Sensory Responsivity as a Predictor of Adaptive Behavior Development

in Toddlers At-Risk for Autism Spectrum Disorders

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Emma Worthley

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**Abstract**

The objective of the current study was to investigate the explanatory role of sensory responsivity in the development of adaptive behavior for toddlers diagnosed with autism spectrum disorder (ASD). Prospective, longitudinal data were collected using the Sensory Experiences Questionnaire (SEQ) and Vineland Adaptive Behavior Scales (Vineland-II). Data were collected for 391 high-familial risk toddlers, 90 of whom received an ASD diagnosis based on clinical best-estimate. A series of multiple linear regression models were computed using sensory responsivity to predict later adaptive behavior development. The current study provided evidence that elevated sensory responsivity profiles, in particular sensory seeking, predict lower adaptive behavior outcomes for three-year-olds with ASD, with potential implications for early intervention. Overall, sensory seeking seems to be an influential predictor for adaptive behavior domain outcomes for toddlers with ASD.

*Keywords:* autism, sensory, adaptive behavior, broader autism phenotype, longitudinal, sensory seeking, repetitive behavior

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# Sensory Responsivity as a Predictor of Adaptive Behavior Development in Toddlers At-Risk for Autism Spectrum Disorders

Atypical sensory responsivity is prevalent and problematic for children with autism and may have cascading developmental effects, particularly concerning deficits in adaptive skill development (Lane et al., 2010; Liss et al., 2006). Adaptive skill development facilitates participation in daily life activities; however, adaptive skills do not develop fluidly for all individuals. Researchers have found evidence to support that children with ASD often exhibit deficits in adaptive behaviors, particularly communication and socialization (Baker et al., 2008; O'Donnell et al., 2012). Additionally, there is longstanding evidence that children with ASD tend to exhibit atypical responses to sensory stimuli (Baranek et al., 2006; Jasmin et al., 2009; McCormick et al., 2016; O'Donnell et al., 2012; Wolff et al., 2019). Aberrations in the development of the sensory system may have secondary consequences on later developing systems, such as adaptive behavior (Watson et al., 2011; Williams et al., 2018). Cross-sectional studies have shown that sensory responsivity and adaptive behavior development are associated (Baker et al., 2008; Jasmin et al., 2009; Liss et al., 2006). However, research has not yet shown a developmental relationship between sensory responsivity and adaptive behavior in young children with ASD, particularly among infants and toddlers who go on to receive a diagnosis. Understanding the role of sensory responsivity in the development of adaptive behavior in toddlers with ASD could inform intervention.

**Sensory responsivity in autism**

Atypical sensory responsivity is a core characteristic of ASD. The American Psychiatric Association (2013) included atypical sensory responsivity as diagnostic criteria for ASD in the most recent version of the Diagnostic and Statistical Manual of Mental Disorders (5th ed.; DSM-5) under the domain of restricted and repetitive behavior (RRB). Atypical sensory responsivity has a reported prevalence of at least 50% and up to 87% in young children with ASD, 2–9 years of age (Baker et al., 2008; Baranek et al., 2006; Jasmin et al., 2009, 2009; Lane et al., 2010; McCormick et al., 2016; O'Donnell et al., 2012; Rogers et al., 2003). Studies using parent-report measures have shown that children with ASD, 2–9 years old, demonstrate differences in sensory responses compared to neurotypical peers, children with developmental delays, and normative scores on parent-report measures, particularly in Under-responsive/ Sensory Seeking domains (Baker et al., 2008; Jasmin et al., 2009; Lane et al., 2010; McCormick et al., 2016; O'Donnell et al., 2012; Rogers et al., 2003). Furthermore, preschool-age children with ASD demonstrate heterogeneity and variability in sensory responses (Jasmin et al., 2009). Relatively less is known about sensory responsivity in infants and toddlers. However, differences in sensory responsivity have been reported in 12-month-old infants later diagnosed with ASD through observational or parent-report measures (Wolff et al., 2019; Zwaigenbaum et al., 2005). Furthermore, differences in sensory responsivity were associated with brain development in infants, as young as 6 months old, later diagnosed with ASD (Wolff et al., 2017).

Atypical sensory responsivity is defined as a more extreme reaction to the sensory environment when compared to typically developing, same-aged peers and can be categorized into different sub-types or profiles (Ausderau et al., 2014; Lane et al., 2010; Tomchek & Dunn, 2007; Watson et al., 2011). In this study, three sensory profiles (hyper-, hypo-responsivity, and sensory seeking) were used to characterize how individuals with ASD respond to sensory stimuli. Hyperresponsivity includes exaggerated responsivity to sensory stimuli or indications of a low threshold for reactivity to elements of the sensory environment. Hyporesponsivity is a lack of or muted responsivity to sensory stimuli, which manifests as being under-responsive to the sensory environment. Sensory seeking is an intense fascination with sensory stimuli that can be repetitive and embodies as intensely seeking sensory stimulation in the surroundings. Sensory seeking behavior may be restrictive and repetitive. Engagement in restrictive and repetitive behavior is a core feature of ASD. It can be problematic for individuals when any of these sensory response patterns are extreme (Ausderau et al., 2014; Baranek et al., 2006; Watson et al., 2011).

**Adaptive behavior**

Adaptive behavior is the set of conceptual, social, and practical skills that individuals regularly implement in everyday life, given their age (Tassé et al., 2012). Adaptive behavior refers to the development and implementation of skills related to personal independence and social competence (Sparrow, Balla, Cicchetti, Harrison, & Doll, 1984). The Vineland Adaptive Behavior Scales is a measure of adaptive behavior and yields an overall adaptive behavior composite in addition to scores for adaptive behavior domains (Vineland II; Sparrow, Balla, & Cicchetti, 2005). Adaptive behavior domains include communication, daily living skills, motor skills, and socialization.

Individuals with ASD have been found, on average, to have deficits in most domains of adaptive behaviors such as communication, socialization, and daily living skills (Baker et al., 2008; O'Donnell et al., 2012; Sacrey et al., 2019). These deficits have been observed in infants as young as 12 months, before ASD diagnosis, and become more severe with age (Sacrey et al., 2019). It is still unknown why individuals with ASD experience increasingly divergent adaptive behaviors over time.

**Theoretical support for links between sensory responsivity and adaptive behavior**

When sensory profiles are too extreme, they can interfere with how individuals interact with and learn from their environment. Extreme hyperresponsivity may cause individuals to be overwhelmed by their sensory environment, making meaningful interactions with their world difficult. Extreme hyporesponsivity may cause individuals to miss salient information in their environment, given diminished responses to sensory stimuli, including attempts from others for social engagement. Individuals with extreme sensory seeking profiles may fixate on specific aspects of their sensory environment and may not attend to salient environmental information. The severity and nature of sensory profiles range greatly within individuals with ASD; furthermore, the relation of such profiles to adaptive behavior is probably variable (Ausderau et al., 2014; Watson et al., 2011; Williams et al., 2018).

Extreme sensory responsivity may limit participation in daily routines, social experiences, and exploration of the environment, thereby impeding learning opportunities to develop adaptive behavior skills (McCormick et al., 2016; O’Donnell et al., 2012; Zwaigenbaum et al., 2005). Extreme sensory responsivity manifests in sensory behaviors, that is, behaviors responding to sensory stimuli. Sensory behaviors could limit participation in routines and activities; additionally, sensory behaviors could increase parental stress and reduce teaching opportunities for caregivers and children to engage in constructive guidance (McCormick et al., 2016). Atypical sensory responses may limit participation in sensory experiences and hinder a child’s exploration of their environment (O’Donnell et al., 2012). For example, the tactile input from the living room rug may be an obstacle for a toddler with hyperreactivity in crawling across the living room floor. Meanwhile, it may be that extreme sensory reactivity is an obstacle for children with ASD to participate in and learn from social experiences. Furthermore, this early relationship between sensory responsivity and adaptive behavior may initiate an atypical pattern of development that could lead to cascading manifestations of autism (Zwaigenbaum et al., 2005).

**Cross-sectional support for associations between sensory responsivity and adaptive behavior**

Cross-sectional studies, sampling independent groups of 1–9-year-old children with ASD, have provided evidence that there is a concurrent association between sensory responsivity and adaptive behavior domains in toddlers and children with ASD. Sensory profiles have been negatively correlated with or explained variance in communication, socialization, and daily living skills in that more aberrant sensory profiles are associated with lower adaptive behavior scores (Baker et al., 2008; Lane et al., 2010; Liss et al., 2006; Wolff et al., 2019). Conversely, sensory seeking profiles have been positively correlated with or explained variance in motor skills (Jasmin et al., 2009; Tomchek & Dunn, 2007). Meanwhile, current knowledge of the developmental effect of sensory responsivity patterns on later adaptive behavior outcomes lacks as longitudinal studies are limited.

**Longitudinal relationship between sensory responsivity and adaptive behavior**

Few longitudinal studies have investigated the relationship between sensory responsivity and later adaptive behavior outcomes and have found mixed results (McCormick et al., 2016; Williams et al., 2018). McCormick et al. (2016) investigated the relationship between the development of sensory symptoms and adaptive behavior in children with ASD at three different time points, spanning 2–8 years of age. Overall, they found that typically developing peers scored, on average, 21 points higher than individuals with ASD on a parent-report sensory measure in which higher scores indicate less sensory symptoms. Contrary to expectation, they did not find a relationship between sensory symptoms and adaptive functioning, after controlling for verbal mental age. One limitation of the results of the study by McCormick and colleagues is that they used the overall adaptive behavior composite as an outcome rather than parsing adaptive behavior apart into domains (e.g., communication and socialization).

Williams et al. (2018) investigated whether atypical sensory profiles (i.e., hyper-, hypo-responsivity, and sensory seeking) at age 5 predicted later adaptive behavior outcomes at age 9 in children with ASD compared to same-aged children with developmental delay (DD) in a longitudinal study. Adaptive behavior outcomes included daily living skills, socialization, communication, and an overall adaptive behavior composite. They hypothesized that higher levels of sensory features would predict deficits in later adaptive behavior for the ASD and the DD group. In particular, higher levels of hyporesponsivity would predict later deficits in socialization and communication. Indeed, they found higher levels of hyporesponsivity and sensory seeking predicted lower socialization scores for children with ASD. They also found that higher levels of hyperresponsivity and sensory seeking predicted scores for lower daily living skills. Incidentally, they found mixed results regarding the effects of sensory profile on communication that varied due to measurement type. Their findings, using a longitudinal dataset, corroborate cross-sectional results that link atypical sensory profiles with deficits in adaptive behavior outcomes in elementary school-aged children with ASD.

There is cross-sectional evidentiary support that atypical sensory responsivity may be, in part, responsible for the divergent development of adaptive behavior in ASD. However, there remains a paucity of longitudinal research investigating associations between atypical sensory responsivity and adaptive behavior in children, particularly during early childhood, when autism begins to emerge. In the present study, the goal was to downward extend the methods and procedures from Williams et al. (2018) to infants and toddlers at risk for ASD in a prospective, longitudinal study.

**The present study**

The specific aims of the study were: (1) to identify whether sensory responsivity explains variance in later adaptive behavior outcomes in toddlers with ASD and (2) determine to what extent the present study corroborates patterns found in Williams et al. (2018). The hypotheses in this study apply to toddlers with ASD. The current hypotheses rely on the premise that infants later diagnosed with ASD will have higher sensory responsivity scores at 12 months of age than high-risk peers (McCormick et al., 2016; O'Donnell et al., 2012; Wolff et al., 2019). Another assumption the current hypotheses rely on is that toddlers diagnosed with ASD will have lower adaptive behavior outcome scores at 36 months of age than toddlers at-risk for ASD who do not develop ASD (Baker et al., 2008; O'Donnell et al., 2012). The main hypotheses in this study are as follows – (1) elevated hyper-, hypo-responsivity, or sensory seeking scores at 12 months of age will each explain variance in lower socialization scores at 36 months of age (Liss et al., 2006; Williams et al., 2018; Wolff et al., 2019); (2) elevated sensory seeking scores at 12 months of age will explain variance in lower communication scores at 36 months of age (Liss et al., 2006; Wolff et al., 2019); and lastly (3) that there is a positive relationship between sensory seeking and motor skills (Jasmin et al., 2009; Tomchek & Dunn, 2007). The rationale for this study is that it is unknown how early sensory profiles relate to later adaptive behaviors in toddlers with ASD. A longitudinal study investigating this relationship between sensory response profiles in infants and adaptive behavior in toddlers with ASD could inform the nature of the relationship between sensory responsivity and the development of adaptive behavior.

# Method

This study analyzed data collected through the ongoing Autism Center of Excellence (ACE) Network Infant Brain Imaging Study (IBIS), a prospective, longitudinal study of brain and behavior in infants at high familial risk for autism and typically developing controls.

## Participants

Participants included 391 toddlers at high risk for developing ASD, comprised of 90 toddlers later diagnosed with ASD (HR-ASD), and 301 who did not develop ASD (HR-Neg). Toddlers are high-risk for developing ASD by having an older sibling diagnosed with ASD confirmed by the Autism Diagnostic Interview, Revised (ADI-R; Lord et al., 1994), and Social Communication Questionnaire (SCQ; Rutter, Bailey, Lord, & Berument, 2003). Group conditions were naturally observed based on diagnostic status. Descriptive and demographic data for participants are discussed in the results and included in Tables 1 and 2.

Inclusion criteria for high-risk infants included age 12 months or less and an older sibling with a confirmed diagnosis of ASD. In order to target participants with ASD without comorbid conditions, participants were excluded from the study if they met any of the following exclusion criteria: (1) evidence of a genetic syndrome or condition; (2) significant neurological or medical condition affecting physical or cognitive development; (3) significant hearing or vision impairment; (4) gestational age <36 weeks or birth weight <2,000 grams or; (5) exposure to neurotoxins in utero or other significant perinatal adversity, (6) contraindication for MRI, (7) primary home language other than

English, (8) different biological parents than an older sibling with ASD, (9) first-degree relative with schizophrenia, bipolar disorder, or psychosis, and (10) twins. ASD diagnosis was confirmed when participants were two years of age; they were assessed by an experienced clinician, part of the IBIS research team, using DSM-IV-TR criteria for autistic disorder or PDD-NOS (collapsed herein as ASD). The Autism Diagnostic Observation Scale (ADOS; Lord et al., 2000), ADI-R, and the Mullen Scales of Early Learning (MSEL-ELC; Mullen, 1995) were used to form a clinical best-estimate diagnosis. After an experienced clinician diagnosed toddlers with ASD, a senior clinician who was naïve to diagnostic classification independently verified the diagnosis.

**Table 1**

*Description of Participant Sample Size and Age*

| Characteristic | HR-ASD | | HR-Neg | | Full sample | |
|---|---|---|---|---|---|---|
| | M (SD) | Range | M (SD) | Range | M (SD) | Range |
| Sample size | | | | | | |
| Total | 90 | | 301 | | 391 | |
| 12-month | 63 | | 228 | | 291 | |
| 36-month | 41 | | 142 | | 183 | |
| Age | | | | | | |
| Elapsed | 26.61 (4.69) | 20–30 | 26.30 (4.53) | 22–31 | 26.37 (4.56) | 20–31 |
| 12-month | 12.85 (1.28) | 12–18 | 12.55 (0.61) | 11–15 | 12.61 (0.81) | 11–18 |
| 36-month | 39.26 (4.44) | 34–42 | 38.99 (4.66) | 35–42 | 39.06 (4.60) | 34–42 |

*Note.* HR-ASD refers to the group of participants later diagnosed with ASD; HR-Neg refers to toddlers at risk for ASD who did not receive a diagnosis. Full sample is comprised of the HR-ASD and HR-Neg groups. Elapsed is the time between data collection at time 1 (12 months of age) and at time 2 (36 months of age).

**Table 2**

*Description of Participant Sociodemographics*

| Characteristic | HR-ASD | | HR-Neg | | Full HR sample | |
|---|---|---|---|---|---|---|
| | n | % | n | % | n | % |
| Sex | | | | | | |
| Female | 19 | 21.1 | 137 | 45.5 | 156 | 39.9 |
| Male | 71 | 78.9 | 164 | 54.5 | 235 | 60.1 |
| Race | | | | | | |
| Asian/ Black/ Other[a] | 3 | 4.1 | 12 | 4.8 | 15 | 4.6 |
| More than one | 6 | 8.2 | 20 | 7.9 | 26 | 8.0 |
| White | 64 | 87.7 | 220 | 87.3 | 284 | 87.4 |
| Ethnicity | | | | | | |
| Hispanic | 4 | 5.5 | 18 | 7.2 | 22 | 6.8 |
| Maternal education | | | | | | |
| Some college or less | 30 | 40.5 | 80 | 32.0 | 110 | 34.0 |
| College degree | 25 | 33.8 | 110 | 44.0 | 135 | 41.6 |
| Graduate degree | 19 | 25.7 | 60 | 24.0 | 79 | 24.4 |
| Income | | | | | | |
| < 50,000 | 19 | 26.0 | 55 | 23.0 | 74 | 23.7 |
| 50,000–150,000 | 28 | 38.4 | 88 | 36.8 | 116 | 37.2 |
| > 150,000 | 26 | 35.6 | 96 | 40.2 | 122 | 39.1 |

*Note.* The HR-ASD group is comprised of n=90 toddlers who are later diagnosed with ASD. The HR-Neg group is comprised of n=301 toddlers at risk for developing ASD but do not receive a diagnosis.

[a] Other includes Alaskan Native, Native American, and Pacific Islander.

Recruitment of participants occurred through a variety of means, including research registries, flyers, brochures, email blasts, and community clinics near the different clinical sites in the IBIS network. Participants were screened and assessed beginning at age 6- or 12-months at one of four clinical sites; the clinical sites for this study included the University of North Carolina – Chapel Hill, Washington University in St. Louis, University of Washington, and Children's Hospital of Philadelphia. Data collection began in July 2007 and is ongoing. Participants were reimbursed separately ($50) at each visit for participating in a behavioral assessment and magnetic resonance imaging for a total of $100 per visit. Participants were also reimbursed for travel expenses to get to the nearest IBIS clinical site and other related expenses. The Human Subjects Review Board for each site approved study procedures. Written and informed consent was obtained and documented for all participants.

## Measures

The measures used to collect data for focal variables included in this study were the Sensory Experiences Questionnaire (SEQ 2.1; Baranek et al., 2006) and the Vineland-II (Sparrow et al., 2005). Additional measures implemented were the MSEL (Mullen, 1995), the ADOS (Lord et al., 2000), and the ADI-R (Lord et al., 1994).

### *SEQ*

The Sensory Experiences Questionnaire, version 2.1 (SEQ; Baranek et al., 2006) is a parent-report questionnaire in which parents answer items about their child's frequency of behavioral responses to sensory stimuli, designed to quantify sensory responses exhibited by children with ASD and DD. The SEQ (Version 2.1) has 53 total items comprised of 33 5-point rating scale items and 20 open-ended questions. The 5-point rating scale items (*Almost Never* = 1 to *Almost Always* = 5) quantify child behavior and produce sensory scores. The SEQ (Version 2.1) is different from the SEQ (Version 1.0) in that it has additional items that fall under the sensory seeking profile. A confirmatory factor analysis validated the three sensory response patterns in the SEQ (Version 2.1; Watson et al., 2011). The SEQ (Version 1.0) has a test-retest reliability of .92 (intraclass correlation coefficient) for children with ASD or DD between the ages of 5 months and 72 months (Little et al., 2011). The SEQ (Version 1.0) has an internal consistency (Cronbach's alpha) of 0.8 (Baranek et al., 2006). The SEQ (Version 2.1) has been found to have the following internal consistency: Hyperresponsiveness = .73, Hyporesponsiveness = .75, Sensory Seeking = .80 (Baranek, Lorenzi, & Freuler, 2013). There is evidence of convergent and concurrent validity for the SEQ (Version 1.0; Baranek et al., 2006; Boyd et al., 2010; Watson et al., 2011).

***Vineland-II***

The Vineland Adaptive Behavior Scales (Vineland-II; Sparrow et al., 2005) is a standardized, semi-structured parent interview designed to assess daily functioning skills in the domains of communication, socialization, daily living skills, and motor skills. The Vineland-II uses data from these domains to compute an overall adaptive behavior composite; however, the current study only included adaptive behavior domain scores.

***MSEL***

The Mullen Scales of Early Learning (MSEL; Mullen, 1995) is a standardized developmental assessment appropriate for children from birth to 68 months of age that measures receptive and expressive language, fine motor skills, and visual reception.

These measures combine to form an Early Learning Composite (ELC) score, serving as an IQ proxy for young children.

***ADOS***

The Autism Diagnostic Observation Scale (ADOS; Lord et al., 2000) is a diagnostic assessment designed to evoke ASD-related behaviors such as restricted, repetitive behavior, and deficits in social communication through semi-structured play. Participants were assessed at approximately 24 months of age to inform diagnostic classification using the ADOS-G, the generic form of the ADOS. The ADOS provides standardized ASD severity scores to diminish the effects of age and IQ (Gotham et al., 2009).

***ADI-R***

The Autism Diagnostic Interview-Revised (ADI-R; Lord et al., 1994) is a semi-structured caregiver interview designed for caregivers of individuals with ASD that inquires about DSM-IV-TR and ICD-10 related criteria. The ADI-R was used to assess participants at approximately 24 months of age to inform diagnostic classification.

**Procedures**

Data for household income and maternal education were collected upon enrollment and verified at the second visit. Parent report forms (e.g., SEQ) were mailed to participants and completed before in-person assessments. Study personnel administered the Vineland-II, MSEL, ADOS, and ADI-R in person at one of the four clinical sites.

### ***Statistical analysis***

The current study hypotheses were tested by computing twelve multiple linear regression models. The focal predictor in each model was a sensory responsivity profile (i.e., hyper-, hypo-responsivity, or sensory seeking), measured as three separate continuous variables. The outcome in each model was an adaptive behavior domain (i.e., communication, socialization, daily living skills, or motor skills) while controlling for sex, age at data collection for the 12-month visit, household income, maternal education, elapsed time between the age of data collection for the sensory profile scores at 12 months of age and age of data collection for adaptive behavior domains at 36 months, the MSEL-ELC, and group. Models including an interaction between the group and sensory profile score were fit; however, none of the interaction terms contributed meaningfully to the model, so they were trimmed to main effects models.

The R software was used for all data analyses (v. 3.6.1; R Core Team, 2019). Relevant data was contained in two datasets. Both datasets were loaded into R using the readxl package (Wickham & Bryan, 2019). Data subsets were created that included only the relevant variables using functions from the dplyr package (Wickham et al., 2019). These data subsets were merged.

Some variables were added to the dataset by transforming existing variables. Williams et al. (2018) included elapsed time as a covariate, which was the elapsed time between data collection at 5 years of age and data collection at 9 years of age. This variable was created in the current dataset by subtracting the age of data collection for SEQ (Version 2.1) at 12 months of age from the age of data collection for Vineland-II at

36 months of age. Another covariate considered in the Williams study was income. The income variable was a categorical variable comprised of income ranges. For the multiple linear regression analysis, an indicator variable was created for income to transform income into a numerical variable. Each SEQ sensory response pattern score was divided by the number of questions that contributed to that score to find the item mean score for each raw SEQ sensory response pattern score. The SEQ item mean score was used for all analyses. The variable indicating whether a participant received an ASD diagnosis was converted from a numerical variable to a factor with two levels, HR-ASD and HR-Neg.

Vineland-II variables were evaluated for any values coded as $0$ or $-99$. Some data collection sites used values such as $0$ or $-99$ when data was missing for Vineland-II domain scores. Each Vineland-II domain score was checked for those values, and if found, those values were replaced with NA. Participant ages were evaluated at the 12-month point of data collection and the 36-month point of data collection. Any participants that were 16 months or older at the collection of the SEQ (Version 2.1) targeted at 12 months had their SEQ scores set to NA. Any participants that were 42 months or older at the collection of the Vineland-II targeted at 36 months had their Vineland-II scores set to NA. This resulted in the loss of SEQ (Version 2.1) data from one participant, the loss of Vineland-II scores for communication, socialization, and motor skills from 34 participants, and the loss of Vineland-II scores for daily living skills from 35 participants. No other data transformations were used in this data analysis.

Marginal distributions for continuous predictor variables, including covariates, were generated and visually examined using the ggplot2 package (Wickham, 2016).

Descriptive statistics for the focal predictor variables and the outcome variables were computed. Relationships between the focal predictor variables and the outcome variables were assessed visually using scatterplots and computationally through correlations using the corrr package (Kuhn et al., 2020). Table 4 displays correlations between sensory profiles. All 12 models met the independence assumption based on a priori, theoretical grounds. The rest of the multiple linear regression assumptions were visually evaluated (Robinson & Hayes, 2019; Zieffler, 2019). All 12 models satisfactorily met the normality, linearity, and homoskedasticity assumptions.

# Results

The primary research question was whether atypical sensory profiles at 12 months of age explain variance in adaptive behavior domain outcomes at 36 months of age for toddlers diagnosed with ASD. This study explored group differences in focal variables such as sensory responsivity and adaptive behavior (see Table 3). This study computed correlations between hyper-, hypo-responsivity, and sensory seeking profiles for toddlers diagnosed with ASD, results are displayed in Table 4.

## Preliminary results

### *Sensory responsivity group differences*

I hypothesized that toddlers with ASD would have more extreme sensory responsivity than the HR-Neg group. In particular, that toddlers with ASD would have more extreme sensory response pattern scores for hyper-, hypo-responsivity, and sensory seeking on the SEQ (Version 2.1). Using one-tailed Welch's two-sample *t*-tests, 12-

month-old toddlers with ASD, on average, had higher sensory response pattern scores for hyperresponsivity ($t = 3.34, p < .001$) and hyporesponsivity($t = 2.47, p = .008$) than the HR-Neg group but there was no statistically significant group difference for sensory seeking scores (see Table 3). Thus, there is evidence to support the hypothesis that toddlers with ASD display more frequent sensory symptoms than the HR-Neg group for hyper- and hypo-responsive profiles. After acquiring empirical evidence that toddlers with ASD have higher hyperresponsivity and hyporesponsivity scores than the HR-Neg group, I evaluated whether the group of toddlers with ASD had lower scores in adaptive behavior domains compared to the HR-Neg group.

**Table 3**

*Group Differences in Key Study Variables*

| Variables | HR-ASD | | HR-Neg | | *t* | *p* | Cohen's *d* |
|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | | | |
| Sensory | | | | | | | |
| Hyper | 1.59 | 0.44 | 1.40 | 0.32 | 3.34 | < .001 | 0.56 |
| Hypo | 1.58 | 0.57 | 1.39 | 0.43 | 2.47 | .008 | 0.41 |
| Seeking | 2.02 | 0.51 | 1.92 | 0.53 | 1.38 | .085 | 0.19 |
| Adaptive behavior | | | | | | | |
| Communication | 85.27 | 16.27 | 101.31 | 10.56 | −5.96 | < .001 | −1.33 |
| Daily living skills | 82.47 | 12.62 | 97.82 | 10.42 | −7.42 | < .001 | −1.40 |
| Motor skills | 86.44 | 9.85 | 95.23 | 10.13 | −5.00 | < .001 | −0.87 |
| Socialization | 83.05 | 12.46 | 99.78 | 10.68 | −7.81 | < .001 | −1.51 |
| IQ proxy | 82.51 | 20.15 | 103.71 | 18.26 | −6.87 | < .001 | −1.12 |

*Note.* Welch's one-tailed two-sample *t*-tests were used to assess group differences. The HR-ASD group is comprised of n=90 toddlers who are later diagnosed with ASD. The HR-Neg group is comprised of n=301 toddlers at risk for developing ASD but do not receive a diagnosis. Sensory scores come from the Sensory Experiences Questionnaire (SEQ 2.1); Adaptive behavior scores come from the Vineland Adaptive Behavior Scales (Vineland-II). The IQ proxy is the Early Learning Composite from the Mullen Scales of Early Learning Early Learning Composite (MSEL-ELC), that was administered when individuals were approximately 36 months old.

**Table 4**

*Correlations Between Sensory Responsivity Profile Scores*

| SEQ profile | 1 | 2 | 3 |
|---|---|---|---|
| 1. Hyperresponsivity | – | | |
| 2. Hyporesponsivity | $.30^{*}$ | – | |
| 3. Sensory seeking | $.28^{*}$ | $.43^{***}$ | – |

*Note.* Spearman's rank-order correlations are displayed. Sensory responsivity profile scores are obtained from the Sensory Experiences Questionnaire 2.1 (SEQ 2.1; Baranek et al., 2006) using a sample size of $n = 77$ toddlers diagnosed with Autism Spectrum Disorder (ASD).

$^{*}p < .05$. $^{***}p < .001$.

***Adaptive behavior group differences***

I hypothesized that toddlers with ASD would have differences in adaptive behavior domain outcomes in socialization, communication, motor skills, and daily living skills. In particular, that toddlers with ASD would have lower scores for adaptive behavior domains on the Vineland-II than the HR-Neg group. This hypothesis was correct; using one-tailed Welch's two-sample *t*-tests, toddlers with ASD had lower scores for all four adaptive behavior domains on the Vineland-II than the HR-Neg group: socialization ($t = -7.81, p < .001$), daily living skills ($t = -7.42, p < .001$), communication ($t = -5.96,\ p < .001$), and motor skills ($t = -5.00, p < .001$). These results are displayed in Table 3. Having demonstrated that toddlers with ASD, on average, have lower scores in communication, socialization, daily living skills, and motor skills, in addition to higher scores for hyper- and hypo-responsivity to sensory stimuli, group differences for co-variables will be discussed.

***MSEL-ELC group difference***

As the high-risk sample included toddlers with and without ASD, participants' diagnostic status may have introduced an unintended variable, potentially obfuscating results. There was a group difference found between toddlers with ASD and the HR-Neg group for the MSEL-ELC, an IQ proxy for young children, using a Welch's two-sample *t*-test ($t = -6.87, p < .001$), with the HR-Neg group scoring higher on average than the ASD group ($d = -1.13,\ 95\% CI[-1.46, -.80]$. The preliminary results indicate that toddlers with ASD, on average, have lower scores in communication, socialization, daily living skills, motor skills, and IQ proxy, in addition to more extreme hyper- and hypo-responsivity to sensory stimuli. Next, I investigated if sensory responsivity at 12 months of age predict adaptive behavior in toddlers at 36 months of age.

**Primary results**

The primary aim of this study was to investigate the extent to which sensory responsivity at 12 months of age explains variance in adaptive behavior outcomes at 36 months of age for toddlers diagnosed with ASD using multiple linear regression models. Regression model results predicting adaptive behavior domain outcomes are in Tables 5–8, organized by outcome variable as follows: socialization (Table 5), communication (Table 6), motor skills (Table 7), and daily living skills (Table 8).

***Socialization***

As seen in Table 5, elevated hyperresponsivity and sensory seeking scores at the 12-month visit explained variance in socialization outcome scores at 36 months of age;

however, contrary to expectation, elevated hyporesponsivity scores did not explain variance in later socialization scores. These results are visually displayed in Figure 1.

**Table 5**

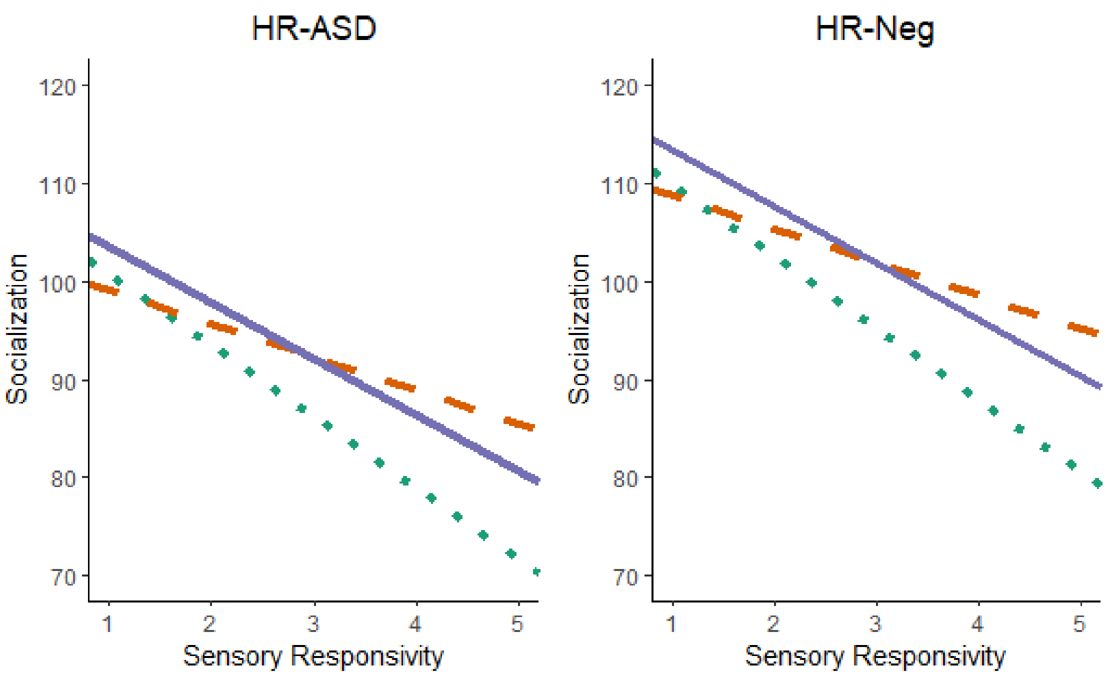
*Socialization Outcome Results from Four Multiple Regression Models*

| Predictors | Sensory profiles | | | |
|---|---|---|---|---|
| | Covariates | Hypo model | Hyper model | Seeking model |
| Covariates | | | | |
| Gender | −3.08 (2.11) | −3.21 (1.93) | −4.04* (1.91) | −3.63 (1.85) |
| 12-month age | −0.35 (1.04) | −1.07 (1.39) | −1.21 (1.34) | −1.45 (1.31) |
| Income | 0.98 (0.54) | 0.68 (0.50) | 0.57 (0.49) | 0.60 (0.48) |
| Maternal ed. | −0.77 (1.41) | −1.24 (1.30) | −1.16 (1.27) | −1.30 (1.24) |
| Elapsed time | 0.41 (0.57) | 0.14 (0.53) | 0.15 (0.52) | 0.16 (0.50) |
| Mullen-ELC | 0.30*** (0.05) | 0.21*** (0.05) | 0.21*** (0.05) | 0.20*** (0.05) |
| Sensory score | | | | |
| Hypo | | −3.39 (2.04) | | |
| Hyper | | | **−7.27*** (2.54)** | |
| Seeking | | | | **−5.74*** (1.54)** |
| Group | | **9.73*** (2.42)** | **8.88** (2.38)** | **9.76*** (2.26)** |
| Intercept | 61.97* (24.17) | 86.89** (26.24) | 96.36*** (25.90) | 100.14*** (25.31) |
| $R^2$ | 0.36 | 0.48 | 0.50 | 0.52 |
| $\Delta R^2$ | | 0.12 | 0.14 | 0.16 |
| *F* statistic | **10.17***** (df = 6; 111) | **12.23***** (df = 8; 108) | **13.48***** (df = 8; 108) | **14.83***** (df = 8; 108) |

*Note.* Model parameters are displayed with standard errors in parentheses. The covariates model is the baseline model. Hyper-, hypo-responsivity, and sensory seeking were each used as the focal predictor variable in three separate models. Income is family income. Maternal ed. is maternal education. Elapsed time is the number of months between the 12-month visit and the 36-month visit. The Mullen-ELC is the Early Learning Composite from the Mullen Scales of Early Learning (MSEL). The three sensory seeking models were computed using the Sensory Experiences Questionnaire (SEQ 2.1).
* < .05. **< .01. *** < .001.

**Figure 1**

*Sensory Profiles as Predictors of Socialization for Toddlers at High-Risk for Autism*




*Note.* The left plot depicts the HR-ASD group, toddlers diagnosed with ASD, *n* = 31. The right plot depicts the HR-Neg group, toddlers at high-risk for autism spectrum disorder (ASD) without an ASD diagnosis, *n* = 119. The solid, periwinkle line depicts the effect of sensory seeking responsivity in which a higher sensory responsivity score indicates a more frequent engagement in sensory seeking behavior. The dotted, teal line depicts the effect of hyperresponsivity. The dashed, orange line depicts the effect of hyporesponsivity. Sensory responsivity scores (hyper-, hypo-responsivity, and seeking) are derived from Sensory Experiences Questionnaire response pattern scores (SEQ 2.1). Socialization score was derived from the Vineland Adaptive Behavior Scales (Vineland-II). All other covariates included in the model predicting socialization outcomes were set to their mean.

Together, hyperresponsivity, group, sex, and IQ proxy explained 50.0% of the variation in later socialization outcomes for toddlers at high-risk for developing ASD in the sample, after controlling for differences in age at 12-month visit, family income, maternal education, and time elapsed between visits. A negative main partial effect of hyperresponsivity on socialization was found ($\beta = -7.27,\ p = .005$). This result indicates that for each 1-unit increase on the SEQ hyperresponsivity score (parent-reported rating scale from 1 to 5), toddlers at risk for ASD are predicted to score 7.27 less on their Vineland-II socialization domain score, on average, after accounting for differences in the variables mentioned above. Furthermore, the partial effect of the diagnostic group was 8.88. This result indicates that the HR-Neg group, on average, is predicted to score 8.88 points higher on the Vineland-II socialization domain score than the HR-ASD group, after accounting for differences in the variables above. This model also found sex to be a substantive predictor of socialization outcomes in which the model predicted female participants to have a socialization score of 4.04 points more than those of male participants, on average. The empirical evidence, $F(8{,}108) = 13.48, p =< .001$, suggests that hyperresponsivity explains some variation in socialization outcomes for toddlers at-risk for ASD in the population. Thus, for toddlers in the HR-ASD group, high hyperresponsivity profiles at 12 months of age are associated with lower socialization outcomes at three years of age, on average.

In addition to hyperresponsivity, sensory seeking profiles were also found to be predictive of variance in later socialization outcomes for toddlers at risk for ASD. Together sensory seeking, group, and IQ proxy explained 52.3% of the variation in socialization outcomes, for toddlers at high risk of developing ASD, in the sample, after controlling for differences in sex, age at 12-month visit, family income, maternal education, and time elapsed between visits. I found a negative main partial effect of sensory seeking on socialization ($\beta = -5.74, p < .001$). This model predicted that for each 1-unit increase on the SEQ sensory seeking score (parent-reported rating scale from 1 to 5), toddlers at high-risk for ASD, on average, would score 5.74 points less on the Vineland-II socialization domain score. Furthermore, the partial effect of diagnostic group was 9.76. This finding indicates that participants in the HR-Neg group are predicted to have a socialization score; on average, 9.76 points higher than participants in the HR-ASD group. The empirical evidence, resulting from the multiple regression, $F(8{,}108) = 14.83,\ p < .001$, provides support that the sensory seeking model explains some variance in socialization outcomes in the population. Thus, for toddlers later diagnosed with ASD, elevated sensory seeking scores at 12 months of age was associated, on average, with lower socialization scores at three years of age.

A secondary aim of this paper was to explore the extent to which findings from Williams et al. (2018), using similar methods on a sample of elementary school-aged children, extend to a younger sample. Both the present study and Williams et al. (2018) found effects in models explaining variance in socialization with some degree of overlap. Williams found a two-way interaction between group (ASD and DD) and sensory seeking in their model predicting socialization, whereas the present study found a main effect of sensory seeking in the model predicting socialization. Both current study findings and findings from Williams et al. (2018) corroborate the hypothesis that sensory seeking is negatively associated with socialization skills for young children with ASD; this association is evident in toddlers and elementary school-aged children.

Williams found a main effect for hyporesponsivity in the model predicting socialization ($B = -7.10, p = .02$). The current study did not replicate the main effect of hyporesponsivity in the model predicting socialization ($B = -3.39, p = .099$). The full model results are in Table 5. These findings suggest that any effect of hyporesponsivity on socialization may not be present in toddlerhood.

***Communication***

After finding support for sensory seeking and hyperresponsive profiles in explaining variance in socialization, I investigated whether elevated sensory seeking scores at 12 months of age explained variance in communication scores at 36 months of age for toddlers with ASD. As Table 6 reveals, contrary to present study expectations, there was no evidence to support the hypothesis that sensory seeking explained variance in communication scores at 36 months of age for toddlers with ASD.

The secondary aim of the present study was to investigate the extent to which findings based on an elementary-school-aged sample extends to a younger population. Williams and colleagues found that their model using parent-report measures of hyperresponsivity, negatively predicted outcomes in communication in elementary-school-aged children; however, this finding did not extend to toddlers in the present sample. This finding suggests that any effect of hyperresponsivity on communication is not present in toddlerhood.

**Table 6**

*Communication Outcome Results from Four Multiple Regression Models*

| Predictor | Sensory profiles | | | |
|---|---|---|---|---|
| | Covariates | Hypo model | Hyper model | Seeking model |
| Covariates | | | | |
| Gender | −2.83 (1.94) | −2.81 (1.88) | −3.05 (1.91) | −2.93 (1.89) |
| 12-month age | −0.62 (0.95) | −2.21 (1.36) | −2.40 (1.34) | −2.46 (1.34) |
| Income | 0.84 (0.50) | 0.62 (0.49) | 0.64 (0.49) | 0.64 (0.49) |
| Maternal ed. | 0.76 (1.29) | 0.30 (1.27) | 0.37 (1.27) | 0.34 (1.26) |
| Elapsed time | 0.45 (0.52) | 0.22 (0.52) | 0.26 (0.52) | 0.27 (0.51) |
| Mullen-ELC | 0.36*** (0.04) | 0.33*** (0.05) | 0.32*** (0.05) | 0.32*** (0.05) |
| Sensory score | | | | |
| Hypo | | −2.09 (1.98) | | |
| Hyper | | | −1.97 (2.54) | |
| Seeking | | | | −1.55 (1.58) |
| Group | | 4.25 (2.36) | 4.35 (2.38) | **4.59* (2.31)** |
| Intercept | 56.71* (22.14) | 87.26*** (25.57) | 89.20*** (25.91) | 90.21*** (25.89) |
| $R^2$ | 0.48 | 0.52 | 0.52 | 0.52 |
| $\Delta R^2$ | | 0.04 | 0.04 | 0.04 |
| *F* statistic | **16.94***** | **14.60***** | **14.47***** | **14.57***** |
| | (df = 6; 111) | (df = 8; 108) | (df = 8; 108) | (df = 8; 108) |

*Note.* Model parameters are displayed with standard errors in parentheses. The covariates model is the baseline model. Hyper-, hypo-responsivity, and sensory seeking were each used as the focal predictor variable in three separate models. Income is family income. Maternal ed. is maternal education. Elapsed time is the number of months between the 12-month visit and the 36-month visit. The Mullen-ELC is the Early Learning Composite from the Mullen Scales of Early Learning (MSEL). The three sensory seeking models were computed using the Sensory Experiences Questionnaire (SEQ 2.1).

* < .05. ** < .01. *** < .001.

***Motor skills***

After not finding sensory profiles to explain variance in later communication outcomes while finding negative main effects of sensory seeking and hyperresponsivity on later socialization outcomes, I lastly examined whether there is a positive relationship between sensory seeking and motor skills in toddlers diagnosed with ASD. As seen in Table 7, there is a negative relationship between sensory seeking and motor skills for toddlers at high-risk for developing ASD. Together sensory seeking and IQ proxy explain 30.1% of the variation in later Vineland-II motor skill outcome scores for toddlers at high-risk for developing ASD, in the sample, after accounting for differences in sex, age at 12-month visit, family income, maternal education, time elapsed between visits, and group. There was a negative main partial effect of sensory seeking on motor skills, $\beta = -3.40, p = .019$. This finding indicates that for each 1-unit increase on SEQ sensory seeking score (1–5 point rating scale), at 12 months of age, participants, on average, are predicted to score 3.40 points less on the Vineland-II motor skills domain score at 36 months of age. There was no additional partial effect of group, indicating that any differences seen were for both the HR-Neg and HR-ASD groups. The results of this multiple regression analysis, $F(8, 107) = 5.77, p < .001$, provides empirical evidence to suggest that for toddlers at high-risk for developing ASD, elevated sensory seeking scores at 12 months of age, on average, are associated with lower motor skills at 3 years of age.

**Table 7**

*Motor Skills Outcome Results from Four Multiple Regression Models*

| Predictor | Sensory profiles | | | |
|---|---|---|---|---|
| | Covariates | Hypo model | Hyper model | Seeking model |
| Covariates | | | | |
| Gender | −2.53 (1.79) | −2.41 (1.75) | −2.69 (1.76) | −2.71 (1.71) |
| 12-month age | 0.04 (0.88) | −1.82 (1.27) | −1.95 (1.25) | −1.95 (1.22) |
| Income | 0.38 (0.46) | 0.19 (0.46) | 0.18 (0.46) | 0.13 (0.44) |
| Maternal ed. | −1.66 (1.19) | −2.09 (1.17) | −2.03 (1.17) | −2.17 (1.15) |
| Elapsed time | 0.27 (0.50) | 0.02 (0.49) | 0.04 (0.49) | 0.06 (0.48) |
| Mullen-ELC | 0.18*** (0.04) | 0.16*** (0.05) | 0.16*** (0.05) | 0.16*** (0.05) |
| Sensory score | | | | |
| Hypo | | −1.77 (1.84) | | |
| Hyper | | | −2.38 (2.36) | |
| Seeking | | | | **−3.40* (1.43)** |
| Group | | 2.84 (2.18) | 2.75 (2.19) | 2.78 (2.09) |
| Intercept | 72.39*** (20.83) | 105.78*** | 108.63*** | 112.14*** |
| | | (24.20) | (24.51) | (23.86) |
| $R^2$ | 0.22 | 0.27 | 0.27 | 0.30 |
| $\Delta R^2$ | | 0.05 | 0.05 | 0.07 |
| *F* statistic | **5.06*** ** | **4.97*** ** | **4.98*** ** | **5.77*** ** |
| | (df = 6; 110) | (df = 8; 107) | (df = 8; 107) | (df = 8; 107) |

*Note*. Model parameters are displayed with standard errors in parentheses. The covariates model is the baseline model. Hyper-, hypo-responsivity, and sensory seeking were each used as the focal predictor variable in three separate models. Income is family income. Maternal ed. is maternal education. Elapsed time is the number of months between the 12-month visit and the 36-month visit. The Mullen-ELC is the Early Learning Composite from the Mullen Scales of Early Learning (MSEL). The three sensory seeking models were computed using the Sensory Experiences Questionnaire (SEQ 2.1).

* < .05. ** < .01. *** < .001.

***Daily living skills***

The present study did not make specific hypotheses regarding daily living skills outcomes as expectations of daily living skills for 3-year olds seemed trivial. Incidentally, the present study found that, together, sensory seeking, group, and IQ proxy explained 45.8% of the variation in daily living skills at 3 years of age, after controlling for differences in sex, age at 12-month visit, family income, maternal education, and time elapsed between visits, in the sample. Model results are displayed in Table 8. A negative main partial effect of sensory seeking on later daily living skills outcomes was found, $\beta = -4.43, p = .004$. This finding indicates that for each 1-unit increase on the SEQ sensory seeking score (1–5 point rating scale), participants are predicted to score 4.43 less on the Vineland-II daily living skills domain score, on average, after controlling for differences in the variables as mentioned above. Additionally, the partial effect of diagnostic group was 6.96. This finding indicates that the HR-Neg group is associated with scoring 6.96 points higher on the Vineland-II daily living skills domain than the HR-ASD group, on average. The results of this multiple regression analysis, $F(8, 107) = 11.30, p < .001$, suggest that the empirical evidence supports the notion that for toddlers diagnosed with ASD, elevated sensory seeking scores are associated with lower daily living skills at 3 years of age in the population.

**Table 8**

*Daily Living Skills Outcome Results from Four Multiple Regression Models*

| | Sensory profiles | | | |
|---|---|---|---|---|
| | Covariates | Hypo model | Hyper model | Seeking model |
| Covariates | | | | |
| Gender | −2.32 (1.97) | −2.36 (1.88) | −2.66 (1.90) | −2.74 (1.82) |
| 12-month age | −0.59 (0.97) | −1.54 (1.36) | −1.71 (1.34) | −1.69 (1.30) |
| Income | 1.15* (0.51) | 0.93 (0.49) | 0.93 (0.49) | 0.85 (0.47) |
| Maternal ed. | −0.74 (1.31) | −1.09 (1.26) | −1.03 (1.26) | −1.20 (1.22) |
| Elapsed time | 0.26 (0.54) | 0.02 (0.53) | 0.05 (0.53) | 0.07 (0.51) |
| Mullen-ELC | 0.27*** (0.05) | 0.20*** (0.05) | 0.20*** (0.05) | 0.19*** (0.05) |
| Sensory score | | | | |
| Hypo | | −2.10 (1.98) | | |
| Hyper | | | −2.56 (2.53) | |
| Seeking | | | | **−4.43** (1.52)** |
| Group | | **7.10** (2.34)** | **7.06** (2.36)** | **6.96** (2.21)** |
| Intercept | 68.19** (22.88) | 92.06*** (25.97) | 94.97*** (26.33) | 100.51*** (25.31) |
| $R^2$ | 0.35 | 0.42 | 0.42 | 0.46 |
| $\Delta R^2$ | | 0.07 | 0.07 | 0.11 |
| *F* statistic | **9.64***** (df = 6; 110) | **9.71***** (df = 8; 107) | **9.69***** (df = 8; 107) | **11.30***** (df = 8; 107) |

*Note.* Model parameters are displayed with standard errors in parentheses. The covariates model is the baseline model. Hyper-, hypo-responsivity, and sensory seeking were each used as the focal predictor variable in three separate models. Income is family income. Maternal ed. is maternal education. Elapsed time is the number of months between the 12-month visit and the 36-month visit. The Mullen-ELC is the Early Learning Composite from the Mullen Scales of Early Learning (MSEL). The three sensory seeking models were computed using the Sensory Experiences Questionnaire (SEQ 2.1).

* < .05. ** < .01. *** < .001.

On the whole, multiple linear regression model results indicated that sensory seeking and hyperresponsivity at 12 months of age were statistically significant predictors of later socialization, motor skills, and daily living skills outcomes for three-year-olds at-risk for developing ASD. There was an effect of group for all explanatory models except for the model using sensory seeking to explain motor skills variation.

## Discussion

This study sought to investigate the relationship between sensory responsivity and adaptive behavior outcomes for toddlers at familial risk for developing ASD, to provide insight into how early sensory profiles relate to later adaptive behaviors. This study had two aims (1) to identify if sensory responsivity explains variance in later adaptive behavior domain outcomes in high-risk toddlers diagnosed with ASD; and (2) to determine if findings with a younger and differently ascertained sample would corroborate findings from Williams et al. (2018).

Regarding the first aim, this study found sensory responsivity to explain variance in some later adaptive behavior domain outcomes in toddlers at risk for ASD. Sensory seeking negatively predicted adaptive behavior domain outcomes for socialization, motor skills, and daily living skills. Additionally, socialization was explained, in part, by hyperresponsivity. It is interesting to note that sensory seeking profiles seem to be the most predictive of the sensory profiles included in the current study. Nevertheless, sensory seeking is the one sensory profile in which there is no group difference between the HR-ASD group and the HR-Neg group. These seemingly discrepant results suggest that sensory seeking profiles may be characteristic of a broader autism phenotype and not unique to participants diagnosed with ASD.

**Comparing results between the present study and Williams et al. (2018)**

The present study did not strictly replicate all methods and procedures from the Williams et al. (2018) study due to differences in age groups, available data, and the overall aims and scope of the studies. Williams and colleagues looked at the overall composite score for adaptive behavior, whereas that was not investigated in this study as the present focus was predictive patterns between sensory profiles and adaptive behavior domains at the domain-specific level. This study included motor skills as an adaptive behavior domain, whereas Williams and colleagues did not. Williams and colleagues considered service use as a covariate, but IBIS did not have sufficient data on service use. Williams and colleagues also had a group of developmentally delayed (DD) participants as a comparison group, whereas the current study had the HR-Neg participants as a comparison group. Finally, Williams and colleagues used two sensory parent-report measures and two sensory observational measures whereas the current study implemented one parent-report measure to gauge each participant's sensory responsivity.

In regards to the second aim, there was some overlap between the current study findings and Williams et al. (2018). Williams and colleagues found a significant negative interaction between group (ASD and DD) and sensory response pattern scores for several models. Specifically, they found that hyporesponsivity explained variance in daily living skills, and sensory seeking explained variance in socialization, communication, and daily living skills. However, comparison groups between studies were different. The current study had a comparison group of high-risk siblings who did not receive an ASD diagnosis, whereas the Williams study had a comparison group of children with DD. Given that the comparison group differed, it was not surprising when interaction effects did not replicate. The current study fit models, including an interaction effect between sensory responsivity and group, but did not find this to contribute meaningfully to any model. The present results suggest that although there are group differences in adaptive behavior domains, the relationship between early sensory response patterns and later adaptive function does not depend on the diagnostic outcome for high-risk toddlers. This finding is not unexpected, given the heritability of traits associated with autism (Constantino, 2018).

Consideration of findings from the present study and Williams et al. (2018) suggests that high sensory seeking profiles may explain variation in later adaptive behavior development. For some adaptive behavior domains, the impact of high sensory profiles is evident in toddlerhood; however, for other adaptive behavior domains, effects are not noticeable until childhood. Both the present study and Williams and colleagues found that parent-reported sensory seeking profiles explained variance in socialization and daily living skills, indicating that the relationship between sensory seeking and these adaptive behavior domains is evident as early as toddlerhood. Williams and colleagues also found that parent-reported sensory seeking profiles explained variance in communication; however, that finding was not extended in the present study, indicating that effects of elevated sensory seeking behavior on communication may not be evident until childhood.

Williams et al. (2018) reported a significant negative main effect of parent-reported hyporesponsivity on socialization scores; the present study did not extend this finding. These disparate results suggest that the effects of elevated hyporesponsivity on socialization may not be evident in toddlerhood but manifest in early childhood as the effects of elevated hyporesponsivity have had more time to impact socialization development. They also found a significant negative main effect of parent-reported hyperresponsivity in the model predicting daily living skills. The present study did not extend this finding, nor did it expect to. Overall sensory seeking seems to be a consequential predictor for later socialization and daily living skills outcomes in both toddlers and elementary-school-aged children with ASD.

**Contributions of the present study**

This study adds a longitudinal perspective on the relationship between aspects of sensory responsivity and adaptive behavior. Other longitudinal studies conducted on this relationship yielded mixed results (McCormick et al., 2016; Williams et al. 2018). McCormick and colleagues used an overall adaptive behavior score as their outcome, whereas Williams and colleagues used the overall score in addition to adaptive behavior domain scores. McCormick and colleagues did not find a longitudinal relationship between sensory responsivity and overall adaptive behavior. However, Williams and colleagues found relationships between sensory responsivity and overall adaptive behavior in addition to specific adaptive behavior domains. The nature of these discrepant findings may be due to the importance of adaptive behavior domains. Using adaptive behavior domain scores may be more informative than an overall adaptive behavior score. The current study used adaptive behavior domain scores and, similar to Williams and colleagues, found associations between sensory profiles and domains of adaptive behavior. Furthermore, identifying specific sensory profiles that explain variation in specific adaptive behavior domains may provide more relevant information to guide targeted intervention.

Given that the present study found that sensory seeking negatively predicted outcomes in socialization and daily living skills, it seems consistent with the theory that engaging in sensory seeking behaviors precluded participation in social opportunities and daily life activities (McCormick et al., 2016; Tomchek & Dunn, 2007; Watson et al., 2011; Williams et al., 2018). Similarly, the finding that elevated hyperresponsivity negatively predicted socialization supports the explanation that acute awareness of one's sensory surroundings may cause individuals to be overwhelmed or distracted by their sensory environment, interfering with active participation in social opportunities (Williams et al., 2018).

One puzzling finding was inconsistency with conjectures about the relationship between sensory responsivity and motor skills. I had hypothesized that there would be a positive relationship between sensory seeking and motor skills given support for this relationship (Jasmin et al., 2009; Tomchek & Dunn, 2007); on the contrary, the study found a negative main effect of early sensory seeking behaviors on motor skill outcomes. I expected higher sensory seeking scores to predict motor skill development in three-year-olds because of an ecological theory of motor development. This theory supposes that an increased interest in sensory aspects of the environment would motivate the exploration of the environment and facilitate the development of motor skills (Needham et al., 2002; Thelen et al., 1991). As the present study instead found a negative relationship, an alternative explanation is that interest in sensory engagement may be restrictive and repetitive. If sensory engagement becomes an RRB, then toddlers may explore their environment less than peers as they are focused on restrictive sensory interests instead of exploring their environment in a multiplicity of ways. This incidental finding is consistent with the theory that sensory seeking behaviors would limit a child's participation in sensory experiences, which would negatively influence their active exploration of the environment, restricting motor development, and access to learning opportunities (O'Donnell et al., 2012).

Cross-sectional research has provided evidence for a link between atypical sensory responsivity and deficits in adaptive behavior domain outcomes for children with ASD (Baker et al., 2008; Jasmin et al., 2009; Lane et al., 2010; Tomchek & Dunn, 2007). The present study and Williams et al. (2018) found further support for the relationship between sensory responsivity and adaptive behavior using longitudinal data. There are now several pieces of evidence to support that sensory responsivity may impact the development of adaptive behaviors in young children at risk for developing ASD, particularly regarding children engaging in more sensory seeking behavior than peers.

**The role of sensory seeking behavior in the development of autism**

Despite the extant research, the causal link between sensory responsivity and adaptive behavior is still up for speculation. Findings from this study implicate sensory seeking to be more predictive of later adaptive behavior development than hyper-, or hypo-responsivity. One way in which the sensory seeking profile stands apart is that it may be restrictive and repetitive. RRB is a core feature of ASD, and atypical sensory responsivity is considered a diagnostic feature of ASD within this domain. Interestingly, as sensory seeking represents a core feature of ASD, at the same time, this study found that the relation between elevated sensory seeking and later adaptive function was not unique to the ASD group. In other words, this study did not observe a group difference in sensory seeking scores between the HR-ASD group and the HR-Neg group while also identifying that an elevated sensory seeking profile score may interfere with the development of socialization, motor skills, and daily living skills regardless of diagnostic outcome.

Given that this study did not find differences in sensory seeking scores, yet sensory seeking scores predicted variance in adaptive behavior domains in which there are group differences suggests that sensory seeking is a broader autism phenotype trait. Further support for this notion comes from Williams et al. (2018). Williams and colleagues found significant group interactions between the ASD and DD group for models using sensory seeking to predict outcomes for each adaptive behavior domain score and overall adaptive behavior score. They found that higher sensory seeking scores negatively affected the ASD group for all adaptive behavior outcome variables and had a positive effect on all adaptive behavior outcome variables for the DD group. These discrepant findings suggest that toddlers at-risk for ASD, on average, display more sensory seeking behaviors, yet this may only pose downstream developmental effects for toddlers who go on to develop ASD.

**Future directions**

One possible explanation for the findings related to sensory seeking is that some but not all elevated sensory seeking scores are restrictive and repetitive. In other words, an elevated sensory seeking score could be just as typical for participants in the HR-Neg group as the HR-ASD group but manifest in quite different behaviors. For example, a toddler diagnosed with ASD may have an elevated sensory seeking score due to restrictive, repetitive interests in limited sensory stimuli. In contrast, an individual in the HR-Neg group may have an elevated sensory seeking score due to some level of sensory exploration throughout most of the items on the sensory questionnaire. It would be interesting to be able to differentiate between sensory seeking individuals with a broad range of sensory interests compared to those with restrictive and repetitive interests, in comparison to diagnostic status. Further work could include a variable to control for restrictive, repetitive interests.

A second path to explore sensory seeking as characteristic of the broader autism phenotype could be to include more participant groups. Ideally, a study would include the following participant groups: HR-ASD, HR-Neg, and additional control group. Including a group of neurotypical peers would enable researchers to investigate broader autism phenotype traits. Williams et al. (2018) included a DD control group and found group interactions between sensory responsivity profiles and diagnostic group (ASD or DD). Further exploration in differences between neurodevelopmental disorders such as fragile

X syndrome and ASD may indicate whether high sensory seeking profiles are unique to the broader autism phenotype or extend to other groups.

Alternatively, underlying neural processes may simultaneously account for elevated sensory response pattern scores and lower adaptive behavior domain outcome scores. There may be underlying atypical neurodevelopment that explain differences in sensory response patterns and lower outcomes for adaptive behavior development. Further work could leverage brain imaging data to explore this potential explanation. Alternatively, there may be neurological differences that mediate or moderate the observed relations between sensory responsivity and later adaptive behavior function. Notably, for children later diagnosed with ASD, adaptive behavior deficits may become compounded over time due to increased engagement in sensory responsive behaviors that could interfere with experience-dependent neurodevelopment.

An additional future direction could be a longitudinal study with more data points collected over a more extended period. The IBIS Network is currently collecting follow-up data on participants now that they have reached elementary school age. It would be interesting to investigate whether and how the relations observed in toddlerhood extend into school age, as well as the opportunity to replicate Williams et al. (2018) more directly in a similar age group. Williams and colleagues theorized that heightened sensory response pattern scores predicted lower adaptive behaviors because heightened sensory responsivity caused individuals to miss learning opportunities. Longitudinal data extending from infancy to early childhood could test this theory.

A final yet pertinent future direction in clarifying our understanding of the relationship between sensory response patterns and later developmental outcomes for toddlers with ASD is to utilize or develop a direct measure of sensory responsivity. The use of such measures, which may not yet be available, may more accurately show the impact of sensory responsivity on development in infants and toddlers with ASD. Furthermore, refined measures could explain how people with autism respond to the sensory world around them. Having alternative measures is essential because sensory responsivity is a core feature of ASD, but also because present study findings provide evidence to suggest that there may be adverse, cascading developmental outcomes resulting from atypical sensory responsivity.

**Limitations**

One apparent limitation of the present work is an inability to conclude whether an elevated sensory seeking response pattern is a trait unique to the broader autism phenotype. The sample was limited to toddlers at high-risk for ASD and did not include a control group. Without a control group, there may be confounding variables associated with ASD-related constructs. A study, including an additional low-risk control group, could shed insight into whether there is further support for exhibiting more sensory seeking behaviors as characteristic of a broader autism phenotype. However, measurement tools need to be carefully considered in such a study to strive for reliability and validity across participant groups.

A second limitation of this paper stems from the possibility of ASD-related confounding variables. In the model, restricted and repetitive behavior was not accounted for as it seemed to be an extraneous variable in a model using sensory responsivity to predict adaptive behavior outcomes. Furthermore, it may be inappropriate to include sensory response pattern scores and a measure of RRB in the same model as atypical sensory responsivity is considered an aspect of RRB in the DSM-5. An RRB variable may be too related to sensory profile and cause collinearity issues in the model.

A third limitation of this study is that the models only included sensory responsivity scores collected during one data collection wave and adaptive behavior scores collected during another data collection wave. Longitudinal mixed-effects models incorporating data collected at more points during development would provide richer information than examining sensory responsivity at one time point and adaptive behavior at one later time point.

A fourth limitation of this study stems from the nature of replicating and extending methods. For the sake of comparison, the present study computed a series of multiple regression models. Using a more modern theoretical framework such as the method of multiple working hypotheses (Elliott & Brook, 2007) may provide a more accurate picture of the relationship between sensory responsivity and adaptive behavior development in young children with ASD.

A final limitation of this study is the implementation of a parent-report measure to quantify sensory responsivity. Although there are benefits to parent-report measures, particularly for participants with limited language skills such as toddlers, perhaps indirect measures do not adequately capture sensory responsivity. Williams et al. (2018) used a combination of parent-report measures and observational assessments to evaluate sensory responsivity for their participants. At times they found discrepant outcomes between the parent-report measures and the observational assessments of the same sensory response pattern predicting the same adaptive behavior domain. As both parent report and observation have their limitations, more objective approaches to quantify sensory responsivity are needed.

## Implications

These findings have important implications for intervention. When coaching parents to create opportunities for their child, interventionists can help parents recognize when sensory-seeking behaviors preclude the child’s engagement with parent-directed opportunities. Alternatively, parents could scaffold the guided opportunities by instructing parents to reduce potential sensory distractions from the toddler’s environment when engaging in intervention activities.

## Conclusion

The present study used sensory responsivity profiles of 12-month olds at high-risk for ASD to explain variation in later adaptive behavior domains. The findings indicate that sensory seeking profiles are associated with adaptive behavior outcomes in socialization, motor skills, and daily living skills in three-year-olds with ASD. In that, toddlers engaging in more sensory seeking behavior are predicted to have lower adaptive behavior domain outcomes at three years of age. This study adds a longitudinal perspective to our understanding of sensory responsivity and adaptive behavior development in the first few years of life, indicating that this relationship is evident early in development. The findings also implicate an elevated sensory seeking response pattern as possibly characteristic of the broader autism phenotype, warranting further examination in future studies.

# Bibliography


Adolph, K. E., Tamis-LeMonda, C. S., & Karasik, L. B. (2010). Cinderella indeed – a commentary on Iverson's 'Developing language in a developing body: The relationship between motor development and language development' *. *Journal of Child Language*, *37*(2), 269–273. : https://doi-org.ezp1.lib.umn.edu/10.1017/S030500090999047X

American Occupational Therapy Association. (1994). Uniform terminology for occupational therapy—third edition. *American Journal of Occupational Therapy*, *48*(11), 1047–1054. https://doi.org/10.5014/ajot.48.11.1047

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

Ausderau, K. K., Furlong, M., Sideris, J., Bulluck, J., Little, L. M., Watson, L. R., Boyd, B. A., Belger, A., Dickie, V. A., & Baranek, G. T. (2014). Sensory subtypes in children with autism spectrum disorder: Latent profile transition analysis using a national survey of sensory features. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *55*(8), 935–944. https://doi.org/10.1111/jcpp.12219

Ausderau, K. K., Sideris, J., Little, L. M., Furlong, M., Bulluck, J. C., & Baranek, G. T. (2016). Sensory subtypes and associated outcomes in children with autism spectrum disorders. *Autism Research*, *9*(12), 1316–1327. https://doi.org/10.1002/aur.1626

Ausderau, K., Sideris, J., Furlong, M., Little, L. M., Bulluck, J., & Baranek, G. T. (2014). National survey of sensory features in children with ASD: Factor structure of the sensory experience questionnaire (3.0). *Journal of Autism and Developmental Disorders*, *44*(4), 915–925. https://doi.org/10.1007/s10803-013-1945-1

Baghdadli, A., Assouline, B., Sonié, S., Pernon, E., Darrou, C., Michelon, C., Picot, M.-C., Aussilloux, C., & Pry, R. (2012). Developmental trajectories of adaptive behaviors from early childhood to adolescence in a cohort of 152 children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *42*(7), 1314–1325. https://doi.org/10.1007/s10803-011-1357-z

Baker, A. E. Z., Lane, A., Angley, M. T., & Young, R. L. (2008). The relationship between sensory processing patterns and behavioural responsiveness in autistic disorder: A pilot study. *Journal of Autism and Developmental Disorders*, *38*(5), 867–875. https://doi.org/10.1007/s10803-007-0459-0

Baranek, G., Lorenzi, J., & Freuler, A. (2013). *Sensory Experiences Questionnaire (SEQ) Manual (Revised)*.

Baranek, Grace T., Boyd, B. A., Poe, M. D., David, F. J., & Watson, L. R. (2007). Hyperresponsive sensory patterns in young children with autism, developmental delay, and typical development. *American Journal on Mental Retardation*, *112*(4), 233–245. https://doi.org/10.1352/0895-8017(2007)112[233:HSPIYC]2.0.CO;2

Baranek, Grace T., David, F. J., Poe, M. D., Stone, W. L., & Watson, L. R. (2006). Sensory Experiences Questionnaire: Discriminating sensory features in young children with autism, developmental delays, and typical development. *Journal of*

*Child Psychology and Psychiatry*, *47*(6), 591–601. https://doi.org/10.1111/j.1469-7610.2005.01546.x

Baranek, Grace T., Watson, L. R., Boyd, B. A., Poe, M. D., David, F. J., & McGuire, L. (2013). Hyporesponsiveness to social and nonsocial sensory stimuli in children with autism, children with developmental delays, and typically developing children. *Development and Psychopathology*, *25*(2), 307–320. https://doi.org/10.1017/S0954579412001071

Barney, C. C., Tervo, R., Wilcox, G. L., & Symons, F. J. (2017). A case-controlled investigation of tactile reactivity in young children with and without global developmental delay. *American Journal on Intellectual and Developmental Disabilities*, *122*(5), 409–421. https://doi.org/10.1352/1944-7558-122.5.409

Becerra-Culqui, T. A., Lynch, F. L., Owen-Smith, A. A., Spitzer, J., & Croen, L. A. (2018). Parental first concerns and timing of autism spectrum disorder diagnosis. *Journal of Autism and Developmental Disorders*, *48*(10), 3367–3376. https://doi.org/10.1007/s10803-018-3598-6

Ben-Sasson, Ayelet, Hen, L., Fluss, R., Cermak, S. A., Engel-Yeger, B., & Gal, E. (2009). A meta-analysis of sensory modulation symptoms in individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *39*(1), 1–11. https://doi.org/10.1007/s10803-008-0593-3

Bodfish, J. W., Symons, F. J., Parker, D. E., & Lewis, M. H. (2000). Varieties of repetitive behavior in autism: Comparisons to mental retardation. *Journal of Autism and Developmental Disorders*, *30*(3), 237–243. https://doi.org/10.1023/A:1005596502855

Boyd, B. A., Baranek, G. T., Sideris, J., Poe, M. D., Watson, L. R., Patten, E., & Miller, H. (2010). Sensory features and repetitive behaviors in children with autism and developmental delays. *Autism Research*, *3*(2), 78–87. https://doi.org/10.1002/aur.124

Brian, J., Bryson, S. E., Smith, I. M., Roberts, W., Roncadin, C., Szatmari, P., & Zwaigenbaum, L. (2016). Stability and change in autism spectrum disorder diagnosis from age 3 to middle childhood in a high-risk sibling cohort. *Autism*, *20*(7), 888–892. https://doi.org/10.1177/1362361315614979

Carter, A. S., Volkmar, F. R., Sparrow, S. S., Wang, J.-J., Lord, C., Dawson, G., Fombonne, E., Loveland, K., Mesibov, G., & Schopler, E. (1998). The vineland adaptive behavior scales: Supplementary norms for individuals with autism. *Journal of Autism and Developmental Disorders*, *28*(4), 287–302. https://doi.org/10.1023/A:1026056518470

Cascio, C. J., Woynaroski, T., Baranek, G. T., & Wallace, M. T. (2016). Toward an interdisciplinary approach to understanding sensory function in autism spectrum disorder. *Autism Research*, *9*(9), 920–925. https://doi.org/10.1002/aur.1612

Constantino, J. N. (2018). Deconstructing autism: From unitary syndrome to contributory developmental endophenotypes. *International Review of Psychiatry*, *30*(1), 18–24. https://doi.org/10.1080/09540261.2018.1433133

Dellapiazza, F., Michelon, C., Oreve, M.-J., Robel, L., Schoenberger, M., Chatel, C., Vesperini, S., Maffre, T., Schmidt, R., Blanc, N., Vernhet, C., Picot, M.-C., Baghdadli, A., Baghdadli, A., Chabaux, C., Chatel, C., Cohen, D., Damville, E., Geoffray, M.-M., … ELENA study group. (2019). The impact of atypical sensory processing on adaptive functioning and maladaptive behaviors in autism spectrum disorder during childhood: Results from the ELENA cohort. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-019-03970-w

Dellapiazza, F., Vernhet, C., Blanc, N., Miot, S., Schmidt, R., & Baghdadli, A. (2018). Links between sensory processing, adaptive behaviours, and attention in children with autism spectrum disorder: A systematic review. *Psychiatry Research*, *270*, 78–88. https://doi.org/10.1016/j.psychres.2018.09.023

Dimian, A. F., Botteron, K. N., Dager, S. R., Elison, J. T., Estes, A. M., Pruett, J. R., Schultz, R. T., Zwaigenbaum, L., Piven, J., Wolff, J. J., & The IBIS Network. (2017). Potential risk factors for the development of self-injurious behavior among infants at risk for autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *47*(5), 1403–1415. https://doi.org/10.1007/s10803-017-3057-9

Elison, J. T., Paterson, S. J., Wolff, J. J., Reznick, J. S., Sasson, N. J., Gu, H., Botteron, K. N., Dager, S. R., Estes, A. M., Evans, A. C., Gerig, G., Hazlett, H. C., Schultz, R. T., Styner, M., Zwaigenbaum, L., & Piven, J. (2013). White matter microstructure and atypical visual orienting in 7-month-olds at risk for autism. *American Journal of Psychiatry*, *170*(8), 899–908. https://doi.org/10.1176/appi.ajp.2012.12091150

Esler, A. N., Bal, V. H., Guthrie, W., Wetherby, A., Weismer, S. E., & Lord, C. (2015). The autism diagnostic observation schedule, toddler module: Standardized severity scores. *Journal of Autism and Developmental Disorders*, *45*(9), 2704–2720. https://doi.org/10.1007/s10803-015-2432-7

Feliciano, P., Zhou, X., Astrovskaya, I., Turner, T. N., Wang, T., Brueggeman, L., Barnard, R., Hsieh, A., Snyder, L. G., Muzny, D. M., Sabo, A., Gibbs, R. A., Eichler, E. E., O'Roak, B. J., Michaelson, J. J., Volfovsky, N., Shen, Y., & Chung, W. K. (2019). Exome sequencing of 457 autism families recruited online provides evidence for autism risk genes. *Npj Genomic Medicine*, *4*(1), 1–14. https://doi.org/10.1038/s41525-019-0093-8

Fisch, G. S., Simensen, R. J., & Schroer, R. J. (2002). Longitudinal changes in cognitive and adaptive behavior scores in children and adolescents with the fragile X mutation or autism. *Journal of Autism and Developmental Disorders*, *32*(2), 107–114. https://doi.org/10.1023/A:1014888505185

Freuler, A., Baranek, G. T., Watson, L. R., Boyd, B. A., & Bulluck, J. C. (2012). Precursors and trajectories of sensory features: Qualitative analysis of infant home videos. *American Journal of Occupational Therapy*, *66*(5), e81–e84. https://doi.org/10.5014/ajot.2012.004465

Gibson, E. J. (2000). Perceptual learning in development: Some basic concepts. *Ecological Psychology*, *12*(4), 295–302. https://doi.org/10.1207/S15326969ECO1204_04

Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development*. Oxford University Press.

Gotham, K., Pickles, A., & Lord, C. (2009). Standardizing ADOS scores for a measure of severity in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *39*(5), 693–705. https://doi.org/10.1007/s10803-008-0674-3

Green, S. A., Ben-Sasson, A., Soto, T. W., & Carter, A. S. (2012). Anxiety and sensory over-responsivity in toddlers with autism spectrum disorders: bidirectional effects across time. *Journal of Autism and Developmental Disorders*, *42*(6), 1112–1119. https://doi.org/10.1007/s10803-011-1361-3

Guthrie, W., Swineford, L. B., Nottke, C., & Wetherby, A. M. (2013). Early diagnosis of autism spectrum disorder: Stability and change in clinical diagnosis and symptom presentation. *Journal of Child Psychology and Psychiatry*, *54*(5), 582–590. https://doi.org/10.1111/jcpp.12008

Iverson, J. (2010). Developing language in a developing body: The relationship between motor development and language development. *Journal of Child Language*, *37*(2), 229–61.

Iverson, J. M., Shic, F., Wall, C. A., Chawarska, K., Curtin, S., Estes, A., Gardner, J. M., Hutman, T., Landa, R. J., Levin, A. R., Libertus, K., Messinger, D. S., Nelson, C. A., Ozonoff, S., Sacrey, L.-A. R., Sheperd, K., Stone, W. L., Tager-Flusberg, H. B., Wolff, J. J., … Young, G. S. (2019). Early motor abilities in infants at heightened versus low risk for ASD: A Baby Siblings Research Consortium (BSRC) study. *Journal of Abnormal Psychology*, *128*(1), 69–80. https://doi.org/10.1037/abn0000390

Jasmin, E., Couture, M., McKinley, P., Reid, G., Fombonne, E., & Gisel, E. (2009). Sensori-motor and daily living skills of preschool children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *39*(2), 231–241. https://doi.org/10.1007/s10803-008-0617-z

Johnson, M. H. (2011). Interactive specialization: A domain-general framework for human functional brain development? *Developmental Cognitive Neuroscience*, *1*(1), 7–21. https://doi.org/10.1016/j.dcn.2010.07.003

Kern, J. K. (2002). The possible role of the cerebellum in autism/PDD: Disruption of a multisensory feedback loop. *Medical Hypotheses*, *59*(3), 255–260. https://doi.org/10.1016/S0306-9877(02)00212-8

Kern, Janet K., Trivedi, M. H., Garver, C. R., Grannemann, B. D., Andrews, A. A., Savla, J. S., Johnson, D. G., Mehta, J. A., & Schroeder, J. L. (2006). The pattern of sensory processing abnormalities in autism. *Autism*, *10*(5), 480–494. https://doi.org/10.1177/1362361306066564

Kogan, M. D., Vladutiu, C. J., Schieve, L. A., Ghandour, R. M., Blumberg, S. J., Zablotsky, B., Perrin, J. M., Shattuck, P., Kuhlthau, K. A., Harwood, R. L., & Lu, M. C. (2018). The prevalence of parent-reported autism spectrum disorder among US children. *Pediatrics*, *142*(6). https://doi.org/10.1542/peds.2017-4161

Kuhn, M., Jackson, S., & Cimentada, J. (2020). *corrr: Correlations in R. R package version 0.4.1*. https://CRAN.R-project.org/package=corrr

Lane, A. E., Young, R. L., Baker, A. E. Z., & Angley, M. T. (2010). Sensory processing subtypes in autism: Association with adaptive behavior. *Journal of Autism and*

*Developmental Disorders*, *40*(1), 112–122. https://doi.org/10.1007/s10803-009-0840-2

Leekam, S. R., Nieto, C., Libby, S. J., Wing, L., & Gould, J. (2007). Describing the sensory abnormalities of children and adults with autism. *Journal of Autism and Developmental Disorders*, *37*(5), 894–910. https://doi.org/10.1007/s10803-006-0218-7

Liss, M., Saulnier, C., Fein, D., & Kinsbourne, M. (2006). Sensory and attention abnormalities in autistic spectrum disorders. *Autism*, *10*(2), 155–172. https://doi.org/10.1177/1362361306062021

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. https://doi.org/10.5014/ajot.2011.000844

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., Pickles, A., & Rutter, M. (2000). The autism diagnostic observation schedule—generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders*, *30*(3), 205–223. https://doi.org/10.1023/A:1005592401947

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism diagnostic interview-revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*, *24*(5), 659–685. https://doi.org/10.1007/BF02172145

McCormick, C., Hepburn, S., Young, G. S., & Rogers, S. J. (2016). Sensory symptoms in children with autism spectrum disorder, other developmental disorders and typical development: A longitudinal study. *Autism*, *20*(5), 572–579. https://doi.org/10.1177/1362361315599755

McIntosh, D. N., Miller, L. J., Shyu, V., & Hagerman, R. J. (1999). Sensory-modulation disruption, electrodermal responses, and functional behaviors. *Developmental Medicine & Child Neurology*, *41*(9), 608–615. https://doi.org/10.1111/j.1469-8749.1999.tb00664.x

Miller, L. J., McIntosh, D. N., McGrath, J., Shyu, V., Lampe, M., Taylor, A. K., Tassone, F., Neitzel, K., Stackhouse, T., & Hagerman, R. J. (1999). Electrodermal responses to sensory stimuli in individuals with fragile X syndrome: A preliminary report. *American Journal of Medical Genetics*, *83*(4), 268–279. https://doi.org/10.1002/(SICI)1096-8628(19990402)83:4<268::AID-AJMG7>3.0.CO;2-K

Mullen, E. M. (1995). *Mullen scales of early learning*. Circle Pines, MN: AGS Publishing.

Needham, A., Barrett, T., & Peterman, K. (2002). A pick-me-up for infants' exploratory skills: Early simulated experiences reaching for objects using 'sticky mittens' enhances young infants' object exploration skills. *Infant Behavior and Development*, *25*(3), 279–295. https://doi.org/10.1016/S0163-6383(02)00097-8

O'Donnell, S., Deitz, J., Kartin, D., Nalty, T., & Dawson, G. (2012). Sensory processing, problem behavior, adaptive behavior, and cognition in preschool children with autism spectrum disorders. *American Journal of Occupational Therapy*, *66*(5), 586–594. https://doi.org/10.5014/ajot.2012.004168

Ozonoff, S., Young, G. S., Belding, A., Hill, M., Hill, A., Hutman, T., Johnson, S., Miller, M., Rogers, S. J., Schwichtenberg, A. J., Steinfeld, M., & Iosif, A.-M. (2014). The broader autism phenotype in infancy: When does it emerge? *Journal of the American Academy of Child & Adolescent Psychiatry*, *53*(4), 398-407.e2. https://doi.org/10.1016/j.jaac.2013.12.020

Robinson, D., & Hayes, A. (2019). *broom: Convert statistical analysis objects into Tidy Tibbles*. R package version 0.5.2. https://CRAN.R-project.org/package=broom

Rogers, S. J., Hepburn, S., & Wehner, E. (2003). Parent reports of sensory symptoms in toddlers with autism and those with other developmental disorders. *Journal of Autism and Developmental Disorders*, *33*(6), 631–642. https://doi.org/10.1023/B:JADD.0000006000.38991.a7

Rogers, S. J., & Ozonoff, S. (2005). Annotation: What do we know about sensory dysfunction in autism? A critical review of the empirical evidence. *Journal of Child Psychology and Psychiatry*, *46*(12), 1255–1268. https://doi.org/10.1111/j.1469-7610.2005.01431.x

Sacrey, L., Zwaigenbaum, L., Bryson, S., Brian, J., Smith, I. M., Raza, S., Roberts, W., Szatmari, P., Vaillancourt, T., Roncadin, C., & Garon, N. (2019). Developmental trajectories of adaptive behavior in autism spectrum disorder: A high-risk sibling cohort. *Journal of Child Psychology and Psychiatry*, *60*(6), 697–706. https://doi.org/10.1111/jcpp.12985

Sandin, S., Lichtenstein, P., Kuja-Halkola, R., Larsson, H., Hultman, C. M., & Reichenberg, A. (2014). The familial risk of autism. *JAMA*, *311*(17), 1770–1777. https://doi.org/10.1001/jama.2014.4144

Sparrow, S., Balla, D., & Cicchetti, D. (2005). *Vineland adaptive behavior scales*, 2nd ed. Shoreview, MN: AGS Publishing.

Sparrow, S. S., Balla, D. A., Cicchetti, D. V., Harrison, P. L., & Doll, E. A. (1984). *Vineland adaptive behavior scales*.

Tassé, M. J., Schalock, R. L., Balboni, G., Bersani, H., Borthwick-Duffy, S. A., Spreat, S., Thissen, D., Widaman, K. F., & Zhang, D. (2012). The construct of adaptive behavior: Its conceptualization, measurement, and use in the field of intellectual disability. *American Journal on Intellectual and Developmental Disabilities*, *117*(4), 291–303. https://doi.org/10.1352/1944-7558-117.4.291

Thelen, E., Ulrich, B. D., & Wolff, P. H. (1991). Hidden skills: A dynamic systems analysis of treadmill stepping during the first year. *Monographs of the Society for Research in Child Development*, *56*(1), i–103. JSTOR. https://doi.org/10.2307/1166099

Tomchek, S. D., & Dunn, W. (2007). Sensory processing in children with and without autism: A comparative study using the short sensory profile. *American Journal of Occupational Therapy*, *61*(2), 190–200. https://doi.org/10.5014/ajot.61.2.190

Tomchek, S.D., Little, L. M., & Dunn, W. (2015). Sensory pattern contributions to developmental performance in children with autism spectrum disorder. *American*

*Journal of Occupational Therapy*, *69*(5), 6905185040p1. https://doi.org/10.5014/ajot.2015.018044

Vernazza-Martin, S., Martin, N., Vernazza, A., Lepellec-Muller, A., Rufo, M., Massion, J., & Assaiante, C. (2005). Goal directed locomotion and balance control in autistic children. *Journal of Autism and Developmental Disorders*, *35*(1), 91–102. https://doi.org/10.1007/s10803-004-1037-3

Watson, L. R., Patten, E., Baranek, G. T., Poe, M., Boyd, B. A., Freuler, A., & Lorenzi, J. (2011). Differential associations between sensory response patterns and language, social, and communication measures in children with autism or other developmental disabilities. *Journal of Speech, Language, and Hearing Research*, *54*(6), 1562–1576. https://doi.org/10.1044/1092-4388(2011/10-0029)

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis* (Second Ed., Use R!). Springer. https://ggplot2.tidyverse.org

Wickham, H., & Bryan, J. (2019). *readxl: Read Excel files*. *R package version 1.3.1*. https://CRAN.R-project.org/package=readxl

Wickham, H., François, R., Henry, L., & Müller, K. (2019). *dplyr: A grammar of data manipulation*. *R package version 0.8.3*. https://CRAN.R-project.org/package=dplyr

Williams, K. L., Kirby, A. V., Watson, L. R., Sideris, J., Bulluck, J., & Baranek, G. T. (2018). Sensory features as predictors of adaptive behaviors: A comparative longitudinal study of children with autism spectrum disorder and other developmental disabilities. *Research in Developmental Disabilities*, *81*, 103–112. https://doi.org/10.1016/j.ridd.2018.07.002

Wolff, J. J., Dimian, A. F., Botteron, K. N., Dager, S. R., Elison, J. T., Estes, A. M., Hazlett, H. C., Schultz, R. T., Zwaigenbaum, L., & Piven, J. (2019). A longitudinal study of parent-reported sensory responsiveness in toddlers at-risk for autism. *Journal of Child Psychology and Psychiatry*, *60*(3), 314–324. https://doi.org/10.1111/jcpp.12978

Wolff, J. J., Swanson, M. R., Elison, J. T., Gerig, G., Pruett, J. R., Styner, M. A., Vachet, C., Botteron, K. N., Dager, S. R., Estes, A. M., Hazlett, H. C., Schultz, R. T., Shen, M. D., Zwaigenbaum, L., Piven, J., Piven, J., Hazlett, H. C., Dager, S., Estes, A., … The IBIS Network. (2017). Neural circuitry at age 6 months associated with later repetitive behavior and sensory responsiveness in autism. *Molecular Autism*, *8*(1), 8. https://doi.org/10.1186/s13229-017-0126-z

Zieffler, A. (2019). *educate: Miscellaneous R functions for educational statistics* (R package version 0.0.1.1). https://github.com/zief0002/educate

Zwaigenbaum, L. (2005). The screening tool for autism in two year olds can identify children at risk of autism. *Evidence-Based Mental Health*, *8*(3), 69–69. https://doi.org/10.1136/ebmh.8.3.69

Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience*, *23*(2), 143–152. https://doi.org/10.1016/j.ijdevneu.2004.05.001