Sensory Processing in ASD and ADHD: A Confirmatory Factor Analysis

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Abstract

Difficulties related to sensory processing in Autism Spectrum Disorder (ASD) and attention/deficit-hyperactivity disorder (ADHD) can manifest within multiple modalities and impact daily functioning. We examined the factor structure of the Short Sensory Profile in ASD and ADHD (N=517). A seven-factor structure held for ASD and ADHD however, differences were found in responses to the sensory measure. At the subscale level, a two-factor structure emerged in ASD, while a single-factor solution emerged in ADHD. Although there are differences in the way those with ASD and ADHD process sensory information, a single inventory can be used to describe processing *patterns* in both groups. Establishing the shared and non-shared features of sensory processing may have the potential to inform more targeted clinical approaches.

Keywords: Autism Spectrum Disorder; Attention-deficit/hyperactivity disorder; sensory processing; confirmatory factor analysis; exploratory factor analysis

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Abstract

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Sensory Processing in ASD and ADHD: A Confirmatory Factor Analysis

Though the *DSM-5* diagnostic criteria for autism spectrum disorder (ASD) and attention/deficit-hyperactivity disorder (ADHD) show little overlap between the two disorders, a number of studies have shown that children with ASD and ADHD have many similar associated features (Frazier et al., 2001; Gadow, Devincent, Pomeroy, & Azizian, 2005), including issues regarding sleep (Mayes et al., 2008), language (Geurts & Embrechts, 2008), attention (Sturm, Fernell, & Gillberg, 2004), and sensory processing patterns (Cheung & Siu, 2009). Sensory processing impairments occur in several modalities including touch, taste, smell, and sound and can impact how a child perceives and responds to everyday events. In turn, these impairments have significant implications for a child's social communication, academic achievement, and quality of interpersonal relationships (Dunn, Little, Dean, Robertson, & Evans, 2016; Ghanizadeh, 2011; Koenig & Rudney, 2010; Lane, Young, Baker, & Angley, 2010). As a result of these overlapping symptoms, differential diagnosis becomes complicated where a child with more varied symptoms of ASD might be at greater risk for delayed diagnosis or misdiagnosis of ADHD (Hartley & Sikora, 2009). Thus, understanding differences in sensory processing across these disorders is essential for differential diagnosis where early identification of these differences has the potential to lead to better, more tailored treatment outcomes for these children.

Sensory Processing Across ASD and ADHD

Sensory processing impairments relate to difficulties in detecting, modulating, and interpreting incoming stimuli from the environment (Ghanizadeh, 2011). There are several types of sensory processing difficulties that impact how a child responds to everyday events including sensory hypersensitivity, where a child might become overly excitable or respond faster and

more intensely to certain toys or events than what is expected (Ghanizadeh, 2011). Another type is tactile sensitivity, where a child might withdraw from splashing water, avoid going barefoot, or express distress during grooming activities (Ghanizadeh, 2011). Although few researchers have directly compared sensory processing patterns in ASD and ADHD (Kennedy, 2009), there are a number of studies that have examined these patterns in ADHD (Cermak, 1988; Mangeot et al., 2001; Parush, Sohmer, Steinberg, & Kaitz, 1997) and ASD (Kern et al., 2006; Leekam, Nieto, Libby, Wing, & Gould, 2007) separately, showing that in addition to impairments caused by core diagnostic symptoms, both groups show atypical sensory processing relative to typically developing groups.

Atypical sensory processing is well documented in ASD and dates back to the original description of autism (Kanner, 1943). More recently, sensory processing difficulties were widely accepted as a common symptom of ASD and included in the diagnostic criteria (APA, 2013). Both hypersensitivity and hyposensitivity are now described as defining characteristics of ASD, however, autistic individuals experience a wide range of atypical sensory processing patterns that affect all sensory modalities including vision (Behrmann, Thomas, & Humphreys, 2006; Kaiser & Shiffrar, 2009; Mottron, Dawson, Soulières, Hubert, & Burack, 2006; Robertson et al., 2014; Simmons et al., 2009), audition (Del Rincon, 2008; Hitoglou, Ververi, Antoniadis, & Zafeiriou, 2010; Kujala, Lepistö, & Näätänen, 2013; O'Connor, 2012), and touch (Puts, Wodka, Tommerdahl, Mostofsky, & Edden, 2014; Tavassoli et al., 2016), as well as multisensory processing (Baum, Stevenson, & Wallace, 2015; Noel, De Nier, Stevenson, Alais, & Wallace, 2017; Noel, Stevenson, & Wallace, 2018; Stevenson et al., 2017a, 2017b; Stevenson et al., 2015; Stevenson et al., 2014a, 2014b).

Given that sensory processing issues commonly occur in several modalities, a number of assessments have been used to examine these difficulties that include, but are not limited to neurophysiological, behavioral, and parent-report measures. In ASD, neurophysiological findings have demonstrated that autistic individuals show atypical neural responses to sensory stimuli including later responses to auditory stimuli (Marco, Hinkley, Hill, & Nagarajan, 2011). Behavioral findings also support differences in sensory processing, showing that autistic individuals have lower detection thresholds for tactile stimuli relative to typically-developing controls (Marco et al., 2011). Finally, parent- and self-reported questionnaires are often used to understand sensory processing difficulties in ASD. Parent reports offer an ecologically-valid assessment of sensory processing in daily life and are also the most commonly used assessment tool in clinical settings. A review of studies examining parent-reported atypical sensory processing indicated elevated sensory processing in ASD and highlighted a need for further investigation into these difficulties in this population (Ben-Sasson et al., 2009).

A better understanding of sensory processing difficulties is also required in ADHD as these difficulties are understudied in this group and most research in this area has used questionnaire measures as the main source of assessment such as the Touch Inventory for Preschoolers (Brasic Royeen, 1987), the Sensory Profile (Dunn, 2014), and the Miller Assessment for Preschoolers (Miller, 1982). A review of studies examining sensory processing difficulties in ADHD consistently found atypical sensory processing patterns compared to typically developing control participants with questionnaire data and limited behavioral data (Ghanizadeh, 2011). Similar to ASD, the sensory processing issues in ADHD spanned sensory modalities and included a wide range of impairments (Ghanizadeh, 2011). Thus, while it is

known that children with ASD and ADHD demonstrate atypical sensory processing patterns, the extent to which these patterns operate similarly across groups remains unclear.

The Short Sensory Profile

The Short Sensory Profile (SSP; Dunn, 2014) is a 38-item parent-report questionnaire derived from the Sensory Profile (Dunn, 1999) that assesses sensory processing in children. More commonly, it is used to evaluate sensory atypicalities in autistic individuals (Watling, Deitz, & White, 2001), but it has also been widely used in typically-developing individuals to differentiate those with and without atypical sensory patterns (Tomchek & Dunn, 2007). The questionnaire evaluates seven key areas of sensory processing including Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Under Responsive/Seeks Sensation, Auditory Filtering, Low/Weak Energy, and Auditory/Visual Sensitivity. To our knowledge, no study to date has established whether items on the SSP are tapping into the same latent constructs (measurement invariance) in children with ASD and ADHD. The aim of the current study was to therefore directly address this to determine the appropriateness of the originally proposed seven-factor model across groups using a well-established measure of basic sensory processing (SSP), and a large, representative sample of children and young adults with a distribution of ASD and ADHD symptoms with three specific aims. First, we will test if the seven-factor model will have good fit for the entire sample using a confirmatory factor analysis (CFA) approach, which we hypothesize will be true. Second, we will use multi-groups analyses to examine if the factors and their corresponding items measure the same constructs in the same fashion in each group. We expect to find configural (i.e. same factor structure), and metric invariance (equivalent factor loadings across groups). Finally, we will conduct an exploratory factor analyses (EFA) using the SSP subscales to determine if different factors clustered differently in ASD and ADHD.

Method

Participants and Procedure

Participants included 571 children and young adults (*Age range* = 1.88 to 21.89 years, *Mean age* = 10.01, *SD* = 3.98, 23.6% female), with diagnosed ASD ($n = 361$) and ADHD ($n = 210$). Only those with a diagnosis of either ASD or ADHD were included in the analysis. With respect to race, 72.6% of participant were White, 4.9% Black, 4.5% Aboriginal, 1.4% Arab, 3.5% Chinese, 2.4% Filipino, .2% Japanese, 5.1% Jewish, .3% Korean, 3.8% Latin American/Hispanic, 3.8% South Asian, 2.1% Southeast Asian, .9% West Asian, 2.6% identified as “other”, and 1.8% either preferred not to answer or reported that they did not know. Although a large portion of participants either did not report on socioeconomic status, reported that they did not know, or preferred not to answer (40.8%), the highest proportion of families (10.1%) reported earning between 100,000 and 149,000 Canadian dollars annually. Parents and participating children provided written consent and families were monetarily compensated for their participation. Participants were recruited through the Province of Ontario Neurodevelopmental Disorders (POND) Network (pond-network.ca). The POND network is a large-scale research and clinical research network in Ontario consisting of multidisciplinary providers including pediatricians, psychiatrists, and psychologists. The POND network collects data from various individuals across development to better understand and improve care for those with neurodevelopmental disorders including ASD and ADHD. Participating families completed a range of measures however, only those who completed the assessment of sensory processing were included in the analysis.

Measure

The Short Sensory Profile (SSP) is a well validated parent-report questionnaire characterizing sensory processing (Ahn, Miller, Milberger, & McIntosh, 2004; Mangeot et al., 2001; Tomchek & Dunn, 2007). The questionnaire has been shown to have strong internal consistency in children with ASD (.89; Tomchek, Huebner, & Dunn, 2014) and children with ADHD (estimates between .49 and .91; Yochman, Parush, & Ornoy, 2004). Parents respond to 38 questions on a five-point Likert scale (always (100% of the time) = 1, frequently (75% of the time) = 2, occasionally (50% of the time) = 3, seldom (25% of the time) = 4, or never (0% of the time) = 5) indicating the frequency with which their child displays sensory behaviors. The questionnaire was developed to assess seven domains of sensory functioning (Dunn & Brown, 1997; Larson, 1982; Royeen & Fortune, 1990), including (1) Tactile Sensitivity (7 items; e.g., *“avoids going barefoot, especially in sand or grass”*, *“rubs or scratches out a spot that has been touched”*), (2) Taste/Smell Sensitivity (4 items; e.g., *“avoids certain tastes or food smells that are typically part of children’s diets”*, *“picky eater, especially regarding food textures”*), (3) Movement Sensitivity (3 items; e.g., *“becomes anxious or distressed when feet leave the ground”*), (4) Unresponsiveness/Sensory Seeking (7 items; e.g., *“touches people and objects”*, *“enjoys strange noises/seeks to make noise for noise’s sake”*), (5) Auditory Filtering (6 items; e.g., *“has trouble completing tasks when radio is on”*, *“has difficulty paying attention”*), (6) Low Energy/Weakness, (6 items, e.g., *seems to have weak muscles”*, *“props to support self (even during activity)”*), and (7) Visual/Auditory Sensitivity (6 items; e.g., *“holds hands over ears to protect ears from sound”*, *“covers eye or squints to protect eyes from light”*). All items that belonged to a sensory domain were totalled for each participant. Lower scores on each item across these domains indicate greater sensory processing abnormalities.

Analysis

Using the software package MPlus 7, CFA was performed on the entire sample using the 38-item SSP to determine whether the overall model for the full sample produces a good fit. Next a series of measurement invariance tests were performed to evaluate whether the same construct was being measured across groups.

A Maximum Likelihood (ML) estimation approach was used to handle missing data. The analysis showed that no participants had missing data on all variables and that in total, there were 52 missing points distributed randomly throughout the dataset. The seven subscales were defined based on the original creation of the SSP and extensive research using the measure as a tool to evaluate sensory processing (see Tables 1 and 2 for descriptive statistics for latent variables and individual items).

Next, a series of tests were conducted to assess measurement equivalence. Tests of measurement equivalence are useful in determining whether the same constructs are being measured in a similar fashion across two specified groups (Murray, Booth, McKenzie, Kuenssberg, & O'Donnell, 2014) and can be assessed at several different levels to identify when there is a lack of invariance between two or more groups. The importance of achieving different levels of invariance and what cut-off values are deemed acceptable has been hotly debated in CFA research (Borsboom, 2006). However, applications for measurement equivalence, including what levels must be achieved for ASD specific research has received less attention with some studies suggesting that Configural invariance alone can be useful in drawing valid conclusions about group equivalence (Murray et al., 2014). Thus, achieving different levels of measurement equivalence could, in part, depend on the groups being assessed as well as the aims of the researcher. Configural invariance is a baseline measure used to determine whether factor

structures are equal across groups while metric invariance implies that the factor *loadings* are similar across groups. Achieving metric invariance may therefore be desirable if the aim is to draw conclusions about whether a questionnaire, such as the SSP, is measuring sensory processing similarly in both ASD and ADHD groups. Achieving scalar invariance might be beneficial in cases where researchers are interested in determining whether potential group differences between groups in sensory processing correspond to mean differences on the latent constructs being assessed by a measure like the SSP.

Based on the goals of the current study, which was to determine whether the SSP can be reliably used to describe sensory processing patterns in ASD and ADHD, the primary analysis focused on Configural and Metric invariance tests to establish whether factor structures and factor loadings are equivalent across the two groups. For thoroughness, Scalar invariance was also tested to evaluate whether underlying items measuring sensory processing are equal across the two diagnostic groups. The decision to accept or reject tests of invariance was based on criteria suggested by Van de Schoot et al. (2012) and involved evaluating whether certain restrictions degraded or improved the model as well as looking at both model fit and adjustment indices where more than just the χ^2 statistic was considered given this value is highly sensitive to sample size. Specifically, invariance was achieved if the fit indices were acceptable overall (i.e. RMSEA $\leq .05$ but $\leq .08$ was also acceptable and a CFI $\geq .90$ but values approaching .90 were also deemed acceptable) and the RMSEA and CFI difference between the two models being compared was $\leq .005$ for CFI and $\leq .01$ for RSMEA (Van de Schoot, Lugtig, & Hox, 2012).

Finally, EFAs were performed using the sensory subscales to evaluate whether the subscales clustered differently to describe sensory processing for ASD and ADHD children. EFAs are useful in evaluating the appropriate number of factors necessary to best explain a latent

construct. In the current study, our goal was to determine whether sensory processing overall was best described by the initial seven domains of sensory functioning in ASD and ADHD children. Specifically, we aimed to evaluate whether the original creation of the SSP can be applied to both groups in our sample or if the sensory domains clustered in distinct ways for each diagnostic group. Final EFA models were decided by selecting optimal factor loadings for each individual factor as well as further examination of fit indices.

Results

Full Sample Model

Results from the seven-factor CFA in the entire sample are presented in Table 5 (see supplementary material). The chi-square test of model fit, root mean square error of approximation (RMSEA), comparative fit index (CFI), and standardized root mean square residual (SRMR) were examined to determine fit indices for all three models. Results showed that the data fit well across all measures of fit including RMSEA with a value of .06 (CI: .059 - .065), a CFI value of .88, and a SRMR value of .06.

The factor loadings for the full sample demonstrated that all items loaded onto the latent variables well with the lowest factor loading being .484 for item two (*“prefers long-sleeved clothing when it is warm or short sleeves when it is cold”*) on the latent variable Tactile. Ideally, past research has suggested a set threshold of .40 for factor loadings and all loadings exceeded this value, with a large number of loadings being above .80 (Van de Schoot et al., 2012). See Figure 1 for an illustration of the seven-factor, full sample model.

The correlations between the latent variables were low to moderate, the highest being that between Tactile and Visual/Auditory ($r = .773$), where a threshold of $r = .85$ between factors is usually considered high (Brown, 2015). Correlations between the individual items were also

moderate overall, with the highest correlation found between item 29 (*“tires easily, especially when standing or holding a particular body position”*) and item 33 (*“poor endurance/tires easily”*; $r = .803$) however, this was still below the .85 threshold. Although this correlation is rather high, these two items belong to the same latent variable (Low Energy/Weak), and it is likely that this high correlation is a result of the similar language that is used within the two items where both contain the words tires and easily.

Measurement Invariance Tests

Measurement invariance, including configural, metric, and scalar were then tested to establish whether factor loadings, intercepts, and residual variance were equivalent across diagnostic groups.

Configural Invariance

After testing the measurement model, an analysis of equal form (also referred to as Configural invariance) was performed to determine whether the factors and pattern of indicator-factor loadings were similar across groups. Our results indicated that the solution provided an acceptable overall fit (See Table 3 for model results) and we can therefore conclude that Configural invariance was achieved, indicating that the constructs measured by the SSP are represented in both groups. Thus, the seven-factor correlated factor structure provides a good (equivalent) fit in both ASD and ADHD groups. Given that the Configural invariance was achieved, a test of Metric invariance was performed.

Metric Invariance

Next, an analysis of equal factor loadings was performed to evaluate whether the factor loadings (unstandardized) of the SSP indicators were equivalent across groups. The aim of this

analysis is to determine whether the measure being used has the same meaning and structure across two identified groups. Similar to the equal forms analysis, results indicated that the equal factor loadings model provided acceptable overall fit. Notably, the equal factor loading model did significantly degrade in fit relative to the equal form model, as indicated by the chi-square difference test $\chi^2(31) = 71.90, p < .001$ (crit $\chi^2(31) = 44.985$ at $p = .05$, crit $\chi^2(31) = 52.191$ at $p = .01$, crit $\chi^2(31) = 61.098$ at $p = .001$) however, this difference was not substantial. Specifically, when comparing the difference between both the CFI and RMSEA values in the two models, the CFI difference was less than a recommended value of $\leq .005$ ($\Delta\text{CFI} = .003$) and the RMSEA difference was less than a recommended value of $\leq .01$ ($\Delta\text{RMSEA} = 0$). Given the small difference between these values, it can be concluded that metric invariance was achieved and that the indicators provide comparable relationships to the latent constructs in children with ASD and ADHD.

Scalar Invariance

Although not of main interest, a test of equal indicator intercepts was performed for thoroughness and to determine whether children with ADHD and ASD had equivalent observed scores on an indicator at a given level of a latent variable. The equal measurement intercepts model produced acceptable fit however, it was found that there was a significant degradation of fit relative to the equal factor loadings solution, $\chi^2(31) = 152.87, p < .001$ (crit $\chi^2(31) = 44.985$ at $p = .05$, crit $\chi^2(31) = 52.191$ at $p = .01$, crit $\chi^2(31) = 61.098$ at $p = .001$). Further, it was found that upon examining CFI and RMSEA values, the difference value for the CFI was above the recommended cut-off ($\Delta\text{CFI} = .011, \Delta\text{RMSEA} = .002$). Thus, the overall model fit was of poorer quality in the scalar invariance model when compared to the metric invariance model, indicating that at least one item on the SSP differs across the two groups. It is important to note, however,

that one criticism in using goodness of fit indices to evaluate measurement invariance is failure to agree upon consistent cut-offs in the CFA literature with some researchers suggesting a CFI difference of $<.005$ and others reporting $<.01$ as indicative of non-invariance (G. W. Cheung & Rensvold, 2002) and we have therefore decided to interpret our results with caution and conclude from this analysis that scalar invariance was not achieved, and that the two groups appear to be responding to the SSP in different ways.

Exploratory Factor Analysis

Our CFA results indicated that, to some extent, the SSP appears to be measuring sensory processing in a similar way in ASD and ADHD. However, further analyses revealed that the two groups differed at a given level of the latent construct, suggesting that parents of children with ASD and ADHD may be using the response scale in a different way. It was therefore decided to compare the subscale scores across groups with the aim of addressing this observed difference. Subscale scores were first compared across ASD and ADHD groups, followed by further EFAs to determine whether subscale scores clustered differently among the two groups to describe sensory processing patterns.

Direct comparisons across diagnoses revealed that the ASD group showed greater impairment in Tactile, Taste/Smell, Movement, Low Energy, and Visual/Auditory (all p -values $<.001$), but not Sensory Seeking ($p = .634$) domains and the ADHD group showed greater impairment in the Auditory Filtering domain (Figure 2). Interestingly, using the SSP subscales, a two-factor structure emerged for the ASD children (Table 4), while only a one-factor structure that was identical to the original creation of the SSP, emerged for the ADHD children to describe sensory processing patterns (Table 4). The first factor for children with ASD could be described as tapping into issues related to vestibular sensitivity with subscales Movement and Low Energy

loading onto this factor while the second factor could be best described as tapping into sensory reactivity with the remaining five subscales loading onto this factor (Tactile, Taste/Smell, Sensory Seeking, Auditory Filtering, Visual/Auditory).

Discussion

Sensory processing issues have been commonly reported in both ASD and ADHD, but to date it is unclear if these issues are presenting in the same manner across the two diagnostic groups. The purpose of this study was to compare ASD and ADHD groups on the same construct (sensory processing) to determine the appropriateness of a seven-factor CFA model across groups. It is important to compare these two groups because of their apparent overlapping sensory difficulties and to empirically test whether the construct measuring sensory processing has the same meaning and measurement properties across ASD and ADHD groups. These analyses produced three primary findings. First, a seven-factor model held for both ASD and ADHD, with both Configural and Metric invariance achieved across groups. Second, examination of group differences revealed that children with ASD show greater impairment in almost all sensory domains excluding sensory seeking and that children with ADHD appear to have greater impairments in the auditory filtering domain. Finally, while a similar seven-factor model fit both groups, these factors themselves clustered differently in each diagnostic group, with a two-factor solution emerging for children with ASD and a one-factor solution for children with ADHD. Each of these findings is discussed in depth below.

Results from the measurement model support previous work suggesting a seven-factor model in ASD and expands this work to show that this model is reliable in describing sensory processing patterns not only in ASD, but also in ADHD. Our data therefore suggests that the SSP is a measure that has strong potential in identifying sensory processing atypicalities in children

with ASD and that this assessment can be extended for use in children with ADHD. Both Configural and Metric invariance held across the two groups, indicating that the seven-factor model fits the current data well and that there is little variation in factor loadings for the model as a function of group membership and/or diagnosis.

Although our previous analysis showed Configural and Metric equivalence, the item-factor relationship between the two groups appears to be dependent on group membership where conditional on the factor scores or ‘true scores’, a child’s item score will depend on their diagnosis. As we failed to achieve Scalar invariance, comparison of the ASD and ADHD groups on the latent means of the factors may not be overly meaningful. Indeed, some researchers have suggested that when Scalar invariance is not achieved, the validity of cross-group comparisons is questionable (Campbell, Barry, Joe, & Finney, 2008). With that said, our results indicate equivalence of factor structure and factor loadings across diagnostic groups and therefore, examining the latent means may still be useful for clarification of how the ASD and ADHD group differ on these latent constructs. It is possible that the ASD group has more severe impairments across sensory domains and responses from parents are reflective of these impairments. Greater sensory impairments overall in ASD may therefore have the potential to explain differential responding to items. It may also be that parents of children with ASD and ADHD are interpreting items from each subscale differently, where children with ASD and ADHD may both present with one specific sensory impairment, but this impairment presents differently as a result of diagnosis and in ways that the individual items might not fully capture. It was therefore of interest to further investigate these group differences with the goal of addressing some of these open questions and more specifically, identify what, if any sensory domains are impaired in ASD and ADHD children.

When comparing the level of sensory impairments within each of these factors, children with ASD showed significantly more impairment than those with ADHD in all factors except two: sensory seeking, for which groups showed equivalent impairment, and auditory filtering, for which the ADHD group showed greater impairment. This finding of greater impairments related to auditory filtering in children with ADHD align with well-documented findings in the ADHD literature (Dunn & Bennett, 2002; Mangeot et al., 2001; Shimizu, Bueno, & Miranda, 2014; Yochman et al., 2004). Items tapping into auditory filtering on the SSP are closely related to symptoms frequently exhibited by children with a formal ADHD diagnosis that impact daily functioning (APA, 2013). For instance, children with ADHD often have difficulties functioning and/or paying attention when in a noisy environment. Given the significant overlap in sensory difficulties in ASD and ADHD, it is important to investigate which sensory areas are particularly troubling for both groups of children in order to better assess why they are exhibiting certain behaviors that can negatively impact social and occupational outcomes. Indeed, research has shown that increased sensory difficulties are related to increased behavioral issues (Shimizu et al., 2014). In particular, difficulties related to auditory processing have been shown to be related to increased symptoms associated with inattention, affective disorder, and conduct disorder in ADHD (Shimizu et al., 2014). Thus, difficulties related to auditory filtering may have the potential to explain why behaviors related to distractibility and inattention are commonly reported in ADHD.

In addition to finding differences between the two groups at the subscale level, differences in the way factors clustered across groups also emerged. While a two-factor structure best described overall sensory processing for ASD, a one-factor structure was better suited to describe sensory processing in ADHD. Given that sensory processing abnormalities are part of

the diagnostic criteria for ASD (APA, 2013), the SSP has been commonly used to screen for these abnormalities in autistic individuals. However, as sensory difficulties have become more widely documented in other diagnostic groups such as ADHD (Ghanizadeh, 2011), obsessive-compulsive disorder (Dar, Kahn, & Carmeli, 2012), and Tourette's syndrome (Belluscio, Jin, Watters, Lee, & Hallett, 2011), the use of this measurement tool has expanded. The SSP was originally validated using a sample of children without disabilities (Dunn & Brown, 1997; Dunn & Westman, 1997) which may explain why our results diverge with that of previous work showing that the seven subscales best describe overall sensory processing. Given the amount of heterogeneity in autistic children in general and within our sample, it could also be that our factors clustered differently as a result of heterogeneous symptom expression in sensory processing and that, at least for our sample, overall sensory processing is best described through a two-factor solution that separates vestibular and reactivity sensitivities.

Collectively, our results suggest that although there are differences in the way children with ASD and ADHD process sensory information, a single inventory of sensory processing can be reliably used to describe sensory processing *patterns* in both groups. Results also highlight the importance of examining sensory processing not just at the individual item level when using the SSP, but also at the subscale level in different groups who exhibit sensory processing atypicalities. Our findings provide a useful next step for those interested in understanding the underlying structure of sensory processing in diagnostic groups who exhibit similar sensory processing patterns as those with ASD and ADHD.

Future Directions

There are several important considerations for future research. First, it is recommended that other groups who encounter similar sensory processing abnormalities be included in future

models to determine if the SSP is a good measure to use in groups outside of those studied here. Second, it would be interesting to compare self-report and parent-report scores on the SSP to determine whether this changes a future model. It is possible that having young adults with a formal diagnosis complete the SSP rather than parents of these children would yield different results. Third, future studies should examine whether the seven-factor structure to describe sensory processing holds across ages in addition to examining a higher-order factor structure where the seven latent variables might be better explained by a higher order factor and/or a bi-factor model. Finally, given that a large portion of our sample were White, future work should consider performing a similar analysis with a more diverse sample to determine whether the factor structure found here holds for different populations of children.

In conclusion, results from the current study demonstrate that the seven-factor model is appropriate to describe sensory processing in ASD and ADHD groups and that there is little variation in the factor loadings for the model as a result of diagnosis. These results provide a useful next step for those who are interested in understanding the underlying structure of sensory processing in diagnostic groups with similar sensory processing abnormalities and show that the SSP could be used in addition to other measures of sensory processing to inform sensory related behaviors in ASD and ADHD groups.

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Figure 1. Seven-factor model for full-sample including cross-loadings, factor loadings, and error variance.

Figure 2. Subscale group differences. Error bars indicate CI. $*p < .001$.

Table 1.

Descriptive Statistics of Latent Variables for Entire Sample.

Latent variables	Mean	SD	Skewness	Kurtosis
Tactile	27.51	5.75	-0.695	-0.194
Taste/Smell	13.85	5.36	-0.443	-1.128
Movement	12.57	2.97	-1.320	1.209
Sensory Seeking	21.64	6.82	0.091	-0.772
Auditory Filtering	16.67	5.02	0.243	-0.138
Low Energy	23.42	7.00	-0.590	0.930
Visual/Auditory	18.22	5.24	-0.525	-0.579

Note. Means, standard deviation (SD), skewness, and kurtosis values. Lower values indicate greater sensory difficulties.

Table 2.

Correlations Among Factors for Full Sample.

	Tactile	Taste/Smell	Movement	Sensory Seeking	Auditory Filtering	Low Energy
Tactile	---	--	--	--	---	---
Taste/Smell	.528	---	---	---	---	---
Movement	.574	.391	---	---	---	---
Sensory Seeking	.451	.190	.185	---	---	---
Auditory Filtering	.530	.297	.221	.638	---	---
Low Energy	.379	.232	.499	.127	.235	---
Visual/Auditory	.773	.504	.501	.404	.491	.380

Table 3.

Measurement Invariance Analysis Results.

	$\chi^2(\text{df})$	$\chi^2\text{diff}$	Δdf	RMSEA 90% CI	CFI	SRMR
<u>Measurement Invariance</u>						
Configural	2852.67 (1288) $p < .001$			0.065 CI: 0.062 – 0.068	0.868	0.067
Metric	2924.57 (1319) $p < .001$	71.90	31	0.065 CI: 0.062 – 0.068	0.865	0.070
Scalar	3077.44 (1350) $p < .001$	152.87	31	0.067 CI: 0.064 – 0.070	0.854	0.072

Note. All chi-square difference tests were found to be significant.

Table 4.

Factor Solutions ASD & ADHD: Exploratory Factor Analysis Using SSP Subscales.

SSP subscale	ASD		ADHD
	Sensory Reactivity	Vestibular Sensitivity	Sensory Processing
Tactile	.680	.417	.855
Taste/Smell	.464	.406	.546
Movement	.175	.830	.671
Sensory Seeking	.764	-.096	.619
Auditory Filtering	.821	.091	.645
Low Energy	.028	.781	.634
Visual/Auditory	.753	.320	.755

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Supplementary Material**Standardized Factor Loadings for Full Sample.**

Table 5.

Standardized Factor Loadings for Full Sample.

	Tactile	Taste/Smell	Movement	Sensory Seeking	Auditory Filtering	Low Energy	Visual/Auditory
Item	<i>SL</i>	<i>SL</i>	<i>SL</i>	<i>SL</i>	<i>SL</i>	<i>SL</i>	<i>SL</i>
1	0.573						
2	0.484						
3	0.518						
4	0.713						
5	0.588						
6	0.684						
7	0.607						
8		0.809					
9		0.863					
10		0.887					
11		0.863					
12			0.766				
13			0.797				
14			0.758				
15				0.635			
16				0.798			
17				0.820			
18				0.729			
19				0.547			
20				0.765			
21				0.491			
22					0.634		
23					0.756		
24					0.674		
25					0.622		
26					0.719		
27					0.673		
28						0.887	
29						0.839	

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30	0.819	
31	0.861	
32	0.755	
33	0.831	
34		0.765
35		0.769
36		0.829
37		0.566
38		0.768

Note. SL = standardized loading; SE = standard error. All factor loadings were significant at $p < .001$.

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Proportion of Endorsment in Each Category for Full Sample.

Table 6.

Proportion of Endorsement in Each Category for Full Sample.

Items	Always(1)	Frequently(2)	Occasionally(3)	Seldom(4)	Never(5)
1	72(12.6)	113(19.8)	101(17.7)	127(22.2)	157(27.5)
2	20 (3.5)	56(9.8)	99(17.3)	111(19.4)	283(49.6)
3	35(6.1)	60(10.5)	65(11.4)	98(17.2)	308(53.9)
4	17(3.0)	50(8.8)	96(16.8)	143(25.0)	260(45.5)
5	23(4.0)	41(7.2)	73(12.8)	100(17.5)	334(58.5)
6	43(7.5)	85(14.9)	116(20.3)	126(22.1)	199(34.9)
7	15(2.6)	31(5.4)	63(11.0)	81(14.2)	369(64.6)
8	76(13.3)	91(15.9)	98(17.2)	106(18.6)	198(34.7)
9	75(13.1)	68(11.9)	59(10.3)	107(18.7)	245(42.9)
10	84(14.7)	73(12.8)	61(10.7)	95(16.6)	248(43.4)
11	113(19.8)	100(17.5)	90(15.8)	92(16.1)	171(29.9)
12	11(1.9)	29(5.1)	52(9.1)	102(17.9)	375(65.7)
13	28(4.9)	65(11.4)	92(16.1)	99(17.3)	287(50.3)
14	29(5.1)	37(6.5)	57(10.0)	99(17.3)	343(60.1)
15	61(10.7)	144(25.2)	120(21.0)	90(15.8)	152(26.6)
16	128(22.4)	172(30.1)	113(19.8)	89(15.6)	66(11.6)
17	91(15.9)	129(22.6)	157(27.5)	102(17.9)	90(15.8)
18	87(15.2)	154(27.0)	123(21.5)	115(20.1)	91(15.9)
19	80(14.0)	113(19.8)	119(20.8)	125(21.9)	131(22.9)
20	71(12.4)	123(21.5)	158(27.7)	119(20.8)	93(16.3)
21	52(9.1)	73(12.8)	101(17.7)	115(20.1)	228(39.9)
22	167(29.2)	197(34.5)	126(22.1)	54(9.5)	26(4.6)
23	82(14.4)	253(44.3)	147(25.7)	65(11.4)	22(3.9)
24	33(5.8)	90(15.8)	150(26.3)	161(28.2)	135(23.6)

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25	45(7.9)	93(16.3)	132(23.1)	152(26.6)	140(24.5)
26	63(11.0)	194(34.0)	164(28.7)	95(16.6)	54(9.5)
27	131(22.9)	234(41.0)	142(24.9)	48(8.4)	16(2.8)
28	48(8.4)	58(10.2)	80(14.0)	96(16.8)	287(50.3)
29	48(8.4)	87(15.2)	102(17.9)	104(18.2)	229(40.1)
30	41(7.2)	43(7.5)	73(12.8)	101(17.7)	309(54.1)
31	46(8.1)	56(9.8)	67(11.7)	97(17.0)	303(53.1)
32	25(4.4)	41(7.2)	76(13.3)	105(18.4)	320(56.0)
33	50(8.8)	76(13.3)	99(17.3)	104(18.2)	239(41.9)
34	78(13.7)	88(15.4)	103(18.0)	105(18.4)	194(34.0)
35	84(14.7)	106(18.6)	117(20.5)	118(20.7)	145(25.4)
36	28(4.9)	55(9.6)	96(16.8)	126(22.1)	264(46.2)
37	36(6.3)	58(10.2)	110(19.3)	144(25.2)	218(38.2)
38	31(5.4)	67(11.7)	110(19.3)	135(23.6)	226(39.6)

Note. Proportion of endorsement in each category; frequency (percentage).