The Role of Parent Responsiveness and Vocal Complexity in Expressive Language Outcome: Intervention Effects in Toddlers at Risk for ASD and Language Impairment

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Abstract

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Up to 40% of later-born siblings of children with autism spectrum disorder (ASD) are diagnosed with: a) ASD (7-19%), which is defined by social communication impairments; or b) other language and/or cognitive delays (14-20%) by age three. Vocal complexity, a measure of the quality and maturity of vocal communication, seems to be a strong predictor of later expressive language in typically developing (TD) and children with ASD, but no studies have examined this relation for these toddlers at high familial risk for ASD (high risk; HR toddlers). Also, previous studies have not examined the role of vocal complexity occurring within preverbal (non-word) vocalizations, distinct from that occurring within words. Low preverbal vocal complexity may signal early language difficulties and need for intervention in HR toddlers.

Vocal complexity may be malleable with intervention. This study examined vocally complex communication within an ongoing longitudinal randomized controlled trial (RCT) of the ImPACT intervention (compared to business as usual; BAU) in 54 12-27-month-old HR toddlers. It found that: 1) nonword vocal complexity was a value-added predictor of later expressive language ability in HR toddlers; 2) families in the ImPACT condition did *not* display greater parent verbal responsiveness (PVR) to toddlers' vocally complex communication acts, greater toddler vocal complexity, or greater toddler expressive language outcome compared to families in the BAU condition; and 3) for toddlers in both treatment conditions, there was an indirect effect of parents' verbal responsiveness on toddlers' later expressive language ability through toddlers' midpoint vocal complexity. This study provides insight into the role of vocal complexity as a risk indicator of language delay and discusses the mechanisms by which vocal complexity may or may not be malleable in response to a parent-implemented social communication intervention.

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GLOSSARY OF ACRONYMS

ADOS	Autism Diagnostic Observation Schedule
ASD	Autism spectrum disorder
BAU	Business as usual
BOSCC	Brief Observation of Social Communication Change
CCA	Child communication act
CI	Consonant inventory
CS	Canonical syllables
CSBS-DP	Communication and Symbolic Behavior Scales- Developmental Profile
EL	Expressive Language
HR	High risk (for ASD)
ImPACT	Improving Parents As Communication Teachers intervention
LR	Low risk (for ASD)
MCDI	MacArthur-Bates Communication Development Inventory
MSEL	Mullen Scales of Early Learning
PCFP	Parent-child free play
PCS	Parent-child snack
PVR	Parent verbal responsiveness
T1-4	Time point 1-4
TD	Typically developing
UW	University of Washington
VC	Vocal complexity
VU	Vanderbilt University

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Introduction

Later-born siblings of children with autism spectrum disorder (ASD) are at elevated risk not only for ASD (7-19%; Grønborg, Schendel, & Parner, 2013; Ozonoff et al., 2011), but also for language or cognitive delays (14-20%; Messinger et al., 2013). Expressive language deficits or delays, in particular, have significant consequences for the everyday functioning and well-being of children, and the acquisition of “useful speech” predicts better long-term functioning in children with ASD (Anderson et al., 2007; Kasari, Gulsrud, Wong, Kwon, & Locke, 2010). Trajectories of communication development vary widely among HR infants and toddlers (e.g., Franchini et al., 2018). The diverse language outcomes of these high-risk (HR) toddlers, the opportunity to observe them at young ages, and the potential for providing early intervention make them an ideal sample in which to study sources of variability in language development and potential risk indicators of language delays and disorders. One such potential risk factor is vocal complexity, a measure of the vocal quality of young children’s prelinguistic and linguistic vocalizations.

Language and Vocal Complexity

There is a clear relation between young children’s phonological abilities, or their ability to make sounds, and their lexical abilities, or their ability to use words (Lewis, 1936; McCathren, Yoder, & Warren, 1999). Phonological development progresses predictably in typically developing infants and toddlers: by 6 to 9 months, infants begin producing canonical babble, or sets of fully formed consonants and vowels vocalized together (Oller, 2000).

Vocal complexity is a measure of the quality of young children’s preverbal and verbal speech. It is often operationalized as the presence of canonical syllables (CS) and/or the number of different consonants (consonant inventory; CI), which are traditional phonological constructs in early vocal development research (McCathren et al., 1999; Murphy, Menyuk, Liebergott, & Schultz, 1983; Stoel-Gammon, 2011). Canonical syllables occur when a vocalization has a consonantal sound, a vowel, and a smooth transition between the consonant and vowel (Oller et al., 2000; Woynaroski, 2014). Consonant inventory is a measure of the number of different consonants that infants produce (Wetherby, Watt, Morgan, & Shumway, 2007). Indices of vocal complexity such as CS and CI have been found to predict expressive language in typically developing (TD) toddlers (McCathren et al., 1999; Murphy et al., 1983; Oller, Eilers, Neal, & Schwartz, 1999; Stoel-Gammon, 2011; Watt, Wetherby & Shumway, 2006; Whitehurst, Smith, Fischel, Arnold, & Lonigan, 1991). CS and CI have also been found to predict expressive language in toddlers with ASD (Plumb & Wetherby, 2013; Sheinkopf, Mundy, Oller, & Steffens, 2000; Wetherby et al., 2007; Woynaroski et al., 2016; Yoder, Watson, & Lambert, 2015). However, no research has yet been done examining whether aspects of vocal complexity predict later expressive language ability for HR toddlers.

In addition, less is known about the vocal complexity of HR infants and toddlers compared to children with ASD and TD children. Children with ASD produce greater proportions of non-speech (e.g., crying, laughing, vegetative sounds) compared to speech sounds than do TD children, a relation that becomes more pronounced over time (Warlaumont, Richards, Gilkerson, & Oller, 2014). Children with ASD have smaller consonant inventories in the second year compared to TD children (Wetherby et al., 2007). Lower levels of CS production have been found in HR relative to low risk (LR) toddlers (Paul, Fuerst, Ramsay, Chawarska, & Klin, 2011) and in toddlers with ASD relative to TD toddlers (Patten et al., 2014). However, HR and LR toddlers may have similarly sized consonant inventories in the second year (Chenausky, Nelson, & Tager-Flusberg, 2017). Overall, research thus far indicates that vocal complexity measured at a single time point differs by ASD risk status and diagnosis, yet also predicts expressive language regardless of diagnosis. Thus, additional research is needed to assess whether low vocal quality may signal early language difficulties and intervention need in those at risk for ASD and language delay.

The second year is a period of great transition from phonological to lexical ability (McMurray, 2007), yet research suggests that there is continuity between children's preverbal and verbal production that could benefit from being measured continuously. Children produce both prelinguistic and linguistic vocalizations for several months within the second year; although children tend to produce their first word around 12 months, they may produce hundreds of word by 24 months (Stoel-Gammon, 2011). Phonological aspects of toddlers' babble and early words are often similar (Locke, 1989; McCathren et al., 1999; Stoel-Gammon, 1992). Furthermore, the amount and timing of babbling predict the amount and timing of early speech (Locke, 1989; McCathren et al., 1999; Roe, 1977; Stoel-Gammon, 2011).

Most studies of young children's early vocalizations have measured single dimensions of vocal quality (e.g., CS or CI) and do not distinguish between preverbal vocalizations and word approximations (Oller et al., 1999; Patten et al., 2014; Paul et al., 2010; Sheinopf et al., 2000; Watt et al., 2006; Yoder et al., 2015). The current study will further refine the measure of vocal complexity by examining whether nonword vocal complexity is a value-added predictor of later expressive language. While aspects of vocal quality have been found to predict later expressive language in typically developing children and children with ASD, no studies have examined these relations for HR toddlers. There is a need for fine-grained measurement of young children's vocal development and interaction across the prelinguistic and linguistic stages, as earlier identification of low or delayed vocal complexity may signal a need for preventative intervention.

Vocal Complexity and Intervention in ASD

Toddlers at high risk for ASD display deficits in expressive vocabulary by 18 months compared to toddlers at no familial risk (Edmunds, Ibañez, Warren, Messinger, & Stone, 2016); these deficits become especially clear when comparing HR toddlers who go on to be diagnosed with ASD to LR toddlers between two and five years of age (Brignell et al., 2018; Iverson et al., 2017; Malesa et al., 2012), and language deficits endure through the preschool and early school-age period (Brignell et al., 2018). Intervention on both language and broader social communication skills is likely more effective when delivered earlier in development, when pivotal skills of language and social communication are emerging (Dawson, 2008; Dawson et al., 2012; Wetherby & Watts, 2006). As such, there is a need to identify malleable early intervention targets for children at risk for language deficits and ASD.

Although vocal complexity appears to be an early pivotal skill that contributes to later social communication outcomes, it is unknown whether it is malleable with intervention. Evidence from speech sound disorder intervention research suggests that the number and type of speech sounds that children produce can increase with intervention (Allen, 2013; Law, Garret, & Nye, 2004; Tyler, 2008). Yet merely increasing speech sounds or vocal complexity may not be the most effective way to facilitate later language production in children with or at risk for ASD. There is a need to examine mechanisms by which treatments are effective (Kazdin & Nock, 2003). In particular, parent-implemented social communication interventions for children with and at risk for ASD are becoming increasingly prevalent, and to justify the potential stress for parents of becoming their child's primary interventionist, it is important to highlight the mechanisms by which we expect parent-implemented interventions to be as or more effective for children than provider-implemented interventions (McConachie & Diggle, 2007).

This study presented a unique opportunity to study vocal complexity and language development in the context of a parent-implemented social communication intervention currently being evaluated through a study conducted at Vanderbilt University (VU; Yoder, PI) and University of Washington (UW; Stone, Site PI). The study is a randomized controlled trial (RCT) in which HR toddlers are randomly assigned to an evidence-based social-communication intervention, Improving Parents As Communication Teachers (ImPACT; Ingersoll & Wainer, 2013), versus a business-as-usual condition (BAU).

ImPACT is a 12-week, naturalistic developmental behavioral intervention (NDBI) that has been shown to improve social communication and language skills in toddlers with ASD (Ingersoll & Wainer, 2013; Schreibman et al., 2015). Toddlers at high risk for ASD also have lower expressive and receptive language as well as social communication skills compared to toddlers at low risk for ASD (Stone, McMahon, Yoder, & Walden, 2007). An important component of ImPACT is its focus on facilitating opportunities for parent-child interaction and increasing parents' linguistic input. ImPACT teaches parents to expand on children's vocalizations and language and respond contingently to toddlers' vocalizations. For example, in certain phases, parents are taught to consider any vocalization their child makes as meaningful and respond with a slightly more advanced type of communication.

In essence, ImPACT teaches parents to amplify their pre-existing role as powerful influencers of their children's language ability within a transactional framework. Transactional theories hold that reciprocal child-environmental influences form the context for language learning (Leve & Cicchetti, 2016; McCathren et al., 1999; McLean & Synder-McLean, 1978;

Sameroff, 1983; Sameroff & Chandler, 1975; Sameroff & Fiese, 2000). Children learn words through referential communication with their social partners (social-cognitive theory; Baldwin & Moses, 1996; McDuffie, Yoder, & Stone, 2005; Tomasello, 2003) and social interaction has been proposed to be essential for speech learning (Kuhl, 2007). In particular, the transactional theory of “speech sound development” holds that parent’s responsiveness to their children’s communication mediates the relation between child canonical syllable use and later expressive language (Woynaroski, Yoder, Fey, & Warren, 2014; Yoder & Warren, 1999).

Parents’ verbal responsiveness and children’s vocal production clearly influence each other in a transactional manner over time, a phenomenon that could have cascading implications for HR children. Caregivers are more likely to respond (or to respond more frequently) to their children’s more complex or more speech-like vocalizations (Gros-Louis, West, Goldstein, & King, 2006; Papousek, 1993; Reeve, Brown, & Poulson, 1992; Warlaumont, Richards, Gilkerson, & Oller, 2014). Parents’ sensitive, language-promoting responses to the vocalizations that both children with ASD and TD children produce have been found to predict increased subsequent vocalizations (Warlaumont, Richards, Gilkerson, & Oller, 2014), increased vocal complexity (Goldstein & Schwade, 2008; Gros-Louis, West, Goldstein, & King, 2006; Stoel-Gammon, 2011; Woynaroski et al., 2015), and better expressive language outcome (Baldwin, 1995; Bottema-Beutel, Yoder, Hochman, & Watson, 2014; Carey & Bartlett, 1978; McDuffie & Yoder, 2010; Oller et al., 2010; Siller & Sigman, 2002; Siller & Sigman, 2008; Spiker, Boyce, & Boyce, 2002; Stoel-Gammon, 2011; Tamis-LeMonda, Bornstein, & Baumwell, 2001; Yoder, Warren, McCathren, & Leew, 1998).

Because parent responsiveness to child vocalizations has been found to predict increased vocal complexity and better expressive language in TD children and children with ASD (Gros-

Louis et al., 2014; McDuffie & Yoder, 2010; Tamis-LeMonda et a., 2001), it is plausible that ImPACT will also increase HR toddlers' vocal complexity by teaching parents to increase their responsiveness to children's attempts to communicate with them. Further, increasing parents' verbal responsiveness may result in better language outcomes specifically for children with or at risk for ASD because these children may not be attending to and processing all of the language input that is present in a social environment that is scaffolded with typical levels of parent responsiveness; these children may need increased scaffolding from parents to increase the "intake" from the environmental language "input" (Tenenbaum, Amso, Righi, & Sheinkopf, 2017). Studies have found that parents initially respond to any of their infant's vocalizations, but as their children mature, parents become more selective and are more likely to respond to more complex sounds (Stoel-Gammon, 2011) and/or sounds perceived as communicative (West & Rheingold, 1978; Yoder & Feagans, 1988). The ImPACT intervention may help parents amplify this ability to facilitate the communication development of their children at high risk for ASD.

This study will assess whether the ImPACT intervention affects toddlers' vocal complexity by increasing parents' verbal responsiveness to vocally complex sounds compared to business as usual (BAU). This study will also model parental verbal responsiveness as a mediator of the effect of ImPACT treatment on vocal complexity and later expressive language ability, consistent with transactional theories (McLean & Synder-McLean, 1978; Sameroff, 1983; Sameroff & Chandler, 1975; Sameroff & Fiese, 2000).

In line with the transactional model of language development, toddlers' vocal complexity will be examined exclusively within their communicative acts, because adults respond differentially to toddlers' vocalizations that seem intentional compared to the rest of their vocalizations, (McCathren, Yoder, & Warren, 2000; Plumb & Wetherby, 2013; Watt, Wetherby

& Shumway, 2006; Wetherby, Watt, Morgan, & Shumway, 2007; Woynaroski, 2014; Yoder, Watson, & Lambert, 2015). Also, infants' prelinguistic vocalizations that are communicative in nature predict increased word use over and above vocalizations that are not directed to others for the purpose of communication (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; McCathren et al., 1999; West & Rheingold, 1978). Indices of vocal complexity that only include vocalizations within communicative acts predict later language ability more strongly compared to indices of vocal complexity that do not consider communicative intent (e.g., derived from automated recording and analyzing devices; Yoder, Oller, Richards, Gray, & Gilkerson, 2013; Woynaroski, 2014).

Thus far, there have only been two randomized control trials that have examined parent-implemented interventions explicitly designed to increase expressive language ability in HR toddlers, and they have found mixed results (Baranek et al., 2016; Kasari et al., 2014). Baranek and colleagues found that although the intervention they tested (Adapted Responsive Teaching) was designed to increase parents' responsiveness to their children and children's language ability, only children's language ability increased relative to the monitoring only control group (2016). In contrast, Kasari and colleagues assessed an intervention similarly designed to increase parent responsiveness and child language ability (Focused Playtime Intervention) and found that parent responsiveness, but not child language, increased from pre- to post-intervention in the treatment group compared to a monitoring only control group (2014). Green and colleagues found that their intervention promoting more synchronous parent-child intervention did not produce significant treatment effects immediately post-intervention but that over the next three years, there were significant cumulative effects of intervention. Research on parent-implemented language interventions designed to increase parent responsiveness in older children diagnosed with ASD has yielded more promising results (Carter et al., 2011; Green et al., 2010; Venker, McDuffie, Ellis Weismer, & Abbeduto, 2011). Green and colleagues and Venker and colleagues found that their interventions increased parent verbal responsiveness and child language ability compared to control groups, while Carter and colleagues did not.

Importantly, no studies have examined longitudinal indirect effects to determine whether parent-implemented social communication interventions increase parents' responsiveness to toddlers' communicative vocalizations, *in turn* increasing later vocal complexity and expressive language. Early transactional communication between toddlers and adults provides a conceptual framework for later verbal and social interaction (McCathren et al., 1999; Mundy, Kasari, Sigman & Ruskin, 1995; Mundy & Hogan, 1994). As social communication is clearly impaired by 2 to 3 years of age in ASD, studying both HR toddler vocal complexity and parent verbal responsiveness in a transactional manner may elucidate differences in early interactive processes for children with language delay and/or ASD. There is also empirical support for the idea that intervention may improve child outcomes through, or mediated by, more synchronous parental interaction (Aldred et al., 2012; Pickles et al., 2016).

The overall aim of this study was to examine vocal complexity within a longitudinal randomized controlled trial of ImPACT (compared to BAU) for HR toddlers. This study assessed whether vocal complexity was a predictor of expressive language ability and tested the malleability of parent verbal responsiveness and vocal complexity in HR toddlers in response to an early social communication intervention.

The specific aims of this study were as follows:

Aim 1. Examine the incremental validity of nonword compared to word vocal complexity in predicting later expressive language in HR toddlers. It is hypothesized that vocal complexity, as it has previously been operationalized as occurring within both words and nonwords, will predict toddlers' expressive language outcome at the end of the second year. It is further proposed that the relation between vocal complexity and expressive language is partially explained by the nonword component of vocal complexity. Specifically, by controlling for the number of words toddlers speak within the same context as vocal complexity is measured, the vocal complexity variable would effectively measure vocal complexity that occurred in *nonwords only.* Vocal complexity controlling for words spoken (i.e., nonword vocal complexity) would therefore become a more developmentally appropriate measure of prelinguistic vocal maturity.

Nonword vocal complexity may better capture the language potential of toddlers who are able to produce few or no words. Younger toddlers are more likely to be using none or few words compared to toddlers closer to their second birthday, and vocally complex nonwords are therefore more likely to be their most complex type of vocalization. Therefore, child chronological age may moderate the association between nonword vocal complexity and later language such that nonword vocal complexity predicts later expressive language more strongly for younger compared to older toddlers.

Aim 2. Investigate the effect of the ImPACT intervention, parent verbal responsiveness, and vocal complexity on expressive language ability. It is hypothesized that, compared to families in the BAU condition, families in the ImPACT condition will have higher parent verbal responsiveness to their children's vocally complex communication acts, higher subsequent toddler vocal complexity, and better toddler expressive language outcomes (H2a). It is also hypothesized that toddlers' initial level of behavioral risk for ASD will moderate the effect of the ImPACT intervention on parent verbal responsiveness, and vocal complexity on later expressive language outcome such that ImPACT may be more effective for toddlers who display greater levels of pre-intervention behavioral risk for ASD, as they may benefit most from the increased parental scaffolding that the ImPACT intervention promotes (H2b).

Aim 3 (exploratory): Investigate longitudinal indirect effects of the ImPACT intervention and parent verbal responsiveness on vocal complexity and expressive language ability. Three additional exploratory hypotheses are proposed (Figure 1). First, the ImPACT intervention may affect toddlers' vocal complexity indirectly through intermediate parent verbal responsiveness to toddlers' vocally complex communication acts (H3a). Also, the ImPACT intervention may affect toddlers' later expressive language indirectly through intermediate vocal complexity (H3b). Finally, post-intervention there may be an indirect effect of parent verbal responsiveness on later expressive language through midpoint vocal complexity (H3c). Aim 3 hypotheses are exploratory given that with the current sample size, we only have .80 power to detect an indirect effect composed of a medium and a large effect (Fritz & MacKinnon, 2007), and also given the fact that there are mixed empirical results thus far on the effects of HR toddler early interventions on expressive language (e.g., Baranek et al., 2015; Carter et al., 2011; Kasari et al., 2014).

This study aimed to: (a) refine the construct and measurement of vocal complexity; and (b) identify the roles of parent verbal responsiveness and vocal complexity as mediators of response to a parent-implemented, social-communication intervention for children at elevated risk for ASD and language delay. Vocal complexity may represent an early indicator for ASD and language delay that could be used in screening tools and clinical evaluations. If vocal complexity is malleable through intervention, then it would represent a unique early intervention target for toddlers at high risk for ASD and language delay.

Method

Participants

Participants were 54 12 to 18-month-old high risk (HR) toddlers and their parents, recruited for the ongoing ImPACT randomized controlled trial at Vanderbilt University [VU] and the University of Washington [UW]. HR toddlers (n = 28) who were randomly assigned to the ImPACT intervention will be referred to as "ImPACT" toddlers. HR toddlers (n = 26) who were randomly assigned to the "business as usual" group will be referred to as "BAU" toddlers. Inclusion criteria were having at least one older sibling with a verified ASD diagnosis and living within 30 miles of UW/VU, having no genetic or neurological conditions, and >50% English spoken at home (Table 1).

Procedures

BAU and ImPACT toddlers were eligible to enroll between 11.5 and 18.5 months of age. Families visited the UW or VU labs at four time points as part of the overarching ImPACT RCT: Time 1 (T1; baseline; 12-18 months of age); Time 2 (T2; immediately after the 3-month ImPACT intervention; 15-21 months of age); Time 3 (T3; 3 months after ImPACT; 18-24 months of age); and Time 4 (T4; 6 months after ImPACT; 21-27 months of age). Toddlers in the ImPACT condition were about 1 month younger at each time point than toddlers in the BAU condition, $.04 < ps < .06$ (Tables 1, 2). For Aim 1, HR toddlers' vocal complexity was measured at T3 and their expressive language was measured at T4. For Aims 2 and 3, HR toddlers' parent verbal responsiveness (PVR) was measured at T2, vocal complexity was measured at T3, and expressive language was measured at T4 (Table 2).

Treatment Conditions

After Time 1 visits to the lab at UW or VU, families were randomly assigned to the BAU treatment condition or the ImPACT intervention treatment condition.

BAU. Toddlers in the BAU condition received assessments and developmental monitoring at all four study time points. They were not restricted from receiving intervention outside of the study, and information on their non-study intervention activity was collected at T1, T2, and T3 through qualitative interviews. There were no significant differences between treatment conditions in the number of hours of outside intervention received at any time point; $.48 < ps < .83$.

Project ImPACT. Toddlers in the ImPACT condition received the intervention in the three months between their T1 and T2 assessment visits. Parents in the ImPACT condition received two one-on-one, in-home coaching sessions per week from bachelors' and masters' level clinicians who received training from the developer of ImPACT, Dr. Brooke Ingersoll. Outside of coaching sessions, parents were asked to use ImPACT strategies with their child one hour per day for five days per week. The ImPACT intervention was selected for the parent study as an appropriate intervention to implement with toddlers at high risk for ASD because of its focus on developmentally tailored and naturalistic settings appropriate for young children in the second year of life and its focus on early pivotal developmental skills such as play, imitation, language, and social engagement. Previous research supports the efficacy of ImPACT in improving elicited and spontaneous imitation skills, joint attention initiations, social-emotional functioning, and expressive language in children with ASD (Ingersoll & Wainer, 2013; Ingersoll, 2012; Stadnick; Stahmer, & Brookman-Frazee, 2015).

Measures

Vocal complexity. Vocal complexity was coded exclusively for the current study, using ELAN, a customizable behavior coding software, from videos of the Communication and

Symbolic Behavior Scales- Developmental Profile Behavior Sample (CSBS-DP) (Wetherby & Prizant, 2002) and the Brief Observation of Social Communication Change (BOSCC; Grzadzinski et al., 2016; Kitzerow et al., 2015) in all ImPACT and BAU toddlers. Previous research has found that aggregating across these procedures produces a stable measure of vocal complexity ($g = .87$) in minimally verbal children (Woynaroski, 2014). The CSBS-DP and BOSCC are both semi-structured examiner-child interactions. The CSBS-DP lasts 20-30 minutes, during which an examiner presents the child with a series of communicative temptations that include toys, book reading, questions, and free play. The BOSCC was developed to capture change in core ASD symptoms in response to intervention and lasts 10-15 minutes. During the BOSCC, an examiner presents a child with a standardized set of toys and engages in a variety of semi-structured and unstructured play with the child using the toys. In these procedures, examiners present toddlers with open-ended presses designed specifically to elicit requests for objects, joint attention, and play.

Vocal complexity was coded using a system that has been employed in previous studies (Woynaroski, 2014). First, five-second intervals that contain a communicative act were identified. Then, intervals that contain communicative acts were coded for: (a) the presence of canonical syllables (CS) and (b) the number of different consonants present (i.e., consonant inventory; CI). Finally, intervals that contain a communicative act and a canonical syllable were identified as either containing words or not containing words.

Specific definitions for communicative acts, canonical syllables, and consonant inventory are presented below and in Figure 2. The following child behaviors were considered to form communicative acts: 1) a non-imitative sign, word, or word approximation with appropriate referential context; 2) a nonword vocalization with evidence of attention to an object or event as well as an adult within 3 seconds of the vocalization; or 3) a gesture with evidence of attention to an object or event and/or an adult, as needed (Yoder, Watson, & Lambert, 2015). A word or word approximation has referential context when it is used in close proximity to its referent. For example, if a toddler said "frog," this word would have referential context if he or she had just looked at a frog toy or frog picture. Evidence of attention was noted in several ways, including toddlers' eye gaze, moving towards the object or adult, giving of objects to the adult, and answering adults' questions (Figure 2).

Canonical syllables (CS) were defined as vocalizations that have a consonantal sound, a vowel, and a smooth transition between the consonant and vowel (Oller, 2000). For example, the classic "ba" sound, pronounced clearly and triumphantly by an infant, would likely be considered a canonical syllable. Consonant inventory (CI) was defined as the number of unique consonants that toddlers say within an observation period. The consonants that were coded for inclusion in each toddlers' consonant inventory were derived from the CSBS-DP manual's True Consonant Inventory List (Wetherby, Watt, Morgan, & Shumway, 2007; Wetherby & Prizant, 2002), which is a subset of 10 possible supraglottal consonants that either emerge earliest or are said frequently by young children and are more reliable to code. Some consonants within the subset appear relatively later in development and were included to reduce the possibility of ceiling effects when studying older toddlers. In previous studies, CS and CI were highly correlated ($r = .84$), supporting the feasibility of aggregation (Woynaroski, 2014). A word was defined as a vocalization that includes vowels and consonants that are functionally recognizable as words or word approximations (Oller, 2000; Woynaroski, 2014). Word approximations were defined as communicative utterances that have sounds that recognizably differ but are derived from adult words (May et al., 1999) in that they contain at least one fully formed syllable of the word, including the actual or an appropriate child-like substitute for both the consonant and the vowel. Child-like substitutes for consonants and vowels within words were coded in accordance with previous research (e.g., Woynaroski, 2014).

Ultimately, two variables were created from toddlers' communication acts during the CSBS and BOSCC: Vocal complexity and words spoken. Vocal complexity was operationalized as a unit-weighted aggregate of a) the proportion of communication acts that contain canonical syllables; and b) consonant inventory. Words spoken was operationalized as the number of words used communicatively (i.e., the number of communication acts that contained words; Table 3).

Parent verbal responsiveness. Parent verbal responsiveness (PVR) was coded exclusively for the current study at Time 2 from two study procedures: Parent Child Free Play (PCFP; Carter et al., 2011; Woynaroski, 2014; Woynaroski et al., 2015; Yoder, Watson, & Lambert, 2015) and Parent Child Snack (PCS; Woynaroski, 2014; Woynaroski et al., 2015; Yoder, Watson, & Lambert, 2015). The PCFP and PCS are both semi-structured parent-child interactions that were conducted during the parent ImPACT study. The PCFP is a 15-minute interaction in which parents and their children are given a standardized set of toys in a lab playroom and told to play as they normally would at home. The PCS is a 10-minute interaction in which parents are given a variety of snacks to offer their child and told to interact as they normally would when trying to elicit their child's communication around their snack preferences.

To code parent verbal responses, we first used a timed event coding scheme to identify all instances of child communication acts that contained canonical syllables (Figure 2). Then, we determined the presence and quality of parents' responses to those vocally complex communication acts. Parent verbal behavior was classified as responsive if, within three seconds or less after the child's vocally complex communication act, a parent said something that aligned with the context or content of the child's communication act and added semantic or phonological value to the child's communication act. Three different types of responsiveness to children's communication acts were considered during coding: linguistic mapping (verbally interpreting the child's communicative act), repeating (repeating what the child said), and expanding (verbally expanding on what the child said; Haebig, McDuffie, & Ellis Weismer, 2013; McDuffie & Yoder, 2010; McDuffie et al., 2013; Venker et al., 2011; Yoder et al., 2015; Woynaroski et al., 2015). However, reliability checks were not conducted for these sub-categories; therefore all three types of parent verbal responsiveness to vocally complex child communication acts were combined into one variable. Three seconds has been considered sufficient for a parent response to be judged as contingent on a child's communication act in other studies of parental response to vocalization (Gros-Louis et al., 2014; Northrup & Iverson, 2015; Talbott et al., 2015). One variable for PVR was used in analyses: the proportion of toddlers' communication acts that contained canonical syllables (CS) to which parents responded with a verbal response that added semantic or phonological information relevant to the child's context (Table 3).

Expressive language. Toddlers' expressive language was measured at T1 and T4 via three widely used measures with strong psychometrics: expressive vocabulary, number of word roots, and an expressive language age equivalent from a cognitive test. Expressive vocabulary was measured using the MacArthur-Bates Communicative Development Inventory (MCDI), a measure of parent-reported expressive vocabulary (Fenson et al., 2007). The MCDI contains a checklist of 396 vocabulary words, and parents endorse the words their child can "understand" and "say." The Words and Gestures Edition was used at T1, and the Words and Sentences Edition was used at T4. The MCDI variable of interest was total number of words parents reported their child both understands and says. The number of word roots observed within the CSBS-DP served as a laboratory-based sampling of expressive language. The final measure included in the expressive language aggregate was the Mullen Scales of Early Learning (MSEL; Mullen, 1995) Expressive Language Age Equivalent. The MSEL is, a standardized experimenter-administered measure of cognitive skills in four domains. The expressive language variable metric served as an indicator of developmental level and was a unit-weighted aggregate of these three measures; in studies with small sample sizes and no *a priori* rationale for weighting a certain procedure more than others in the measurement of the construct, unit-weighted aggregation can be a suitable alternative to latent factor analysis (Yoder, Lloyd, & Symons, 2018).

Behavioral risk for ASD. A continuous measure of pre-intervention behavioral risk for ASD was derived using raw scores from behavioral screeners that toddlers' parents completed at Time 1. Toddlers 15 months and younger were given the First Year Inventory (FYI), and toddlers older than 15 months were given the Modified Checklist for Autism in Toddlers, Revised with Follow-Up (M-CHAT-R/F) (Watson et al., 2007; Robins et al., 2009). Both the FYI and the M-CHAT-R/F have cut-off scores that indicate risk for ASD, and each toddler's raw score on the FYI or M-CHAT was standardized with respect to the clinical cut-off score for the screener their parents completed and then combined into a single behavioral ASD risk variable. Positive values of behavioral ASD risk indicate a toddler is above the clinical cutoff for ASD risk, and higher values of behavioral ASD risk indicate greater risk for ASD. We used a continuous measure of behavioral ASD risk rather than indicating whether a toddler scored above or below the dichotomous clinical cutoff for risk because the use of dichotomous variables can reduce power (Rucker, McShane, & Preacher, 2015).

The First Year Inventory (FYI) was designed for one-year-olds and asks parents to report on eight child behaviors organized into two domains: social-communication (comprised of social orienting and receptive communication, social affective engagement, imitation, and expressive communication constructs) and sensory-regulation (comprised of sensory processing, regulatory patterns, reactivity, and repetitive behaviors constructs). Cutoff scores for ASD risk in 14-month-olds have been determined to be 22.50 for the social-communication domain and 14.75 for the sensory-regulation domain (Turner-Brown et al., 2012). Toddlers' raw FYI domain scores were standardized with respect to the risk cutoff score for that domain and then averaged together to yield a single ASD risk score.

The Modified Checklist for Autism in Toddlers, Revised with Follow-up (M-CHAT-R/F) was designed for 16- to 30-month-olds and asks parents about behaviors such as difficulties with social referencing, initiating joint attention, and response to joint attention (Robins, Fein, & Barton, 2009). After parents fill out the form, a follow-up interview is conducted for scores above 2. A score of 2 or higher after follow-up indicates risk for ASD (Robins et al., 2014). Toddlers' scores after follow-up were standardized with respect to a cutoff score of 2.

Covariates. Toddlers' Time 1 motor imitation was included as a covariate in several analyses due to significant pre-treatment group differences on this variable despite randomization (see Analysis of necessary covariates section in Results). Toddlers' imitation abilities were measured using the Semi-structured Imitation Scale (SSIS). In this semi-structured examiner-child interaction, the examiner models 10 actions for toddlers to imitate. It is a shortened version of a procedure designed for use with toddlers and preschoolers with ASD to measure interactive motor imitation (Ingersoll & Meyer, 2011).

Reliability of coded measures. Vocal complexity and PVR were coded specifically for the current study. Procedures were selected based on their proven record of use with children at young ages. To establish reliability on vocal complexity and parent verbal responsiveness, trained undergraduate coders blind to treatment condition and hypotheses read a manual, engaged in continued discussion of discrepancies in coding, and met 80% reliability on three samples. Twenty percent of subsequent videos were double-coded to establish ongoing reliability. CS and CI have high reliability using this coding system (CS ICC: .96; CI ICC: .96; Woynaroski, 2014; Woynaroski et al., 2015). Sample-level interobserver reliability was assessed using intraclass coefficients (ICCs) with two-way random model using absolute agreement. The ICC for T2 PVR was .81. Reliability for T3 vocal complexity and T3 word spoken was ICC = .95 and ICC = .89, respectively (see Table 4).

Results

Preliminary Analyses

T3 vocal complexity aggregate formation. We planned to aggregate the proportion of canonical syllabic communication (CS) and consonant inventory (CI) if they were significantly correlated at $r = .40$ or greater (Cohen & Cohen, 1984). In the current sample, the metrics of CS and CI, averaged across the CSBS and the BOSCC, were highly correlated $r = .73$, $p < .001$. Therefore, they were z-score transformed using the mean and SD of each variable and then averaged to form a unit-weighted aggregate for T3 vocal complexity (Yoder, Lloyd, & Symons, 2018).

T4 expressive language aggregate formation. We planned to aggregate three measures of expressive language developmental level: the Expressive Language Subscale Age Equivalent from the T4 Mullen, the Expressive Vocabulary score from the T4 MCDI, and the number of word roots used during the T4 CSBS (see Table 5). These component variables were significantly correlated with each other at $r = .65$ and higher. The T4 expressive language component variables were therefore z-score transformed and averaged to form a unit-weighted aggregate using the mean and SD of each variable (Yoder, Lloyd & Symons, 2018).

Assessment of necessary covariates. Randomization to treatment condition should in theory produce groups with baseline equivalence on variables of interest and auxiliary variables. However, random assignment does not always create baseline equivalence, especially in relatively small samples. Any auxiliary variable that a) differed by treatment condition at Time 1 (pre-intervention) and b) significantly predicted outcome variables of interest could have impeded the causal inferences that could be made about the effect of the ImPACT intervention on parent and child behaviors of interest, because it could serve as an alternate explanation of the treatment effect. A variety of auxiliary T1 covariates were available from the overarching RCT for use in these analyses. A complete analysis of potential covariates was conducted using these covariates (see Table 5).

The only T1 covariate that was found to significantly differ by treatment condition and also predict any outcome variables of interest was toddlers' T1 imitation ability. As such, it is described in the methods section of this study. The other variables listed are not described within the methods section of this study, but further information is available upon request. At Time 1, toddlers in the ImPACT condition displayed lower imitation compared to toddlers in the BAU condition, and T1 imitation significantly predicted T3 vocal complexity and T4 expressive language. However, the effect of imitation on T3 vocal complexity and T4 expressive language did not vary by treatment condition, thus the assumption of homogeneity of slopes was not violated. Imitation was included as a covariate in any model in which treatment condition was a predictor and T3 vocal complexity or T4 expressive language was the outcome variable (Aims 2 and 3).

Model building principles. Ordinary least squares (OLS) multiple linear regression models were used to assess each aim. In models that included interaction terms to assess moderation, the component variables were centered before inclusion in the model and formation of the interaction term. Models were fitted using a systematic model building process: first, the hypothesized *a priori* models were tested. Non-significant predictors were removed from the model. If an interaction term was significant, any main effect terms, whether significant or non-significant, remained in the model. Tables 8, 9, and 11 display the *a priori* model as well as the final model for each aim, though there may have been intermediate steps in the model building process.

Tests of assumptions of multivariate regression. Each multiple regression model was examined to determine whether it met the assumptions of multivariate regression (Berry, 1993), including: 1) a linear relationship between the independent variables and the dependent variable; 2) no perfect multicollinearity; 3) multivariate normality, i.e., that the model residuals are normally distributed without the undue influence of outliers; and 4) homoscedasticity, i.e., that the variance of the residuals is similar across values of the independent variables. Multivariate normality was assessed by examining the skewness, kurtosis, and Q-Q plots of the residuals for each model. Any outliers identified using Cook's distance were also identified and assessed. Homoscedasticity was examined by plotting the predicted values against the residuals for each model. Outlier analyses, skewness and kurtosis of model residuals, and plots of predicted values against residuals for each aim are available upon request.

Assumptions of homoscedasticity were met for all models, and there was no undue influence of outliers on any model. However, models for research aims that involved T2 PVR produced non-normal residuals. An examination of individual variables revealed that all met criteria for reasonable skewness (> |.8|) and kurtosis (> |3.0|) except for T2 PVR (skew = -1.21), T3 words spoken (skew = 2.00, kurtosis = 3.94), T4 expressive language (EL) aggregate, and T1 ASD behavioral risk (skew = 1.70, kurtosis = 4.27) (Tabachnick & Fidell, 2001; see Table 6). T3 words spoken, T4 expressive language, and T1 ASD behavioral risk were not transformed because the assumptions of multivariate regression, including multivariate normality, were met for the regression models that involved these variables, and some researchers suggest that refraining from transforming variables can aid interpretability of the results by keeping variables in their original units (Feng et al., 2014). However, as the significant negative skew and high kurtosis of T2 PVR resulted in non-normal residuals for models in which it was included, it was reflected and log transformed for use in analyses. Models using the reflected and log-transformed T2 PVR variable met all assumptions of multivariate regression, including multivariate normality.

Missing data and attrition. Out of the 59 families who entered the study, 5 families (8% of the sample) dropped out after T1 (3 BAU; 2 ImPACT); these participants did not have data for any variables of interest and were not included in the current sample. One toddler (BAU) dropped out of the study after T3 and is thus missing T4 expressive language data; this participant is included in the current sample. Finally, three toddlers (5% of the sample) were missing data for T2 PVR due to video recording error (2 BAU; 1 ImPACT); these participants were also included in the current sample. Listwise deletion thus occurred for analyses that involved T4 expressive language or T2 PVR. Missingness for each variable was not correlated with variables of interest, $.27 < ps < .97$. All analyses were repeated using a generalized linear model framework with maximum likelihood estimation to create model estimates that accounted for missing data; model estimates and fit were not substantially different from those obtained using OLS regression. Because of this, and because OLS regression is more parsimonious and enabled the calculation of bootstrapped confidence intervals for the mediation analyses in Aim 3, models using OLS regression are reported here.

For each aim, we assessed overall attrition as well as differential attrition by treatment condition. Overall attrition for analyses addressing research aims ranged from 8.5% (part of Aim 2) to 15.2% (Aim 3). Differential attrition by treatment condition ranged from 3.6% (part of Aim 2) to 10.7% (Aim 3). Differential attrition rates for all analyses were within liberal boundaries for determining whether a study has low overall attrition (IES, 2017). Therefore, differential attrition would not be not a likely alternate explanation for our findings regarding treatment effects. Attrition for this study is lower than or comparable to what has been reported for other intervention studies with HR toddlers (e.g., Carter et al., 2011; Kasari et al., 2014).

Descriptive Analyses

Toddlers' expressive language grew from T1 to T4, F (1, 47) = 90.76, $p < .001$, but there were no significant differences in growth by treatment condition, F (1, 47) = 0.59, $p = .45$, (see Table 1). Means, standard deviations, and ranges for study variables are presented in Table 6. Of note, on average, parents responded to 69% of their toddlers' communication acts with canonical syllables at T2 (SD = 0.23). Also, at T1, toddlers scored on average 0.52 standard deviations below ASD risk cutoffs (SD = 0.91; Table 6).

Pearson product-moment zero-order correlations between study variables revealed that T2 parent verbal responsiveness (PVR) was significantly correlated with T3 vocal complexity (r = .36), but not T4 expressive language (r = .28) (see Table 7). T3 vocal complexity was significantly correlated with T4 expressive language, (r = .73). T1 behavioral risk for ASD was significantly correlated with T4 expressive language (r = -.27), but not with other variables of interest. Of note, T1 ASD behavioral risk was proposed as a potential moderator of treatment effect in Aim 2. Thus, it would not be expected that T1 behavioral risk is necessarily significantly zero-order correlated with other variables of interest, regardless of treatment condition.

Main Analyses

Aim 1. The goal of Aim 1 was to examine the incremental validity of vocal complexity (regardless of word status) controlling for word use in predicting later expressive language in HR toddlers. This aim used a previously validated operationalization of vocal complexity (i.e., an aggregate of the proportion of communication acts with canonical syllables [CS] and consonant inventory [CI]) that does not distinguish between vocal complexity occurring within words and nonwords. However, by controlling for T3 words spoken (i.e., number of verbal communication acts) in this aim, the T3 vocal complexity variable is effectively measuring vocal complexity that occurs in *nonwords,* which is a distinct construct from expressive language outcome. Further, it was hypothesized that the relation between T3 nonword vocal complexity and T4 expressive language would be moderated by child age such that nonword-based vocal complexity would more strongly predict later expressive language for younger compared to older toddlers.

To assess this aim, both T3 vocal complexity and T3 words spoken were entered into a model predicting T4 expressive language, such that with T3 words spoken controlled for in the model, the T3 vocal complexity variable became a nonword-centric measure of vocal complexity. T3 age (M = 20.44 months; SD = 17.64 – 24.90 months) and an interaction term between T3 age and T3 vocal complexity were also entered into the *a priori* model. The relation between T3 nonword vocal complexity and T4 expressive language did not vary by toddlers' T3 age, $\beta = .04$, $p = .72$. There was no main effect of T3 age, thus T3 age and its interaction term were removed from the model. The final model included T3 words spoken and T3 vocal complexity as significant predictors of T4 expressive language, $\beta = .44$, $p = .001$ and $\beta = .41$, $p = .002$, respectively. Adding T3 vocal complexity into the model, while controlling for T3 words spoken, resulted in a significant R squared change of .08; thus nonword T3 vocal complexity explained an additional 8% of the variance in T4 expressive language growth after controlling for other variables in model (see Table 8). The interpretability of the vocal complexity metric within models controlling for T3 words spoken becomes quite complicated, however. Future research should investigate a cleaner way of isolating vocal complexity within nonwords.

In subsequent analyses for Aims 2 and 3 involving T3 vocal complexity, T3 words spoken was not included as a covariate. This allowed us to assess the effect of the ImPACT intervention on overall vocal complexity as it has been operationalized in all previous literature and to increase the interpretability of the vocal complexity metric. Indeed, one would expect vocal complexity to eventually be manifested in word use. Refraining from controlling for word use enabled the vocal complexity variable to reflect word and nonword vocal complexity that included consonants.

Aim 2. The goal of Aim 2 was to investigate the effect of the ImPACT intervention on T2 parent verbal responsiveness (PVR), T3 vocal complexity, and T4 expressive language. Two main hypotheses and one exploratory hypothesis were advanced. First, it was hypothesized that toddlers in the ImPACT condition will have greater T2 PVR, greater T3 vocal complexity, and greater T4 expressive language (H2a). Second, it was hypothesized that effects of treatment condition on T2 PVR, T3 vocal complexity, and T4 expressive language may be moderated by toddlers' T1 ASD behavioral risk such that the ImPACT intervention may be more effective for those at greater ASD risk (H2b). Predictors were mean-centered before the creation of interaction terms and inclusion in models (Aiken & West, 1991). H2a and H2b were addressed together, in three regression models: one each for T2 PVR, T3 vocal complexity, and T4 expressive language.

The effect of intervention on T2 PVR. Treatment condition did not significantly predict T2 PVR, $\beta = -.03$, $p = .86$, suggesting that at Time 2 (immediately post-intervention), parents of toddlers in the ImPACT and BAU conditions responded to similar proportions of their children's vocally complex communication acts. Further, toddlers' T2 PVR did not differ by T1 behavioral ASD risk, and T1 behavioral ASD risk did not moderate of the effect of treatment condition on T2 PVR, *p*s > .05 (see Table 9).

The effect of intervention on T3 vocal complexity. Treatment condition did not significantly predict T3 vocal complexity, $\beta = -.05$, $p = .74$, suggesting that there was no significant difference in the degree of vocally complex communication of toddlers in the ImPACT condition compared to the BAU condition at Time 3, three months after intervention. Toddlers' T3 vocal complexity did not differ by T1 behavioral ASD risk, and T1 behavioral ASD risk did not moderate of the effect of treatment condition on T3 vocal complexity, controlling for T1 imitation, *p*s > .05 (see Table 9).

The effect of intervention on T4 expressive language. Treatment condition did not significantly predict T4 expressive language, $\beta = .09$, $p = .53$. Further, toddlers' T4 expressive language did not differ by T1 behavioral ASD risk, and T1 behavioral ASD risk did not moderate of the effect of treatment condition on T4 expressive language, *p*s > .05, controlling for T1 imitation (see Table 9). Although the final model presented in Table 9 includes the non-significant effect treatment condition because it was the main *a priori* predictor of interest, the most parsimonious final model predicting T4 expressive language would contain a single significant predictor: T1 behavioral ASD risk. All HR toddlers who were at greater behavioral risk for ASD at T1 had lower expressive language at T4, β = -.27, p = .05, R^2 change = .07.

Post-hoc, exploratory analyses for Aim 2: Examining the effect of intervention on components of the variables of interest. In order to investigate the lack of significant differences by treatment condition for T2 PVR, T3 vocal complexity, and T4 expressive language, treatment group differences were examined for the component parent and child behaviors that comprise these variables in a post-hoc, exploratory fashion (see Table 10). The original variables of interest were either proportions or aggregates, and while the *a priori* rationales for the operationalization of each metric remain sound, an examination of the more basic behaviors can shed light on what effects the ImPACT intervention may have had on parent and child communication.

There were no significant treatment group differences on components of the T2 PVR variable, p = .22 (see Table 10). Similarly, there were no significant treatment group differences in components of the T4 expressive language aggregate, .50 < ps < .96. Considering the components of the T3 vocal complexity variable, ImPACT toddlers made significantly more communication acts, p = .05, and trended to making more communication acts with canonical syllables compared to BAU toddlers, p = 08. However, ImPACT toddlers did not have a higher *proportion* of communication acts with canonical syllables compared to BAU toddlers, p = .97. Of note, toddlers in the ImPACT condition also produced more word roots with canonical syllables during the CSBS and BOSCC at T3 compared to toddlers in the BAU condition, p = .05. This suggests that while ImPACT may have increased toddlers' overall number of communication acts compared to BAU, it did not increase the *vocal complexity* of toddlers' communication or their later expressive language ability.

Aim 3. The goal of Aim 3 was to examine mediation pathways by which T2 parent verbal responsiveness (PVR) and T3 vocal complexity may relate to T4 expressive language. Indirect effects were estimated with OLS regression using the PROCESS macro (Hayes, 2013). 95% confidence intervals for each of the indirect effects were calculated using bias-corrected bootstrapping. Bias-corrected bootstrapping is regarded as the most powerful method of computing confidence intervals around the indirect effect (Cole & Maxwell, 2003; Fritz & MacKinnon, 2007; Hayes, 2013; Preacher, Rucker, & Hayes, 2007).

First, it was hypothesized that there would be an indirect effect of treatment condition on T3 vocal complexity through T2 PVR (H3a). T2 PVR was not found to be a significant mediator of the effect of ImPACT on toddlers' T3 vocal complexity. Treatment condition did not significantly predict T2 PVR (path *a*), and T2 PVR did not significantly predict T3 vocal complexity controlling for treatment condition (path *b*). The indirect effect of ImPACT on T3 vocal complexity through T2 PVR, *ab*, was not significant (see Table 11).

Second, it was hypothesized that T3 vocal complexity would mediate the effect of treatment condition on T4 expressive language (H3b). T3 vocal complexity was not found to be a significant mediator of the effect of ImPACT on toddlers' T4 expressive language. Treatment condition did not significantly predict T3 vocal complexity (path *a*), though T3 vocal complexity significantly, positively predicted T4 expressive language controlling for treatment condition (path *b*). The indirect effect of ImPACT on T4 expressive language through T3 vocal complexity, *ab*, was not significant (see Table 11).

Finally, as hypothesized, there was a significant indirect effect of T2 PVR on toddlers' T4 expressive language via toddlers' T3 vocal complexity (H3c; see Table 11). T2 PVR significantly predicted T3 vocal complexity (path *a*), and T3 vocal complexity significantly predicted T4 expressive language controlling for T2 PVR (path *b*). The indirect effect *ab* indicated that parents' increased verbal responsiveness to their children's vocally complex communication acts at Time 2 significantly predicted toddlers' expressive language at Time 4 in part through increased toddler vocal complexity at Time 3 *ab* = 1.74, 95% CI [0.64, 3.19] (see Table 11 and Figure 3). Interestingly, this indirect effect also remained significant when controlling for T3 words spoken, indicating that, when parents respond to a higher proportion of their toddler's vocally complex communication acts, it may positively impact toddlers' later vocally complex nonword communication, which may facilitate their later expressive language ability.

Discussion

This study found that vocally complex communication was a value added predictor of later expressive language ability in toddlers at familial risk for ASD (HR toddlers), above and beyond toddlers' spoken word use within the same time point and measurement context (Aim 1). This study also found that the ImPACT intervention condition did not significantly increase parents' verbal responsiveness (PVR) to their children's vocally complex communication acts compared to business as usual (BAU). Also, post-intervention vocal complexity and expressive language outcomes for toddlers in the ImPACT condition did not significantly differ from that of toddlers in the BAU condition (Aim 2). However, ImPACT did facilitate verbal communication 3 months after treatment ended. Finally, this study found that for all HR toddlers, parents' verbal responsiveness indirectly predicted toddlers' later expressive language ability through increased midpoint nonword vocal complexity (Aim 3).

The Role of Vocal Complexity in Later Expressive Language for Young HR Toddlers

Capturing toddlers' vocal complexity that occurs within nonwords may result in a more developmentally appropriate metric of the maturity of vocal communication than previous metrics of vocal complexity, which measure canonical syllables and/or consonant inventory within words as well as nonwords. This study established that, as hypothesized, the proportion of toddlers' communication acts that are vocally complex significantly predicted later expressive language ability, *above and beyond* the word-based communication they are using in the second year of life. Contrary to hypotheses, we found that this relation was not conditional on toddlers' age; in other words, that nonword vocal complexity at 18—24 months of age predicted later expressive language for all toddlers who are at high familial risk for ASD. This finding is not surprising, given that indices of babbling, including canonical babbling, have long been found to be associated with later language abilities in both typically developing young children and young children with ASD throughout the first three years of life (e.g., Stoel-Gammon, 2011; Watt, Wetherby & Shumway, 2006; Oller et al., 2010; Sheinkopf et al., 2000). However, regardless of toddlers' chronological age, it may be that as toddlers' repertoire of more advanced communication becomes more robust (i.e., they communicate more with vocally complex words), their nonword vocally complex communication becomes less predictive of later expressive language. Toddlers routinely use both words and nonword vocalizations communicatively in the second year, as their vocabulary is rapidly expanding (Stoel-Gammon, 2011), and parents tend to give more language-promoting responses to their toddlers' more vocally complex communication acts (e.g., Gros-Louis et al., 2006; Talbott, Nelson, & Tager-Flusberg, 2015). It may be that once toddlers achieve a certain proportion of word-to-nonword communication, the vocal complexity in their nonword-based communication is a weaker predictor of later expressive vocabulary compared to the vocal complexity (i.e., types of consonants) in their word-based communication, because nonwords are no longer toddlers' most developmentally advanced form of communication.

Most importantly, this study further validated a metric of overall vocal complexity (i.e., within words and nonwords) that is increasingly being used in research by confirming its association with later expressive language. In addition, this is the first study to find that both overall vocal complexity and nonword vocal complexity are predictive of later language for toddlers at high familial risk of ASD. Establishing this predictive association as early as the second year suggests that interventions for HR toddlers could be designed specifically to target toddlers' vocal complexity in order to increase their later language ability.

There are several future directions in which to take this metric of vocal complexity in HR toddlers. First, it would be important to assess whether HR toddlers differ from toddlers at low familial risk for ASD (LR toddlers) on this vocal complexity metric in the second year of life. Previous research findings in this area are mixed. One longitudinal study found that HR infants produced a smaller proportion of canonical syllabic communication compared to LR infants at 9 months, but not at 6 or 12 months of age, and that HR infants had smaller consonant inventories than LR infants at all three ages (Paul et al., 2011). Another cross-sectional study found that infants later diagnosed with ASD produced less canonical syllabic communication compared to LR infants at 9-12 and 15-18 months (Patten et al., 2014). It may also be that HR children are merely delayed on average compared to LR children in adding mature sounds such as consonants to their vocal repertoire and using them regularly in canonical syllabic communication.

In addition, it would be important to investigate whether this vocal complexity metric is sensitive to growth in the second year. This question is most easily illustrated using the canonical syllable component of the vocal complexity construct in an example: this study has found that, on average, 53% of HR toddlers' vocal communication to adults at Time 3 is comprised of canonical syllables. However, did toddlers' propensity to communicate in canonical syllables increase from Time 1? Does vocal complexity, even within nonwords, continue to grow into the second year? Determining whether HR toddlers' vocal complexity level and growth differ from that of LR toddlers would provide stronger evidence for its potential as an indicator of risk for language delay. Overall, this study's finding that vocal complexity was a significant predictor of later expressive language for HR toddlers provides support for the theory that low vocal quality in the second year may signal early language difficulties and intervention need in this population.

The Effect of Parent-Implemented Social Communication Interventions on HR Toddlers' Expressive Language Ability

The few studies thus far that have investigated the effect of early intervention on social communication and language ability in HR toddlers are all striving to answer the following questions: First, what social contexts and fundamental skills are most important for toddlers' language learning, given they are at high risk for ASD? And second, are those contexts and skills malleable with intervention, and do those gains potentially ameliorate deficits in social communication and language that some HR toddlers display by the end of the second year? This study hypothesized and found that increased parent verbal responsiveness (PVR) created a more supportive context for toddler's early vocal complexity and promoted greater later expressive language learning for all HR toddlers, just as previous research has found for typically developing toddlers (e.g., Gros-Louis et al., 2006; Talbott et al., 2015). However, this study did not find that the ImPACT intervention increased PVR, vocal complexity, or later expressive language compared to a BAU condition. We also did not find moderation of the effect of ImPACT on these variables by the degree of toddlers' behavioral risk for ASD at study onset, suggesting that ImPACT may be designed to promote parenting and teaching strategies that would benefit all children, regardless of risk. Below, we examine our results in the context of previous findings and the specific ways we measured the parent and child skills that we hypothesized ImPACT would improve.

Previous attempts to intervene on the language and social communication of HR toddlers have produced mixed results. To our knowledge, there have been five prior randomized controlled trials assessing the effectiveness of social communication interventions for toddlers at high risk for ASD (Carter et al., 2011; Rogers et al., 2012; Kasari et al., 2014; Baranek et al., 2015; Green et al., 2015; 2017). Of these five studies, only two studies found treatment effects on parent behaviors (increased responsiveness, Kasari et al., 2014; decreased directiveness Baranek et al., 2015), and only one study found treatment effects on child language ability within 6 months of intervention (Baranek et al., 2015). Baranek and colleagues implemented a modified Adaptive Response Teaching intervention protocol for a 6-month period for 1-2 sessions per week, which was twice as long as the intervention period for the current ImPACT intervention study as well as for three of the other four studies (Carter et al., 2011; Kasari et al., 2014; Rogers et al., 2012).

Green and colleagues did find that their intervention, Video Interaction for Promoting Positive Parenting, which used video feedback to promote parent-child synchrony, produced cumulative gains in both parent synchrony and child outcomes such as ASD symptomatology (though not expressive language). However, Green and colleagues only found these effects only when aggregating gains made across 3 years post-intervention (2015; 2017). The study by Green and colleagues was also the only study to include all toddlers at high familial risk for ASD, regardless of whether or not they met criteria for risk for ASD on a screener, similar to the current study. It may be that in an effort to make sure that interventions are not too intense or burdensome for families of HR children who may be developing typically, low-intensity treatments only evidence gains across longer periods of time. In addition, it may be that treatment effects on basic social and communication skills (e.g., toddlers' attention and vocalizations) early in development may only produce gains in more distal, clinically significant child characteristics such as ASD symptomatology or expressive language ability after children are able to incorporate these basic skills in language-learning contexts over time (Green et al., 2017). According to the research thus far, it seems to be particularly difficult to promote skill growth in HR toddlers via early interventions that coach parents to increase the supportiveness of their interactions with their children.

Interventions that seek to improve child skills by changing parents' behavior are common, but special considerations need to be made when examining parent-implemented interventions for children at high risk, but not diagnosed with, ASD. Unsurprisingly, all five intervention studies with HR toddlers examined a parent-implemented intervention, likely for two reasons. First, high parent involvement is developmentally appropriate in the second year, when most toddlers' play still heavily involves parents. Second, a parent-implemented intervention may be a way to reduce the cost of other early intensive behavioral interventions without reducing the benefit; a smaller amount of intervention time with parents compared to a larger amount of intervention time with providers may still lead to better generalization of treatment gains (NRC, 2001). However, parent-implemented intervention for children at high risk for ASD but without a diagnosis of ASD could be creating more stress for the 60-80% of parents of HR toddlers whose children are developing typically. Parent feedback from a community-based implementation study involving Reciprocal Imitation Training (RIT; Ingersoll,

2012) suggests that although RIT is a much simpler parent-implemented intervention than ImPACT, parents feel exhausted and stressed trying to use RIT with their children (Stone & Ibañez, 2018). Researchers and intervention developers need to be respectful of parents' time and expectations when developing interventions for HR toddlers (Singh & Zeliadt, 2015; Lord, 2015).

A more fine-grained analysis of what specific parent behaviors the ImPACT intervention is designed to increase may further explain our lack of treatment group differences in T2 parent verbal responsiveness, T3 vocal complexity, and T4 child expressive language. ImPACT interventionists coached parents to treat any child behavior, including nonword vocalizations, as intentional and respond to it. Although the ImPACT interventionists encouraged parents to be most responsive to their children's more complex communication acts, they did not specifically coach parents to respond differentially to more complex *nonword* communication acts such as canonical syllabic babbling, compared to less complex nonword communication acts such as vowel-only vocalizations. The intervention materials provide a guide for parents stating that if a child is using mostly gestures, they should model and prompt single words, and if a child is using mostly word approximations and single words, they should model and prompt single words and two-word phrases (Ingersoll & Dvortcsak, 2010). In other words, ImPACT does not "zoom in" to coach parents to focus on micro-improvements in the developmental complexity of nonwords and word approximations.

In many ways, focusing specifically on preverbal vocal development is not one of the main goals of the ImPACT intervention, which focuses instead on multimodal social communication growth in joint engagement, gestures, language, and play in an effort to make the broadest possible impact on ASD symptomatology. ImPACT was also originally designed for a wide range of children from ages 18 months to 8 years (Ingersoll & Wainer, 2013), while the current study implemented ImPACT with toddlers aged 12-18 months at the start of intervention. As such, ImPACT may not prioritize communication development of canonical syllables and consonants within the preverbal stage. It therefore may be that the ImPACT intervention does not further facilitate the sensitive, selective responding that parents already naturally provide to children's more complex babbling (e.g., Gros-Louis et al., 2006; Warlaumont et al., 2014). Toddlers in the ImPACT condition may be instead be beginning to make more word-based communication acts. Indeed, toddlers in the ImPACT condition produced more communication acts and trended towards producing more words with canonical syllables at T3 compared to those in the BAU condition.

In addition, parents of high risk toddlers may already be highly responsive to their children because they have an older child diagnosed with ASD. Research thus far on parent responsiveness in HR toddlers has only been conducted within the first year of life and suggests that parents of HR infants are as responsive as parents of LR infants when general parent responsiveness to children is measured in a global fashion (Harker, Ibañez, Nguyen, Messinger, & Stone, 2016; Wan et al., 2012) as well as when parent verbal responsiveness specifically to children's communication acts is measured, similarly to the current study (Talbott, Nelson, & Tager-Flusberg, 2015). Further, by the second year of their HR toddler's life, parents may even be more responsive to their children's communication acts compared to parents of LR toddlers or parents with an only child with ASD. Parents across both treatment conditions in our study responded to 69% of toddlers' vocally complex communication acts at Time 2; it is possible that there was little additional growth that parents could make. It may be that parents of HR children become more highly responsive to their children's communication acts by the second year because they become more aware of their children's risk for ASD in the context of rapidly increasing communication ability in the second year, and are vigilant for signs of language delay by 18 months, which is often one of parents' first ASD-related concerns (Karp, Ibañez, Warren, & Stone, 2017).

The current study's finding represents a very high estimate of PVR compared to estimates of parent responsiveness reported in other research. The current study is also the only intervention study to examine parents' responsiveness to children's communication acts, as compared to parents' verbal responsiveness to children's focus of attention (McDuffie & Yoder, 2010). For example, Kasari and colleagues reported that pre-intervention, parents' "percent responsivity" was 7% and 15% for the control and treatment group, respectively, and that post-intervention, control parents were 11% responsive and treatment parents were 49% responsive. Kasari and colleagues' responsivity variable specifically represented the proportion of overall time parents spent responding to children's focus of attention, without controlling for the amount of time that children were focused on something meaningful, like a toy. Carter and colleagues found that parents spent on average a third of the time being responsive to their HR children's focus of attention, regardless of treatment condition (2011). Using an observational design, Bottema-Beutel and colleagues (2014) also found that for toddlers diagnosed with ASD, parents responded to only one third of instances of higher-order supported joint engagement, a state in which children signal awareness of an adult in a shared activity. It could be that parents of children at high risk for ASD are highly responsive to their children's communication acts, but less responsive on average to their children's focus of attention.

Fine-Tuning Transactional Theories of Language Development as They Apply to Toddlers at High Risk for ASD

To our knowledge, this was the first study to assess whether intervention can increase parents' *sensitivity* to their children's vocally complex communication acts (i.e., can increase the proportion of vocally complex communication acts to which parents respond), as well as whether intervention can increase the *proportion* of children's communication acts that are vocally complex. Although the current study found that the ImPACT intervention does not increase PVR to vocally complex communication acts for parents of children at risk for ASD, it *did* find evidence that for all HR toddlers, parents' increased verbal responsiveness to their children's vocally complex acts predicted subsequent increased toddler vocal complexity within both words and nonwords, which in turn predicted increased later expressive language ability.

There is ample evidence to support the idea that the transactional, longitudinal interaction between parents and young children facilitates language development in both typically developing children and children with ASD, but evidence is mixed as to whether or how this transactional process is disrupted for children with ASD who have language deficits. A specific transactional theory, the social feedback loop theory, posits that children with ASD may ultimately have deficits in language and communication because they produce *fewer* developmentally complex communication acts (Warlaumont et al., 2014) earlier in development, which creates fewer opportunities for adults to respond. Indeed, it has been found that young children diagnosed with ASD produce fewer speech-like (i.e., not atypical growling or squealing) nonword vocalizations compared to typically developing children (Chenausky, Nelson, & Tager-Flusberg, 2017; Paul et al., 2011; Warlaumont, Richards, Gilkerson, & Oller, 2014).

In contrast, another transactional theory, the speech attunement framework, posits that vocal communication learning is a process of children both "tuning in" or attending to adult feedback and being able to "tune up" or improve the developmental maturity of their responses (Schoen, Paul, & Chawarska, 2011; Shriberg, Paul, Black, & van Santen, 2011). Some research has found that children with ASD may have particular difficulty "tuning in" to parental input to learn language because these children demonstrated gains in language learning with more perceptually scaffolded language input designed to increase their attention to relevant parts of the language learning environment (Tenenbaum et al., 2017). However, research with HR infants and toddlers has found that these children *can* make use of parental verbal input that is specific to their more developmentally advanced gestures (Leezenbaum, Campbell, Butler, & Iverson, 2013) and more vocally complex nonword vocalizations (Talbott et al., 2015) in that these types of parental input predict children's expressive language.

Evidence as to whether children with ASD have difficulty "tuning up" their vocal responses is also mixed. On one hand, children with ASD have been found to be more likely to produce a speech-like vocalization if the previous speech-like vocalization had been responded to by their parents (Warlaumont et al., 2014). On the other hand, HR children and children with ASD have been found to make more atypical or non-speech-like vocalizations compared to TD peers (Paul et al., 2011; Schoen, Paul, & Chawarska, 2011), suggesting that children with or at risk for ASD are not properly "winnowing" their vocal communication to be more developmentally appropriate as they grow.

Further, we propose that language deficits in children with ASD are influenced in part by the fact that parent responses are less *contingent* on their children's communication. Similar levels of PVR in parents of HR compared to LR children (Harker et al., 2016; Wan et al., 2012; Talbott, Nelson, & Tager-Flusberg, 2015), combined with fewer vocally complex communication acts in HR compared to LR children, may result in a response style for parents of

HR children that is less discriminative of the vocal complexity of children's communication acts. Indeed, Warlaumont and colleagues (2014) found that parents of children with ASD provide less contingent feedback to their children's speech-like vocalizations. In the current study, children in the ImPACT condition produced more communication acts compared to the children in the control condition, but there was no accompanying group difference in PVR. More fine-grained longitudinal analyses are needed to further investigate this question.

In order to best test these transactional theories of development, parent-child vocal interchanges should be operationalized as inherently transactional variables as opposed to discrete "parent" and "child" variables. Further, more research should examine parent-child vocal interaction within a time frame of minutes rather than months. A new calculation allows researchers to conceptualize parent-child vocal interchanges as a dyadic variable by assessing whether adult vocal responses to child communication acts increase the probability of a child vocal response (child response → adult response → child response), controlling for the overall frequency of child communication (Harbison et al., 2018). We would likely gain a greater understanding of whether and how parent-child vocal interactions are malleable to change by examining intervention effects on transactional dyadic rather than two-part operationalizations of parent-child interaction.

Limitations

This study has several limitations. The small sample size may have precluded detection of significant effects in analyses that involved moderation or mediation with the dichotomous variable of treatment condition. It is also a limitation that the analyses did not include the three families who dropped out of the study after the Time 1 baseline assessment. For future research aims within the ImPACT study, intent-to-treat analyses with multiple imputation or maximum likelihood estimation should be investigated if it is determined that data are missing at random or completely at random (MAR, MCAR; Baraldi & Enders, 2010; Graham, 2009). In addition, although differences by treatment condition were examined for all available Time 1 variables and either controlled for (imitation) or determined not to differ by treatment condition, measures of PVR and vocal complexity were not available at Time 1. It was assumed that the random assignment of families to treatment conditions in the parent RCT would create treatment groups with equivalent T1 PVR and vocal complexity, but if there were differences by treatment condition in these variables, then it would aid interpretation of this study's null findings. For example, it is possible that PVR and vocal complexity increased more from pre- to post-intervention for families in the ImPACT condition compared to the BAU condition. However, T1 proxy variables that measure highly similar constructs to T2 PVR and T3 vocal complexity were available and did not differ by treatment condition (see Table 5). T1 expressive language was available and did not differ significantly by treatment condition. In addition, all analyses were run with residualized gain scores in expressive language from T1 to T4 as the outcome variable, and results did not change (Castro-Schilo & Grimm, 2018).

Although this study pioneered a novel continuous metric of ASD risk, it is also a limitation that only 28% of the study's toddlers scored above the clinical cutoffs for ASD risk at T1. Only one other study has examined the effect of a "pre-emptive" intervention (Insel, 2007) for HR toddlers as a whole and only found treatment group effects when examining the cumulative change in parent synchrony and ASD symptomatology (Green et al., 2017). It is challenging to hypothesize the degree to which a naturalistic, developmentally appropriate social communication intervention may impact parents and children who are at less risk for social communication deficits. Such an intervention would not likely be iatrogenic, especially in a low-intensity format. However, given that one of the main mechanisms by which ImPACT is theorized to affect child outcomes is by increasing parents' responsiveness to early pivotal child skills such as attempts at communication, children who are typically developing may not need additional scaffolding from parents for optimal social communication growth. Therefore, ImPACT may not improve the social communication and language outcomes of children who are typically developing.

Future Directions

This study's finding that parents influence their children's expressive language outcomes by providing targeted responses to both their word and nonword attempts at communication suggests that continued examinations of parent-child interactions would help researchers discover micro-level mechanisms of toddlers' incremental language growth that could potentially inform interventions for language delay. It is possible that this process is altered for toddlers who go on to be diagnosed with ASD, as they may not take in as much information from their environment, perhaps due to less attention to relevant parts of a speaker's face (e.g., Tenenbaum et al., 2017) or at suboptimal times (e.g., Bottema-Beutel et al., 2014). If that is the case, then future interventions designed to specifically target children's language development may benefit from introducing specific strategies for directing children's attention to relevant aspects of the input, in addition to providing increased overall social scaffolding via enriched parent interaction and coaching.

A few additional recommendations for future research on early social communication interventions for HR toddlers can be made. First, it is reasonable for researchers to prioritize lower-intensity or dosage for an intervention designed for toddlers before ASD diagnosis is possible. If an intervention is low-intensity, intervention trials should include multiple opportunities for follow up into the long term (i.e., Green et al., 2017) to provide opportunities to observe gradual, cumulative change over time in both proximal parent and child skills and more distal child outcomes (Vivanti et al., 2014). Second, it is essential to identify *a priori*, pre-intervention moderators of treatment effect when working with HR toddlers, because many of them are likely to have typically developing social communication and would therefore contribute significant variability to overall treatment effects (e.g., Carter et al., 2011). Early risk for ASD has been proposed as a moderator in previous studies; what other child characteristics might help children particularly benefit from a treatment? Third, future research should continue to hypothesize potential mediators of treatment effect that are informed by the theorized mechanisms of treatment efficacy (Kraemer et al., 2002). For instance, the rationale for the ImPACT intervention clearly implicates the role of increasing parents' responsiveness to their children's behaviors to provide a more scaffolded environment for social communication learning. One of the main strengths of this study was that it included PVR as a theoretically and empirically motivated potential mechanism of treatment effectiveness.

Finally, more research is needed to examine the benefits of intervening within the second year, before an ASD diagnosis, *relative* to intervening as soon as an ASD diagnosis can be made. The overall goal of our field is to give children with ASD and their families access to effective, evidence-based services as soon as possible. However, given the mixed evidence thus far for the benefit of pre-emptive intervention for children at high risk for ASD, it may be that the most efficient and effective way to do help children and families is to first work to reduce their wait for a diagnostic evaluation.

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Table 1. Participant Characteristics

	ImPACT	**BAU**
	M (SD), Range	*M (SD), Range*
Age at T1 (months)	13.76 (2.17), 11.43 - 18.43	14.87 (1.94), 11.66 - 18.46
Number of siblings with ASD	1.13 (0.50), 1 – 3	1.07 (0.67), 1 – 2
T2 Number of weekly non-study intervention hours	0.65 (1.98), 0 - 8	0.48 (1.76), 0 - 8
T3 Number of weekly non-study intervention hours	1.12 (3.44), 0 – 16	0.58 (1.76), 0 - 8
MSEL Expressive Language		
T1, T-Score	41.60 (10.45)	39.08 (9.92)
T1, Age Equivalent (months)	11.36 (3.35)	11.54 (2.97)
T4, T-Score	43.57 (18.50)	43.13 (10.88)
T4, Age Equivalent (months)	19.68 (9.43)	20.67 (4.51)
	N (%)	*N (%)*
Gender- Female	11 (37.5)	7 (28.6)
Site	15 (53.6)	13 (50.0)
UW	15 (53.6)	13 (50.0)
VU	13 (46.4)	13 (50.0)
Education Level of Primary Caregiver		
High School/GED	1 (3.6)	2 (7.7)
Some College	2 (7.1)	4 (15.4)
Bachelors	12 (42.9)	11 (42.3)
Graduate degree +	13 (46.4)	9 (24.6)
Ethnicity		
Hispanic/Latino	2 (7.1)	1 (3.8)
Not Hispanic/Latino	26 (92.9)	25 (96.2)
Race		
Black	1 (3.6)	1 (3.8)
Asian	3 (10.7)	2 (7.7)
White	21 (75.0)	19 (73.0)
Multiracial	3 (10.7)	4 (15.4)

MSEL = Mullen Scales of Early Learning. Note: there were no significant group differences in T1, T4, or T1-T4 growth in expressive language variables.

Table 2. Time Points of the Project ImPACT Randomized Controlled Trial

Time Point	**Study Stage**	**Possible Age Range (Mean Age) of Toddlers**	**Constructs(s) of Interest Measured**
Time 1 (T1)	"Pre-intervention"	12 – 18 months (14.29 months)	• Behavioral ASD Risk • Motor imitation
Time 2 (T2)*	"Immediately post-intervention"	15 – 21 months (17.48 months)	• Parent verbal responsiveness (PVR)
Time 3 (T3)	"Three months post-intervention"	18 – 24 months (20.44 months)	• Vocal Complexity (VC) • Words Spoken
Time 4 (T4)	"Six months post-intervention"	21 – 27 months (23.30 months)	• Expressive Language (EL)

*Between T1 and T2, ImPACT participants received 12 weeks of intervention, and BAU participants did not receive ImPACT intervention.

Note: Possible age ranges include ages that round to that range, i.e., 12 – 18 months = 11.5 – 18.5 months

Table 3. Constructs, Time Points, Procedures, and Metrics for Study Variables

Construct	**Time Point**	**Procedure**	**Variable Metric**
Variables of Interest			
Parent Verbal Responsiveness (PVR)	Time 2	PCFP, PCS	Proportion of toddlers' communication acts that contain canonical syllables (CS) to which parents respond with a verbal response that adds semantic or phonological information relevant to the child's context, i.e.: # parent verbal responses to toddlers' comm. acts with CS / # toddlers' comm. acts with CS
Vocal Complexity (VC)	Time 3	CSBS-DP, BOSCC	Aggregate of: a) proportion of communication acts with canonical syllables (CS); and b) number of different consonants used in communication acts (CI), i.e.: a) # CS comm. acts / # comm. acts b) # of different consonants in comm. acts
Words Spoken	Time 3	CSBS-DP, BOSCC	Frequency of spoken words used communicatively
Expressive Language	Time 4	MSEL MCDI CSBS-DP	Aggregate of: a) MSEL expressive language subscale age equivalent (in months); b) MCDI expressive vocabulary (number of words reported understood and said); and c) number of word roots observed during the CSBS
Hypothesized Moderators			
Behavioral ASD Risk	Time 1	FYI or M-CHAT-R/F	Score on the FYI or M-CHAT (depending on age), standardized with respect to the clinical cut off value indicating ASD risk, i.e., value of 0 = at ASD risk cutoff
Covariates			
Imitation	Time 1	SSIS	Number of motor actions that toddlers imitated within a semi-structured play interaction

All variables are created from behaviors that were aggregated across the procedures listed unless otherwise specified. Final variables aggregated across both procedures and component variables. PCFP = Parent Child Free Play; PCS = Parent Child Snack; CSBS = Communication and Symbolic Behavior Scales-Developmental Profile; BOSCC = Brief Observation of Social Communication Change; MSEL = Mullen Scales of Early Learning; MCDI = MacArthur-Bates Communicative Development Inventory; ADOS-T = Autism Diagnostic Observation Schedule, Toddler Module; SSIS = Semi-Structured Imitation Scale. Aggregate = average of component variables. The component variables are z-score transformed, as different metrics are used for each variable. Comm = communication.

Table 4. Reliability of Coded Variables

Variable	Intraclass Correlation Coefficient†
T2: Coding PVR	
Frq CCA with CS	.988
Frq Parent verbal responses	.979
PVR (full variable; proportion)	.816
T3: Coding Vocal Complexity	
Frq Total CCA	.996
Frq Words spoken	.883
Frq CCA with CS	.996
Proportion of CCA with CS	.942
Consonant inventory	.952
Vocal complexity aggregate	.954

Abbreviations: Frq = frequency. CCA = child communication acts, PVR = parent verbal responsiveness. CS = canonical syllables.

† 2-way, random effects, single measures, absolute agreement

Table 5. Assessment of Whether T1 Variables Need to Be Controlled for Tests Involving Treatment Condition

Variable	**Rationale for inclusion**	**Significant difference by treatment condition?**	**Predicts T2 PVR?**	**Significantly predicts T3 vocal complexity?**	**Significantly predicts T4 expressive language?**
T1 Imitation	Early developmental skill that likely correlates with dependent variables	Yes, lower for ImPACT vs. BAU	No	Yes (r = .37)	Yes (r = .36)
T1 Play	Early developmental skill that likely correlates with dependent variables	No	No	No	No
T1 Cognitive Ability	Measure of general functioning	No	No	Yes (r = .42); but n/a because no difference by treatment condition	Yes (r = .50); but n/a because no difference by treatment condition
T1 Age	Proxy of general ability, considering most of the sample has typical cognitive development	Yes, lower for ImPACT vs. BAU	No	No	No
T1 Parent Modeling	Closest T1 proxy to T2 PVR	No	No	No	No
T1 Intentional Communication	Closest T1 proxy to T3 vocal complexity	No	No	No	Yes (r = .29)
T1 Expressive Language	T1 version of T4 EL aggregate	No	No	Yes (r = .48); but n/a because no difference by treatment condition	Yes (r = .52); but n/a because no difference by treatment condition

BAU = business-as-usual; PVR = parent verbal responsiveness; EL = expressive language

Note: this table provides justification for including T1 imitation as a covariate in all models in which treatment condition is predicting T3 vocal complexity and T4 expressive language.

Table 6. Descriptive Characteristics for Study Variables

Time Point	**Variable**	**N**	**Mean (SD)**	**Range**	**Skewness**		**Kurtosis**	
					M	**SD**	**M**	**SD**
Time 2	Parent Verbal Responsiveness (PVR)	51	0.69 (0.23)	(0, 1.00)	-1.21	0.33	2.24	0.66
Time 2	PVR [reflected and log transformed]	51	0.27 (0.16)	(0, 69)	0.61	0.33	0.93	0.66
Time 3	Vocal Complexity (VC)	54	0.49 (0.24)	(0, 0.93)	-0.07	0.33	-0.90	0.64
Time 3	Words Spoken	54	10.64 (14.11)	(0, 65)	2.00	0.33	3.94	0.64
Time 4	Expressive Language	53	0.01 (0.90)	(-1.48, 2.50)	0.98	0.33	0.66	0.64
Time 1	Behavioral ASD Risk	54	-0.52 (0.91)	(-1.73, 2.99)	1.70	0.33	4.27	0.64
Time 1	Imitation	51	3.16 (2.28)	(0, 9)	0.49	0.33	-0.38	0.66

Note: In all future tables, reflected and log-transformed parent verbal responsiveness (PVR) was used and denoted simply as “PVR”

Table 7. Zero-Order Correlations Among Study Variables

	1	2	3	4	5	6	7
1. T2 PVR	--						
2. T3 Vocal Complexity	.36**	--					
3. T3 Words Spoken	.22	.73**	--				
4. T4 Expressive Language	.25	.73**	.74**	--			
5. T1 Behavioral ASD Risk	-.07	-.09	-.02	-.27*	--		
6. T1 Imitation	.09	.37**	.30*	.36*	-.27		

* $p < .05$. ** $p < .01$.
PVR = parent verbal responsiveness.

Table 8. Aim 1: Nonword Vocal Complexity Predicts Later Expressive Language Regardless of Toddler Age

Predictors	*A priori model*					*Final model*				
	B	SE	*β*	*t (p)*	95% CI	B	SE	*β*	*t (p)*	95% CI
Intercept	-.29	0.12		-2.49 (p = .02)	[-0.53, -0.06]	-1.07	0.20		-5.34 (p < .001)	[-1.47, -0.67]
T3 words spoken	0.03	0.01	.42	3.01 (p =.003)	[0.01, 0.04]	0.03	0.01	.44	3.44 (p = .001)	[0.01, 0.04]
T3 vocal complexity	1.64	0.52	.43	3.16 (p = .003)	[0.60, 2.67]	1.57	0.48	.41	3.27 (p = .002)	[0.61, 2.53]
T3 age	0.001	0.03	.002	0.02 (p = .99)	[-0.07, 0.67]					
T3 VC x T3 age	0.08	0.17	.04	0.44 (p = .66)	[-0.27, 0.43]					
	F (4, 48) = 19.93, R^2 = .62					F (2, 50) = 41.24, R^2 = .62				

VC = vocal complexity. Note that adding T3 vocal complexity resulted in an R^2 change of .08.

Table 9. Aim 2: The Effect of the ImPACT Intervention on T2 PVR, T3 Vocal Complexity, and T4 Expressive Language

Outcome: T2 parent verbal responsiveness (PVR)

Predictors	*A priori model*					*Final model*				
	B	SE	β	*t (p)*	95% CI	B	SE	β	*t (p)*	95% CI
Intercept	-0.25	0.03		7.32 ($p < .001$)	[0.18, 0.32]	-0.25	0.03		7.51 ($p < .001$)	[0.19, 0.32]
Treatment condition	-0.01	0.05	-.04	0.24 ($p = .81$)	[-0.08, 0.11]	-0.01	0.05	-.03	0.18 ($p = .86$)	[-0.08, 0.10]
Behavioral ASD risk	-0.04	0.04	-.20	1.03 ($p = .31$)	[-0.03, 0.11]					
Tx*ASD risk	0.05	0.05	.19	-0.95 ($p = .35$)	[-0.15, 0.05]					
	F (3, 47) = 0.47, R^2 = .03					F (1, 49) = 0.03, R^2 = .001				

Outcome: T3 vocal complexity

Predictors	*A priori model*					*Final model*				
	B	SE	β	*t (p)*	95% CI	B	SE	β	*t (p)*	95% CI
Intercept	0.51	0.05		10.98 ($p < .001$)	[0.42, 0.61]	0.52	0.05		11.25 ($p < .001$)	[0.43, 0.61]
T1 imitation	0.04	0.02	.37	2.48 ($p = .02$)	[0.01, 0.07]	0.04	0.01	.36	2.57 ($p = .01$)	[0.01, 0.07]
Treatment condition	-0.02	0.07	-.04	-0.28 ($p = .77$)	[-0.15, 0.11]	-0.02	0.07	-.05	-0.33 ($p = .74$)	[-0.15, -0.11]
Behavioral ASD risk	0.03	0.05	.12	0.63 ($p = .53$)	[-0.05, 0.13]					
Tx*ASD risk	-0.09	0.07	-.25	-1.35 ($p = .18$)	[-0.23, 0.05]					
	F (4, 46) = 2.48, R^2 = .18					F (2, 48) = 3.95, R^2 = .14				

Outcome: T4 expressive language

Predictors	*A priori model*					*Final model*				
	B	SE	β	*t (p)*	95% CI	B	SE	β	*t (p)*	95% CI
Intercept	-0.08	0.20		-0.39 ($p = .70$)	[-0.47, 0.32]	-0.04	0.19		-0.19 ($p = .85$)	[-0.41, 0.34]
T1 imitation	0.13	0.06	.33	2.21 ($p = .03$)	[0.01, 0.25]	0.16	0.06	.39	2.71 ($p = .01$)	[0.04, 0.27]
Treatment condition	0.11	0.26	.06	0.42 ($p = .68$)	[-0.41, 0.63]	0.17	0.26	.09	0.64 ($p = .53$)	[-0.35, 0.69]
Behavioral ASD risk	-0.14	0.19	-.14	-0.72 ($p = .47$)	[-0.52, 0.23]					
Tx*ASD risk	-0.18	0.26	-.13	-0.70 ($p = .49$)	[-0.71, 0.35]					
	F (4, 45) = 2.73, R^2 = .20					F (2, 47) = 3.71, R^2 = .14				

Table 10. Aim 2 Post-Hoc Exploratory Analyses: Descriptive Statistics and Differences by Treatment Condition for Component Variables Comprising T2 PVR, T3 Vocal Complexity, and T4 Expressive Language

		Treatment Condition				
Construct	**Component Variable**	**ImPACT**		**BAU**		
		Mean (SD)	**Range**	**Mean (SD)**	**Range**	***t* (df), *p***
T2 PVR	Frequency of CCA	24.83 (19.42)	1.50 – 88.00	19.17 (12.14)	1.00 – 42.00	-1.21 (48), *p* = .23
	Frequency of CCA with CS	14.13 (17.49)	0.00 – 73.00	8.33 (7.00)	0.50 – 28.00	-1.49 (37), *p* = .13
	Frequency of parent responses to CCA with CS	9.80 (12.82)	0.00 – 53.00	6.31 (5.56)	0.00 – 20.50	-1.23 (49), *p* = .22
T3 Vocal Complexity	Frequency of CCA[t]	37.03 (14.64)	8.50 – 86.00	27.38 (20.72)	6.00 – 64.50	4.06 (48), *p* = .049*
	Frequency of CCA with CS[t]	20.12 (19.37)	0.00 – 65.50	12.25 (12.05)	1.00 – 48.00	3.15 (48), *p* = .08^
	Proportion of CCA with CS[t]	0.42 (0.27)	0.00 – 0.89	0.44 (0.23)	0.08 – 1.00	0.02 (48), *p* = .97
	Consonant inventory	5.07 (2.80)	0 – 10	6.12 (2.21)	2 – 10	1.51 (52), *p* = .14
T4 Expressive Language	MSEL EL Age Equivalent[t]	21.07 (9.41)	1 – 40	20.00 (4.15)	12 – 27	0.25 (46), *p* = .62
	MCDI number of words said[t]	197.18 (185.95)	0 – 668	163.14 (161.00)	5 – 646	0.47 (47), *p* = .50
	Number word roots on the CSBS	16.11 (17.61)	0 – 52	16.36 (19.06)	2 – 75	0.05 50), *p* = .96

**p < .05; ^ p* < .10. CCA = child communication act; CS = canonical syllables; EL = expressive language; MSEL = Mullen Scales of Early Learning; MCDI = MacArthur-Bates Communication Development Inventory; CSBS = Communication and Symbolic Behavior Scales.
[t]Analyses controlled for T1 imitation because T1 imitation correlated with both these variables and treatment condition; *F* instead of *t* value presented.
Note: All T2 PVR variables are averaged across the PCS and PCFP. All T3 VC-related variables are averaged across the CSBS and BOSCC. Hence, some frequency variables have non-integer values.

Table 11. Aim 3, Indirect Effects: Treatment Condition, T2 PVR, T3 Vocal Complexity, and T4 Expressive Language

H3a: Tx → T2 PVR → T3 VC

Time 2 PVR (mediator)

	Model	B	SE	*p*
Tx condition	*a*	0.01	0.04	.79
Constant	-	0.23	0.03	<.001

F (1, 47) = 0.07, R^2= .002

Time 3 Vocal Complexity (outcome)

	Model	B	SE	*p*
Tx condition	*c'*	-0.01	0.07	.85
T2 PVR	*b*	0.42	0.23	.07
Constant	-	0.51	0.09	<.001
T1 imitation	cov	0.03	0.02	.04

F (3, 45) = 3.24, R^2= .18

	B	SE	*LLCI*	*ULCI*
Indirect effect	**0.01**	**0.02**	**-0.06**	**0.03**
Direct effect	0.10	0.07	-0.14	0.12

H3b: Tx → T3 VC → T4 EL

Time 3 Vocal Complexity (mediator)

	Model	B	SE	*p*
Tx condition	*a*	-0.04	0.07	.58
Constant	-	0.43	0.08	<.001
T1imitation	cov	0.03	0.01	.03

F (2, 47) = 3.41, R^2= .13

Time 4 Expressive Language (outcome)

	Model	B	SE	*p*
Tx condition	*c'*	0.26	0.19	.17
T3 vocal complexity	*b*	2.68	0.42	<.001
Constant	-	-1.67	0.28	<.001
T1 imitation	cov	0.07	0.04	.13

F (3, 46) =18.24, R^2= .54

	B	SE	*LLCI*	*ULCI*
Indirect effect	**-0.10**	**0.17**	**-0.45**	**0.23**
Direct effect	0.26	0.19	-0.12	0.65

H3c: T2 PVR → T3 VC → T4 EL

Time 3 Vocal Complexity (mediator)

	Model	B	SE	*p*
T2 PVR	*a*	0.60	0.19	.003
Constant	-	0.65	0.06	<.001

F (1, 48) = 9.46, R^2= .16

Time 4 Expressive Language (outcome)

	Model	B	SE	*p*
T2 PVR	*c'*	-0.28	0.63	0.65
T3 vocal complexity	*b*	2.90	0.42	<.001
Constant	-	-1.50	0.33	<.001

F (2, 47) = 26.61, R^2= .53

	B	SE	*LLCI*	*ULCI*
Indirect effect	**1.74**	**0.65**	**0.64**	**3.19***
Direct effect	0.28	0.63	-0.98	1.54

* $p < .05$. PVR= parent verbal responsiveness; VC= vocal complexity; EL = expressive language; LLCI = lower limit of 95% confidence interval; ULCI = upper limit of 95% confidence interval; cov = covariate.

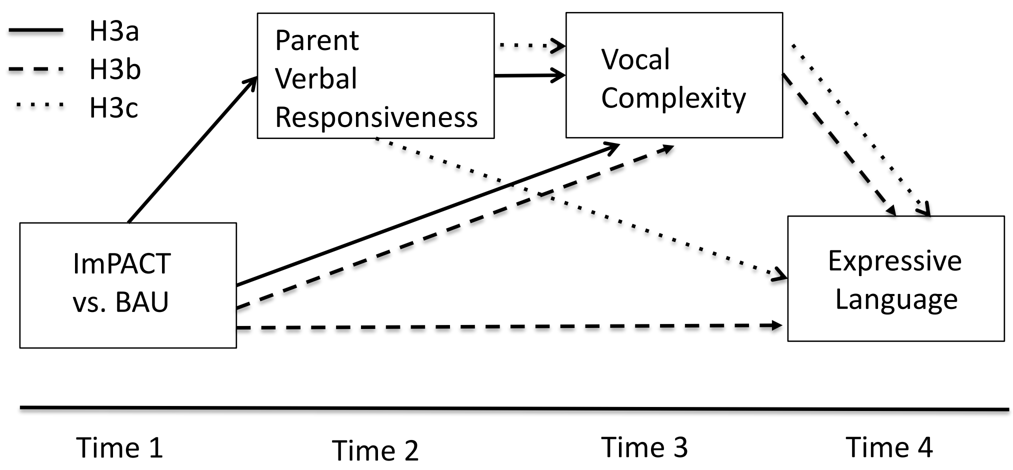

Figure 1. Illustration of Aim 3, exploratory mediation hypotheses.

BAU = business-as-usual. PVR = parent verbal responsiveness.

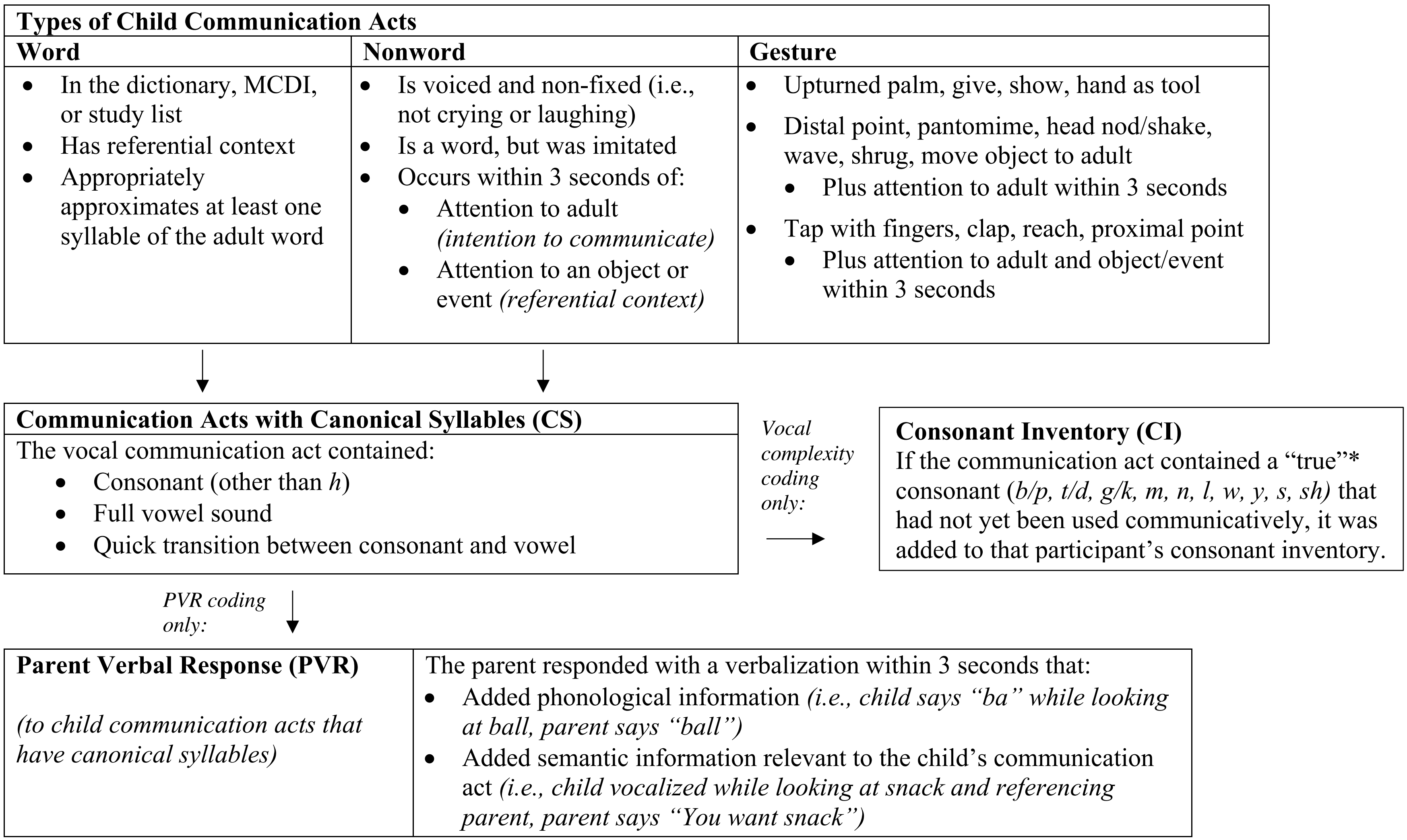

Figure 2. Flow chart for coding child communication acts and parent verbal responsiveness

Note: This flow chart was used to code the component child and parent behaviors necessary to derive both T2 PVR (by coding the PCS and PFCP at T2) and T3 vocal complexity (by coding the CSBS and BOSCC at T3). Coding systems diverged where noted in the table. Signed words were also coded and analyzed separately. *From Wetherby's true consonant inventory list (Wetherby & Prizant, 2002). See text for definitions of referential context, attention, and other terms.

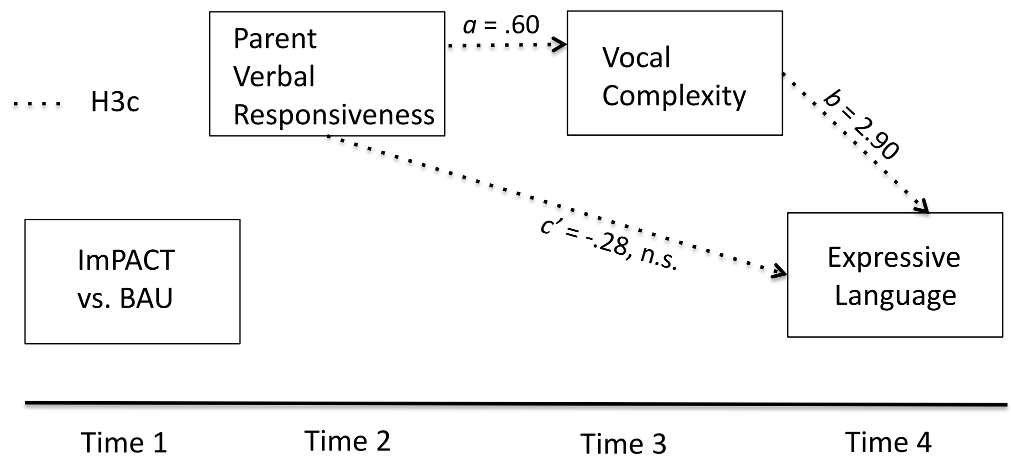

Figure 3. Graphical representation of significant mediation from Aim 3: H3c

Note: H3a and H3b paths and indirect effects are not represented in this figure because they were non-significant.