of atypical sensory processing on social impairments in autism spectrum disorder. *Developmental Cognitive Neuroscience, 29*, 151–167.

Tomchek, S. D., Huebner, R. A., & Dunn, W. (2014). Patterns of sensory processing in children with an autism spectrum disorder. *Research in Autism Spectrum Disorders*, *8*(9), 1214–1224.

Vasiliadis, H.-M., Diallo, F. B., Rochette, L., Smith, M., Langille, D., Lin, E., Kisely, S., Fombonne, E., Thompson, A. H., Renaud, J., & Lesage, A. (2017). Temporal trends in the prevalence and incidence of diagnosed ADHD in children and young adults between 1999 and 2012 in Canada: A data linkage study. *The Canadian Journal of Psychiatry, 62*(12), 818–826.

Verhulst, F. C., & Van der Ende, J. (1992). Agreement between parents' reports and adolescents' self-reports of problem behavior. *Journal of Child Psychology and Psychiatry, 33*(6), 1011–1023.

Wallace, M. T., Woynaroski, T. G., & Stevenson, R. A. (2020). Multisensory integration as a window into orderly and disrupted cognition and communication. *Annual Review of Psychology, 71*, 193–219.

Williams, Z. J., Failla, M. D., Gotham, K. O., Woynaroski, T. G., & Cascio, C. (2018). Psychometric evaluation of the Short Sensory Profile in youth with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, 1–19

Young, H., Oreve, M.-J., & Speranza, M. (2018). Clinical characteristics and problems diagnosing autism spectrum disorder in girls. *Archives de Pediatrie, 25*(6), 399–403.

Young, S., Adamo, N., Ásgeirsdóttir, B. B., Branney, P., Beckett, M., Colley, W., Cubbin, S., Deeley, Q., Farrag, E., Gudjonsson, G., & Hill, P. (2020). Females with ADHD: An expert consensus statement taking a lifespan approach providing guidance for the identification and treatment of attention-deficit/hyperactivity disorder in girls and women. *BMC Psychiatry, 20*(1), 1–27.