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ORIGINAL PAPER

Early Predictors of Growth in Diversity of Key Consonants Used in Communication in Initially Preverbal Children with Autism Spectrum Disorder

Tiffany Woynaroski[1] · Linda Watson[2] · Elizabeth Gardner[3] · Cassandra R. Newsom[4] · Bahar Keceli-Kaysili[5] · Paul J. Yoder[6]

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Abstract Diversity of key consonants used in communication (DKCC) is a value-added predictor of expressive language growth in initially preverbal children with autism spectrum disorder (ASD). Studying the predictors of DKCC growth in young children with ASD might inform treatment of this under-studied aspect of prelinguistic development. Eighty-seven initially preverbal preschoolers with ASD and their parents were observed at five measurement periods. In this longitudinal correlational investigation, we found that child intentional communication acts and parent linguistic responses to child leads predicted DKCC growth, after controlling for two other predictors and two background variables. As predicted, receptive vocabulary mediated the association between the value-added predictors and endpoint DKCC.

Keywords Vocal communication · Consonant inventory · Predictors · Autism · Intentional communication · Parent linguistic responses · Receptive vocabulary

✉ Paul J. Yoder
Paul.Yoder@vanderbilt.edu

[1] Department of Hearing and Speech Sciences, Vanderbilt University, Nashville, TN, USA

[2] Speech and Hearing Sciences, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

[3] Vanderbilt Kennedy Center, Vanderbilt University, Nashville, TN, USA

[4] Pediatrics, Psychiatry, & Psychology, Vanderbilt University, Nashville, TN, USA

[5] Special Education, Ankara University, Ankara, Turkey

[6] Special Education, Vanderbilt University, Nashville, TN, USA

Introduction

Attaining useful speech by 5 years of age predicts occupational and social outcomes in individuals with autism spectrum disorder (ASD; e.g., Billstedt et al. 2007; Eisenberg 1956; Howlin et al. 2000; Kobayashi et al. 1992; Venter et al. 1992). Yoder et al. (2015) identified four variables with incremental validity in predicting (i.e., added value in explaining) the development of useful speech in initially preverbal preschoolers with ASD. Diversity of key consonants used in communication (DKCC) was one of these value-added predictors.

Rationale for Studying Diversity of Key Consonants Used in Communication

One next step in this line of research is to identify the factors that have incremental validity in predicting DKCC. DKCC is the least studied of the value-added predictors of useful speech in initially preverbal children with ASD (Yoder et al. 2015). The Yoder et al. (2015) study replicated an earlier finding that DKCC predicted later expressive language in who are in the early stages of language learning (Wetherby et al. 2007). Other measures of diversity in consonant use have been shown to predict "useful speech" or spoken language in previous studies involving preschoolers with ASD (Schoen et al. 2011) and children at risk for ASD (Paul et al. 2011). DKCC was called "consonant inventory in communication acts" in our previous report Yoder et al. (2015) and in the Wetherby et al. (2007) study. The variable label has been changed here to avoid confusion with consonant inventory variables in the broader literature.

Given its value-added status as a predictor of useful speech growth in young children with ASD, it is surprising that we do not yet know how to facilitate, or whether we can facilitate, DKCC in initially preverbal children with ASD. Identifying the value-added predictors of DKCC growth can shed light on potential mechanisms by which DKCC growth occurs in children with ASD and help us think more precisely about potential reasons that children with ASD vary in DKCC growth. Perhaps most importantly, identifying the value-added predictors of DKCC growth can inform potential treatment targets. Future intervention research might then test whether targeting the identified predictors of DKCC yields highly generalized DKCC growth in preverbal children with ASD.

Theoretical Support for Four Potential Predictors of DKCC

Stoel-Gammon (2011) has articulated a theory that implicates four potential predictors of DKCC. The tenets of Stoel-Gammon's theory, as they relate to each of the four potential predictors, are as follows. The vocal tracts of immature speakers are different from adults, and young vocalizers' control over the muscles used to produce speech is less than the control of adults. Thus, we expect some aspects of motor control, such as motor imitation, to be a predictor of DKCC. However, motor imitation also requires attention to others' models. Thus, interaction with others (e.g., adults) is an important part of the theory. During interactions with adults, immature speakers hear words for the objects that match the foci of the young vocalizers' attention and communication. Parent linguistic input may facilitate growth of consonant use in vocal communication, in part, because it helps children notice and emulate the range of sounds that adults use to communicate about objects or events in their environment and/or because children try to say words that have been modeled by adults. However, parent linguistic input would not be beneficial unless children attend to it. Therefore, we expect both parent linguistic responses to child leads and attention to child-directed speech to be predictors of DKCC. The intent to communicate is necessary to use consonants to communicate. Therefore, we expect intentional communication to be a predictor of DKCC.

We call this theory a "transactional theory of speech sound development" because it proposes that not only child factors, but also parent responses to child leads, will best account for individual differences in DKCC growth in initially preverbal preschoolers with ASD. Like other applications of the transactional theory, it is assumed that parents and children affect each other in ways that change over time. The sequence delineated in the previous paragraph is a simplified version of the bidirectional influence between parents and children that likely contributes to DKCC growth.

Given our interest in the transactional theory of speech sound development, the DKCC's exclusive focus on vocal *communication* is critical. We know from the developmental literature that mothers are more likely to interpret their babies' vocalizations as communicative (Yoder and Feagans 1988) and to respond with linguistic input (West and Rheingold 1978) when the vocalizations are directed to the mother than when the vocalizations are undirected or directed to an object only. The special role that consonants play is highlighted by the finding that mothers tend to interpret *consonant*–vowel vocalizations as language-oriented and to respond more to vocalizations with a consonant than to vowel-only vocalizations (Gros-Louis et al. 2006).

Empirical Support for the Potential Predictors of DKCC

Of the four potential predictors of DKCC outlined above (motor imitation, attention to child directed speech, parent linguistic responses, and intentional communication), only the first two have empirical support as predictors of later DKCC in preverbal children with ASD. Patten et al. (2012) found that motor imitation and attention to child-directed speech were correlates of later DKCC in initially preverbal children with ASD. No research has been conducted to test whether intentional communication or parent linguistic responses to child leads predict growth in DKCC in children with ASD. Additionally, the effect of the intercorrelation of the four potential predictors on the value-added status of predictors of DKCC has not been studied. Further, predictors of the *growth* of DKCC have not been studied.

Rationale for Considering Additional Background Variables in Models of DKCC Growth

Ruling out covarying variables that provide less compelling explanations for predicted associations improves the clinical value of expected correlational findings. This is particularly true if the covarying variables are less malleable than the theoretically-motivated potential predictors. Level of cognitive impairment and degree of autism symptomatology are among the most salient child background variables that could account for our predicted associations. Thus, these background variables need to be considered (i.e., controlled) when testing whether more theoretically-motivated predictors account for growth in DKCC in our sample.

Why Receptive Vocabulary Might be a Mediator for the Prediction of DKCC

Although tested in a correlational design, motivating theories for the prediction that receptive vocabulary will mediate the association between value-added predictors and later DKCC are stated in causal terms. Two paths of influence motivate the prediction. The first path of influence is quantified by the association between the predictor (e.g., early parent linguistic responses) and the mediator (i.e., midpoint receptive vocabulary). The second is quantified by the association between midpoint receptive vocabulary and endpoint DKCC. The transactional theory of speech development posits both of these pathways.

The first path has already been empirically established for three of four putative predictors of DKCC growth. Past work has demonstrated that parent linguistic responses to child leads are associated with later receptive language in children with ASD who are in the early stages of language development (Haebig et al. 2013a, b; Yoder et al. 2015). Studies have additionally shown links for early attention to child directed speech and intentional communication with later receptive language in this population (Yoder et al. 2015). Motor imitation ability has specifically been identified as a replicated predictor of productive language in children with ASD (Charman et al. 2003; Yoder et al. 2015), but production and reception are strongly related in children with ASD (Woynaroski et al. 2015).

The second path of influence was predicted because, as children develop, there might be an increasing probability that instances of consonant use in communication acts are manifestations of children attempting to say words they understand. Children's prelinguistic vocal patterns in place and manner of articulation of consonants appear to be carried forward to first words (Stoel-Gammon and Cooper 1984; Vihman et al. 1985). If children attempt to say the words they understand prior to their ability to make themselves fully understood, it would manifest as the production of a variety of consonants in what appear to be prelinguistic communication acts. That is, it is proposed that one link for the above-indicated continuity is through receptive vocabulary. A larger receptive vocabulary means more words with varying consonants that the child has available to say.

Research Questions

Two research questions were examined:

1. Controlling for level of cognitive impairment and autism symptomatology, which of the four potential predictors add value in explaining the variability in growth of DKCC in initially preverbal children with ASD?
2. Are the associations between value-added predictors and later DKCC mediated through receptive vocabulary?

Methods

Participants

The 87 children (71 male and 16 female) participating in the study were between 20 and 48 months chronological age and had a clinical diagnosis of autism or PDD/NOS. If children had an existing diagnosis of autism or PDD/NOS through licensed and experienced community providers, their diagnoses were confirmed using the revised diagnostic algorithm on Autism Diagnostic Observation Schedule module I (ADOS; Lord et al. 2000; Gotham et al. 2007), which was administered by research staff who were research reliable on this instrument. Children who did not enter the study with a previous diagnosis were assessed and diagnosed by a licensed clinician on the research team who was independently research reliable on the ADOS and experienced with evaluating young children with ASD. Research diagnoses were based on best clinical judgment that the child met criteria for autism or PDD/NOS according to the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition-Text Revision (American Psychiatric Association 2000) based on the data from the ADOS and a clinical interview. With one exception, children met the autism spectrum cut-off using the ADOS algorithms revised for improved diagnostic validity (Gotham et al. 2007). One child who was diagnosed by community clinicians as having PDD/NOS scored under the autism spectrum disorder cut-off on the ADOS, but was also judged to have PDD/NOS by the licensed examiner on the research team. Ninety-five percent of the participants met criteria for autism, and the remaining met criteria for PDD/NOS.

Participants, at the time of enrollment, were reported to say no more than 20 different words according to parent report on the MacArthur-Bates Communicative Development Inventories: Words and Gestures checklist (MB-CDI; Fenson et al. 2003) and produced no more than five different word roots during a 15-min language sample. We excluded children with severe sensory or motor impairments, identified progressive neurological disorders, and identified genetic syndromes.

Based on parent report, ethnic distribution for participants was 5 % Hispanic and 95 % non-Hispanic. According to parent report, the racial distribution of the children was 75 % White, 18 % Black/African American, 6 % Asian, and 1 % Native American or Alaska Native. Primary caregivers' self-reported levels of formal education were 5 % some high school education, but did not graduate; 22 % high school diploma or equivalent; 24 % 1–2 years of college or technical school education; 32 % 3–4 years of college or technical school education; and 17 % some graduate or professional school. Additional descriptive information on participants is provided in Table 1.

Table 1 Description of participant characteristics at time 1

	M	SD	Min	Max
Chronological age in months	34.7	7.2	20.4	47.9
MSEL early learning composite	50.9	4.1	<50	122
Mental age in months	12.1	4.7	3.75	26.5
Developmental ratio	.36	.15	.17	.75
MB-CDI words understood	75.8	85.4	0	385
MB-CDI words said	3.7	5.0	0	18
UCS number of different words	.7	1.2	0	5
ADOS social affect and restricted and repetitive behavior total	22.6	3.8	6[a]	28

MSEL Mullen Scales of Early Learning; Early Learning Composite reflects standard scores; Mental age = mean age equivalent across Visual Reception, Fine Motor, Receptive Language, and Expressive Language subscales of the MSEL; Developmental ratio = mental age/chronological age; *MB-CDI* MacArthur-Bates Communicative Development Inventories: Words and Gestures checklist; *UCS* Unstructured communication sample with examiner. *ADOS* Autism Diagnostic Observation Schedule

[a] Only one child scored 6, the next lowest score was 15

Design

This study used a longitudinal correlational design with five measurement periods, each of which was separated by approximately 4 months. The dependent variable, DKCC, was measured at every measurement period. Motor imitation, attention to child-directed speech, a component variable for intentional communication and both background variables were measured at Time 1, providing a 16-month interval between these variables and estimated level of DKCC at the study endpoint. Parent linguistic responses and one of the component variables for intentional communication were measured at Time 2 to reduce the burden on families at Time 1. The interval between Time 2 and Time 5 was 12 months. The potential mediator, receptive vocabulary, was measured at Time 3 because mediation analysis assumes the mediator is measured after the predictors (i.e., value-added predictors of DKCC growth), but before the dependent variable. In the tests of mediated relations, Time 5 DKCC growth was used as the dependent variable to meet the assumption that the outcome be measured after the mediator. Table 2 provides a summary of the constructs, procedures, measurement periods, and variables used to address the research questions.

Procedures and Variables

A brief description of all procedures relevant to this study is provided here. A more detailed description of the procedures is available in Yoder et al. (2015). Unless otherwise stated, all coded variables were derived by observing recorded sessions. We measured each putative predictor in two contexts and, when the component variables from the two measurement contexts were sufficiently intercorrelated, aggregated across them. Doing so increases the stability, and thus the potential validity of the estimate for a predictor, particularly when children are in the earliest stages of development (Sandbank and Yoder 2014). Further support for, and detail regarding, the aggregated measures is presented in the Results section. No putative predictors were measured from the same procedure as DKCC to avoid associations due to shared measurement method variance (Podsakoff et al. 2003).

Interobserver reliability was estimated for all coded variables on a random sample of at least 20 % of the sessions from all relevant measurement periods. Reliability observers coded independently from the primary coder. The primary coder did not know which sessions would be selected for reliability coding. The reliability estimate used was an absolute intraclass correlation coefficient (ICC) from a two-way random model.

Measure and Metric for DKCC (The Dependent Variable)

DKCC was measured using the Communication and Symbolic Behavior Scales—Developmental Profile Behavior Sample (CSBS; Wetherby and Prizant 2002) at all five measurement periods. This structured communication sample was designed for use with children who have a functional communication age between 6 and 24 months. The authors of the scale indicate this developmental span often corresponds to a chronological age range of approximately 6 months–6 years in children with ASD.

The metric for DKCC was the weighted raw score for Subscale 11, derived according to the CSBS manual. Subscale 11 inventories a child's production of 13 select consonants (i.e., m, n, b, p, d, t, g, k, y, w, l, s, sh) in communication acts (i.e., vocalizations directed to an adult). These 13 consonants were selected for coding in Subscale 11 because they are early-emerging and/or because they can be

Table 2 Constructs, procedures, untransformed component variables, and analyzed variables

Construct	Procedures/ periods	Untransformed component variables	Analyzed variable
Receptive vocabulary	MB-CDI @ T3	Number of words understood only + number of words understood and said	Log 10-transformed sum
Intentional communication	UCS @ T1	Number of intentional communication acts	Square root-transformed average z score
	ESCS @ T2	Number of communication acts summed across pragmatic functions	
Attention during child-directed speech (ACDS)	ACDS @ T1	% of the total time that CDS "vignettes" were presented that the child was looking to the presentation window	Untransformed score
Motor imitation	MIS @ T1	Total raw score	Log 10-transformed average z score
	NVOA @ T1	Total raw score	
Parent linguistic responses	PCFP @ T2	Number of 5-s intervals with child's attentional lead followed by adult utterance about child's referent	Average z score
	PCS @ T2	Number of 5-s intervals with child attention or communication lead followed by adult utterance about child's referent	
Diversity of key consonants used in communication	CSBS @ T1-T5	Subscale 11 weighted raw score	Untransformed scale score
Level of cognitive impairment	MSEL @ T1	Average age equivalency across Visual Reception, Fine Motor, Receptive Language, and Expressive Language subscales/chronological age	Untransformed developmental ratio
Autism symptomatology	ADOS module I @ T1	Diagnostic algorithm score	Reflected log 10-transformed score

CSBS Communication and Symbolic Behavior Scales- Developmental Profile Behavior Sample, *MB-CDI* MacArthur-Bates Communication Development Inventory, *ESCS* Early Social Communication Scales, *UCS* Unstructured communication sample with examiner, *ACDS* Attention during child directed speech procedure, *MIS* Motor Imitation Scale, *NVOA* Nonverbal Volitional Oral Abilities subscale, *PCFP* Parent–child free play, *PCS* Parent–child snack, *MSEL* Mullen Scales of Early Learning, *ADOS* Autism Diagnostic Observation Schedule

coded reliably even in young children (Wetherby and Prizant 2002). However, some of these consonants are relatively later-occurring (e.g., l, s, sh). Including later-occurring consonants in the count reduces the probability of ceiling effects in the developmental period studied (i.e., the transition to linguistic communication). Cognates (i.e., pairs of consonants that are articulated in the same place along the vocal tract) that differ only in terms of voicing (i.e., d vs. t, b vs. p, and g vs. k) are not credited separately because some young children do not consistently distinguish between voiced and voiceless cognates and because collapsing across cognate members increases the reliability of the measure (Wetherby and Prizant 2002). Thus, the maximum raw score that could be achieved by a child on Subscale 11 is 10. The *weighted* raw score was the raw score multiplied by 2, making the possible maximum score 20. The interobserver reliability for DKCC was .95 at Time 1, .96 at Time 2, .95 at Time 3, .95 at Time 4, and .90 at Time 5.

Measures and Metric for Intentional Communication (A Potential Predictor of DKCC)

Intentional communication was measured in an unstructured communication sample (UCS) at Time 1 and in the Early Social Communication Scales (ESCS; Mundy et al. 2003) at Time 2. The UCS is a 15-min unstructured sample in which the examiner follows the child's lead in playing with a standard set of developmentally appropriate toys. The examiner uses topic-following comments and questions, and avoids presenting directives when the child is already productively engaged with an object or activity. The number of intentional child communication acts was coded from the UCS using a timed-event behavior sampling method. Intentional communication acts in the UCS were defined as: (a) nonconventional gestures, non-word vocalizations, or imitative symbols (signs or words) that occurred with coordinated attention to an object and an adult; (b) conventional gestures with attention to the adult; or (c) non-imitative spoken word and American Sign Language approximations. The ICC for intentional communication in the UCS at Time 1 was .88.

The ESCS was used in addition to the UCS to increase the number and structure of sampling opportunities for intentional communication. The ESCS is a structured procedure designed to motivate young children to communicate for the purpose of regulating the behavior of another person, socially interacting with another person, or directing the other person's attention to an object or event.

The number of intentional communication acts (regardless of pragmatic function) was coded from the ESCS using event behavior sampling. For this procedure, intentional communication acts were defined in accordance with the ESCS manual, and included child gestures, vocalizations, and/or verbalizations that were directed to an adult and that served an identifiable communicative function. The ICC for intentional communication from the ESCS at Time 2 was .97. The metric for intentional communication that was used in analyses was an aggregate of the number of intentional communication acts produced across the UCS and ESCS samples.

Measure and Metric for Attention During Child-Directed Speech (ACDS; A Potential Predictor of DKCC)

ACDS was measured using a procedure from Watson et al. (2010) at Time 1. In this procedure, the child is seated at a table facing a puppet theater that contains a window in which all stimuli are presented. Three 1-min child-directed speech (CDS) vignettes were presented. These were a video of a woman reading a children's picture book, a brief live puppet show delivered by a research assistant, and a video of a woman playing with and describing a novel toy. All speakers were adult females who used vocal intensity, pitch, and duration consistent with characteristics of natural child-directed speech. The ACDS media files were coded using a timed-event behavior sampling method to quantify the duration of child looking at the CDS stimuli presented in the puppet theater window, or child not looking at the CDS stimuli presented in the puppet theater window. The metric for ACDS was the proportion of seconds in which CDS vignettes were present that the child looked at CDS stimuli. The ICC for this variable was .99.

Measures and Metric for Motor Imitation (A Potential Predictor of DKCC)

Motor imitation was measured using the Motor Imitation Scale (MIS; Stone et al. 1997) and the Nonverbal Volitional Oral Abilities Scale (NVOA; adapted from Amato and Slavin 1998) at Time 1. The MIS consists of 16 single-step motor imitation items, eight involving body movements only and eight involving actions with objects. Each item is scored in situ as 0, 1, or 2 points on the basis of the quality and accuracy of the imitation. Points were summed across all 16 MIS items to derive the MIS total score. In the NVOA, the participant is prompted to imitate 11 oral motor movements, such as tongue lateralization, blowing, and puckering lips, as demonstrated by the examiner. Each item is scored as 0, 1, or 2 points on the basis of similarity to the model. Points were summed across all 11 items to derive the NVOA total score. The metric for motor imitation that was used in analyses was an aggregate of total raw scores across the MIS and NVOA.

Measures and Metric for Parent Linguistic Responses (A Potential Predictor of DKCC)

Parent linguistic responses to child leads were measured in a 15-min parent–child free play (PCFP) and a 10-min parent–child snack session (PCS). In the PCFP, the parent was provided with a standard set of developmentally appropriate toys and instructed, "Play as you would at home if you had no interruptions and had time to play with your child." The child and parent were free to position themselves as they chose throughout the sample. In the PCS, the parent was provided with a 4 oz. cup, a pitcher of juice, and several single-bite cookies, crackers, or parent-provided snack and was told, "We want to see how your child communicates during snack times. Just interact with him as you would at home if you wanted to elicit his communication." The parent and child were seated at a table throughout the PCS.

A 5-s partial interval behavior sampling method was used to code each codable interval in the PCFP for child attention leads (i.e., the child touching or looking at an object) and parent linguistic responses to child attention leads (i.e., parent talking about the object referenced by the child lead, the action referenced by the child lead, or both). The PCS was coded similarly, with two exceptions. In addition to child attention leads and parent linguistic responses to child attention leads, child communication leads (see UCS section for the definition of intentional communication) and parent linguistic responses to child communication leads were coded. The PCFP could not be reliably coded for child communication leads (and thus parent linguistic responses to child communication leads) because the free positioning of the parent–child dyad during the PCFP sample prevented the reliable use of child gaze to adult's face to judge presence or absence of attention to the adult. Thus, parent linguistic responses were to child attention (PCFP and PCS) or communication (PCS only) leads. The ICC for parent linguistic responses to child leads was .98 for the PCFP and .98 for the PCS procedures. The metric for parent linguistic responses that was used in analyses was an aggregate of the number of linguistic response raw scores across the PCFP and PCS.

Measure and Metric for Receptive Vocabulary (A Potential Mediator of DKCC Growth)

Receptive vocabulary was measured using the MB-CDI (Fenson et al. 2003). Parents were asked to check a list of early vocabulary items to indicate which words their child "understands only" and "understands and says." The sum of the raw number of words understood only + the raw number of words both understood and said (i.e., total number of words understood) was used as the metric for receptive vocabulary in the mediation analyses.

Measure and Metric for Level of Cognitive Impairment (A Controlled Covariate of DKCC Growth)

Level of cognitive impairment was measured using the Mullen Scales of Early Learning (MSEL; Mullen 1995) at Time 1. We used developmental ratio (i.e., mental age divided by chronological age), rather than the standard score (i.e., the Early Learning Composite score), as the index of cognitive impairment because the majority of participants had the lowest possible standard score of 49. Thus, using the developmental ratio produced more variability in cognitive levels than did the standard scores. Mental age was the average age equivalency score from four MSEL subscales: Visual Reception, Fine Motor, Receptive Language, and Expressive Language.

Measure and Metric for Autism Symptomatology (A Controlled Covariate of DKCC Growth)

Autism symptomatology was measured using the ADOS Module 1 Social Affect and Restricted and Repetitive Behavior Total (Gotham et al. 2007) at Time 1. The algorithm score was reflected (i.e., the maximum score + 1 was subtracted from the original score so that adaptive scores were high) to allow for necessary transformations to this variable and to aid interpretation.

Data Analysis Decisions

A summary of data analysis decisions most relevant to the present report is provided here. More detailed rationale for data analysis decisions are provided in Yoder et al. (2015). In preliminary analyses, we aggregated variables, transformed variables that were not normally distributed, and imputed missing data points. We confirmed that all component variables that we intended to aggregate were not only theoretically, but also empirically related, as evidenced by intercorrelation $\geq .40$. Aggregates were then formed by averaging z-transformed component variable scores. All variables to be utilized in analyses that had univariate skewness $>|.8|$ or kurtosis $>|3.0|$ were transformed in accordance with Tabachnick and Fidell (2001). Missing data were multiply imputed (Enders 2010).

In primary analyses, growth curve modeling was used to quantify growth of DKCC because parameters from growth curves provide more precise estimates of change than alternatives when five or more measurement periods are used (Maxwell 1998). Time in Study was centered at Time 5 so the intercept would be interpretable as Time 5 DKCC outcome. In the mediation analyses, we used the Time 5-centered intercept of DKCC growth as the dependent variable. A mediated relation is tested for significance by examining whether the product of the two unstandardized coefficients for the associations comprising the indirect relation has a confidence interval that excludes zero (Hayes 2009). Table 2 provides a summary of the constructs, procedures, measurement periods, and variables used to address the research questions.

Results

Preliminary Analysis

Details of the preliminary analysis results, including the multiple imputation procedure used, are in Yoder et al. (2015). Briefly, all planned aggregate variables met the empirical criterion for aggregation. Several variables were transformed to address extreme skewness or kurtosis. The untransformed component variables and variables used in final analyses, after aggregation and transformation, are summarized in Table 2. An expectation maximization method and 40 imputations using all continuous observed variables were used to impute missing data. Depending on the variable, potential predictors had between 0 and 33 % missing data.

Growth curve modeling showed that DKCC grew in a simple linear fashion, and that there was much variability in DKCC growth. A repeated measures ANOVA indicated a simple linear Time effect, $F(1,62) = 34.9$, $p < .001$, and a simple linear growth trajectory best fit the data. The unconditional growth model indicated that, on average, children incremented the number of key consonants they used in communication acts about every 6.9 months. The statistically significant fixed effects indicated that the average DKCC at Time 5 and the average rate of DKCC growth across the study period were different from zero, both p values $<.001$. Significant random effects suggested that there was significant among-participant variability to be explained in the DKCC outcome at Time 5 and in the rate of DKCC growth across the study period, both p values $<.001$. See Table 3 for descriptive statistics on DKCC at all time periods.

All four potential predictors were significant zero-order correlates of DKCC growth. Table 4 indicates the proportion of explainable variance (pseudo-R square) in DKCC growth accounted for by each predictor. Table 5 indicates the intercorrelations among the predictors and background variables. Intentional communication was significantly associated with motor imitation and ACDS. Number of

Table 3 Means and 95 % confidence intervals for diversity of key consonants used in communication by period

Measurement period	Mean	95 % CI	
		Lower bound	Upper bound
1	5.6	4.3	7.0
2	6.2	4.9	7.5
3	7.4	5.9	8.9
4	8.7	7.1	10.3
5	10.1	8.5	11.2

Scores displayed in this table are *weighted* raw scores (i.e., raw scores for production of up to 13 consonants in up to ten cognate categories multiplied by 2), derived in accordance with the CSBS manual for subscale 11. Thus, the max score for this subscale is 20

parent linguistic responses was nonsignificantly associated with the other three predictors. Cognitive impairment was significantly associated with all four predictors and with autism symptomatology, which was associated with three of the four predictors of DKCC growth. The intercorrelations among the predictors and between the predictors and the background variables needed to be statistically controlled to identify which of these variables had added value in explaining DKCC growth.

Primary Analyses

In the growth curve model with all four predictors and the two background variables, only parent linguistic responses and intentional child communication were value-added predictors of DKCC growth. As shown in Table 6, the model with only these two value-added predictors accounted for medium to large amounts of explainable variance (i.e., pseudo-R squared values) in the intercept and slope, respectively. The total model accounted for a large amount of explainable variance in the growth of DKCC.

We used the structural equation from the final model of DKCC growth to compute the estimated DKCC at Time 1 and Time 5 for hypothetical participants who were −1 SD from the mean, at the mean, and +1 SD from the mean on the two value-added predictors, then plotted the three resulting growth trajectories in Fig. 1. As shown in the figure, even the children with relatively low numbers of intentional communication and parent linguistic responses showed positive growth in DKCC. However, the average rate of DKCC growth was much faster for children who entered the study with relatively more frequent intentional communication and parent linguistic responses. The structural equation for the final model is provided in the notes section of Fig. 1.

Table 4 Pseudo-R squared values for significant zero-order associations of potential predictors with intercept or slope of growth in diversity of key consonants used in communication

Predictors	Growth parameter for change in DKCC	
	T5-centered intercept	Linear slope
Intentional communication	.28	.13
Motor imitation	.14	ns
Attention during child-directed speech	.07	ns
Parent linguistic responses	.07	.09

Pseudo R squared = (Growth parameter's random coefficient from the unconditional model-growth parameter's random coefficient from the model with predictor)/Growth parameter's random coefficient from the unconditional model

Table 5 Intercorrelation of background variables and significant zero-order correlates of at least one of the growth parameters for change in diversity of key consonants used in communication

Variables	ACDS	Motor imitation	Intentional communication	Level of cognitive impairment	Reflected autism symptomatology
Parent linguistic responses	.12	.14	−.09	.32*	.24*
ACDS		.15	.27*	.49**	.27*
Motor imitation			.40**	.35**	.09
Intentional communication				.42**	.30**
Level of cognitive impairment					.57*

ACDS attention during child-directed speech

* $p < .05$; ** $p < .01$

Table 6 Pseudo-R squared change for value-added predictors of growth in diversity of key consonants used in communication by linear growth parameter

Model	Growth parameter for change in DKCC	
	T5-centered intercept	Linear slope
Intentional communication	.33***	.17**
Parent linguistic responses	.12**	.13**
Total model	.37***	.24**

** $p < .01$; *** $p < .001$

Both of the significant value-added predictors were related to the Time 5 estimated level of DKCC (i.e., intercept of Time-5-centered DKCC) through receptive vocabulary at Time 3. These mediational models are illustrated in Fig. 2. The kappa square values (i.e., an effect size metric for indirect effects) for the indirect effects of parent linguistic responses and intentional communication predicting Time-5-centered DKCC intercept through Time 3 receptive language were .36 and .44, respectively. These are large effect sizes. Both indirect effects had confidence intervals that excluded zero, meaning that the associations between the value-added predictors and DKCC were significantly reduced after controlling for receptive vocabulary. These results confirmed the predicted mediated associations (Hayes 2009).

Discussion

This study was conducted to identify the value-added predictors of an under-studied predictor of useful speech in initially preverbal children with ASD: DKCC. Of the four potential predictors and two background variables, only children's intentional communication and parents' linguistic responses to children's attention and communication leads added value to the prediction of growth in DKCC. Variation in midpoint receptive vocabulary, at least in part, mediated the associations between these predictors and endpoint variation in DKCC. Within the context afforded by a correlational design, the mediational model findings are consistent with an interpretation that receptive vocabulary is partly responsible for the associations between the value-added predictors and endpoint DKCC.

Three weaknesses are apparent in this study. First, like all other correlational studies, we cannot rule out alternative explanations for the detected associations. Additionally, we examined only one aspect of vocal communication: diversity of selected consonant use. Finally, we examined only four potential predictors of DKCC.

Seven strengths are apparent in this study. First, selecting preverbal or nonverbal children with ASD and observing them for 16 months allowed predicting growth of DKCC from the period before many of the children were talking through a period when many of the children acquired their early spoken vocabularies. Second, imputing missing data enabled use of all participants and minimized the bias that likely would have resulted from other methods of handling missing data (Enders 2010). Third, using multiple potential predictors and two background variables in the same statistical model allowed us to rule out the possibility that covariation with the other variables in the statistical model explained the associations between value-added predictors and growth of DKCC. Fourth, using growth curve modeling over five measurement periods enabled a better estimate of change in DKCC than is produced by other methods of quantifying change (Maxwell

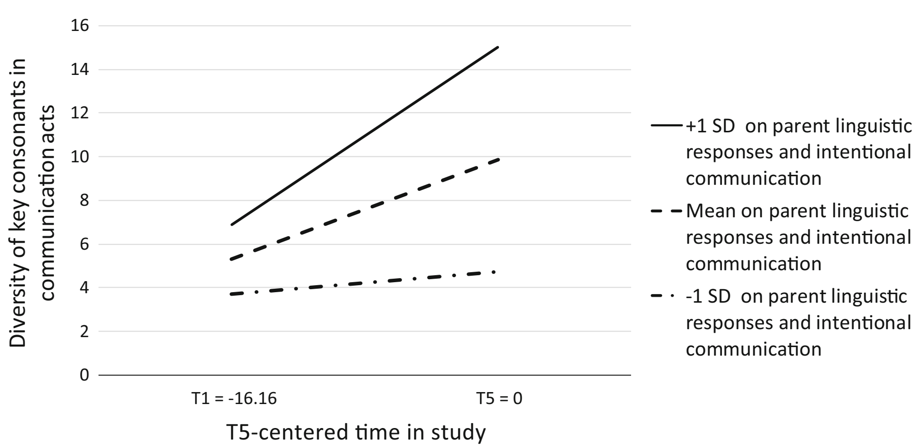

Fig. 1 Growth of diversity of key consonants used in communication (CSBS Subscale 11 weighted raw score) as a function of three values on the value-added predictors. The structural equation used to generate the illustrated trajectories was: eDKCC = −1.55–10(Time) + 2.11(PLR) + 9.71(COMM) + .13(TIME*PRL) + .33(TIME*COMM). In aforementioned formula, estimated DKCC is "eDKCC," T5-centered time is "TIME," parent linguistic responses is "PLR," and intentional communication is "COMM."

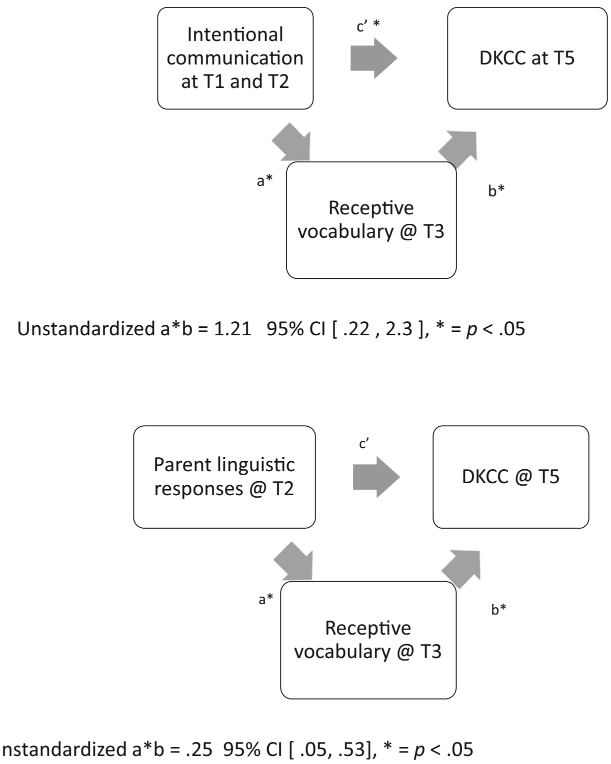

Fig. 2 Results of simple mediation models for the value-added predictors of T5-centered intercept for the growth curve of DKCC (i.e., diversity of key consonants used in communication)

1998). Fifth, when justified and available, two measures of several of the predictors were used to improve the stability, and thus the potential validity of estimates for these emerging skills (Sandbank and Yoder 2014). Sixth, all variables were derived from different procedures, preventing shared measurement method variance from explaining the associations. Finally, because theory suggested that receptive vocabulary might help explain the associations between value-added predictors and growth of DKCC, we were able to predict and confirm that these associations were, at least in part, mediated through receptive vocabulary. Had we not tested these simple mediational models, we would have missed the important role that receptive vocabulary might play in understanding why children's intentional communication and parent linguistic responses predict growth in DKCC.

These findings lend empirical support to the transactional theory of speech sound development. We confirmed that one parent factor (linguistic input) and two child factors (intentional communication and receptive vocabulary) suggested by Stoel-Gammon (2011) contribute in a dynamic manner to growth in vocal communication development (i.e., DKCC) in initially preverbal children with ASD. As indicated in the introduction, most of the prior work motivated by the transactional theory of speech sound development has focused on typically developing infants and their caregivers. One such report also detailed a complex interplay between one form of child communication (specifically, vocal communication), parental responses, and vocabulary as it relates to increased vocal complexity in typically developing infants (Gros-Louis et al. 2014). We are hopeful that future work across laboratories will increase our understanding of how parent and child factors impact vocal and verbal development in various populations in the early stages of language development.

Very little study of the *predictors* of vocal development in initially preverbal children with ASD has been undertaken to date. In one of the only such studies to our knowledge, two child factors that are seemingly consistent with Stoel-Gammon's (2011) theory of phonological development, motor imitation and attention to child-directed speech, were identified as predictors of DKCC in preverbal children with ASD (Patten et al. 2012). The findings from the Patten et al. (2012) study were the result of an earlier analysis of the current study's participants. It differed from the current analyses in the following ways: (a) it used an endpoint analysis of DKCC, (b) the DKCC metric was derived only for Time 1 and Time 3, and (c) only a subset of the current study's predictors were examined. The present study shows that motor imitation and ACDS are significantly correlated with intentional communication and, when entered into the same model, become nonsignificant predictors of DKCC growth. Thus, if the current study's findings are replicated, they suggest a need to place higher weights on intentional communication, parent linguistic responses, and receptive vocabulary than on motor imitation as potential goals for treatment of DKCC in preverbal children with ASD.

Because of the paucity of data on predicting DKCC growth in children with ASD, the findings of the current study require replication. The proposed causal chain indicated in the transactional model of speech sound development can be most rigorously tested in a treatment study that uses an internally-valid experimental research design. In such a study, parent linguistic responses and intentional communication would be treated, with receptive vocabulary as a short-term goal and DKCC growth as a longer-term goal for children with ASD. The results of simple mediation analyses would have to show an indirect effect of treatment on DKCC growth through receptive vocabulary. Confirmation of such a mediation relation in a well-controlled treatment study would increase our confidence that targeting child intentional communication and parent linguistic responses produces early effects on children's receptive vocabulary, which translate to gains in DKCC growth, possibly because children begin to try to produce the words that they have come to understand through transactions with their adult communication partner.

To our knowledge, this is the first study to identify intentional communication and parent linguistic responses as value-added predictors of DKCC growth in preverbal children with ASD. These value-added predictors were found to be indirectly related to DKCC through receptive vocabulary. It is hoped that this correlational research will motivate experimental treatment studies to test whether these associations are causal.

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Author Contributions Tiffany: Data Collection/Coding, Data Analysis, Interpretation of Results, Writing/Revision of Manuscript Linda: Acquisition of Funding, Management of Personnel, Interpretation of Results, Writing/Revision of Manuscript Elizabeth: Management of Personnel, Data Collection/Coding, Writing/Revision of Manuscript Cassandra: Data Collection/Coding, Writing/Revision of Manuscript Bahar: Data Collection/Coding, Writing/Revision of Manuscript Paul: Acquisition of Funding, Management of Personnel, Data Collection/Coding, Data Analysis, Interpretation of Results, Writing/Revision of Man

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