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Patterns of Sensory Processing in Young Children with Autism: Differences in Autism Characteristics, Adaptive Skills, and Attentional Problems

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Abstract

Sensory processing differences are widely reported in autism. However, our understanding of sensory profiles in this population has been complicated due to the heterogeneous presentation of sensory symptoms. We addressed this by using latent profile analysis, allowing for the identification of more homogeneous sensory classes in a large cohort (*n*=211 [52 females], 2–4 years) of autistic children using subscale scores from the Short Sensory Profile. Based on the patterns of both severity and sensory modality, four classes emerged: *Moderate/Mixed* (35.5%), *Severe/Mixed* (8.5%), *Moderate/Broad* (14.6%), and *Low/Mixed* (41.1%). While a subset of children displayed normative sensory-related behaviors, the majority showed a combination of both hypo- and hyper-reactivity across various sensory modalities. Subsequent analyses showed that the class characterized by *Severe/Mixed* sensory differences exhibited greater problems in a variety of areas such as social and adaptive skills and ADHD symptoms, whereas the *Low/Mixed* class showed overall fewer problems. Identification of homogenous classes may be useful for neurophysiological/imaging studies focusing on studying underlying mechanisms linked with specific sensory patterns. These findings may help clinicians identify children with particular sensory profiles that might relate to other social, adaptive, or behavioral domains with potential implications for intervention.

Keywords

Autism spectrum disorders; Latent Profile Analysis; Sensory processing; Sensory classes

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Introduction

Sensory symptoms are core to the diagnostic criteria for autism spectrum disorder (ASD). Recent estimates have suggested high but variable prevalence rates of sensory differences (ranging from 42–96%) among autistic[1] individuals (Baranek et al., 2006; Ben-Sasson et al., 2009; Lane et al., 2011; Leekam et al., 2007), and impairments in sensory processing have been associated with social, linguistic, and adaptive skills (Baranek et al., 2018; Hannant et al., 2016; Lane et al., 2010; K. Williams et al., 2018). While sensory differences in autism are widely acknowledged, our understanding of sensory *profiles* has been complicated due to the heterogeneity in symptom presentation. For instance, differing profiles of both hypo- and hyper-reactivity have been observed across and within sensory modalities in *some* autistic individuals (Baranek et al., 2006). Additionally, autistic individuals may display different sensory sensitivity/avoiding (indicative of hyper-reactivity) and sensory seeking/registration (indicative of hypo-reactivity) behaviors depending on context and task demands (Baranek et al., 2014; Little et al., 2015). Using person-centered statistical approaches that allow for the identification of more homogeneous sensory classes in otherwise heterogenous groups could help to better understand this heterogeneity. While intuitively appealing, studies identifying sensory subtypes have found variability in both the nature and number of sensory classes along with differences in identifying classes based on sensory modalities and/or severity of responses (Ben-Sasson et al., 2008; Lane et al., 2014; Tillmann et al., 2020; Uljarević et al., 2016).

For example, Ben-Sasson et al. (2008) examined sensory-defined classes based on the Infant Toddler Sensory Profile (ITSP; Dunn, 2002) in 170 autistic toddlers (18–33 months). Using cluster analysis, three classes emerged: low, high frequency of under- and over-responsivity and seeking, and mixed symptoms characterized by high frequency of under and over-responsivity and low frequency of seeking. Toddlers with under- and over-responsivity were more likely to have depressive/withdrawal symptoms. In a sample of 144 autistic children (mean [*SD*] age: 102.4 [50.1] months), Liss et al. (2006) identified four classes based on the severity of over-reactivity, under-reactivity, and sensory seeking scores on the Sensory Profile (Dunn, 1999): overfocused, low functioning, mildly overfocused, and no sensory problems. More significant differences were associated with lower social and communication skills across classes. In contrast, Simpson et al. (2019) identified only two classes in a sample of 271 autistic children (4–11 years) using the Short Sensory Profile-2 (SSP-2; Dunn, 2014), described as uniformly elevated (higher scores on all SSP-2 domains) and higher avoiding and sensitivity (elevated scores on avoiding and sensitivity domains on the SSP-2). Severity-based sensory classes (adaptive, moderate, severe) were also observed in a small sample (n=57) of older autistic children (11–17 years) using the Short Sensory Profile (SSP; McIntosh et al., 1999) (Uljarević et al., 2016), and in studies spanning wide age ranges (2–12 years; Ausderau, Furlong, et al., 2014). In the latter study (Ausderau, Furlong, et al., 2014), four classes were identified based on Sensory Experiences Questionnaire scores (SEQ; Baranek et al., 2006): mild, sensitive-distressed, attenuated-preoccupied, and extreme-mixed.

[1]Consistent with the terminology guidelines of this journal, we have prioritized the use of identity-first language throughout.

Others have examined both severity (mild/severe) and modality (tactile, auditory, visual, taste/smell, movement, proprioception) of sensory processing to identify sensory classes. Using the SSP, Lane et al. (2010) identified three classes in a sample of 54 autistic children (33–115 months): Sensory-modulation with movement sensitivity (SMMS), sensory-based inattentive-seeking (SBIS), and sensory-modulation with taste/smell sensitivity (SMTS). These classes were mainly differentiated by motor-related sensory behaviors and taste/smell sensitivity. Further, SMMS and SMTS classes predicted maladaptive behaviors and communication competence. Such groupings were replicated using model-based cluster analysis in an independent sample of 30 autistic children (41–113 months; Lane et al., 2011). In another study, Lane et al. (2014) identified four sensory classes in a sample of 228 autistic children (2–10 years) using the SSP: typical sensory processing with mild differences in auditory filtering and under-responsivity, extreme taste and smell sensitivity and greater differences in auditory filtering and under-responsivity, extreme scores in low energy/weakness and greater differences in auditory filtering and under-responsivity, and generalized differences across domains. These findings were partially replicated by Tomchek et al. (2018), in which a sample of 400 autistic children (3–6 years) were classified into four classes (sensorimotor, selective-complex, perceptive-adaptive, and vigilant-engaged), differentiated by variation in taste/smell sensitivity, seeking, hypo-responsiveness, and auditory/visual sensitivity.

These studies indicate there may be homogenous classes based on distinct sensory responsivity patterns in autism, but variation in the number and characteristics of classes is evident. Some discrepancies in the number of sensory classes, as well as characteristics of various classes identified across studies, highlight the overall heterogeneity of sensory symptoms in autism. For example, while the classes in Simpson et al. (2019) report elevated sensory differences in all or some of the sensory domains, other studies (Ausderau, Furlong, et al., 2014; Uljarević et al., 2016) have identified classes that are characterized by only mild sensory differences or showing mostly typical responses along with other classes indicative of severe sensory problems. It is also important to be cognizant of differences in the analytical approach utilized, selection of sensory measures, as well as age groups studied while interpreting similarities and differences among studies. Finally, although the studies summarized above have shown different patterns of results with respect to how sensory classes may be identified, across studies, it appears that children with autism can be broadly categorized into (1) mild or mostly typical sensory responsivity, (2) mixed patterns of sensory responsivity (i.e., more sensory problems in certain domains/modalities over others *or* intermediate level of sensory problems), and (3) severe or uniformly elevated sensory problems in all domains.

Research has also shown a continuum of sensory processing differences in individuals with other neurodevelopmental disorders such as attention-deficit/hyperactivity disorder (ADHD) (Dellapiazza, Michelon, Vernhet, et al., 2021; Ghanizadeh, 2011; Little et al., 2018; Mimouni-Bloch et al., 2018), and associations between sensory reactivity and attentional difficulties in autism have been found (Dellapiazza et al., 2018), suggesting a two-way relationship in that attention may be impacted by perceptual salience of sensory input (Marco et al., 2011; Talsma et al., 2010). Conversely, behavioral responses to sensory input may be impacted by attention affecting overall sensory function (Cascio et al., 2016). Given the potential relationship between attentional difficulties and sensory processing in autism as well as the frequent co-occurrence of autism and ADHD (Craig et al., 2015), further research is warranted to understand whether homogenous sensory profiles in autism differ in terms of attention and ADHD-related traits. This may provide insight for clinicians and researchers that aim to understand whether autistic children who exhibit distinct sensory patterns are more or less likely to also experience ADHD-related traits.

This study had two aims: (1) to identify homogenous classes of sensory processing in young autistic children based on both severity and modality using subscale scores from the SSP, and (2) to examine whether sensory classes differ in terms of autism characteristics, adaptive skills, and ADHD symptoms. We hypothesized that distinct sensory classes would emerge within a sample of autistic children, and that these classes would differ in terms of autism characteristics, adaptive skills, and ADHD symptoms. We extend the existing literature by focusing on identifying sensory classes in a large sample of young autistic children characterized by a narrow age range (2–4 years), thereby addressing some of the limitations of prior work reliant on broad age ranges and smaller sample sizes. The inclusion of attention/ADHD-relevant behaviors as outcomes of interest in young autistic children also adds to the existing literature. Finally, we use Latent Profile Analysis (LPA) for identifying homogenous sensory classes which is a probabilistic and a more flexible alternative to traditional cluster analysis methods used in a number of prior studies.

The present study utilizes data overlapping with a sample of children included in prior research on sensory classes in autism and typical development (TD) based on longitudinal data between two time points (2–5 years [160 ASD, 85 TD]; 4–10 years [87 ASD, 55 TD]; Dwyer et al., 2020). Past research also examined differences in anxiety and sleep problems between sensory classes derived using factor mixture modeling (Dwyer et al., 2021). The present cross-sectional study is distinct from these prior longitudinal studies in several ways. First, rather than using total raw SSP scores to identify classes (Dwyer et al., 2020), we utilize SSP subscale scores to identify homogenous sensory classes in an effort to obtain a more fine-grained assessment of the ways in which classes may be distinguished by different modalities, in addition to severity of sensory differences. Second, we focus on the individual communication, socialization, and daily living domains of the Vineland Adaptive Behavior Scale-2 (VABS-2) as measures of adaptive functioning versus the total composite score based on prior research showing links between sensory reactivity and social, communication, and daily living skills in autism (Liss et al., 2006; Watson et al., 2011; K. Williams et al., 2018). Third, although various SSP factor structures have been suggested (e.g., Dwyer et al., 2021; Williams et al., 2018), we elected to use the original seven SSP subscales (McIntosh et al., 1999), which are more frequently used in clinical settings and may therefore provide more clinically-relevant information. Fourth, given the association between attention skills and sensory processing in autism (Dellapiazza et al., 2018), we also focus on examining differences in attention and ADHD-relevant behaviors across sensory classes. Finally, while previous studies included both autistic and TD children, we elected to include just the autistic group allowing us to identify sensory-based classes *within* the sample of autistic children, reasoning that any differences between sensory classes would not simply be a result of the presence of the TD children in one or more of the classes. Overall, the methodological differences (i.e., reliance on SSP subscales and VABS subdomains, inclusion of attention/ADHD-relevant behaviors as outcomes of interest, derivation of cross-sectional patterns rather than longitudinal) and focus on clinical utility differentiates this paper from prior investigations relying on overlapping samples.

Methods

Participants

Participants were enrolled in either the Autism Phenome Project (APP) study or the Girls with Autism – Imaging of Neurodevelopment (GAIN) study. The study protocols are identical; the GAIN study was initiated to enrich the APP cohort with females. Both studies were approved by University of California, Davis Institutional Review Board, and written informed consent was obtained from parents. Both studies conducted baseline assessments with children at 2–5 years of age, following them longitudinally across childhood. The current study utilized behavioral assessments from the baseline visits. All participants in the autism group met *DSM* and Collaborative Programs of Excellence in Autism (CPEA) network criteria for autism based on meeting the autism cut-off on the Autism Diagnostic Interview-Revised (ADI-R; Lord et al., 1994) and the Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord et al., 2000) or Autism Diagnostic Observation Schedule-2 (ADOS-2; Lord et al., 2012) along with expert clinical judgement by a licensed psychologist trained to research standards. All participants were native English speakers and did not have vision or hearing problems, known genetic disorders (e.g., Fragile X), or any other neurological conditions.

Although the baseline age range of initial assessments spanned up to 5 years, we elected to include participants with SSP data acquired between 2–4 years of age in order to examine sensory classes in a narrower developmental window, since autistic children have been shown to display changes in sensory profiles with age (Baranek et al., 2013; Ben-Sasson et al., 2009; Dellapiazza, Michelon, Picot, et al., 2021). Of 383 participants in the autistic group with baseline data, 217 had SSP data, with 211 having SSP data acquired between ages 2–4 years (mean age=37 months; 52 females). Of 211 participants, 144 had DQ scores below 70. Although the full cohorts included TD children, because we aimed to examine sensory classes *within* the autistic group, we excluded TD participants from analyses.

Measures

Short Sensory Profile (SSP)—The SSP (McIntosh et al., 1999) is a 38-item parent-report questionnaire designed to measure everyday sensory reactivity in children across seven domains: Tactile Sensitivity (TS), Taste/Smell Sensitivity (TSS), Movement Sensitivity (MS), Under-responsive/Seeks Sensation (USS), Auditory Filtering (AF), Low Energy/Weak (LEW), and Visual/Auditory Sensitivity (VAS). Raw scores from each subscale were utilized in analyses. Lower scores indicate atypical sensory behaviors (definite differences), whereas high scores indicate relatively typical sensory behaviors (probable/mild differences or typical performance).

Mullen Scales of Early Learning (MSEL)—The MSEL (Mullen, 1995) is a standardized measure of verbal and nonverbal development for children from birth to 68 months. Participants were administered four MSEL subscales: Visual Reception (VR), Fine Motor (FM), Expressive Language (EL), and Receptive Language (RL). Developmental quotients (DQ) were calculated by dividing the average of age-equivalent subscale scores (i.e., mental age) by chronological age and multiplying by 100. Nonverbal DQ was included as a covariate since it is conceptually separate from language skills that may impact scores on the VABS communication and socialization domains, which are outcomes of interest.

Autism Diagnostic Observation Schedule-Generic (ADOS-G)/Autism Diagnostic Observation Schedule-2 (ADOS-2)—The ADOS-G (Lord et al., 2000)/ADOS-2 (Lord et al., 2012) is a semi-structured, standardized assessment of communication, social interaction, play, and restricted and repetitive behaviors. The ADOS-G was administered to children enrolled prior to 2012. Children were administered Module 1 or 2 based on the module-specific language level requirements per the ADOS manual. ADOS-2 comparison scores (i.e., calibrated severity scores [CSS]) were used as a measure of degree of autism characteristics, with higher scores indicating a greater degree of autism characteristics (Gotham et al., 2009).

Social Responsiveness Scale-2nd Ed. (SRS-2)—The SRS-2 (Constantino, 2012) is a caregiver-report questionnaire that provides a quantitative measure of autism-related characteristics. The Preschool Age form was completed by participants' primary caregivers. SRS-2 Total scores, as well as Social Communication and Interaction (SCI) and Restricted Interests and Repetitive Behavior (RRB) subscale scores, were used as indices of autism characteristics, with higher scores reflecting a greater degree of autism characteristics.

Vineland Adaptive Behavior Scales-2nd Ed. (VABS-2)—The VABS-2 (Sparrow et al., 2005) is a parent/caregiver questionnaire designed to assess adaptive functioning in four domains: Communication, Daily Living Skills, Socialization, and Motor Skills. Standard scores for the Communication, Daily Living Skills, and Socialization scales were used.

Childhood Behavior Checklist (CBCL), Ages 1.5–5—The CBCL (Achenbach & Rescorla, 2000) is a caregiver rating scale designed to assess a broad range of behavioral, social, and emotional problems. We utilized continuous raw scores for the ADHD and Attention Problems subscales, electing to use raw scores instead of T-scores to account for the full range of variation in behavior since T-scores are truncated (Achenbach & Rescorla, 2000). Higher scores indicate greater challenges.

Statistical approach

Using latent profile analysis (LPA), we sought to identify distinct patterns of sensory profiles based on subscale SSP scores. In preliminary analyses, we examined the extent to which age and nonverbal DQ were related to the latent classes by including them in the LPA models. Since neither of them had an effect on the latent profiles, we elected to employ LPA models that did not include covariates. Models were estimated using maximum likelihood; participants with incomplete data were included in analyses under the missing at random assumption. Two- through five-class models were compared. In addition to statistical goodness-of-fit criteria, we considered whether the classes captured clinically meaningful features and the proportion of participants represented in the classes (Nylund et al., 2007). Goodness-of-fit criteria included Bayesian information criterion (BIC) and sample-size adjusted BIC, Akaike Information Criterion (AIC), entropy, and Vu-Lo-Mendell-Rubin (VLMR), Lo-Mendell-Rubin adjusted (LMR), and Parametric Bootstrapped likelihood ratio tests (Lo et al., 2001; Nylund et al., 2007). Smaller AIC and BIC values indicate better fit and entropy values closer to 1 indicate better classification quality. The likelihood ratio tests compare the fit of the specified class solution to models with one less class, and a significant *p*-value indicates the specified model is preferred.

Each LPA model provides two important pieces of information: it identifies the number of latent classes (subgroups) within the overall sample and estimates posterior probabilities for each participant's assignment to each latent class. Because the best fitting model generated class assignments with a high level of classification certainty, we used the highest posterior probability from this model to assign each child to the most likely class for subsequent analyses.

Differences in social skills and degree of autism characteristics across latent classes were assessed using linear models, accounting for age and nonverbal DQ. The decision to control for age and nonverbal DQ was based on previous evidence of age- and development-related differences in sensory reactivity in young autistic children (Baranek et al., 2007; Baranek et al., 2013) and to ensure that group differences observed in the outcome variables were not driven by differences in age or NVDQ. Residual analyses and graphical diagnostics were used to check if model assumptions were met. Following a significant overall test for group, pairwise differences between latent classes were examined, controlling for multiple comparisons using Tukey's adjustment. Finally, we conducted a sensitivity analysis accounting for the uncertainty in class assignments by using multiple pseudo-class draws (Bandeen-Roche et al., 1997) when examining differences in social skills and degree of autism characteristics across latent classes. Children were randomly classified into latent classes 100 times based on their distribution of posterior probabilities from the best fitting LPA model. The subsequent analyses were performed 100 times (i.e., for each draw) and results were combined across draws using standard methods for multiple imputation for missing data (Rubin, 1987).

LPA was performed in *Mplus* version 8.0 (Muthen & Muthén, 2017). All other analyses were implemented using SAS Version 9.4 (SAS Institute Inc., Cary, NC). All tests were two-sided, and *p*-values <0.05 were considered statistically significant.

Community involvement statement

At the beginning of the larger studies focus groups were conducted to determine what components of the research plan were acceptable to the families. Subsequently, several faculty members involved have conducted lectures at local regional centers (i.e., state-run network of community-based, non-profit developmental disability centers) and have participated in meetings such as the HELP Group annual symposium to disseminate research findings to many segments of the community.

Results

Latent profile analyses results

Fit indices for two-class to five-class solutions are summarized in Supplementary Table 1. They provided a mixed picture of the optimal number of classes. BIC and AIC indices never increased with added classes, BLRT continued to support the larger model up to five classes, while LMR likelihood ratio tests suggested that a four-class solution was optimal (four-class was better than three-class, and five-class was not better than four-class). Four- and five-class solutions provided similar classification quality (entropy 0.85 and 0.87, respectively). In latent profile analyses, AIC and BIC may not increase with additional parameters, but the resulting models may have additional classes that are not meaningful. For example, in the five-class model, one class with impairments across modalities was differentiated into two classes that were not meaningfully different. Moreover, the five-class model identified a class that included <5% of the sample. Thus, the four-class solution was selected as the most parsimonious model that still provided adequate fit and the most clinically meaningful distribution of classes.

Based on the pattern of both severity and modalities, the four classes were named *Moderate/Mixed* (35.5%), *Severe/Mixed* (8.5%), *Moderate/Broad* (14.6%), and *Low/Mixed* (41.1%). Classification of moderate, severe, and low refers to the severity of sensory problems, whereas mixed vs. broad refers to the extent of modalities affected. In particular, a mixed class is characterized by sensory patterns that are indicative of both typical and atypical sensory behaviors across domains, whereas a broad class is indicative of uniform patterns of sensory difficulties across modalities. As shown in Figure 1, the *Moderate/Mixed* class was characterized by probable-to-definite differences in all modalities except for MS and LEW. This class showed a mixed pattern of both hypo- and hyper-reactivity to various sensory experiences, while exhibiting typical proprioceptive and vestibular functioning. The *Severe/Mixed* class was the smallest and was characterized by definite sensory differences in all modalities except for LEW. The *Moderate/Broad* class was the only class that showed probable-to-definite sensory differences in *all* modalities. The *Low/Mixed* class was the largest and exhibited primarily typical sensory patterns in most modalities with only probable differences in TSS, US, and AF.

Using the highest posterior probability to assign children to one of these four classes, n=77 were assigned to the *Moderate/Mixed* Class, n=18 to the *Severe/Mixed* Class, n=31 to the *Moderate/Broad* Class, and n=85 to the *Low/Mixed* Class (average assignment probabilities for the classes were 0.88, 0.97, 0.94, and 0.93, respectively). Table 1 shows demographic and clinical characteristics of the four classes. The *Moderate/Mixed* class had the lowest MSEL scores, while children in the *Moderate/Broad* class had higher scores on the MSEL.

Differences in autism characteristics, adaptive skills, and ADHD symptoms

We next examined whether the four sensory classes differed in autism characteristics, adaptive skills, and attention/ADHD-relevant symptoms after controlling for NVDQ and age. Table 2 shows adaptive and symptom measurements for the four classes, and Figure 2 summarizes the standardized average scores for the four groups across these variables.

Autism characteristics—While there were no differences in ADOS-2 comparison scores among the four classes (*F*(3, 204)=.4, *p*=.73), the classes significantly differed on SRS-2 SCI (*F*(3, 185)=24.6, *p*<.001), RRB (*F*(3, 196)=30.8, *p*<.001), and Total scores (*F*(3, 185)=29, *p*<.001). Post-hoc tests adjusting for multiple comparisons and controlling for age and NVDQ showed that children in the *Severe/Mixed* class had higher SRS-2 SCI, RRB, and Total scores compared to the remaining three classes. The *Severe/Mixed* class had significantly higher SCI scores than all other three classes (estimated difference[est.]=8.4, 95% CI [2.2, 14.5] for *Moderate/Mixed*; est.=7.8, 95% CI [0.8, 14.7] for *Moderate/Broad*; est.=16.9, 95% CI [10.8, 23.0] for *Low/Mixed*, *p*s=.002, .02, and <.001, respectively). The pattern was similar for RRB, with the *Severe/Mixed* class scoring 11.4 (95% CI [3.2, 19.6]) points higher than the *Moderate/Mixed*, 12.2 (95% CI [2.9, 21.5] points higher than the *Moderate/Broad*, and 25.0 (95% CI [16.8, 33.1] points higher than the *Low/Mixed* classes, *p*s=.002, .004, and <.001, respectively. A similar pattern was observed for Total score, with the *Severe/Mixed* class scoring 9.3 (95% CI [3.0, 15.7]) points higher than the *Moderate/Mixed*, 9 (95% CI [1.9, 16.3]) points higher than the *Moderate/Broad*, and 19.1 (95% CI [12.8, 25.4]) points higher than the *Low/Mixed* classes, *p*=.001, .007, and <.001, respectively. Additionally, children in the *Low/Mixed* class had lower SRS-2 SCI scores compared to the remaining classes (est.=− 8.6, 95% CI [−12.3, −4.9] for *Moderate/Mixed*; est.=−9.2, 95% CI [−14.1, −4.3] for *Moderate/Broad*; all *ps*<.001). The pattern for the *Low/Mixed* class was similar for RRB and Total scores (RRB: est.=−13.6, 95% CI [−18.6, −8.7] for *Moderate/Mixed*; est.=−12.8, 95% CI [−19.4, −6.2] for *Moderate/Broad*; Total: est.=−9.8, 95% CI [−13.6, −6.0] for *Moderate/Mixed*; est.=−10.0, 95% CI [−15.1, −4.9] for *Moderate/Broad* [all *ps*<.001; Supplementary Table 2]).

Adaptive Skills—The four classes significantly differed on the Vineland Social subscale (*F*(3, 192)=7.2, *p*<.001). Post-hoc tests adjusting for multiple comparisons and including covariates showed that children in the *Severe/Mixed* class had lower scores compared to the *Moderate/Mixed*, est.=−9.9, 95% CI [−17.4, −2.4] and *Low/Mixed* classes, est.=−11.8, 95% CI [−19.2, −4.4], *p*s=.004, <.001, respectively. Children in the *Moderate/Broad* class had lower scores than the *Low/Mixed* class, est.=−6.2, 95% CI [−11.8, −0.5], *p*=.02. The four classes also significantly differed on the Vineland Daily Living subscale (*F*(3, 196)=3.42, *p*=0.018). Post-hoc tests adjusting for multiple comparisons and including covariates showed that children in the *Moderate/Broad* class had lower scores compared to the *Low/Mixed* class, est.=−6.1, 95% CI [−12.1, −0.02]. The four classes did not, however, differ on the Vineland Communication subscale (*F*(3, 197)=1.1, *p*=.34).

ADHD Symptoms/Attention Problems—Finally, we examined whether the sensory classes differed in terms of ADHD-relevant CBCL scores. As predicted, sensory classes differed on the *DSM*-oriented ADHD (*F*(3, 199)=13.9, *p*<.001) and Attention Problems subscales (*F*(3, 199)=11.7, *p*<.001). Post-hoc tests showed that children in the *Moderate/Mixed* and *Severe/Mixed* classes exhibited higher ADHD symptoms compared to the *Low/Mixed* class (est.=2.4, 95% CI [1.4, 3.4]; est.=2.5, 95% CI [0.8, 4.2] respectively, *p*s<.001). Children in the *Moderate/Mixed*, *Severe/Mixed*, and *Moderate/Broad* classes exhibited higher Attention Problems scores compared to the *Low/Mixed* class (est.=1.6, 95% CI [0.7, 2.4]; est.=2.2, 95% CI [0.8, 3.6]; est.=1.8, 95% CI [0.7, 2.9]; *ps*<.001).

The results of the sensitivity analysis (Supplementary Table 3) supported the primary analyses. Results of exploratory correlational analysis between all measures are included in Supplementary Table 4.

Discussion

This study aimed to identify homogenous sensory classes within a sample of young autistic children and to further examine whether sensory classes differ in terms of autism characteristics, adaptive skills, and attention/ADHD-related symptoms. We used person-centered methods that allowed the data to inform participant groupings based on a parent-reported sensory measure between 2–4 years of age, attempting to parse the heterogeneity observed in sensory symptoms across autistic individuals (Ben-Sasson et al., 2008; Tomchek et al., 2018). Our results revealed four classes differing based on sensory symptom severity as well as modality.

The *Moderate/Mixed* (35.5%) class was characterized by profiles ranging from typical reactivity to definite sensory differences across modalities. While children in this class showed typical performance in proprioceptive and vestibular functioning, they displayed probable-to-definite hypersensitivity in tactile, taste/smell, visual, and auditory domains. Children in this class also exhibited differences suggestive of hyposensitivity and seeking. This class is consistent with a class identified in prior research with autistic children (33–115 months), characterized by differences across all modalities except in movement sensitivity and low energy/weakness (Lane et al., 2010). Our results extend these findings to a sample of younger children within a narrower developmental window. Children in this mixed pattern class may show varying levels of aversion to variety of sensory experiences but also exhibit differences while registering other sensory stimuli.

The *Severe/Mixed* (8.5%) class was characterized by definite sensory differences in most domains measured by the SSP except in LEW. This is the only class to show definite sensitivity in visual and auditory modalities. Partially consistent with the current findings, Little et al. (2017) also found an ‘intense sensory profile’ in 19.5% of autistic children (3–14 years) that showed severe sensory differences across domains. Like the *Moderate/Mixed* class, the *Severe/Mixed* class exhibited definite hypersensitivity to taste/smell. Although this has been frequently observed in autism and is often reported by caregivers (Field et al., 2003; Martins et al., 2008; Schreck & Williams, 2006), it remains unclear how taste/smell sensitivities may impact the presentation of the autism phenotype; this warrants further exploration.

Consistent with previous findings (Lane et al., 2011; Lane et al., 2010), the *Moderate/Broad* (14.6%) class was characterized by some level of sensory differences across *all* modalities. This was the only class to show definite differences in the LEW domain, which is characterized by under-responsivity in the proprioceptive and vestibular domains that may manifest in the form of poor muscle control, weakness, and poor postural control. Additionally, because under-reactivity in proprioceptive and vestibular systems may be linked to motor coordination delays (Miller et al., 2007), special attention should be given to exploring whether characteristics of sensory classes with LEW differences may impact motor skills in autistic children.

The largest class–*Low/Mixed* (41.1%)–was characterized by mostly typical functioning across most SSP domains. The size of this class indicates that severe levels of sensory dysfunction across modalities are not observed in *all* autistic children, at least based on parent perception of sensory symptoms. This was the only class to show probable differences in USS and AF domains, whereas all other classes showed definite differences. These results support previous research involving older autistic children and wider age ranges that identified similar classes with mostly typical sensory profiles with mild differences in USS and AF (37.5% and 44% respectively in Lane et al., 2014; Lane et al., 2010), extending findings to a sample of younger children and suggesting that some sensory profiles may be consistently present across ages. This was the only class to show typical performance in tactile, visual, and auditory sensitivity. Identification of a class with more typical sensory functioning in autism lends support to the larger sensory literature that has yielded mixed findings showing both typical and atypical sensory characteristics in autistic individuals (Marco et al., 2011; O’connor, 2012), further documenting that sensory differences may not be universally present and, when observed, may not always be severe.

These results also add to the larger literature on sensory clusters across development. For instance, Ben-Sasson et al. (2008) identified sensory classes characterized by varying degrees of sensory difficulties (low, mixed, high) in autistic toddlers. Other studies examining older children (Little et al., 2017; Tomchek et al., 2018; Uljarević et al., 2016) also identified similar patterns of low, mixed, and high sensory reactivity problems suggesting that across studies, albeit with some variation in the number and characteristics of classes identified, broad categories of mild, moderate, and severe sensory differences area relevant. The present study supports the larger developmental literature by demonstrating similar broader patterns of sensory classes in young children.

Next, while the four classes identified differed based on severity and modality, sensory patterns in all classes (including mild differences in some modalities in the *Low/Mixed* class) reflected varying symptoms of both hypo- and hyper-reactivity (e.g., doesn’t respond when name is called, can’t work with background noise). This supports the findings of Baranek et al. (2006), who showed that both hypo- and hyper-reactivity to sensory stimuli are present in autistic children, and suggest that sensory reactivity may depend on context and task demands. The classification of sensory patterns in terms of severity, modality, and context may be more relevant than defining sensory performance based on broad categories of hyper- and hypo-reactivity.

Nevertheless, prior studies have used sensory scores that were already categorized into over-reactivity, under-reactivity, and seeking rather than using individual subscale scores to identify sensory classes (Liss et al., 2006). Our results slightly differ from that of Ausderau, Furlong, et al. (2014) who showed that while hypo- and hyper-reactivity do co-occur in autistic children, this is prominent in some, but not all, sensory classes. Similar to Liss et al. (2006), Ausderau, Furlong, et al. (2014) also used sensory factor scores that were classified into hypo-reactivity, hyper-reactivity, sensory interests/seeking, and enhanced perception instead of individual modality-specific scores. Moreover, the age range in our study was much narrower than in these prior studies (2–12 years in Ausderau et al., 2014; mean (*SD*) age=102.4 (50.1) months in Liss et al., 2006). This age-based distinction among studies is of importance given previous research showing differences in sensory profiles across developmental periods (Baranek et al., 2013; Ben-Sasson et al., 2009; Dellapiazza, Michelon, Picot, et al., 2021). Finally, Ausderau, Furlong, et al. (2014) used a different sensory measure (SEQ 3.0; Baranek, 2009) and Liss et al. (2006) reconstructed their sensory measure by combining 60 items from the Sensory Profile (Dunn, 1999) with 43 newly developed items reflecting specific sensory behaviors. Discrepancies in findings could therefore be attributed to the analytical approach utilized, selection of sensory measures, and age groups studied.

Ultimately, our findings provide support to the notion of utilizing sensory classes (based on both severity and modality) in identifying clinically meaningful phenotypes within autism.

Differences in autism characteristics, adaptive skills, and ADHD symptoms

Our second objective was to examine whether sensory-based classes differed in terms of autism characteristics, adaptive skills, and ADHD symptoms.

Autism characteristics—While the four classes did not differ in ADOS-2 comparison scores, they showed differences in SRS-2 scores with the *Severe/Mixed* class showing greater levels of autism characteristics. This was true for total scores and both subscales (SCI, RRB), and is consistent with studies linking sensory differences with autism characteristics (Baranek et al., 2013; Foss-Feig et al., 2012; Kadlaskar et al., 2019; Watson et al., 2011). Our results extend prior findings by showing that certain sensory classes may be more likely to show a greater degree of autism characteristics compared to others (Liss et al., 2006).

Of note, the lack of difference in ADOS-2 scores is consistent with prior research (Wolff et al., 2019) showing that parent-reported measures of sensory performance are more strongly linked with other parent-reported measures rather than observation-based measures. Additionally, exploratory analysis showed that ADOS-2 and SRS-2 scores were not significantly correlated, consistent with prior studies showing a lack of strong association between SRS-2 and ADOS-2 comparison scores (Hus et al., 2013; Morrier et al., 2017; Reszka et al., 2014). The discrepancy between ADOS-2 and SRS-2 scores could potentially be attributed to contextual variations in children’s behaviors (e.g., ADOS-2 measures behaviors in research/clinical settings, SRS-2 measures day-to-day behaviors). Differences in measurement type as well as environmental context in which behaviors are observed, therefore, may impact our understanding of how sensory profiles are linked with autism characteristics.

Adaptive skills—A similar pattern was observed for the socialization domain of the VABS-2. Specifically, children in the *Severe/Mixed* and *Moderate/Broad* classes exhibited lower social skills compared to the *Low/Mixed* class. Additionally, the *Moderate/Broad* class showed less developed daily living skills compared to the *Low/Mixed* class. These results are supported by previous research showing links between sensory differences and adaptive skills (Neufeld et al., 2021; Watson et al., 2011). Sensory difficulties may detrimentally impact adaptive skills (mainly socialization and daily living skills) in autism, although further longitudinal research is needed to understand whether there is a causal link in autistic children. Finally, the four classes did not differ in the VABS-2 communication domain. While this is contrary to our prediction, we speculate that sensory differences may not always impact one's ability to communicate, but may affect the *quality* with which one communicates, reflected in the socialization domain of the VABS-2.

ADHD and attention-related problems—The classes characterized by varying degrees of sensory differences (i.e., *Moderate/Mixed*, *Severe/Mixed*, *Moderate/Broad*) showed higher ADHD and attention-related problems compared to the *Low/Mixed* class but did not differ themselves on the CBCL-derived ADHD and attention-problems subscale. Notably, many of the SSP items on the USS and AF subscales are associated with attention, hyperactivity, and impulsivity (e.g., becomes overly excitable during movement activity, has difficulty paying attention). The *Moderate/Mixed*, *Severe/Mixed*, and *Moderate/Broad* classes showed definite differences in USS and AF, whereas the *Low/Mixed* class only showed probable differences.

Our findings related to higher ADHD symptoms in the *Moderate/Mixed*, *Severe/Mixed*, and *Moderate/Broad* classes are consistent with research showing links between inattention symptoms and sensory processing in autism (Ashburner et al., 2008; Dellapiazza, Michelon, Vernhet, et al., 2021). Moreover, a recent study examining the factor structure of the SSP in autistic children identified nine SSP subscales (Z. Williams et al., 2018) and proposed Hyperactivity/Inattention as one of the factors, indicating a high degree of overlap between the SSP and the ADHD symptom measures.

Although there is evidence for differences in USS and AF (partly indicative of attention/ADHD-related problems) in autism (Ausderau, Sideris, et al., 2014; Baranek et al., 2013; Freuler et al., 2012; O'connor, 2012), more research is needed to understand whether these seemingly common traits in autism are related to sensory difficulties, or whether they may be the result of attentional differences that are also commonly reported in autism (Keehn et al., 2013). These findings are particularly relevant given that many autistic children also exhibit co-occurring ADHD symptoms or formal diagnoses (Lai et al., 2019; Murray, 2010; Van Der Meer et al., 2012) and could suggest that there are underlying links between sensory response patterns and attention, which could deepen our understanding of potentially overlapping mechanisms underlying autism and ADHD phenotypes.

Limitations

Our study is not without limitations. First, while the SSP, VABS-2, SRS-2, and CBCL are widely used in research and clinical practice, they are all parent-report measures and subject to shared method variance. Second, the SRS-2 RRB subscale includes several items related to sensory reactivity, which could explain some of the differences between the four sensory classes (i.e., the *Severe/Mixed* class showing greater RRB scores compared to others). Third, SSP items are not distinguished by context (i.e., social vs. non-social) and some may actually be measuring hyperactivity and attentional difficulties, potentially explaining the association with ADHD symptoms. Fourth, the relatively small size of the *Severe/Mixed* class may have resulted in underpowered group comparisons in some instances (e.g., the non-significant difference in daily living skills between the *Severe/Mixed* and *Low/Mixed* classes). Finally, the use of diverse clustering methods and sensory measures have provided slightly different results in terms of number of classes identified and characteristics of these classes in the larger literature. This may pose a challenge for future studies that aim to classify autistic individuals into homogenous sensory classes for further analysis. Future studies, therefore, should carefully select clustering methods based on the overlap between sample characteristics of proposed studies and the prior literature in terms of age of participants and sensory measures of interest.

Conclusion

In sum, we found evidence of distinct sensory classes in a sample of young autistic children based on parent report of sensory symptoms. While a subset of children displayed normative sensory-related behaviors, the majority exhibited a combination of both hypo- and hyper-reactivity to sensory stimuli. Identification of more homogenous, sensory-based classes may be useful for neurophysiological and neuroimaging studies that aim to examine underlying mechanisms linked with specific sensory patterns. Results may help clinicians identify children with greater differences in sensory processing, which might impact difficulties in social, adaptive, or attention/behavior regulation domains with potential implications for intervention. Our findings could provide a rationale for examining the efficacy of sensory interventions for autistic children during early development that are tailored to the needs of each of individual sensory classes (e.g., teaching coping strategies in response to overwhelming sensory environments, making modifications to one's environment) and that specifically focus on sensory symptoms that are distressing/impairing during day-to-day functioning.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

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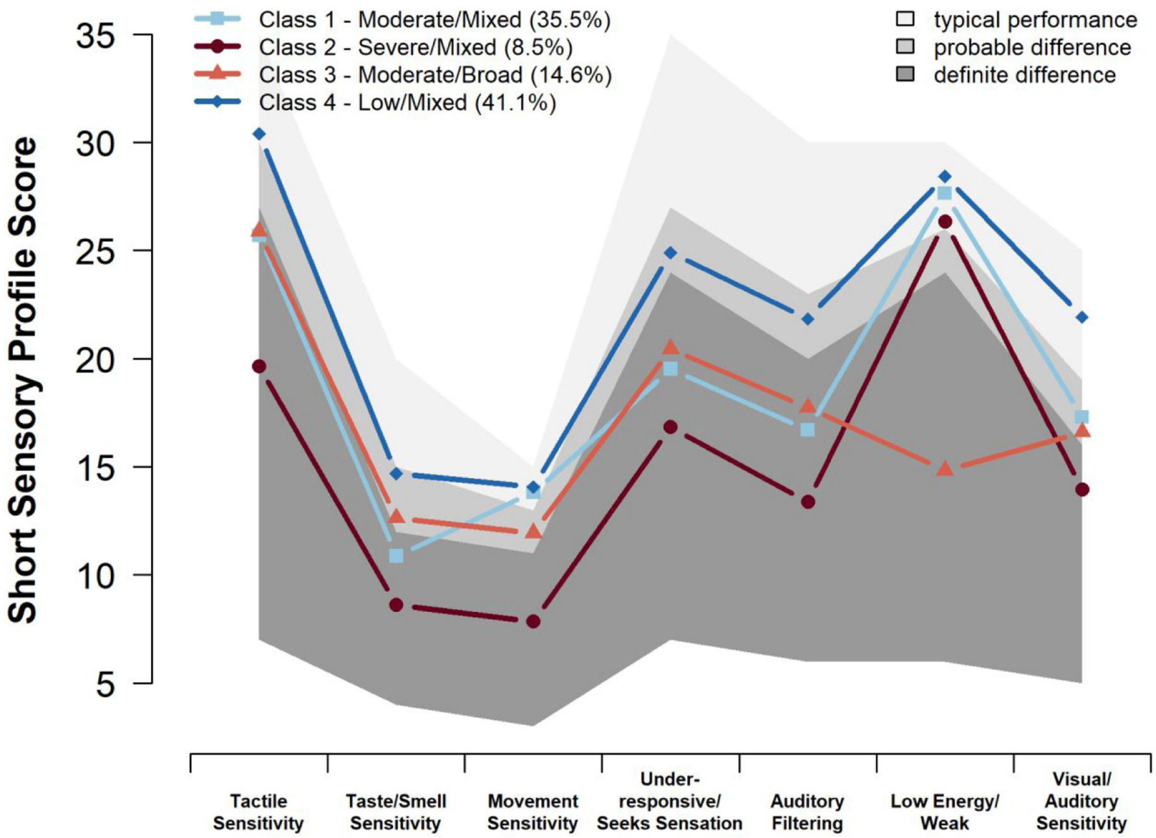

Figure 1.

Profile of the four sensory classes. Shaded areas represent the three categories of performance for sensory subscales.

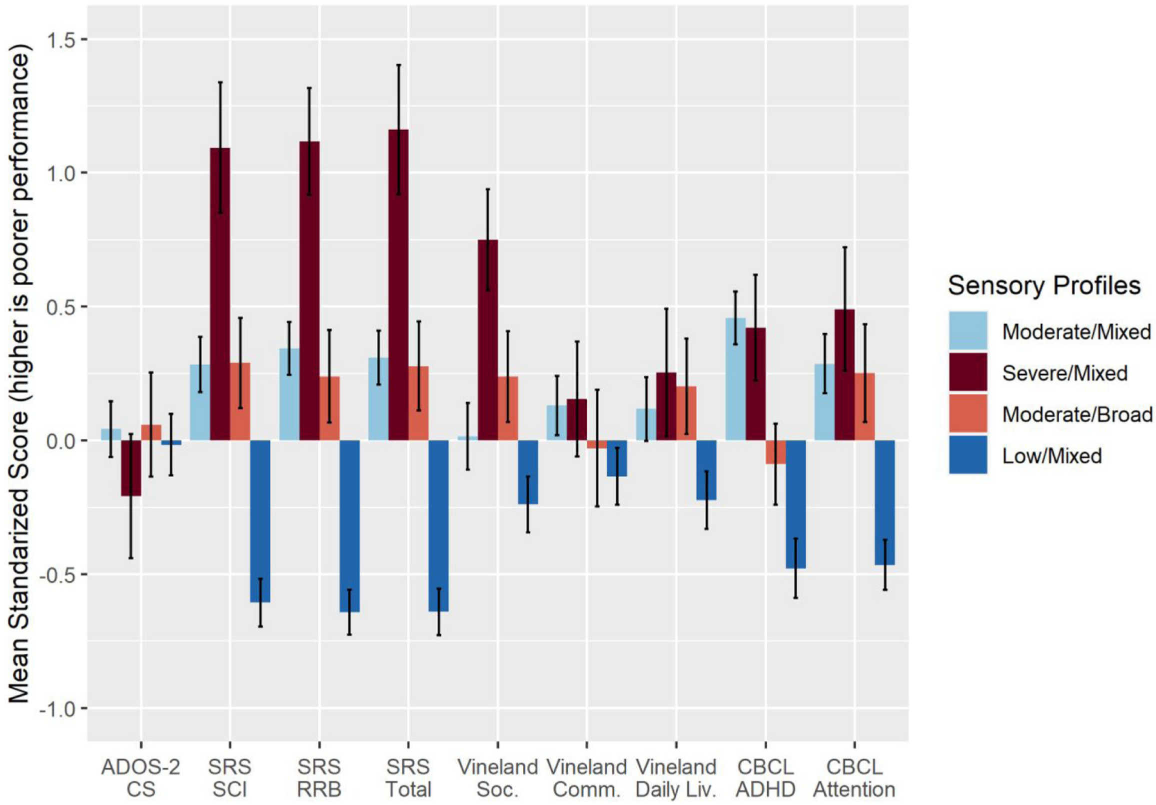

Figure 2.

Standardized mean scores for the LPA-derived classes. ADOS, Autism Diagnostic Observation Schedule; SRS, Social Responsiveness Scale; SCI, Social Communication and Interaction; RRB, Restricted and Repetitive Behaviors; Vineland Soc, Vineland Socialization; Vineland Comm, Vineland Communication; CBCL, Child Behavior Checklist; ADHD, Attention-Deficit/Hyperactivity Disorder. Error bars represent +/− 1 Standard Error.

Table 1.

Participant characteristics for the LPA-derived sensory classes.

	Moderate/Mixed (*n*=77)	Severe/Mixed (*n*=18)	Moderate/Broad (*n*=31)	Low/Mixed (*n*=85)	*P*-value
Gender, *n* (%)					0.32
Female	17 (22%)	6 (33%)	11 (35%)	18 (21%)	
Male	60 (78%)	12 (67%)	20 (65%)	67 (79%)	
Race[a], *n* (%)					0.09
White	45 (61%)	12 (71%)	25 (81%)	63 (77%)	
Non-White	29 (39%)	5 (29%)	6 (19%)	19 (23%)	
Hispanic Ethnicity[b], *n* (%)					0.80
Hispanic	16 (22%)	3(18%)	5 (16%)	20 (24%)	
Non-Hispanic	58 (78%)	14 (82%)	26 (84%)	63 (76%)	
Maternal Education[c], *n*					0.11
Less than College	32 (47%)	12 (75%)	11 (41%)	44 (56%)	
College or Higher	36 (53%)	4 (25%)	16 (59%)	34 (44%)	
Paternal Education[d], *n* (%)					0.07
Less than College	39 (57%)	11 (79%)	10 (37%)	43 (58%)	
College or Higher	29 (43%)	3 (21%)	17 (63%)	31 (42%)	
Age (months), *mean* (*SD*)	36.4 (6.3)	37.0 (5.7)	38.4 (4.8)	37.1 (5.4)	0.49
Mullen Scales of Early Learning[e], *mean* (SD)					
DQ	58.2 (17.8)	67.1 (21.9)	71.3 (30.2)	63.2 (19.6)	0.03
Verbal DQ	50.4 (22.8)	61.3 (27.3)	67.9 (33.5)	55.7 (23.7)	0.01
Nonverbal DQ	66.0 (15.4)	72.9 (18.4)	74.7 (28.6)	70.6 (18.1)	0.13

Note. LPA, Latent Profile Analysis; SD, Standard Deviation; DQ, Developmental Quotient.

Overall group differences assessed using χ^2 tests for categorical variables, Kruskal-Wallis test for age, and one-way ANOVA for all other continuous variables.

Missing for:

[a] *n*=3 in *Moderate/Mixed*, *n*=1 in *Severe/Mixed*, *n*=3 in *Low/Mixed*;

[b] *n*=3 in *Moderate/Mixed*, *n*=1 in *Severe/Mixed*, *n*=2 in *Low/Mixed*;

[c] n=9 in *Moderate/Mixed*, n=2 in *Severe/Mixed*, n=4 in *Moderate/Broad*, n=7 in *Low/Mixed*;

[d] n=9 in *Moderate/Mixed*, n=4 in *Severe/Mixed*, n=4 in *Moderate/Broad*, n=11 in *Low/Mixed*;

[e] n=1 in *Low/Mixed*.

Table 2.

Adaptive and symptom measurements for the LPA-derived sensory classes.

	Moderate/Mixed (*n*=77)	Severe/Mixed (*n*=18)	Moderate/Broad (*n*=31)	Low/Mixed (*n*=85)	*P*-value
ADOS-2 Comparison Score, *mean (SD)*	7.7 (1.6)	7.3 (1.7)	7.7 (1.9)	7.6 (1.8)	0.73
Social Responsiveness Scale-2 T-Score, mean *(SD)*					
Social Communication and Interaction[a]	73.2 (8.8)	81.4 (9.8)	73.3 (9.0)	64.3 (7.9)	<0.001
Restricted and Repetitive Behaviors[b]	76.1 (12.2)	87.1 (11.7)	74.6 (13.4)	62.1 (10.7)	<0.001
Total[a]	74.3 (9.1)	83.4 (10.3)	73.9 (9.4)	64.1 (8.0)	<0.001
Vineland-2, mean *(SD)*					
Socialization[c]	74.1 (11.8)	65.9 (8.1)	71.6 (10.3)	76.9 (10.5)	<0.001
Communication[d]	71.9 (16.1)	71.5 (13.8)	74.5 (19.9)	76.3 (16.4)	0.34
Daily Living[e]	76.9 (12.5)	75.2 (11.8)	75.8 (12.0)	81.1 (12.1)	0.03
Childhood Behavior Checklist, mean *(SD)*					
ADHD Subscale[f]	8.6 (2.4)	8.5 (2.3)	7.1 (2.3)	6.0 (2.7)	<0.001
Attention Problems Subscale[f]	5.9 (2.2)	6.4 (2.3)	5.8 (2.3)	4.2 (2.0)	<0.001

Note. LPA, Latent Profile Analysis; ADOS-2, Autism Diagnostic Observation Schedule-2; ADHD, Attention-Deficit/Hyperactivity Disorder.

Overall group differences assessed using general linear models controlling for age and Nonverbal Developmental Quotient (NVDQ).

Data missing for:

[a] *n*=5 in *Moderate/Mixed*, *n*=2 in *Severe/Mixed*, *n*=3 in *Moderate/Broad*, *n*=9 in *Low/Mixed*;

[b] *n*=2 in *Moderate/Mixed*, *n*=1 in *Severe/Mixed*, *n*=1 in *Moderate/Broad*, *n*=4 in *Low/Mixed*;

[c] *n*=5 in *Moderate/Mixed*, *n*=3 in *Severe/Mixed*, *n*=1 in *Moderate/Broad*, *n*=3 in *Low/Mixed*;

[d] *n*=2 in *Moderate/Mixed*, *n*=3 in *Severe/Mixed*, *n*=1 in *Moderate/Broad*, *n*=1 in *Low/Mixed*;

[e] *n*=4 in *Moderate/Mixed*, *n*=2 in *Severe/Mixed*, *n*=1 in *Moderate/Broad*, *n*=1 in *Low/Mixed*;

[f] *n*=2 in *Moderate/Mixed*, *n*=3 in *Low/Mixed*.