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Research Article

Joint Attention and Sensory-Regulatory Features at 13 and 22 Months as Predictors of Preschool Language and Social-Communication Outcomes

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Purpose: The purpose of this study was to understand how joint attention and sensory-regulatory features are related in early childhood and predict language and social-communication outcomes in preschool in order to build mechanistic theories that can inform early intervention directed at improving these outcomes.
Method: Cross-lagged panel analysis models were used to examine the association between joint attention and sensory-regulatory features at 13 and 22 months of age in children (n = 87) who were identified via community screening at 12 months as having a higher likelihood than the general population for being diagnosed with autism spectrum disorder.
Results: Significant concurrent correlations and predictive correlations were found between these constructs at 13 and 22 months. Joint attention skills at 13 months predicted both joint attention and sensory-regulatory features at 22 months. Distal language and social-communication outcomes at preschool age (n = 48) were best predicted by sensory-regulatory features at 22 months.
Conclusions: Both joint attention and sensory regulation are important factors in the first and second years of life for impacting later preschool language and social-communication outcomes in this sample. These findings may have implications for future early childhood intervention research for children at a higher likelihood for autism spectrum disorder.

Social communication is a core symptom domain in autism spectrum disorder (ASD; American Psychiatric Association, 2013). Early social-communication challenges in children with ASD, particularly in joint attention (JA), are foundational and have cascading effects on outcomes. For instance, early JA deficits are correlated with reduced duration, frequency, and quality of parent–child interactions (Laurent & Gorman, 2018; Morales et al., 2005; Siller et al., 2013). As children get older, social-communication deficits have been shown to negatively impact academic performance (Welsh et al., 2001) and affect social inclusion outcomes in adulthood including friendships and employment (Howlin et al., 2013). Sensory-regulatory differences in very early childhood, specifically hyporesponsiveness and sensory seeking behaviors, also have cascading effects on later childhood outcomes such as social and language skills (Baranek et al., 2013, 2018; Cascio et al., 2016; Watson et al., 2011). In both sibling samples (Damiano et al., 2018) and community samples (Baranek et al., 2018) of young children at a greater likelihood of ASD, elevated sensory seeking behaviors at the end of the second year of life significantly predicted later social-communication symptoms. These relationships were mediated by reduced social orienting (defined as hyporesponsiveness to social stimuli such as hearing one's name called) in both studies, indicating that a transactional relationship between these early sensory-regulatory and social communicative deficits contributes to later social-communication symptoms. The current study aimed to explore the relationship between JA and early sensory-regulatory features in children with a higher

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likelihood of ASD and examine how development of these pivotal skills affects preschool language and social-communication proficiency.

Behavioral risk markers of a later diagnosis of ASD, including social-communication and sensory-regulatory features, can be identified as early as 12 months of age by parent report (e.g., First Year Inventory; Reznick et al., 2007) and via observational measures (e.g., Autism Diagnostic Observation Schedule, Toddler Module; Luyster et al., 2009). Therefore, it may be feasible to address prodromal symptoms early in life and ameliorate the cascading effects of these deficits on language and social-communication outcomes. In this article, we extend the findings of Baranek et al. (2018) by examining the relationship between JA and sensory-regulatory features longitudinally in early childhood. Moreover, we add the preschool outcomes of receptive language, expressive language, and narrative retell skills to the social-communication symptom severity outcomes previously explored. These early associations may be critical to understanding developmental mechanisms, designing early interventions to improve later language and social-communication skills, and ultimately optimizing adult outcomes.

Language in Children With ASD

Much like social-communication deficits, language disorders in early childhood have long-term effects on outcomes, particularly for people with ASD. For example, children with ASD and comorbid language disorders have demonstrated poorer psychosocial outcomes in adulthood (e.g., less independence, greater likelihood of unemployment, more difficulty with social relationships) compared to children diagnosed with specific language impairment and pragmatic language impairment (Whitehouse et al., 2009). Neurocognitive research suggests that social-communication and language processes are two different, yet interacting, systems (Willems & Varley, 2010). Language is the understanding and use of structural aspects of communication, including what words mean (semantics), formulating word parts (morphology), putting words together into sentences (syntax), and assembling sounds into words for speaking, spelling, and reading (phonology; American Speech-Language-Hearing Association [ASHA] 2017b). Social communication is a broader construct that includes using language for different communicative functions (e.g., requesting, commenting) and other forms of communication (e.g., gestures, eye contact), altering language to fit the social context, using social cognitive skills (e.g., theory of mind, presupposition), sequencing events into narratives, and following the rules of conversation and social interaction (ASHA, 2017a, 2017c). There is a need to understand early factors predicting language and social-communication outcomes among young children with prodromal symptoms of ASD in order to build mechanistic theories that can inform early intervention directed at improving these outcomes.

Joint Attention

JA encompasses a set of behaviors such as eye gaze, pointing, and showing, which are implemented to include outside objects, people, and events during a communicative exchange (Carpenter et al., 1998; Charman, 2003). These exchanges allow a young child to associate language with referents (Tomasello & Farrar, 1986). In the development of children with ASD, JA deficits are known to be critical precursors of later social and language skills (Charman, 2003; Poon et al., 2012). Impairments in JA skills are one of the earliest symptoms of ASD (Werner & Dawson, 2005) and are thought to contribute to the poor language outcomes in ASD (e.g., 25%–30% of individuals with ASD do not develop functional language [Anderson et al., 2007; Norrelgen et al., 2014, Tager-Flusberg et al., 2005], and over 60% of children with ASD have co-occurring language disorders [Levy et al., 2010]). Based on a meta-analysis of nearly 4,000 children, half with ASD and half with typical development, Bottema-Beutel (2016) concluded that JA was more closely related to language outcomes in children with ASD than those with typical development. Bottema-Beutel theorized that this was because there is a threshold of JA skill acquisition that, once met, language outcomes are no longer tied to any variations in JA skills. This threshold is met in children with typical development and some with ASD, but development of language in many children with ASD remains dependent upon JA skills for an extended period of time.

Theoretical Foundations

According to the Parallel and Distributed Processing (PDP) model, JA involves parallel processing of self-referenced information and processing of another person's attention and behavior, as well as integration of the information about self and others with information about a mutually referenced object or event (Mundy & Jarrold, 2010). The PDP model posits that JA skills contribute to the neurocognitive foundation of social cognition, symbolic thought, and self-awareness, all of which are critical for effective information sharing during social interactions (Mundy & Jarrold, 2010). This model provides some support for the JA skills threshold hypothesized by Bottema-Beutel (2016). The PDP model also aligns with the cascading effects of theory of sensory-regulatory functions (Baranek et al., 2018; Cascio et al., 2016; Damiano et al., 2018) in that, at the same developmental time periods, JA skills and sensory-regulatory skills are hypothesized to be interacting and forming the foundation for multiple higher level social, language, and cognitive abilities. For example, the PDP model suggests that sensory perceptual and sensory motor skills are integral to forming knowledge of "self" and visual and attention skills form knowledge of "other." The integration of these skills allows a child to engage in parallel processing of their own attention with the attention of others, which is the basis of JA (Mundy & Jarrold, 2010). In this way, it is critical to understand how these two pivotal skill areas of JA and sensory regulation (SR) are associated longitudinally in early development. We will use the PDP model for this study, to examine how JA skills are associated with sensory-regulatory features at 13 and 22 months and how those early associations affect preschool language and social-communication outcomes.

Sensory-Regulatory Features in ASD

This study focuses on two early sensory-regulatory features: (a) Hyporesponsiveness is a lack of or delayed response to sensory stimuli (e.g., lack of response to a loud noise, mild or delayed response to pain), and (b) sensory seeking behaviors are defined as a craving for or a fascination with sensory stimuli in an intense and/or fixated manner (e.g., touching certain textures, staring at ceiling fans; Ausderau et al., 2014). Both of these behaviors are known from previous research to be associated with language and social-communication skills in children with ASD (Baranek et al., 2013; Watson et al., 2011). Watson et al. (2011) measured the sensory features, language, and social-communication skills of children diagnosed with ASD ($n = 72$; $M_{\text{age}} = 52$ months) and children with other developmental disorders. Hyporesponsiveness and sensory seeking behaviors had significant positive associations with social-communicative symptom severity and significant negative associations with language abilities in children with ASD (Watson et al., 2011).

One reason for these associations is that social interactions require flexible attention to, and integration of, multiple sources of sensory input (Dionne-Dostie et al., 2015). Baranek et al. (2001) proposed the *Optimal Engagement Band Model for Sensory Processing in Young Children with Autism* (see figure published in Baranek et al., 2001), which describes how sensory processing challenges, including hyper- and hyporesponsiveness to environmental stimuli in children with ASD, could restrict the band of optimal engagement for these children and therefore reduce the frequency and variety of the social experiences in which they learn. For instance, if a child is fixated on the glare or ripples on the surface of a swimming pool (sensory seeking behavior), thereby neglecting other social stimuli such as other children or nonsocial stimuli such as toys (hyporesponsive behavior), they may have a restricted experience of the swimming pool environment resulting in fewer opportunities to socialize or learn new language or motor skills compared to peers. Having a restricted optimal engagement band and threshold for social and nonsocial experiences in early childhood as compared to peers is theorized to have cascading long-term negative effects on social communication.

Two related behaviors that contribute to these associations between sensory-regulatory features and social-communication symptoms are attention disengagement (shifting attention from one stimulus to another) and attention orienting (attending to a new stimulus in the environment). Both hyporesponsive and sensory seeking behaviors are significantly associated with slower attention disengagement and decreased orienting in children with ASD, indicating that attentional control and sensory features may be intertwined (Sabatos-Devito et al., 2016). Children with hyporesponsive behaviors may be less sensitive to novel stimuli, which impact the speed and frequency of their attention disengagement, while children with sensory seeking behaviors may be so intensely engaged with a nonsocial aspect of their environment that they struggle to disengage with it and orient their attention to other stimuli ((Sabatos-Devito et al., 2016). In a sample of children at a higher likelihood for ASD, Baranek et al. (2018) documented that reduced attention disengagement at 13 months mediated the relationship between sensory seeking behaviors and social orienting at 22 months in infants at a higher likelihood for ASD. Further research is needed to disentangle the association between attention modulation and sensory-regulatory features in ASD. In this study, we will use the term *sensory-regulatory features* to refer to the high/low thresholds of stimulation that may result in hypo or hyper responses, with the caveat that attention orienting is an associated construct (e.g., hyporesponsiveness was measured with a series of attention orienting trials; see Method section) that may be particularly influential at the first time point of our analyses based on previous research.

Associations Between JA and SR

The relationship between JA and sensory-regulatory features has been previously explored by Baranek et al. (2013), who reported that hyporesponsiveness was significantly negatively correlated with JA skills in a sample of children with ASD and developmental delay (DD) and that this correlation was stronger in younger children. Moreover, they documented that, in children with ASD, hyporesponsive behavior was negatively related to expressive and receptive language (Baranek et al., 2013). These, as well as the associations found in Watson et al. (2011), were concurrent and in older children and did not offer information about the association between these constructs longitudinally or predictively. In 2018, Baranek and colleagues explored these constructs further and concluded that social orienting at 22 months of age mediated the association between sensory seeking behaviors at 22 months of age and social-communication symptom severity at 3–5 years old (Baranek et al., 2018). Though this is an important step in understanding the impact of early sensory seeking behaviors on social-communication symptoms, it presents some research gaps that this study aims to fill: (a) It did not examine the critical role of JA during this developmental period, (b) it did not model sensory-regulatory behaviors longitudinally, and (c) it did not look at outcomes other than ASD diagnostic aspects of social-communicative symptoms such as receptive language, expressive language, and narrative retell abilities. These outcomes may be more indicative of overall language and social communicative function.

In summary, the relationship between JA and sensory-regulatory features in early childhood is essential in the development of language and social-communicative competence in children with ASD (Mundy & Jarrold, 2010). However, no studies have examined these features longitudinally in the early development of children at a higher likelihood of being diagnosed with ASD. This study aimed to expand upon the existing literature on the relationship between JA and early sensory-regulatory features in children with a higher likelihood of ASD and examine how these pivotal skills affect later language and social-communication skills. The methods included analyses using extant data from a community sample of children who were identified at 12 months of age via screening as being at a higher likelihood for a diagnosis of ASD. Specifically, we aimed to examine the following research questions:

1. What are the concurrent and predictive correlations between JA and sensory-regulatory features at 13 and 22 months of age in a community sample of children identified at 12 months as at a higher likelihood for ASD?
2. To what extent do JA and sensory-regulatory features at 13 and 22 months of age predict general preschool language outcomes in a community sample of children identified at 12 months as at a higher likelihood for ASD?
3. To what extent do JA and sensory-regulatory features in children at risk for ASD at 13 and 22 months of age predict aspects of preschool social-communication competence, including narrative retell, in a community sample of children identified at 12 months as at a higher likelihood for ASD?

Based on previous literature on concurrent (e.g., Baranek et al., 2013; Watson et al., 2011) relationships between these constructs and evidence supporting cascading effects on social-communication outcomes in children with ASD (e.g., Baranek et al., 2018; Bottema-Beutel, 2016; Mundy & Jarrold, 2010), it was hypothesized that there would be significant concurrent and predictive correlations between early JA and sensory-regulatory feature variables at 13 and 22 months in cross-lagged panel models. Moreover, we anticipated that JA and sensory-regulatory features at 22 months would predict language and social-communication skills during the preschool years but that different behaviors (e.g., JA vs. sensory-regulatory features) at 22 months might be more associated with different preschool outcomes. Specifically, previous literature (i.e., Baranek et al., 2013; Watson et al., 2011) supported the hypothesis that both JA and sensory-regulatory skills at 22 months would be significant predictors of receptive and expressive language outcomes in preschool. Based on Baranek et al. (2018), we further hypothesized that sensory-regulatory features, including attention orienting, at 22 months may account for more variance in social-communication outcomes in preschool than JA at 22 months. See Figure 1 for a conceptual model of these hypotheses.

Method

Participants were drawn from the larger (The Early Development Project [EDP2]), a randomized controlled trial (RCT) of a parent-mediated intervention (Baranek et al., 2015). Children enrolled in (EDP2) were identified using the First Year Inventory (Baranek et al., 2003), which was mailed to parents in a five-county catchment area of central (North Carolina) based on birth records. Children met criteria for a higher likelihood of a future diagnosis of ASD based on cutoff scores in both sensory-regulatory and social-communication domains of the (First Year Inventory). Ninety-seven eligible children and a primary caregiver of each participated in the first assessment (at ~13 months of age), and 87 of those families consented to randomization. Among randomized families, 84 completed postintervention assessments for the parent study (~22 months of age), and 48 of those participants returned for in-person behavioral assessments at a follow-up when the children were between 3 and 5 years old (see Figure 2).

The majority of children in this sample had average to above-average cognitive abilities at follow-up assessments in preschool (Differential Ability Scales–Second Edition; Elliott, 2007; M = 103.37, SD = 13.58). Seventeen of the children seen for follow-up assessments were diagnosed with ASD (35%). Extant data for the 87 children who completed pre-intervention assessment and enrolled in the intervention phase of the RCT were used to address the first research question. Data from the 48 children who completed assessments at all three time points were used to address the second and third research questions about distal outcomes. Demographic characteristics of these samples can be viewed in Table 1. There were no significant

Figure 1. Conceptual model.

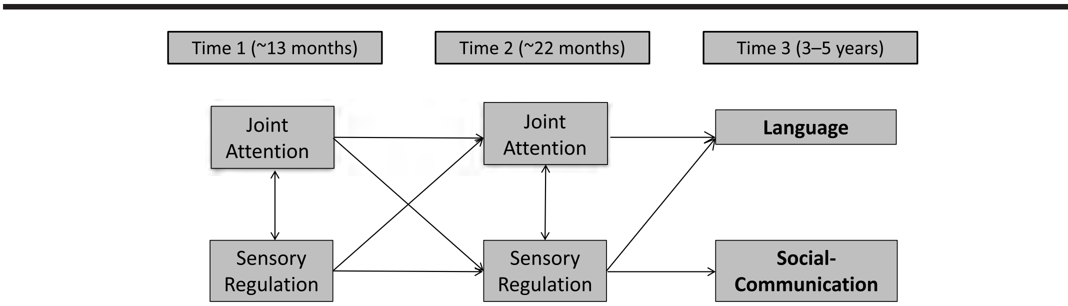


Figure 2. Flow chart of The Early Development Project (EDP2) sample recruitment and retention. FYI = First Years Inventory; ART = Adapted Responsive Teaching; REIM = Referral to Early Intervention and Monitoring.

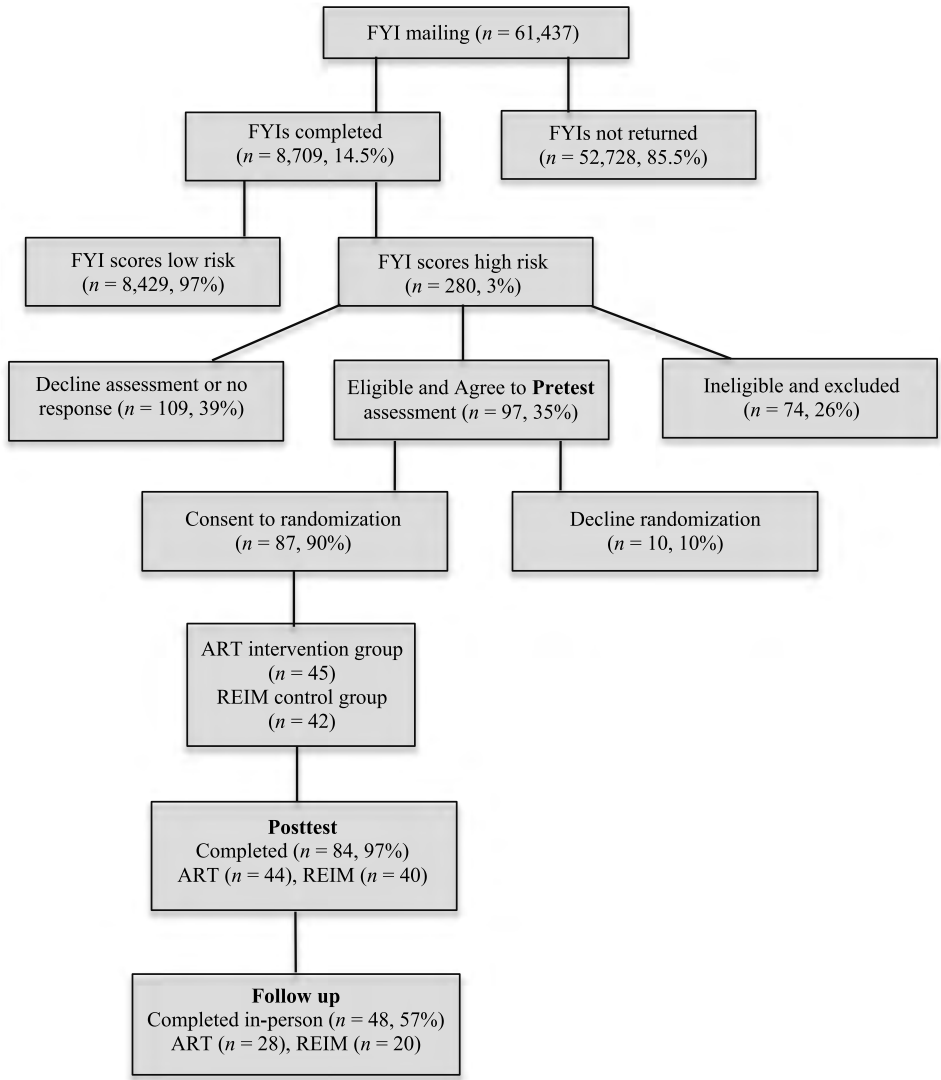


Table 1. Sample demographic information.

Sample demographics					
Time point	*N*	Chronological age in months, *M* (*SD*) Range	Developmental quotient, *M* (*SD*) Range	Sex	Race
At pretest	87	13.75 (0.72) 13–16	81.39 (14.63) 50–120	Female = 27 (31%)	Non-White = 26 (30%)
At follow-up	48	53.96 (11.06) 35–73	102.21 (15.97) 49–141	Female = 16 (33%)	Non-White = 8 (17%)

Note. Developmental quotient = Mullen Scales of Early Learning, Early Learning Composite for pretest, and the Differential Ability Scales–Second Edition General Conceptual Ability Standard Score for follow-up. Note that two children at follow-up received the Mullen Scales of Early Learning.

differences in sex between children who returned for follow-up assessments in preschool and those who did not, $\chi^2(1, 87) = 0.43$, $p \leq .51$, but there were significant differences found for race, $\chi^2(1, 86) = 7.85$, $p \leq .01$, with fewer non-White families returning for follow-up than participated in the pre- and post-assessments. There were no significant differences found for measures of interest to this study (i.e., Sensory Processing Assessment and Communication and Symbolic Behavior Scales variables) between children who did and did not return for follow-up assessments. The intervention did not have any main effects on any of the variables included in the current analyses; however, treatment group was included in the initial models to test for potential influence of treatment group on results and then removed from the final models if it had no significant effect.

Instrumentation

Observational Measure of JA

The Communication and Symbolic Behavior Scales (CSBS)–Developmental Profile (Wetherby & Prizant, 2003) is a standardized behavioral measure of early communication ability for children who are developmentally between 6 and 24 months old. It was administered to the (EDP2) sample at pre- and posttest assessments. The CSBS behavior sample includes three types of coded JA behaviors: (a) Gaze Shifts: coded as presence or absence of initiating JA during each of six presses, for a score range of 0–6; (b) Gaze Point Follow: coded as the presence or absence of child attention shifts when the clinician uses eye gaze paired with pointing to share an object or event during two presses, for an actual score range of 0–2, but this scale is multiplied by 3 to be equally weighted with other scales on the CSBS, for a score range of 0–6; (c) JA: using verbal or nonverbal communication for the purpose of directing someone's attention to an object or event during each of six presses, for a score range of 0–6. For all of these variables, higher scores signify better, or more developmentally advanced, JA skills. See Table 2 for distributions of CSBS variables.

Observational Measure of Sensory-Regulatory Features

The Sensory Processing Assessment (SPA; Baranek, 1999) is a play-based observational assessment designed to measure responses to sensory stimuli across three modalities (i.e., auditory, visual, and tactile) in young children. Scores on the SPA are obtained for Hyperresponsiveness, Hyporesponsiveness, and Seeking behaviors. During the SPA administration, children are exposed to a variety of novel toys with sensory components (e.g., a toy blow fish with rubber spikes or a switch-activated fan). While the child is engaged with a novel toy, the examiner introduces another sensory stimulus that is either nonsocial (e.g., a noise maker or a flashing light) or social (e.g., name call, shoulder tap). The child has three trials, or opportunities, to shift their attention away from the toy with which they are engaged and orient to the new sensory stimulus. Orienting is scored on a 1–4 scale

Table 2. Communication and Symbolic Behavior Scales (CSBS) and Sensory Processing Assessment (SPA) individual and composite variable distributions.

Construct	Time 1 (*n* = 87)	Time 2 (*n* = 82)
	M (*SD*) Range	*M* (*SD*) Range
CSBS		
Gaze Shift	5.57 (0.88) 2–6	5.42 (1.06) 1–6
Gaze Point Follow	4 (1.98) 0–6	5.38 (1.47) 0–6
Joint Attention	1.87 (1.87) 0–6	3.34 (1.85) 0–6
Composite Joint Attention	3.82 (1.20) .67–6	4.71 (1.17) .33–6
SPA		
Sensory Seeking	2.63 (0.84) 1–4.43	2.59 (0.89) 1–4.43
Hyporesponsiveness	2.31 (0.85) 1–5	2.17 (0.67) 1–3.66
Composite Sensory Regulation	2.47 (0.63) 1.29–4.43	2.38 (0.64) 1–3.93

with 1 = *child oriented on the first trial*, 2 = *oriented on the second trial*, 3 = *oriented on the third trial*, and 4 = *not orienting on any trial*. The Hyporesponsiveness score on the SPA is the mean Orienting score during trials of seven different sensory stimuli. Higher scores indicate greater difficulty with orienting to sensory stimuli. Throughout the 20- to 30-min SPA administration, the examiner notes all sensory-related stereotyped behaviors demonstrated by the child (e.g., arm or hand flapping, mouthing nonfood objects). There are eight total stereotypies scored on the SPA as present ("Yes") or absent ("No"). "Yes" is scored as a "1," and the sum of the stereotypies creates the Seeking score, where higher scores indicate greater sensory seeking behaviors observed during the SPA. See Table 2 for distributions of SPA variables.

SPA Hyporesponsiveness has been associated with social-communication symptom severity (Watson et al., 2011) and poorer JA abilities (Baranek et al., 2013). SPA Sensory Seeking behaviors also have been found to be significantly correlated with social communicative symptom severity for children with ASD, but not for children with other developmental disabilities (Watson et al., 2011). Moreover, in the (EDP2) sample, SPA Sensory Seeking behaviors at 20–24 months were found to significantly predict social-communication symptom severity on the Autism Diagnostic Observation Scale–Second Edition (ADOS-2) in the preschool years, and this relationship was mediated by social orienting at 20–24 months (Baranek et al., 2018). SPA Hyperresponsiveness has been less sensitive to differences between ASD and other disability groups (Brock et al., 2012) and has not been systematically related to social-communication features of ASD (Watson et al., 2011). Thus, hyporesponsiveness and sensory seeking were of greater interest for these research questions than hyperresponsiveness.

Observational Preschool Language and Social-Communication Outcome Measures

The Preschool Language Scales–Fifth Edition (PLS-5; Zimmerman et al., 2011) is a standardized structured behavioral assessment of developmental language skills in English-speaking children from 2 to 7 years of age. It was administered to all children at follow-up (n = 47) except for one due to behavioral refusal. Standard scores on the two language scales, namely, Auditory Comprehension (sample M = 102.38, SD = 17.01, range: 50–142) and Expressive Communication (sample M = 102.23, SD = 17.81, range: 50–133), were used to address Research Question 2.

A narrative retell task from the PLS-5 was administered to all children in the study at follow-up and was used as one distal social-communication outcome in the analyses for this study. We measured social-communication skills from children's narrative retellings at the higher levels of discourse organization (narrative macrostructure). Narrative retell abilities measured at the macrostructure level (organization, goal-oriented planning) are considered to reflect social communication because recounting events is an important aspect of conversation that requires skills beyond the scope of structural language such as topic maintenance, event sequencing, coherence, and presupposition (ASHA, 2017c). Stories were audio-recorded and transcribed by a trained undergraduate research assistant for analyses. Story retell tasks are considered useful measures of language competence (Ketelaars et al., 2012) that are easier to score reliably than story generation tasks (Merritt & Liles, 1989). Formal assessments of narrative retell are not presently normed for preschool-aged children; therefore, we used the most sensitive measure for early elementary-aged students with the passage from the PLS-5, which was written at a preschool level. Heilmann et al. (2010) compared four story retell analysis measures and concluded that the Narrative Scoring Scheme (NSS) was most sensitive for children ages 5–7 years. The NSS, as detailed in Heilmann et al. (2010), was the narrative retell analysis coding system used in the current study. Using training materials available on the Systematic Analysis of Language Transcripts website (Miller et al., 2018), a research assistant and the study Principal Investigator established reliability (> 80% agreement) on rating the seven NSS items (introduction, character development, mental states, referencing, conflict resolution, cohesion, and conclusion). Items were rated on a scale from 0 to 5, with higher scores reflecting more mature narrative skills, and summed to form a total narrative retell ability score (range: 0–35). Scores of "0" were assigned when children refused to participate (e.g., said "all finished" or "I can't do it," did not respond, conversed with examiner about other topics). Interrater reliability was acceptably high (Intraclass Correlation Coefficient = .81) for coding the NSS in this sample. The total NSS score was used in analyses to address Research Question 3 (sample M = 5.27, SD = 6.04, range: 0–20).

The ADOS-2 (Lord et al., 2012) is a semistructured standardized behavioral measure of ASD symptoms. It was administered to all children at follow-up (n = 45) using the module that aligned with their language level. Due to behavioral refusal or family time limitations, valid ADOS scores could not be obtained for three children. The ADOS was administered by either a research-reliable speech-language pathologist or a psychology graduate student who was supervised by a research-reliable licensed psychologist. The Social Affect Calibrated Severity Score (Hus et al., 2014) is a standardized domain score that is calculated from the ADOS Social Affect raw score from each respective ADOS module and allows social-communication symptom severity comparison across ADOS modules (i.e., controlling for developmental level). Since children in the sample received different modules of the ADOS, the Social Affect Calibrated Severity Score was used as a second measure of distal social-communication outcomes to answer Question 3. Scores ranged from 1 to 10, with higher scores indicating greater social-communication symptom severity (sample M = 3.78, SD = 2.57). Seventeen (35%) of the high-risk children included in our sample met criteria for a diagnosis of autism on the ADOS.

See Figure 3 for variables targeting each construct of interest by time point in a cross-lagged model.

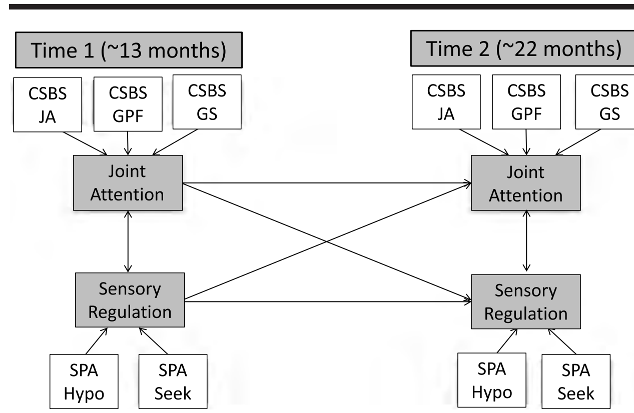
Procedure

All assessments were administered either in a university clinic setting or at another outpatient pediatric clinic (e.g., regional early intervention clinic). Assessments used for the present analyses were part of a larger behavioral assessment protocol lasting 2–3 hr per time point. Study procedures were approved by the institutional review board at (The University of North Carolina at Chapel Hill). Informed parental consent was obtained for all participants. Study analyses were completed using JMP Pro Version 13.0 (JMP, 2007) and Mplus Version 7.4 (Muthén & Muthén, 2015).

Analytic Strategy

We used cross-lagged panel correlation analysis, a quasi-experimental longitudinal design, to demonstrate that

Figure 3. Cross-lagged panel model. CSBS = Communication and Symbolic Behavior Scales; GPF = Gaze Point Follow; GS = Gaze Shift; Hypo = Hyporesponsiveness; JA = Joint Attention; Seek = Sensory Seeking.



the relationship between JA and SR over time is likely to be truly associated rather than due to the effects of a third variable (Kenny, 1975). The method does this by adjusting the test statistic for the predictive correlations by controlling for the concurrent correlations and the temporal stability of the two variables (Raghunathan et al., 1996). In other words, this allowed us to test Time 1 JA predicting Time 2 SR while controlling for Time 1 SR and to test Time 1 SR predicting Time 2 JA while controlling for Time 1 JA. This is a more conservative approach than traditional regression models because both dependent variables are allowed to correlate in the model (Green et al., 2012). Though correlations can never rule out all alternative explanations for an association, cross-lagged associations allow interpretation that one variable has a superior impact on another over time (Woynaroski et al., 2016). In this case, the cross-lagged models increase the extent to which we can interpret if SR or JA at 13 months has a greater influence on these variables at 22 months.

First, composite variables were established for the two constructs of interest: JA and SR. Composite variables were empirically tested through examination of variable distributions, correlations, principal component analyses, and exploratory factor analyses. This was necessary because our analytic approach assumes multivariate normality (Tabachnick & Fidell, 2001). For the CSBS, distributional irregularities were observed and one variable (JA) had more restricted variability compared to the other two. To account for this finding, the CSBS variables were run as ordinal variables for the exploratory factor analyses (Forero et al., 2009; Muthén & Muthén, 2015).

Exploratory factor analyses were used to (a) empirically test the constructs, (b) see whether it was worthwhile to use factor analytic scores rather than variable composite scores in the models, and (c) determine if the factor structure was consistent across measurement time points for JA and SR (i.e., if measurement invariance holds). Results of the exploratory factor analyses combined with the results of the principal component analyses indicated that the individual JA and sensory-regulatory variables were empirically valid to combine into composite variables. The SR composite is a mean of the SPA Hyporesponsiveness and SPA Seeking variable scores. The JA composite is a mean of the three CSBS JA item scores. Composite variables at each time point were approximately normally distributed. As expected, correlations between composite variables at each time point were statistically significant (see Table 3).

Full information maximum likelihood estimation was used in all models to accommodate missing data on proximal and distal measures. Cross-lagged panel correlations were examined to determine the bidirectional effects between JA and self-regulation at 13 and 22 months (see Figure 3). This method simultaneously tested (a) JA at 13 months predicting SR at 22 months while controlling for SR at 13 months and (b) SR at 13 months predicting JA at 22 months while controlling for JA at 13 months. The model was reduced through a principled model reduction strategy using a series of model comparisons to determine the most parsimonious set of predictors for the data (Appelbaum & Cramer, 1974; Cramer & Appelbaum, 1980; Darlington & Hayes, 2017; Maxwell et al., 2018; Nelder, 1977).

Table 3. Pearson correlations between composite variables at each time point.

Composite variable	T1 JA	T1 SR	T2 JA	T2 SR
T1 JA	1.00	−.44**	−.41**	−.31**
T1 SR		1.00	−.24*	.32**
T2 JA			1.00	−.58**
T2 SR				1.00

Note. T1 = pretest; JA = Joint Attention; SR = Sensory Regulation; T2 = posttest.

**Significant at a .01 alpha level. *Significant at a .05 alpha level.

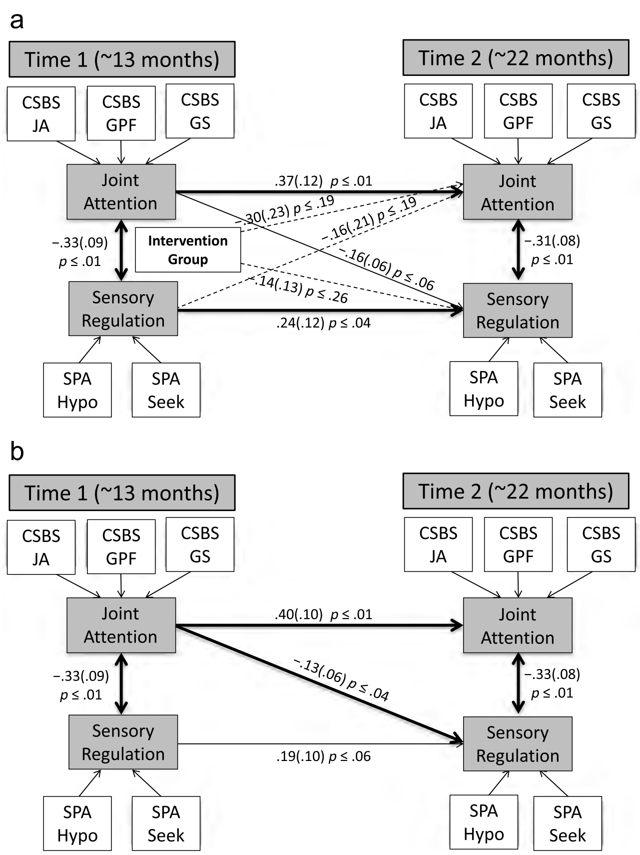
The distal language and social-communication outcomes from the third (preschool) study time point were added to the final cross-lagged panel correlation analysis model. First, models adding the PLS Receptive and Expressive Language scores from Time 3 as distal outcomes were run. Next, models were run with the ADOS Social Affect Calibrated Severity Scores and NSS Total Scores from Time 3 as distal outcomes. These models allowed examination of the extent to which the direct effects of JA and SR variables at 22 months as well as the indirect effects of those variables at 13 months predicted various aspects of communication competence in preschool.

Despite the lack of main effects of the intervention in the EDP2, a categorical intervention group variable was included in the initial models to account for the potential influence of intervention on outcomes. Furthermore, there was a broader time gap between posttest and follow-up assessments (mean gap = 31.53 months, *SD* = 11.34) than pre- and posttest assessments (mean gap = 8.79 months, *SD* = 0.97), and there was much greater age variability at follow-up. Children's ages spanned a 3-year range at follow-up as compared to 3- to 5-month ranges at pre- and posttest assessments. This is because enrollment for the RCT was rolling over the course of 3 years, whereas the follow-up was funded to occur over a brief 5-month time period with all participants. Chronological age at follow-up was included in the models addressing distal outcomes as a covariate to control for this variability in age.

Results

To determine the concurrent and predictive associations between JA and SR at 13 and 22 months in this sample of children at a higher likelihood for ASD, a cross-lagged panel model was run. The initial model (see Figure 4a) supported the hypothesis that JA and SR were related in early childhood. All concurrent correlations between JA and sensory-regulatory features were significant in this model, as were predictive relationships between JA from

Figure 4. Question 1: Cross-lagged models. Solid bold lines indicate statistical significance at a .05 alpha level; solid thin lines indicate statistical significance at a .10 alpha level; dashed thin lines indicate $p \geq .10$. (a) Question 1: Initial cross-lagged model. (b) Question 1: Final cross-lagged model. CSBS = Communication and Symbolic Behavior Scales; GPF = Gaze Point Follow; GS = Gaze Shift; Hypo = Hyporesponsiveness; JA = Joint Attention; Seek = Sensory Seeking.



13 to 22 months and sensory-regulatory features from 13 to 22 months. Intervention group was not a significant predictor of either JA or sensory-regulatory features at 22 months, so it was dropped from the model. Although JA at 13 months significantly predicted both JA and SR at 22 months, the predictive relationship between SR at 13 months and JA at 22 months was not statistically significant. Therefore, this predictor was dropped from the final model (see Figure 4b). The final cross-lagged panel correlation model was used to estimate the relationships between JA and sensory-regulatory features at 22 months and distal language and social-communication outcomes at preschool follow-up.

The final model indicates that JA skills at 13 months of age in this sample of children at a higher likelihood for ASD were associated with both JA and sensory-regulatory features at 22 months of age. Sensory-regulatory features at 13 months are predictive of later sensory-regulatory features, but not JA skills, at 22 months.

Distal Language Outcomes

Receptive Language

The Auditory Comprehension standard score from the PLS-5 was added to the cross-lagged model as a distal receptive language outcome measure. The full model with chronological age and intervention group covariates is in Figure 5a. In this model, there were no significant correlations found between sensory-regulatory features or JA skills at 22 months and child receptive language at preschool follow-up; however, SR approached significance. Since intervention group was not a significant predictor in the model, it was dropped.

The model was further reduced through a series of model comparisons. The final and most parsimonious model (see Figure 5b) shows that sensory-regulatory features at 22 months was the only variable needed in the model predicting receptive language skills at preschool follow-up. Though JA was critical at 13 months for predicting JA at 22 months, JA at 22 months was not needed to predict receptive language in preschool in the presence of SR.

Expressive Language

The Expressive Communication standard score from the PLS-5 was used as a distal outcome measure of expressive language in the model. The full model with covariates (see Figure 6a) demonstrated similar results to the Auditory Comprehension model. Neither JA nor sensory-regulatory features significantly predicted expressive communication on the PLS-5 when controlling for intervention group and chronological age. SR at 22 months accounted for more of the variance in preschool Expressive Communication than did JA. Intervention group was dropped from the final model since it was not a significant predictor.

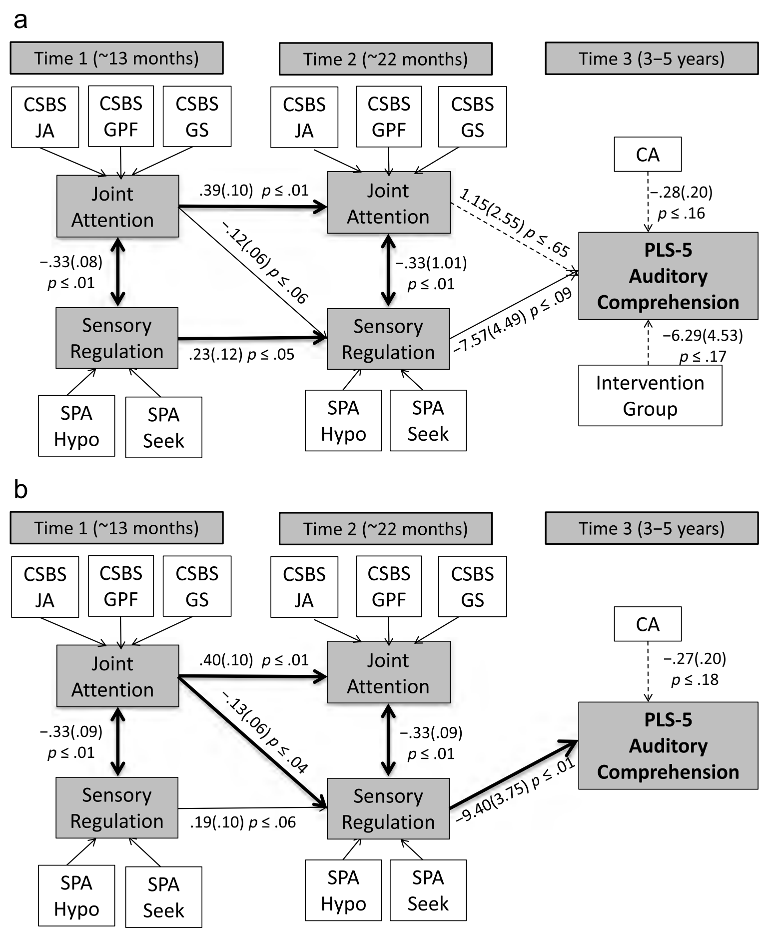
A series of model comparisons were used in an effort to further reduce the model to its most parsimonious form. The models were inconclusive because results were contradictory. In the absence of SR at 22 months (see Figure 6b), JA at 22 months significantly predicted Expressive Communication in preschool; however, in the absence of JA at 22 months (see Figure 6c), SR also was a significant predictor of preschool Expressive Communication. Neither variable at 22 months was significant in the presence of the other. This indicates that the significant correlation between these variables at 22 months caused each one to suppress the effects of the other, but the data do not contain enough information to distinguish which effect was stronger or dominant (Appelbaum & Cramer, 1974; Cramer & Appelbaum, 1980; Darlington & Hayes, 2017; Maxwell et al., 2018). These results likely reflect our small sample size impacting the stability of the model.

Distal Social-Communication Outcomes

Social-Communication Symptom Severity

The ADOS-2 Social Affect Calibrated Severity Score was used in the model as a distal outcome measure of social-communication symptom severity. In the full initial

Figure 5. Models with auditory comprehension as a distal outcome of the cross-lagged panel analysis. Solid bold lines indicate statistical significance at a .05 alpha level; solid thin lines indicate statistical significance at a .10 alpha level; dashed thin lines indicate $p \geq .10$. (a) Initial model with auditory comprehension as a distal outcome of the cross-lagged panel analysis. (b) Final model with auditory comprehension as a distal outcome of the cross-lagged panel analysis. CSBS = Communication and Symbolic Behavior Scales; GPF = Gaze Point Follow; GS = Gaze Shift; Hypo = Hyporesponsiveness; JA = Joint Attention; CA = chronological age; Seek = Sensory Seeking; PLS-5 = Preschool Language Scales–Fifth Edition; SPA = Sensory Processing Assessment.



model (see Figure 7a), SR at 22 months was a significant predictor of the social-communication symptom severity in preschool, but JA at 22 months was not. This result held throughout the model reduction process, and the final model can be seen in Figure 7b.

Narrative Retell

The NSS total score was used as a distal outcome measure of pragmatic language ability in the model. This outcome variable differed from the others in that it was not standardized. Since the sample was chronologically and developmentally at the lowest end of being able to complete a narrative retell task, scores were positively skewed with 21 of the children producing unscorable narratives. To account for the nonnormal distribution, the NSS was run as a negative binomial count variable in the model (Hilbe, 2011; Muthén & Muthén, 2015). The full model is displayed in Figure 8a where chronological age is the only significant predictor of NSS. This relationship remained the only significant predictor of narrative retell ability throughout model reduction procedures, and the final model reflects this finding (see Figure 8b) that neither JA nor sensory-regulatory features at 22 months were significant predictors of narrative retell ability in preschool. Overall, results of the models run to determine the extent to which JA and sensory-regulatory features predicted social-communication outcomes in preschool indicate that SR at 22 months was a significant predictor of social-communication symptom severity in preschool.

Discussion

We employed cross-lagged panel correlation analysis methods to (a) examine the concurrent and predictive

Figure 6. Models with expressive communication as a distal outcome of the cross-lagged panel model. Solid bold lines indicate statistical significance at a .05 alpha level; solid thin lines indicate statistical significance at a .10 alpha level; dashed thin lines indicate $p \geq .10$. (a) Initial model with expressive communication as a distal outcome of the cross-lagged panel model. (b) Reduced Model 1 with expressive communication as a distal outcome of the cross-lagged panel analysis. (c) Reduced Model 2 with expressive communication as a distal outcome of the cross-lagged panel analysis. CSBS = Communication and Symbolic Behavior Scales; GPF = Gaze Point Follow; GS = Gaze Shift; Hypo = Hyporesponsiveness; JA = Joint Attention; CA = chronological age; Seek = Sensory Seeking; PLS-5 = Preschool Language Scales–Fifth Edition; SPA = Sensory Processing Assessment.

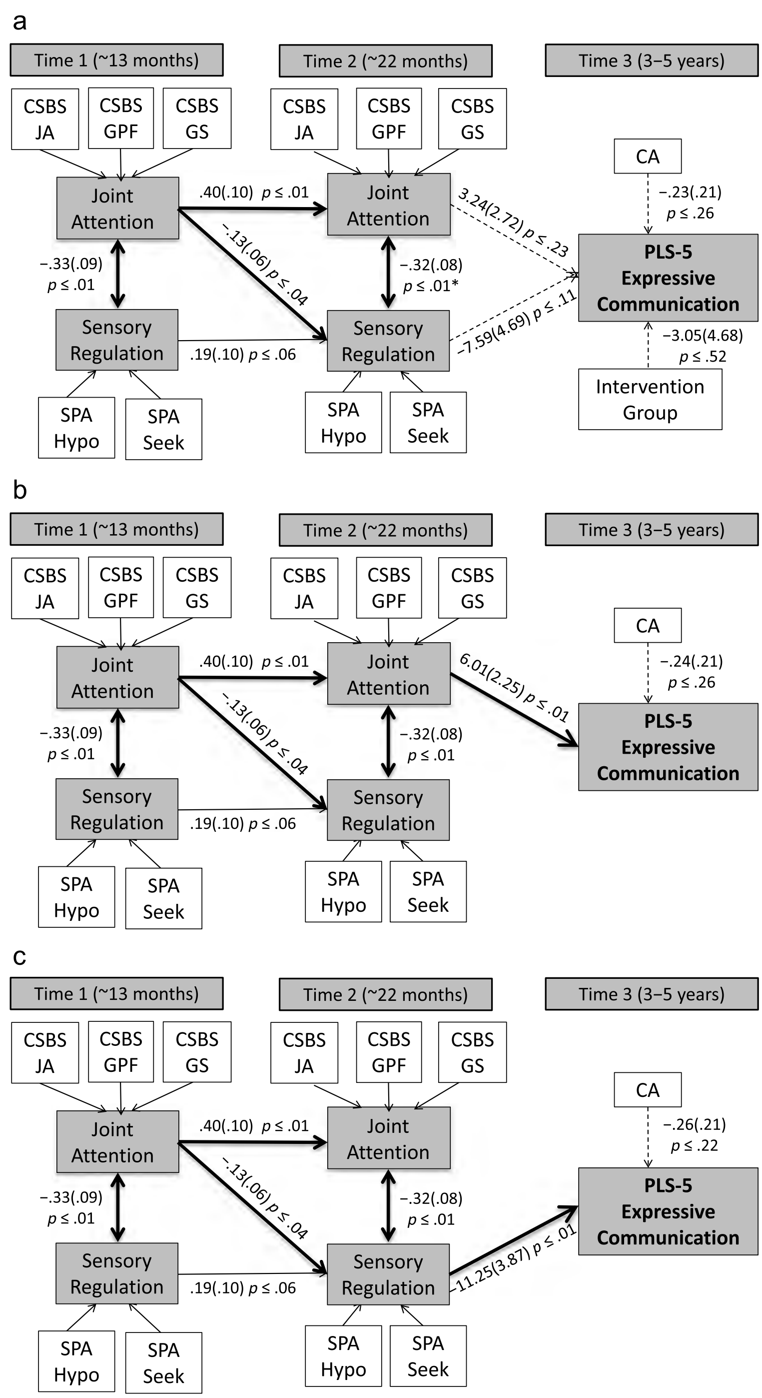
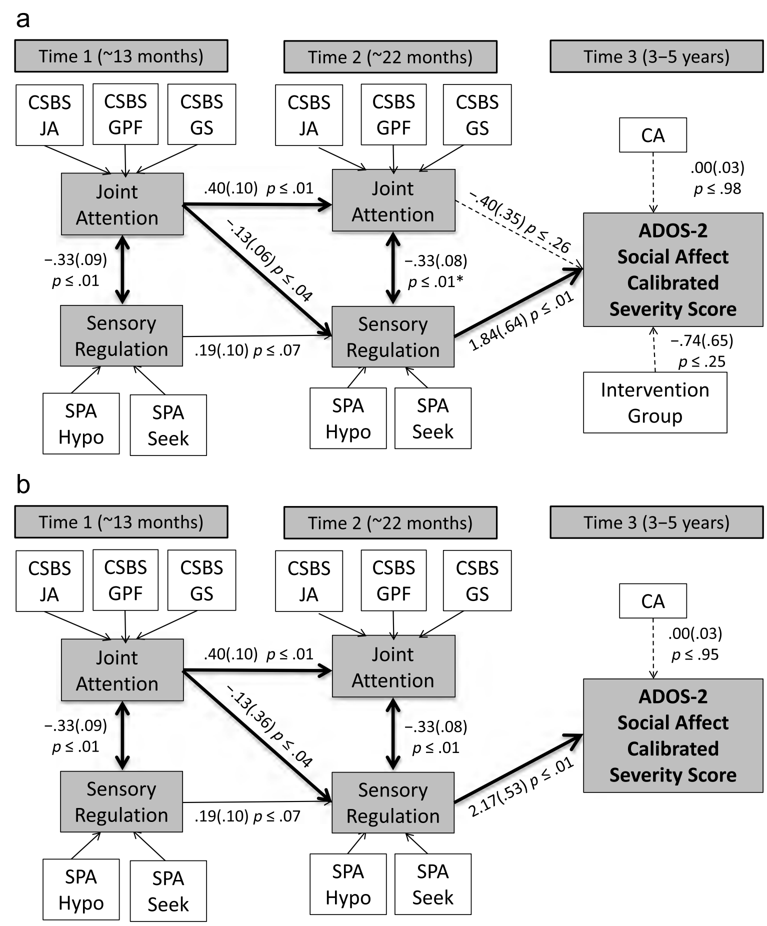


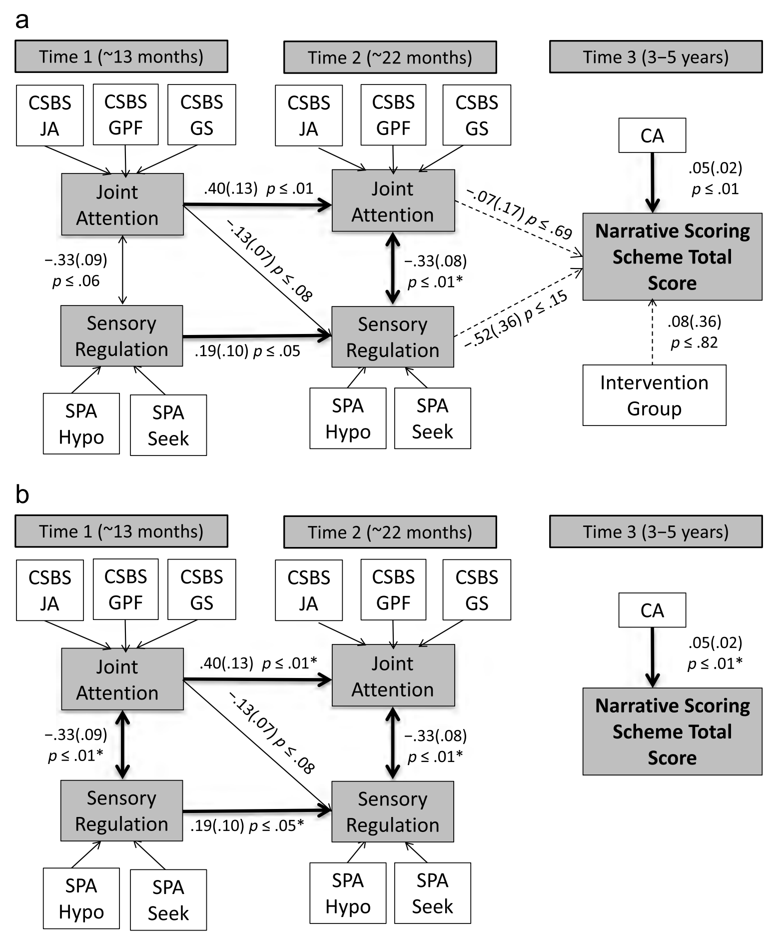
Figure 7. Models with ADOS-2 Social Affect Calibrated Severity Score as a distal outcome of the cross-lagged panel analysis. Solid bold lines indicate statistical significance at a .05 alpha level; solid thin lines indicate statistical significance at a .10 alpha level; dashed thin lines indicate $p \geq .10$. (a) Initial model with ADOS-2Social Affect Calibrated Severity Score as a distal outcome of the cross-lagged panel analysis. (b) Final model with ADOS-2 Social Affect Calibrated Severity Score as a distal outcome of the cross-lagged panel analysis. ADOS-2 = Autism Diagnostic Observation Scale–Second Edition; CSBS = Communication and Symbolic Behavior Scales; GPF = Gaze Point Follow; GS = Gaze Shift; Hypo = Hyporesponsiveness; JA = Joint Attention; CA = chronological age; Seek = Sensory Seeking; SPA = Sensory Processing Assessment.



relationships between JA and early sensory-regulatory features between 13 and 22 months of age in a sample of children identified at 12 months at a higher likelihood for ASD and (b) determine the extent to which JA and early sensory-regulatory features at 13 and 22 months predict distal language and social-communication outcomes at 3–5 years. The final model for the first aim confirmed the initial hypothesis that there were significant concurrent relationships between the JA and sensory-regulatory constructs at 13 and 22 months, but significant predictive relationships were found primarily between JA at 13 months and sensory-regulatory features at 22 months. This is consistent with findings from a cross-sectional study documenting correlations between hyporesponsiveness and both response to JA and initiating JA in young children diagnosed with ASD and other developmental disorders (Baranek et al., 2013). Interestingly, in our findings, JA at 13 months was the only variable needed in the model to predict both JA and sensory-regulatory features at 22 months and the sensory-regulatory construct at 13 months was dropped from the final model. Results suggest that development of JA skills at 13 months may benefit the domains of both JA and SR at 22 months.

To address the second and third research questions, the cross-lagged panel correlation model was extended to predict individual distal language and social-communication outcomes in the sample at preschool age. Receptive language skills in preschool were best predicted by a cross-lagged panel model with sensory-regulatory features at 22 months as the only significant predictor. This model suggests that, for children similar to this sample, SR may be a critical developmental domain to address in intervention with

Figure 8. Models with NSS total score as a distal outcome of the cross-lagged panel analysis. Solid bold lines indicate statistical significance at a .05 alpha level; solid thin lines indicate statistical significance at a .10 alpha level; dashed thin lines indicate $p \geq .10$. (a) Initial model with NSS total score as a distal outcome of the cross-lagged panel analysis. (b) Final model with NSS total score as a distal outcome of the cross-lagged panel analysis. CSBS = Communication and Symbolic Behavior Scales; GPF = Gaze Point Follow; GS = Gaze Shift; Hypo = Hyporesponsiveness; JA = Joint Attention; CA = chronological age; NSS = Narrative Scoring Scheme; Seek = Sensory Seeking; SPA = Sensory Processing Assessment.



toddlers in order to impact receptive language outcomes between 3 and 5 years of age. This finding extends previous research that found that elevated sensory seeking behaviors at the end of the second year of life significantly predicted later social-communication symptoms (Baranek et al., 2018; Damiano et al., 2018) by adding that sensory behaviors at the end of the second year predict preschool receptive language skills.

The models for preschool expressive language provided a less definitive conclusion than those for receptive language in that both JA and sensory-regulatory features at 22 months were significant predictors of outcome, but one suppressed the other when they were both in the model. Future intervention studies are needed to test the contribution of various JA and SR components and the timing of intervention. However, our findings highlight that SR during the toddler period may play an especially important role for improving language outcomes for children who are showing early delays in both the receptive and expressive language modalities, especially children at a higher likelihood for ASD such as those in this study.

Similar to receptive language, social-communication symptom severity in preschool was best predicted by a cross-lagged panel correlation model with sensory-regulatory features at 22 months as the only predictor. This finding replicates previous research on community and familial ASD risk samples showing the association between sensory features at the end of the second year of life and social-communication symptom severity in preschool (Baranek et al., 2018; Damiano et al., 2018). Narrative retell skills in preschool did not demonstrate any association with JA or sensory-regulatory features at 22 months and were only predicted by chronological age. This lack of association may be because this measure is not standardized and because preschool-aged children were scoring at the lowest end of the measure, which limited score variability (sample mean = 5.27, NSS total score possible range: 0–35). Unfortunately, it is difficult to draw conclusions about these narrative scores in preschool-aged children at a higher likelihood for ASD, because most studies of narrative ability in children with ASD have consisted of samples aged 6.5 years or older (Baixauli et al., 2016). In a review of 24 studies with older children diagnosed with ASD compared to typically developing children, Baixauli et al. (2016) found that children with ASD struggled with narrative cohesion, referencing, use of emotional state words, and general difficulty "seeing the big picture" relative to age-matched typically developing peers. Moreover, a recent study of preschool narrative ability in verbal children with ASD (Westerveld & Roberts, 2017) extended the findings of studies with older children in that the preschoolers with ASD told less coherent narratives with fewer events but had generally good sentence structure relative to typically developing preschoolers. Unfortunately, only 19 of the 29 children (66%) in the Westerveld and Roberts study produced codeable narratives, while the other children refused the task, told a different story, or attempted to retell the story but did not produce meaningful utterances. In that study, child participation in narrative retelling was not related to overall language level or cognitive level (Westerveld & Roberts, 2017). This finding is similar to this study where less than 60% of children (including some children who were less verbal than in the Westerveld and Roberts study) produced codeable narratives. Considering previous literature and the current results, it is possible that narrative retell skills in preschool, as measured by currently available assessment instruments and protocols, is not a stable or valid construct. Future research should explore modified assessment protocols to elicit narratives from preschool children with ASD or with symptoms characteristic of ASD (Westerveld & Roberts, 2017) since narrative retell skills have been shown to predict later language and literacy outcomes in children with other developmental disabilities (Bishop & Adams, 1990; Bishop & Edmundson, 1987).

The results from the distal preschool language and social-communication outcome models support the PDP model in that JA and sensory-regulatory features were found to be significantly related constructs in early childhood development that have cascading effects on some important aspects of language and social communication in preschool (i.e., receptive language, expressive language, and social-communication symptom severity). These results replicate and expand upon previous literature. Baranek et al. (2013) found that hyporesponsiveness to both social and nonsocial stimuli was related to deficits in JA skills in children with autism, DD, and typical development. We replicated that finding over two time periods of early childhood for toddlers at a higher likelihood for ASD using a composite SR variable that included hyporesponsiveness. Watson et al. (2011) found a positive association between sensory seeking behaviors and social-communication symptom severity in children with ASD, which did not hold for children with DD. We found this same association between a composite sensory-regulatory variable, which included sensory seeking and social-communication symptom severity in preschool. Both groups of children in the Watson et al. (2011) study showed a negative correlation between hyporesponsiveness and language. This relationship was replicated in this study with lower levels of hyporesponsiveness (i.e., better orienting responses) at 22 months predicting greater receptive and expressive language skills in the preschool age range.

Taken together, our results suggest that, for optimal outcomes in both language and social communication at preschool age, JA may become an especially important factor around the beginning of the second year of life, while SR may become an especially important factor as children approach 2 years of age. These results support Bottema-Beutel's (2016) hypothesis that there may be a threshold for learning JA skills in early development, after which receptive and expressive language outcomes are less contingent upon variability in JA skills. In this way, young children with ASD may be relying on their JA skills through the second year of life while sensory-regulatory skills become more important predictors of language and social outcomes by 22 months. We did not have the sample size to test differences in these models between the children in the sample who went on to be diagnosed with ASD (n = 17) and those who did not. Future research is needed to examine this theory in depth.

Both the PDP model (Mundy & Jarrold, 2010) of JA and the cascading effects theory of SR (Baranek et al., 2014, 2018; Cascio et al., 2016; Damiano et al., 2018) posit that these are pivotal skills in the early development of children with ASD, without which there are long-term impacts on language and social-communication outcomes. Our findings support these developmental models and the longitudinal associations between them. JA skills around 13 months of age seem to be foundational for JA and sensory-regulatory behaviors at 22 months, which then affect social-communicative and language skills in preschool. These findings may have implications for future early childhood intervention research for children at a higher likelihood for ASD.

There were some limitations to this study. First, the variables chosen for analysis in this study are somewhat restricted with respect to variables derived from extant data; however, the extant data made it possible to conduct a preliminary investigation of these longitudinal models to help guide future studies. Future prospective studies should use a more direct measure of JA rather than extracting items from a larger measure (e.g., Early Social Communication Scales: Mundy et al., 2003; JA Protocol: Watson et al., 2003). Models with different aspects of JA such as response to and initiation of JA are also important next steps for this research. Regarding sensory-regulatory features, this study only examined hyporesponsiveness and sensory seeking features. With a larger sample, it may be interesting to explore these models with hyperresponsivity to ensure that the hyperresponsive aspect of SR is not contributing to language and social-communication outcomes, as suggested by previous literature, and to look at differences between hyper- and hyporesponsivity models. Furthermore, the interceptive and proprioceptive feedback that are theorized by Mundy and Jarrold (2010) to be important for the development of JA were less of a focus of the SPA, which prioritized auditory, tactile, and visual experiences; these may be future directions to explore. Finally, our social-communication outcome measures were limited to the ADOS calibrated severity score and the narrative retell task. The ADOS is a diagnostic tool designed for clinical use, and therefore the severity score may not be sensitive to variability in broader social-communicative functioning in individuals without ASD across settings. Narrative retell was used in an attempt to broaden our social-communication outcome, but it ended up being an inappropriate measure for this sample. Social communication is a broad construct with substantial measurement limitations, particularly for preschool-aged children. More research is needed to reliably and validly measure aspects of social communication in young children.

There was no comparison group of children who were not identified as having a higher likelihood for ASD in this study. Having a control group would allow comparison of these models to children who were not at a higher likelihood for ASD and provide insight into whether the results hold for the general population of toddlers or are unique to this population. It would also be beneficial to look at toddlers who were identified as at a higher likelihood for being diagnosed with ASD based on familial/genetic risk to see if the results are replicable in that population. It is important to note that our study cannot make claims about the developmental mechanisms at play prior to the age of 13 months. We acknowledge that SR skills, especially attention orienting, may be foundational to the JA skills in our models at 13 months based on previous research. Finally, since this was a developmental study rather than an intervention study, intervention implications discussed in this article are possible future research directions, which need to be tested in the context of an intervention study with a larger sample.

Author Contributions

Linda R. Watson: Conceptualization (Equal), Funding acquisition (Lead), Investigation (Equal), Methodology (Supporting), Supervision (Lead), Writing - review & editing (Lead). **Elizabeth R. Crais:** Funding acquisition (Lead), Investigation (Equal), Supervision (Equal), Writing - review & editing (Equal). **Grace T. Baranek:** Conceptualization (Supporting), Methodology (Supporting), Supervision (Supporting), Writing - review & editing (Equal). **Richard A. Faldowski:** Formal analysis (Equal), Methodology (Equal), Writing - review & editing (Equal). **Lauren Turner-Brown:** Funding acquisition (Equal), Investigation (Equal), Project administration (Supporting), Resources (Equal), Writing - review & editing (Supporting).

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Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

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