LONGITUDINAL TRAJECTORIES OF EARLY COORDINATED COMMUNICATION IN TODDLERS WITH AUTISM: PREDICTING LANGUAGE OUTCOMES AT AGE THREE

A Thesis
Presented to
The Academic Faculty

by

Vicky Yu

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Psychology in the
Georgia Institute of Technology

Georgia Institute of Technology
May 2025

LONGITUDINAL TRAJECTORIES OF EARLY COORDINATED COMMUNICATION IN TODDLERS WITH AUTISM: PREDICTING LANGUAGE OUTCOMES AT AGE THREE

Approved by:

Dr. Agata Rozga, Advisor
School of Interactive Computing
Georgia Institute of Technology

Dr. Woon Ju Park
School of Psychology
Georgia Institute of Technology

Date Approved: April 17th, 2025

ACKNOWLEDGEMENTS

I would like to thank my mom, dad, grandpa, sister, and friends for their unconditional love and support. I would also like to thank Dr. Agata Rozga for her mentorship and dedication on this thesis and Dr. James Roberts for his help with the statistical analyses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ASD	Autism Spectrum Disorder
CCS	Communication Complexity Scale
MV	Minimally verbal
LI	Language impaired
LU	Language unimpaired
MSEL	Mullen Scales of Early Learning
KU	University of Kansas
VUMC	Vanderbilt University
PV	Predictor variable
OV	Outcome variable
SAS	Statistical Analysis System
MLR	Multivariate Linear Regression
MMR	Multivariate Multiple Regression
CDA	Canonical Discriminant Analysis

SUMMARY

Early coordinated communication behaviors—such as gestures, gaze, and vocalizations—are known predictors of language development in children with Autism Spectrum Disorder (ASD), yet few studies have examined how these behaviors unfold longitudinally across early development greater than two timepoints and how their trajectories predict later language skills. This study examined whether longitudinal growth trajectories in early coordinated communication, measured through linear, quadratic, and cubic components of Communication Complexity Scale (CCS) scores, and gesture frequency at the first visit predicted language outcomes at age three in toddlers with ASD. Using data from 20 children across at least four time points, I modeled communication growth and assessed language acquisition via the Mullen Scales of Early Learning. Results partially supported the hypotheses. The overall shape of communication trajectories—linear, quadratic, or cubic—was not significantly related to language outcomes. However, the slope of the linear growth component, representing the overall magnitude and direction of communication change, significantly predicted increases in receptive language scores. This relationship held even for children whose communication growth was best characterized by non-linear (quadratic or cubic) patterns, emphasizing that the overall developmental trend, rather than the specific trajectory shape, matters most for language outcomes. Gesture frequency at intake did not predict language outcomes, nor did it moderate the association between linear slope and language acquisition. In exploratory analyses, initial CCS scores significantly predicted both receptive and expressive language levels at age three, highlighting the predictive utility of early coordinated communication measured at a single time point.

These findings highlight the importance of modeling developmental processes in context rather than isolation. Static, single-timepoint measures may obscure important patterns of growth that unfold over time. Despite limitations including small sample size and measurement ceilings, this study underscores the need for dynamic, longitudinal approaches in understanding early communication and informing individualized interventions in ASD.

CHAPTER 1. INTRODUCTION

1.1 Research Question and Significance

Early communication skills, particularly spoken language by age five, are strong predictors of later success in academic, social, and vocational domains (Venter et al., 1992; Lord et al., 2004; Sigman & McGovern, 2005). However, language development in Autism Spectrum Disorder (ASD) is marked by significant variability, with some children developing fluent speech while others, approximately 25%-30%, remain minimally verbal, never acquiring functional spoken language (Tager-Flusberg & Kasari, 2013; Norrelgen et al., 2015; Rose, 2016). Even within minimally verbal groups, developmental trajectories vary considerably, with some children showing improvement in language skills over time whereas others do not (Venker et al., 2014). Early delays, specifically in spoken expressive language, are commonly the first noticeable developmental concerns in children subsequently diagnosed with autism and have been linked to poorer long-term social outcomes and reduced adaptive skills (Tager-Flusberg et al., 2005). Infants exhibiting slower developmental trajectories in coordinated communication – particularly in gestures coordinated with vocalizations – experience negative cascading effects of later social interaction and linguistic development (Parladé & Iverson, 2015). Collectively, these findings highlight the necessity of identifying early predictors of language outcomes to optimize interventions and underscore the critical role of early communication abilities in predicting social functioning and adaptive outcomes in individuals with ASD.

Most studies examining communication development in ASD in the first few years of life focus on coordinated communication – the combined use of gestures, gaze, and/or vocalizations to convey meaning – and typically measure change over two time points. However, this approach

risks oversimplifying the complexity of early developmental trajectories and thus their impact on subsequent acquisition of spoken language. The current study investigates short-term changes in coordinated communication across multiple time points in toddlers with autism and the impact of these changes on language acquisition, as measured by receptive and expressive language abilities, at age three. This study aims to capture a comprehensive view of growth trajectories and developmental fluctuations over time, providing a more nuanced understanding of how communication development unfolds in children with ASD.

1.2 Variability in Language Development in ASD

Language acquisition in children with ASD varies significantly, influenced by a combination of genetic, cognitive, and environmental factors. Speech delays are the most common reason for referrals to autism diagnostic clinics, and language abilities are pivotal predictors of later adaptive skills, independence, and educational outcomes (Lord et al. 2004; Cui et al., 2023; Mayo et al., 2013; Miranda et al., 2023). However, language development in ASD follows diverse trajectories. Some children initially nonverbal begin speaking by age nine, while others do not progress beyond basic phrases.

Early language development in young children with ASD is notably delayed compared to typically developing peers, particularly concerning expressive language skills. Parents frequently report initial concerns about their child's development due to unusual patterns or delays in speech, typically observable by age two (Tager-Flusberg et al., 2005). Delays in the emergence of first words are also well-documented in children with ASD. Tager-Flusberg et al. (2005) noted that while typically developing children often speak their first words around 12 months, children with ASD frequently do not produce first words until well after 18 months, and some remain nonverbal beyond age three. Wetherby et al. (2007) similarly found that late onset of single

words, combined with deficits in gesture use and social communication acts, differentiated toddlers with ASD from both typically developing and developmentally delayed peers by age two. Moreover, in a longitudinal analysis of nonverbal preschoolers with ASD, Yoder et al. (2015) identified early receptive vocabulary, intentional communication, and response to joint attention as value-added predictors of spoken language growth over time, indicating that early difficulties in language acquisition are rooted in both social and linguistic processing challenges that are observable before age three.

Research consistently documents considerable variability in language development trajectories among children with ASD, which profoundly influences later adaptive functioning and educational outcomes (Lord et al., 2004). Longitudinal studies have identified distinct language profiles emerging as early as the preschool period. For example, Latrèche et al. (2024) tracked a large longitudinal sample of preschoolers with ASD aged between 1.5 and 5.7 years, identifying three primary developmental trajectories: minimally verbal (MV), language impaired (LI), and language unimpaired (LU). Approximately 20% of children fell into the minimally verbal category, characterized by limited vocabulary and minimal syntactic abilities, typically not exceeding three-word spoken phrases. Of those who acquired functional spoken language, about half displayed significant structural language impairments across phonology, morphology, syntax, or semantics, while the other half showed typical language acquisition (Latrèche et al., 2024). Additionally, longitudinal research by Kjelgaard and Tager-Flusberg (2001) found substantial heterogeneity among 89 children aged 4-14 years with ASD, indicating that while some children acquired age-appropriate language skills, others experienced profound delays. Later work by Venker et al. (2014) identified four distinct trajectories of autism severity using calibrated ADOS scores: Persistent High, Persistent Moderate, Improving, and Worsening.

Children in the Persistent High group showed the most significant delays across domains, including language, while the Improving group showed measurable gains in both receptive and expressive language, indicating variability even within clinically diagnosed ASD populations. These longitudinal insights underscore that trajectories in AD language acquisition are highly individualized, reinforcing the need for continued tracking and assessment beyond single or dual time points which current research often focuses on (Lord et al., 2004; Shank, 2011; Venker et al., 2014).

1.3 Early Coordinated Communication

Early coordinated communication encompasses behaviors such as non-verbal gestures, eye gaze shifts, and vocalizations, which support essential communicative functions such as joint attention and behavior regulation (Crais et al., 2009; Salley et al., 2020). Behavior regulation refers to the ability to influence another person's actions through communication, such as using vocalizations or gestures to request or reject objects or activities. Joint attention, sharing focus with another person on an object or event, is similarly foundational, as it facilitates word-object associations, and it achieves and maintains shared attention and engagement. These concepts are critical components of communication, particularly in early developmental stages, as they reflect a child's ability to engage socially and express needs effectively even before they can speak (Brady et al., 2012; Wetherby et al., 2007; Charman et al., 2003).

Children with ASD often exhibit delays in early communicative behaviors, and the quality and quantity of their gestures, gaze shifts, and vocalizations differ significantly from those of typically developing children. According to Parladé and Iverson (2015), infants who were later diagnosed with ASD showed significantly slower developmental trajectories, specifically in gestures coordinated with vocalizations, compared to both low-risk peers and

high-risk infants without ASD. This delay was evident as early as 8-18 months of age, a critical period for the emergence and consolidation of social communication behaviors. Additionally, Stone et al. (1997) observed that two and three-year-old children with ASD engaged less frequently in nonverbal communication behaviors such as pointing, showing objects, or using eye gaze shifts compared to developmentally delayed peers, instead often communicating by manipulating another person's hand rather than using conventional gestures or gaze to express intent. For instance, deictic gestures, which direct attention to specific referents like pointing, are crucial for language development but are less frequently produced by children with ASD. These deficits result in slower language acquisition and highlight the need for targeted interventions (Ramos-Cabo, 2019; Brady et al., 2020). Further supporting these findings, Wetherby et al. (2007) identified significant impairments in gestures and joint attention behaviors in toddlers with ASD by 18-24 months, distinguishing them from both typically developing and developmentally delayed children. This study emphasized that initiating joint attention and using gestures for social purposes were notably reduced in the ASD group. Collectively, these findings suggest that early disruptions in foundational pre-language communication behaviors are early markers of ASD.

In terms of how young children with ASD utilize these early pre-linguistic behaviors functionally in interactions, research highlights significant differences compared to typically developing children. According to Stone et al. (1997), children with autism aged two to three years used pre-linguistic communication behaviors predominantly for behavior regulation purposes, such as requesting or directing another person's actions, rather than for establishing joint attention by sharing focus on objects or events. Specifically, these children produced fewer communicative acts aimed at commenting or sharing interest, which is essential for joint

attention. Parladé and Iverson (2015) similarly noted that infants later diagnosed with ASD displayed a marked impairment in coordinating gestures and vocalizations to initiate or maintain shared attention, which are behaviors strongly predictive of later language and social communication skills. Wetherby et al. (2007) further demonstrated that behavior regulation acts, such as requests and protests, were more frequently observed in toddlers with ASD than joint attention acts, particularly those used for social purposes like commenting or showing. Their findings indicate that joint attention behaviors are significantly impaired in ASD. Drew et al. (2007) also found that while the frequency of overall communicative acts may not differ, the function of these acts does: children with ASD were less likely to initiate social interactions or share experiences through gestures. These data suggest that young children with autism are notably less likely to utilize pre-linguistic behaviors for social engagement purposes such as joint attention and more likely to limit their communication to behavior regulation like requesting assistance or obtaining objects.

1.4 Language Acquisition and Its Predictors

Receptive and expressive language abilities are core components of language acquisition. Receptive language refers to understanding spoken or signed language, while expressive language pertains to producing spoken or signed communication. Early predictors, such as gestures like pointing and showing, as well as early symbolic gestures, are strongly associated with later language gains in children with ASD, underscoring the importance of targeted early interventions during a sensitive developmental period (Landa, 2007; Sigman & McGovern, 2005; Bopp & Mirenda, 2011; Brady et al., 2020). The frequency and diversity of these early gestures are linked to better subsequent language outcomes, underscoring the critical role of early communicative behaviors in predicting later language development (Wetherby et al., 2007).

Furthermore, early intentional nonverbal communication, such as coordinated attention between child and caregiver, strongly predicts later language competence and overall developmental progress, emphasizing prelinguistic interaction skills as a foundation of linguistic and social adaptability (Calandrella & Wilcox, 2000). Children with ASD demonstrating early deficits in nonverbal communication, including fewer gestures and less frequent eye contact, later exhibit significant impairments in social communication (Stone et al., 1997).

In addition to communicative behaviors themselves, behavioral functions are vital for language acquisition. Wetherby et al. (2007) found that early social communicative functions such as initiating joint attention and behavior regulation were strong predictors of later language and developmental outcomes. Not only does the presence of these functions predict language outcomes, but it is the quality and coordination of early communicative acts—especially those used for joint attention rather than behavior regulation—that most robustly predict later spoken language acquisition (Drew et al., 2007; Yoder et al., 2015; Toth et al., 2006). Similarly, early deficits in pre-linguistic communicative behaviors and their associated functions consistently predict poorer language outcomes. Preschool language outcomes in ASD can generally be categorized into minimally verbal, language impaired, and language unimpaired profiles, with each profile significantly influenced by early nonverbal cognitive and communication abilities (Venker et al., 2014; Latrèche et al., 2024). Notably, Charman et al. (2003) found that early gesture use and joint attention predicted expressive language development even after controlling for nonverbal mental age, reinforcing the unique and independent role of these early social communicative skills. Together, these findings highlight that early coordinated communication serves as a foundational mechanism for language acquisition in children with ASD, particularly when used for social engagement.

1.5 Current Study

This study addresses a critical gap in the longitudinal literature by examining early coordinated communication across multiple time points, providing a more intricate understanding of developmental change. While it is well-established that children with autism exhibit highly variable language trajectories, especially early in life, and that early coordinated pre-verbal communication skills predict later language outcomes, few studies have investigated the relationship between these two factors longitudinally in the first years of life. This is a central contribution of the current work. Most longitudinal research to date typically examines change between only two time points. In contrast, this study uses at least four assessments to capture a more detailed picture of how communication development unfolds—highlighting not just steady growth, but also periods of rapid progress, plateaus, or regression. Additionally, unlike prior studies that rely primarily on standardized language assessments like the Mullen Scales of Early Learning (MSEL), which offer relatively coarse measures of change, this study also leverages the Communication Complexity Scale (CCS) as an observational tool capable of capturing fine-grained, short-term changes in the complexity of early coordinated communication. By linking these patterns of early communication change to language outcomes at age three, this research offers a richer and more dynamic perspective on early developmental pathways in autism, with important implications for individualized early intervention. These insights are critical for optimizing early interventions and tailoring strategies to individual growth patterns.

This study hypothesizes that different growth trajectories in early coordinated communication, characterized by linear, quadratic, and cubic growth components in CCS scores, will be predictors of language acquisition, measured by the MSEL, at age three for toddlers with

ASD. This study additionally hypothesizes that a higher frequency of gestures produced at the first visit by toddlers with ASD will be a predictor of higher language acquisition at age three.

CHAPTER 2. METHODS

2.1 Participants

Data for this study was drawn from an NIH-funded longitudinal study which is a collaborative effort involving the Georgia Institute of Technology, University of Kansas (KU), and Vanderbilt University (VUMC). The participants were children diagnosed with autism spectrum disorder (ASD) who were between the ages of 18 and 30 months at the time of their first visit to the study. Inclusion criteria required that children (1) have a clinical diagnosis of autism; (2) do not have genetic conditions commonly associated with autism (e.g., Fragile X, Tuberous Sclerosis); (3) are able to sit upright independently, hold and grasp small items, and take a few steps, and (4) have English as their primary language and/or are exposed to spoken English in the home.

Recruitment for the study was carried out through multiple channels across Georgia, Tennessee, and Kansas. This included contacting school principals, teachers, speech-language pathologists, directors of special education, clinic staff members, and other professionals affiliated with local diagnostic and assessment clinics, who were asked to present materials about the study to caregivers of children who meet the inclusion criteria. Additionally, recruitment fliers were posted in the waiting rooms of early intervention providers. The team had established points of contact with the Babies Can't Wait program, Georgia's Birth-to-Three initiative, and other local autism centers (e.g., Marcus Autism Center, Emory Autism Center).

Participants received compensation for their time and travel. Those recruited through KU or VUMC received $75 for completion of the initial visit and $50 for each regular study visit. Additionally, families traveling over 30 miles were compensated $15 per visit for time spent

traveling. Participants recruited through Georgia Tech received $75 for each completed visit, with travel compensation provided for families traveling over 25 miles.

For the purposes of my specific study, I used data from participants who met the following additional criteria: children who were 18-28 months old at their first visit, had completed their 3-year visit by February 2025, and had completed a minimum of four visits from their first visit to the 3-year visit.

2.2 Design

This study employed a longitudinal, repeated measures design to examine the relationship between early coordinated communication growth trajectories and language acquisition in toddlers with ASD. Participants were assessed at a minimum of four time points up to a maximum of 6 time points: the first visit (between 18-28 months of age), and subsequent visits at 3-month intervals leading up to 3 years old.

2.3 Procedure

At the beginning of the first study visit, participants' parents signed an informed consent form, which outlined the study procedures, potential risks, and benefits. Additionally, parents were asked to fill out relevant questionnaires to gather background information. During the visit, the child underwent assessments of receptive and expressive language using the Mullen Scales of Early Learning (MSEL). The MSEL was administered by a trained examiner. In addition to the MSEL, the Communication Complexity Scale (CCS) was administered by a trained examiner. At the end of the visit, the participant's parent received compensation for their time. For the follow-up visits, participants returned every three months until their age-3 visit, with the same procedures followed for each visit, except for the initial informed consent administration. During these follow-up visits, the MSEL and CCS were administered. After each visit, the MSEL and

CCS were scored, and the number of gestures produced by the child were coded. These data were used to track changes in communication and language development across the study's multiple time points.

2.3.1 Demographic and Medical History Questionnaire

A caregiver-reported questionnaire was administered at the start of the study to collect demographic information about the child (e.g., age, gender, and ethnicity) as well as medical history and any relevant developmental milestones prior to the study's beginning. This allowed for controlling for potential confounding factors and ensuring that eligibility criteria were met.

2.3.2 Video and Audio Recordings

To ensure accurate and detailed analysis of participant sessions, all CCS assessments were video and audio recorded. These recordings provided a reliable basis for later coding and gesture production counts. The recordings were captured using high-quality recording equipment, including ORDRO cameras, a Panasonic camera, and a Tascam audio recorder with an external microphone. This setup allowed for clear visual and audio documentation of each session, ensuring that both subtle gestures and vocalizations were accurately captured.

The recorded sessions were securely stored and used exclusively for research purposes, such as coding gesture production during the CCS. This method not only enhanced the reliability of the data collection process but also allowed researchers to revisit and verify observations as needed, contributing to the overall validity of the study's findings.

2.4 Materials

The following standardized measures, observational tasks, and coding systems were used to assess the growth in early coordinated communication and language acquisition:

2.4.1 Communication Complexity Scale (CCS)

Early coordinated communication was assessed using the Communication Complexity Scale (CCS). The Communication Complexity Scale (CCS) is a structured observational tool that evaluates early communication behaviors in children, such as the use of gestures and vocalizations, and communicative functions including joint attention and behavior regulation. The CCS provides a developmental continuum of communication skills, ranging from presymbolic communication (e.g., gestures and body movements) to more advanced symbolic communication (e.g., word use) (Brady et al., 2012). The CCS has demonstrated excellent reliability and validity. Inter-rater reliability was high, with overall kappa scores between independently scored assessments at .83. The test-retest reliability was also strong, with a correlation of .84 between initial scores and retests completed within two weeks (Brady et al., 2018). Furthermore, concurrent validity was demonstrated by significant correlations between CCS scores and other established measures of early communication, including the Communication Matrix (Rowland, 2011) and the Vineland Adaptive Behavior Scales II expressive communication scale (Sparrow, Cicchetti, & Balla, 2005), suggesting that the CCS reflects the same underlying communication construct while providing unique information (Brady et al., 2018).

The CCS was administered at each study visit to assess the child's communication, and the CCS scores were used to track changes in communication development across multiple time points. During the assessment, the participant was presented with multiple sets of toys where one was functional and the other non-functional as well as several surprising events. This provided opportunities for the participant to initiate communication with the examiner. A score was given on a scale of 0-12 for each toy event based on the rating scale in Table 1. The optimal score was

calculated by averaging the three highest scores. These optimal scores were used as the CCS scores for the purposes of this study.

Growth trajectories for each participant were calculated using CCS scores at each visit, allowing for the identification of linear, quadratic, and cubic growth components in communication abilities and slopes for each component based on the rate and direction of change in early communication skills over time. The linear, quadratic, and cubic growth components and the corresponding slopes were six predictor variables (PV) used to characterize growth trajectories of the CCS scores. These were analyzed to determine whether the trajectory of early communication growth predicts language acquisition.

Table 1 – CCS Rating Scale with Behavioral Descriptions

No.	Definition	Communication level
0	No response	
1	Alerting – a change in behavior, or stops doing a behavior	Preintentional
2	Single orientation only – on an object, event, or person; can be communicated through vision, body orientation, or other means	Preintentional
3	Single orientation only and a PCB[1]	Preintentional
4	Single orientation only + more than 1 PCB	Preintentional
5	Dual orientation – shift in focus between a person and an object, between a person and an event using vision, body orientation, and so on (without PCB)	Preintentional
6	Triadic orientation (e.g., eye gaze or touch from object to person and back)	Intentional nonsymbolic
7	Dual orientation + 1 PCB (e.g., dual focus + gesture)	Intentional nonsymbolic
8	Dual orientation + 2 or more PCB (e.g., dual focus + gesture + vocalization, and switch closure)	Intentional nonsymbolic
9	Triadic orientation + 1 PCB (e.g., triadic + vocalization)	Intentional nonsymbolic
10	Triadic orientation plus more than 1 PCB (e.g., triadic plus vocalization and differential switch closure)	Intentional nonsymbolic
11	One-word verbalization, sign, or AAC symbol selection	Intentional symbolic
12	Multi-word verbalization, sign, or AAC symbol selection	Intentional symbolic

Note. Copyright © 2017 by The University of Kansas. Printed with permission. CCS = Communication Complexity Scale; PCB = potentially communicative behavior; AAC = augmentative and alternative communication.

2.4.2 Gesture Production Count

Gesture production counts, a direct measure of the frequency of the child's use of gestures, a form of non-verbal communication, were also recorded during the CCS at the first visit. This observational measure focuses on non-verbal communicative gestures such as pointing, waving, or showing objects, which are early indicators of coordinated communication (Ramos-Cabo, 2019). Only gestures that were initiated by the participant and served a clear communicative purpose were counted; gestures prompted by the examiner were excluded. The number of gestures were coded for each visit using the Mangold INTERACT software, and the frequency of gesture production was analyzed as a separate predictor of communication development. This data was used to determine whether an initial snapshot of non-verbal communication predicts language acquisition.

2.4.3 Mullen Scales of Early Learning

The Mullen Scales of Early Learning (MSEL) is a comprehensive tool used to assess cognitive, motor, and language development in children aged 0-68 months (Mullen, 1995). The MSEL includes both receptive and expressive language subscales, which served as the primary measure of language acquisition in this study. The receptive language subscale evaluates the child's ability to understand spoken language, while the expressive language subscale assesses their ability to produce language (Bradley-Johnson, 1997). These subscales were administered at the initial visit and again at the visit around age three, providing a measure of language change over time. The age equivalents were derived from the MSEL manual, which lists the age equivalent in months that corresponds to the scale raw score. The MSEL reliably evaluates these domains, offering separate scales for verbal and nonverbal abilities, which is particularly beneficial for assessing children with ASD (Shank, 2011; Bradley-Johnson, 1997). The measure

demonstrates strong reliability, with internal consistency ranging from 0.75 to 0.83 for its scales and an Early Learning Composite reliability between 0.83 and 0.95 (Shank, 2011). The tool also shows robust validity, with correlations to age-related score increases and concurrent validity with other established measures (Shank, 2011).

Language acquisition can be understood as both a developmental process over time and an outcome measured at a final assessment. For this study, I chose to measure both concepts, resulting in four outcome variables: receptive and expressive age equivalent at 3-years-old (final assessment), and change in receptive and expressive age equivalent from the first to final assessments. This allowed for an examination of whether different patterns of early coordinated communication are associated with greater gains in language skills over time.

2.5 Analysis

2.5.1 Characterization of Growth Trajectories

To statistically determine growth trajectories in CCS scores across all time points, each subject's pattern of communication development was decomposed into orthogonal polynomial components: linear, quadratic, and cubic. For each subject, an R-squared value was calculated for each growth component, representing the proportion of variance in their CCS scores over time accounted for by each trend. These R-squared values were derived by fitting orthogonal polynomial regression lines to each participant's raw trajectory, minimizing the squared deviations between observed and predicted values. These values served as three distinct predictor variables – each reflecting the strength of a specific growth component – allowing for analysis of how different growth patterns relate to language acquisition. In addition to the R-squared values, the slope of each polynomial regression line was also calculated for every participant, resulting in linear slope, quadratic slope, and cubic slope. These slope values captured the direction and

magnitude of change for each growth component and served as three additional predictor variables. Together, the R-squared values and slopes provided a comprehensive characterization of each participant's growth trajectory, enabling analyses of how both the strength and directionality of communication growth relate to language acquisition at age three.

2.5.2 Predictors Against Language Acquisition

Statistical analyses were performed using the Statistical Analysis System (SAS) software with the assistance of Dr. James Roberts. Multivariate Linear Regression (MLR), Multivariate Multiple Regression (MMR), and Canonical Discriminant Analysis (CDA) were selected as the appropriate procedures for the analyses to assess the impact of the predictors, trajectories of coordinated communication over time and initial gesture use, on language acquisition at age 3.

A multivariate approach was used in this analysis to account for the interrelationships among the four outcome variables (OVs): receptive and expressive age equivalent at 3-years-old and change in receptive and expressive age equivalent from the first to final assessments. This approach is particularly advantageous when the OVs are expected to be correlated, as it considers their covariation rather than treating them independently. By modeling the shared variance among the OVs, multivariate regression can provide greater statistical power than conducting multiple univariate ANOVAs, which assume independence among outcomes. In this case, taking into account the covariation among the OVs enhanced power and contributed to the detection of significant effects that would likely have been missed in a series of separate univariate tests.

Following a significant multivariate result, CDA was conducted to further explore the impact of early communication skills and trajectories over time on language outcomes at age 3 This technique created a composite variable – a linear combination of the OVs – with weights

selected to maximize the correlation with the predictor variable (PV). The resulting canonical variate offered more power for detecting group differences than any individual OV alone, providing a more sensitive and interpretable summary of the multivariate effect. The canonical correlation value was calculated from the correlation between the predictor variable and the canonical variate. The canonical structure matrix provided the correlations between each outcome variable and the canonical variate, allowing for interpretation of the relationships between each OV with each PV.

A total of five analyses were conducted: three addressed the hypotheses, and two were exploratory. The first analysis examined growth trajectories in communication complexity as a predictor of language acquisition using MMR and CDA. The second analysis tested whether gesture frequency at time 1 predicted language acquisition using MLR, and the third repeated this analysis using MMR while controlling for age. The fourth analysis tested the interaction between linear slope in communication complexity—the only statistically significant growth predictor—and gesture frequency, using MMR. Interaction terms involving all other growth components were not included to preserve degrees of freedom. Including all possible interactions would have severely compromised statistical power, rendering the results statistically unreliable. Finally, the fifth analysis assessed whether initial CCS scores at Time 1 predicted language acquisition, also using MMR and CDA.

CHAPTER 3. RESULTS

3.1 Characterization of Growth Trajectories

The raw CCS scores for each participant across the four study visits are shown by Figure 1. The variation in slope and curvature among individual lines illustrates the heterogeneity in communication development trajectories within the sample. Visual inspection of these trajectories revealed that most patterns of growth aligned with linear, quadratic, or cubic shapes, motivating the decision to model each participant's trajectory using orthogonal polynomial components. These raw data were used to derive each participant's polynomial growth components (linear, quadratic, cubic), which were then used as predictors in later analyses of language outcomes.

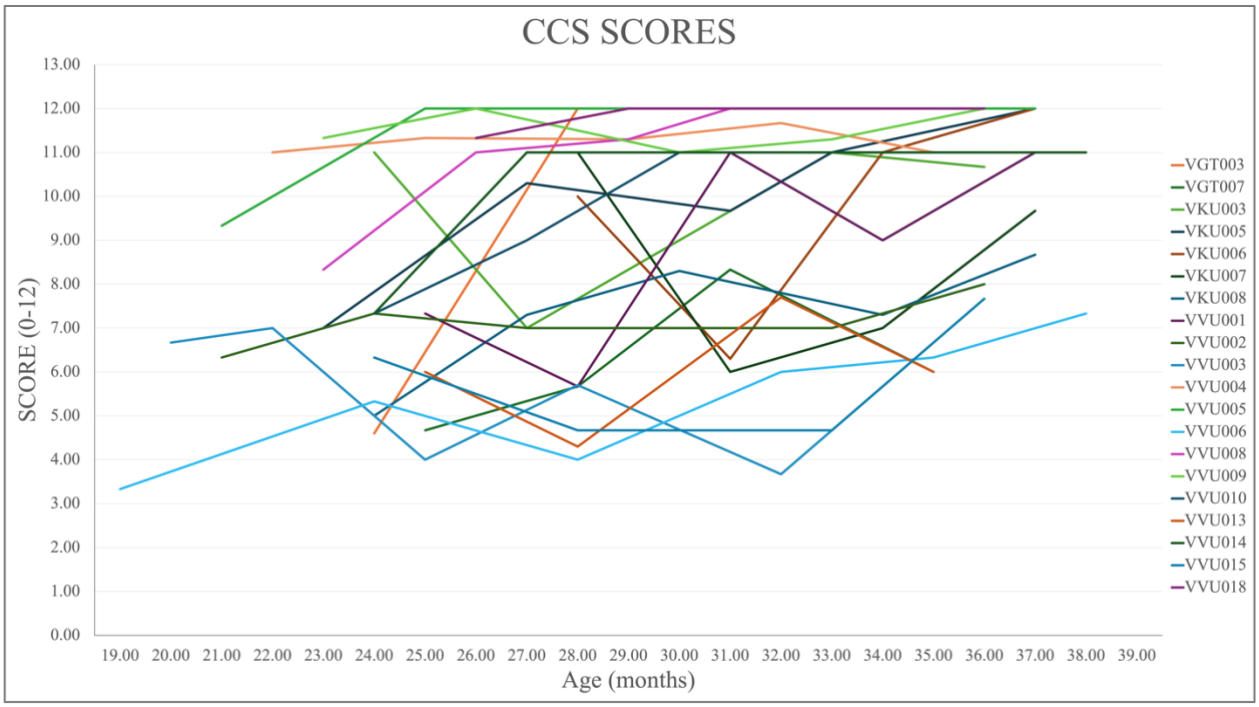

Figure 1 – Raw CCS Scores Per Participant
Note. Each line represents an individual participant's CCS scores across the four-six time points.

The calculated R^2 values and slope directions for each participant's linear, quadratic, and cubic growth components are illustrated in Figure 2. The height of each point reflects how well each polynomial component explained variance in the participant's CCS trajectory, while the arrow length and direction indicate the magnitude and direction of the slope. Each participant's most representative growth pattern—the component with the highest R^2—is circled in red. As shown, most participants were best characterized by linear growth, suggesting relatively consistent communication development over time. However, several participants showed stronger fits for quadratic or cubic components, indicating more complex, non-linear growth patterns such as acceleration or multi-phase change. The direction and shape of the slopes further highlight individual differences in the trajectory of early communication. These R^2 values and slope estimates were extracted for all three growth components and served as the six predictor variables in the subsequent analyses of language outcomes.

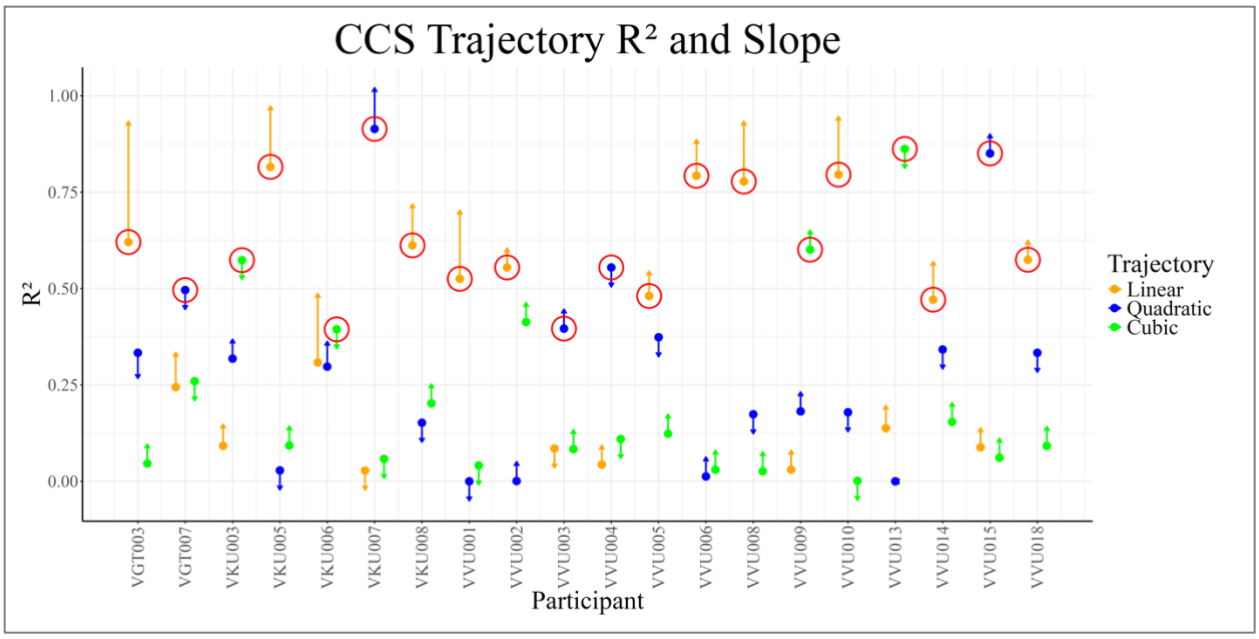

Figure 2 – R^2 Growth Component and Slope Per Participant
Note. Each dot represents the R^2 value for a participant's linear (blue), quadratic (orange), and cubic (green) growth component. Lines extending from each point depict the slope of that component: longer lines indicate greater slope magnitude, and the direction (up or down) indicates whether the slope was positive or negative. Red circles mark the highest R^2 for each participant, representing their most representative growth shape.

The linear, quadratic, and cubic slopes each represent different aspects of how a child's communication changed over time. The linear slope captures the overall direction and magnitude of change across the measured timepoints, representing the best-fitting straight-line trend onto the child's trajectory. Positive linear slope values indicate that, on average, a child's communication complexity increased over the assessment period, even if their trajectory included nonlinear periods, and negative values indicate an overall decreasing trend. The quadratic slope captures acceleration or deceleration in development; a positive value suggests communication growth sped up over time, while a negative value indicates early gains that slowed or plateaued. The cubic slope reflects more complex, S-shaped trajectories that involve multiple phases of change, such as initial growth followed by a decline and then a second

increase. Together, these slopes provide a detailed picture of the direction and shape of each participant's communication development.

Table 2 – Means and Standard Deviations for Each Predictor and Outcome Variable

Variable	Mean	SD
Predictor – Linear growth in CCS optimal score (R^2 value)	0.404	0.290
Predictor – Quadratic growth in CCS optimal score (R^2 value)	0.297	0.261
Predictor – Cubic growth in CCS optimal score (R^2 value)	0.211	0.236
Predictor – Gesture frequency at intake	7.250	7.608
Outcome – Receptive Language age equivalent at 36-month visit (in months)	21.350	10.777
Outcome – Expressive Language age equivalent at 36-month visit (in months)	19.500	10.050
Outcome – Change in Receptive Language age equivalent from visit 1 to 36-month visit (in months)	11.450	9.128
Outcome – Change in Expressive Language age equivalent from visit 1 to 36-month visit (in months)	8.750	7.482

3.2 Analysis 1 – Growth Trajectory of Communication Complexity as a Predictor of Language

Although this study included 22 total participants, two were excluded from the statistical analysis, resulting in a final sample of $N = 20$ for all analyses. One case had missing data, which prevented its inclusion in the multivariate regressions. The other case was identified as an outlier, exhibiting high degrees of leverage and influence and contributing disproportionately to the overall variance.

This analysis tested Hypothesis 1, namely that growth trajectories in early coordinated communication would predict language acquisition at age 3 for toddlers with ASD. Linear, quadratic, and cubic growth components in CCS scores over time and the slopes for each component were the 6 PVs. The 4 OVs were receptive and expressive age equivalents at 3 years of age (outcome assessment for purposes of this analysis), as well as the change in receptive and

expressive age equivalents from the first to outcome assessment. The results showed that the effect of linear growth rate on the combined set of language acquisition variables was not statistically significant, Pillai's Trace = .45, $F(4, 10) = 2.03$, $p > .05$. Similarly, quadratic growth was not statistically significant, Pillai's Trace = .31, $F(4, 10) = 1.14$, $p > .05$, nor was cubic growth, Pillai's Trace = .42, $F(4, 10) = 1.80$, $p > .05$. These findings indicate that the type of growth rate in early coordinated communication – whether linear, quadratic, or cubic – was not significantly related to later language acquisition.

The slope of the quadratic trajectory was not statistically significant, Pillai's Trace = .34, $F(4, 10) = 1.28$, $p > .05$, and neither was the slope of the cubic trajectory, Pillai's Trace = .27, $F(4, 10) = .93$, $p > .05$. However, the slope of the linear trajectory was statistically significant, Rc = .78, Pillai's Trace = .60, $F(4, 10) = 3.82$, $p < .05$. According to the canonical structure matrix, change in receptive language had a strong negative correlation (-.5042) with the canonical variate, which is the weighted combination of the OVs that captures the maximum shared variance with the PVs. Receptive language at age 3 showed a weak negative correlation with the canonical variate (-.2154), and expressive language at age 3 and change in expressive language had no correlation with the canonical variate (-.0004 and .0111, respectively). This indicates that change in receptive language was most strongly related to the overall pattern in the data linked to linear slope – making it the primary contributor to the effect found. In other words, it played the biggest role in explaining how linear slope was associated with differences in language outcomes. In contrast, receptive language at age 3 contributed less to the effect due to its weaker association with the canonical variate. This finding suggests that linear slope is most strongly associated with change in receptive language, whereas receptive language outcomes did not contribute much to the relationship.

Although change in receptive language was negatively correlated with the canonical variate, this does not necessarily mean that higher linear slope was associated with lower language scores. In canonical correlation analysis, the sign of the canonical correlation is not inherently meaningful, as the canonical correlation itself (Rc = .78, in this case) can only be positive, meaning that it solely measures the strength of the relationship between the predictor and the canonical variate. To determine the direction of the relationship, it is necessary to plot the predictor against the canonical variables. As shown in Figure 3, linear slope showed a negative relationship with the canonical variate. To understand the relationship between the predictor and outcome variables, we return to the canonical structure matrix (Table 3). Change in receptive language has a strong negative relationship with the canonical variate. Since linear slope was negatively associated with the canonical variate, and the canonical variate had a strong negative relationship with receptive language, this implies a strong positive relationship between linear slope and change in receptive language. Similarly, receptive language at age three also showed a positive, though weak, relationship with linear slope. These results suggest that children that exhibited bigger and positive linear slope in early coordinated behaviors tended to have greater growth in language skills.

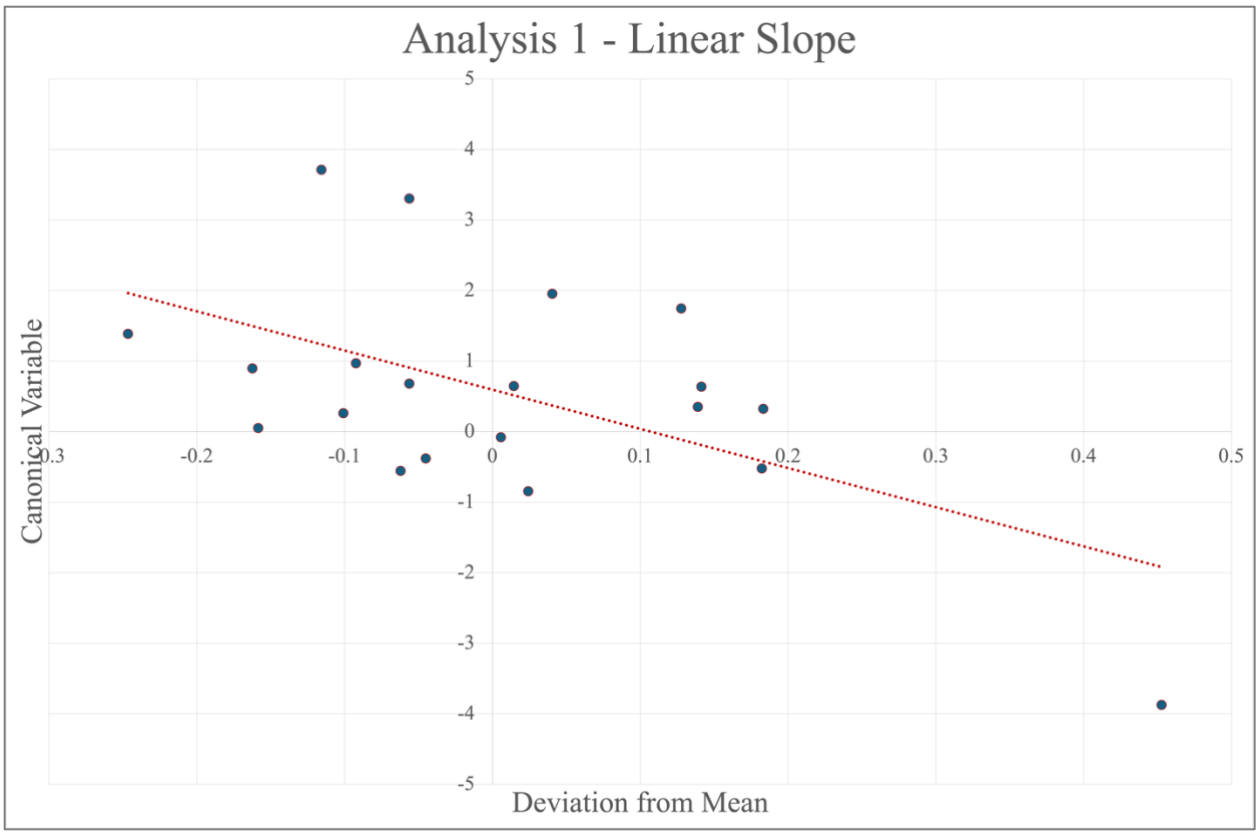

Figure 3 - Scatterplot of Linear Growth Deviations Against the Canonical Variable

Note: The x-axis is the deviations of each participant's linear slope from the mean, and the y-axis is the canonical variable for each participant.

Table 3 - Canonical Structure Matrix for Linear Slope in Analysis 1

Canonical Structure

	Total Can1	Between Can1	Within Can1
AGE3_RL_AE	-0.2154	-1.0000	-0.1983
AGE3_EL_AE	-0.0004	-1.0000	-0.0199
CHANGE_RL_AE	-0.5042	-1.0000	-0.4000
CHANGE_EL_AE	0.0111	-1.0000	-0.0397

3.3 Analysis 2 – Gestures as a Predictor of Language

This analysis tested Hypothesis 2, namely that gesture frequency at the initial assessment is a predictor of language acquisition at age 3. The total number of gestures produced at Time 1 is the PV, and the 4 language OVs are the same as in the previous analysis.

The results revealed that the effect of gesture frequency at the first visit on the combined set of language acquisition variables was not statistically significant, Pillai's Trace = .32, $F(4, 15) = 1.75$, $p > .05$, indicating that the number of gestures produced was not related to later language acquisition.

3.4 Analysis 3 – Gestures as a Predictor of Language, Controlling for Age

This analysis repeated Analysis 2 controlling for variability in participant age at Time 1. After controlling for age, the effect of gesture frequency on the combined set of language acquisition variables remained not statistically significant, Pillai's Trace = .38, $F(4, 14) = 2.10$, $p > .05$. This suggests that even after controlling for age, gesture use at the first visit is not a predictor of language acquisition at age 3. The effect of age itself on the language acquisition variables was not statistically significant, Pillai's Trace = .35, $F(4, 14) = 1.85$, $p > .05$.

3.5 Analysis 4 – Interaction Between Linear Growth in Communication Complexity and Gestures in Predicting Language

This analysis explored whether gesture use moderated the relationship between the linear slope and language acquisition. Prior to the interaction analysis, the predictors were centered around their mean to reduce multicollinearity between main effects and interaction terms and to make the results easier to interpret.

The interaction between linear CCS slope and gesture use was not statistically significant, Pillai's Trace = .31, $F(4, 13) = 1.437$, $p > .05$, indicating that gesture use did not moderate the

effect of linear slope on language outcomes. Similarly, a significant main effect was not found for linear slope in the interaction model, Pillai's Trace = 38, $F(4, 13) = 2.007$, $p > .05$, nor was it found for the main effect of gesture use, Pillai's Trace = .33, $F(4, 13) = 1.576$, $p > .05$. These findings indicate that gesture use does not moderate the relationship between linear growth and language acquisition such that children with more gesture use did not consistently exhibit higher receptive and expressive language scores at age 3 and change in scores, regardless of their linear growth magnitude and direction.

3.6 Analysis 5 – Initial Communication Complexity as a Predictor of Language

This analysis tested if the score on the Communication Complexity Scale at the initial intake is a predictor of language acquisition at age 3 while controlling for age. The CCS scores at time 1 is the PV, and the 4 language OVs are the same as in the previous analyses.

The results revealed that the effect of CCS scores at the first visit on the combined set of language acquisition variables was statistically significant, Rc = .70, Pillai's Trace = .49, $F(4, 14) = 3.314$, $p < .05$, with receptive language and expressive language scores at age 3 showing strong negative correlations with the canonical variate (-.6278 and -.5899, respectively). Change in receptive and expressive language showed weak negative correlations with the canonical variate (-.2998 and -.3679, respectively). Figure 4 shows that CCS scores at time 1 have a negative correlation with the canonical variate, and since the canonical variate is negatively correlated to all outcome variables (Table 4), it implies that higher CCS scores at time 1 are strongly related to higher receptive and expressive language at age 3 and weakly related to greater change in receptive and expressive language.

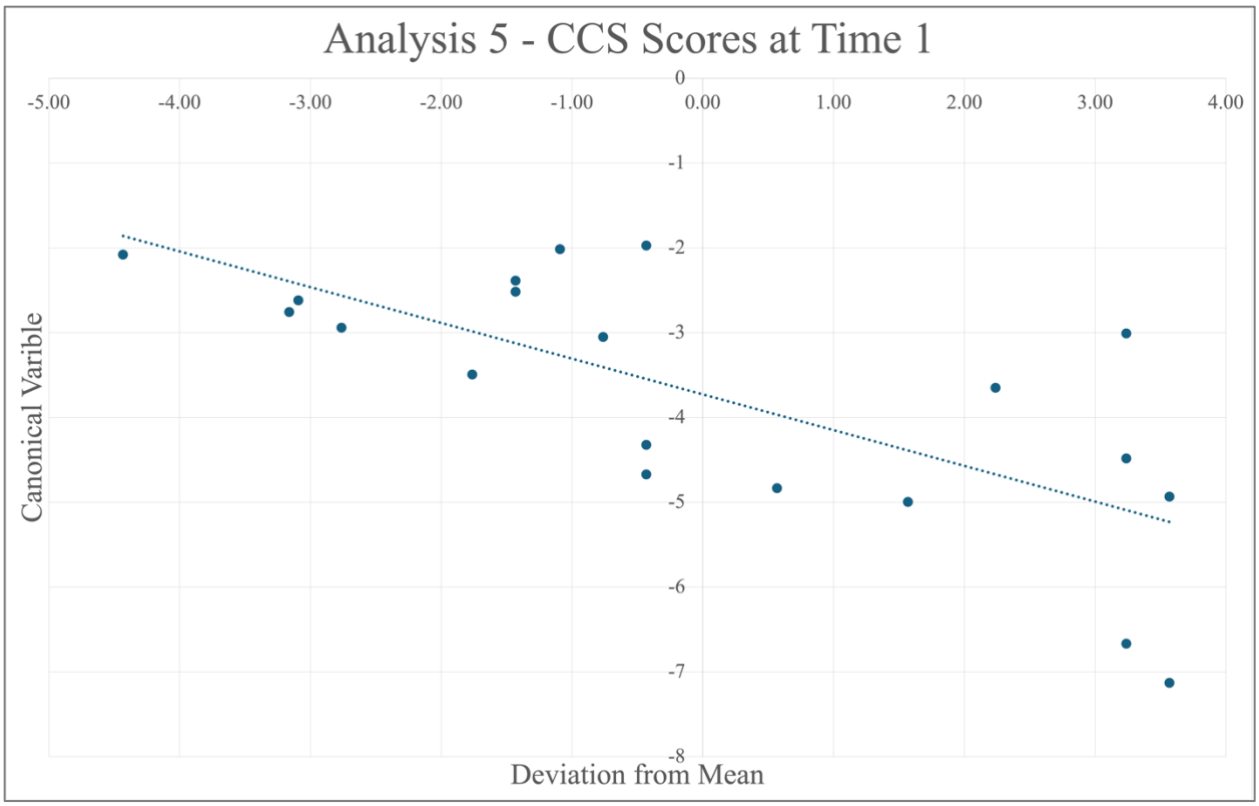

Figure 4 - Scatterplot of Time 1 CCS Score Deviations Against the Canonical Variable

Note: The x-axis is the deviations of each participant's CCS scores at time 1 from the mean, and the y-axis is the canonical variable for each participant.

Table 4 - Canonical Structure Matrix for CCS Score at Time 1 in Analysis 5

Canonical Structure

	Total Can1	Between Can1	Within Can1
AGE3_RL_AE	-0.6278	-1.0000	-0.4832
AGE3_EL_AE	-0.5899	-1.0000	-0.4922
CHANGE_RL_AE	-0.2998	-1.0000	-0.2240
CHANGE_EL_AE	-0.3679	-1.0000	-0.3293

3.7 Summary

Partial support was found for the hypotheses examined in this study. Hypothesis 1, which tested whether growth trajectories in early coordinated communication would predict language acquisition at age 3, was not supported when growth shape—represented by linear, quadratic, and cubic components—was considered. None of the polynomial trajectory types were significantly associated with language acquisition. However, the slope of the linear component, representing the average rate and direction of change in communication complexity over time, was significantly related to gains in receptive language. The predictive value of the linear slope was observed across participants, meaning that this effect applies even in cases where a quadratic or cubic model better fit their individual trajectories. These findings indicate that direction and magnitude of change, rather than trajectory shape, were relevant to language outcomes, specifically change in receptive language. Hypothesis 2, which examined whether gesture frequency at the initial visit predicted language acquisition, was not supported. Gesture use was not significantly related to any of the four language variables. This remained true after controlling for participant age at the first assessment. Age itself was not a significant predictor of language acquisition either.

Two additional exploratory analyses were conducted. First, an interaction model tested whether gesture use moderated the relationship between linear slope and language acquisition. The interaction effect was not significant, and neither main effect remained significant in the interaction model. Second, CCS score at the initial visit was found to significantly predict final receptive and expressive language scores, suggesting that a snapshot of initial coordinated communication abilities may reflect stable individual differences that are predictive of later acquisition. In conclusion, while growth shape and gesture frequency were not predictive of later

language acquisition, both the linear rate of growth and initial communication complexity demonstrated statistically significant associations with language acquisition.

CHAPTER 4. DISCUSSION

This study examined whether early developmental patterns in coordinated communication, captured by growth trajectories, and initial gesture use could predict language acquisition at age three in toddlers with ASD. While the overall hypothesis that early coordinated communication trajectories would serve as predictors of later language acquisition was only partially supported, the findings offer important insights into different aspects of early growth. Specifically, results suggest that it is not the shape of a child's communication trajectory that holds predictive value, but rather the rate and direction of growth over time. Additionally, initial coordinated communication abilities, measured by CCS scores at intake, was significantly associated with later receptive and expressive language abilities, highlighting the utility of both dynamic and static assessments in forecasting developmental outcomes.

The first hypothesis proposed that individual growth trajectories in early coordinated communication, modeled through linear, quadratic, and cubic components of CCS scores, would predict language acquisition at age three. This hypothesis was not supported when examining trajectory shape alone. That is, whether a child's trajectory was best characterized by a linear, accelerating (quadratic), or S-shaped (cubic) pattern did not significantly relate to their language outcomes. These findings challenge the assumption that non-linear patterns of early development necessarily carry functional significance in predicting later language skills. However, a more nuanced pattern emerged when looking beyond trajectory shape to consider trajectory direction and magnitude. Specifically, the slope of the linear growth component, which represents the direction and magnitude of the best-fitting straight-line trend across timepoints regardless of whether that line captures the most representative trajectory shape, was significantly associated with gains in receptive language. This indicates that it is not the form or curvature of a child's

developmental trajectory that matters most, but rather the average rate of change over time. Importantly, this relationship held regardless of which polynomial function best fit a child's overall trajectory. In other words, even for children whose communication development involved periods of regression, plateau, or rapid change, a strong positive linear slope still predicted increase in receptive language. This finding suggests that it is not the consistency or smoothness of growth, but rather the net direction and strength of communicative development over time that is most meaningful for predicting later language skills in children with ASD. It reframes the interpretation of growth from how to how much a child's communication progressed overall, regardless of fluctuations along the way. These results align with prior work emphasizing the importance of developmental momentum in early communication (Yoder et al., 2015; Brady et al., 2020) and contribute to a growing literature supporting rate-based metrics as robust predictors of future language competence in children with autism.

The second hypothesis proposed that gesture frequency at the initial assessment would predict language acquisition at age three. This hypothesis was not supported. Gesture use, when measured as the number of gestures produced during the first CCS session, was not significantly associated with any of the four language outcomes: neither final receptive and expressive scores nor change scores. This finding was consistent even after controlling for individual differences in age at the initial visit. Although this result may appear unexpected given the breadth of research linking early gesture use to later language outcomes in ASD (Wetherby et al., 2007; Charman et al., 2003), it aligns with more recent studies suggesting that gesture production alone, in the absence of coordination with other skills such as eye gaze or vocalizations, may not be sufficient as a lone predictor of language development (Talbott et al., 2020; Blume et al., 2021). It is the coordinated use of gestures, such as pointing paired with vocalizing, that appears most robustly

predictive of future language competence (Parladé & Iverson, 2015; Talbott et al., 2020; Blume et al., 2021). In this sense, the null findings of this analysis contribute to a growing understanding that early communicative gestures must have a communicative purpose and be interpreted in context, not simply in isolation or by frequency alone. Future research should address this by examining not only gesture frequency, but the extent to which gestures are integrated with other modalities.

In addition to the primary hypotheses, two exploratory analyses were conducted to further examine predictors of language acquisition at age three. The first explored whether gesture use moderated the relationship between linear slope in communication complexity and language acquisition. This model did not yield significant results: neither the interaction term nor the main effects of linear slope nor gesture frequency were significant within the interaction model. These findings suggest that gesture use does not alter the strength or direction of the association between early communication growth and language acquisition, or at least not when gesture frequency is measured at a single time point and modeled without coordination with other communicative skills. While the interaction was not significant, the fact that the linear slope was not a significant predictor in the interaction model, despite being significant in the earlier main effects model, may reflect issues of statistical power or variance overlap. Given the small sample size and addition of multiple predictors, it is possible that multicollinearity introduced instability in the estimation of main effects once interaction terms were added. These null findings do not imply that meaningful interactions do not exist between early gesture use and communication growth, but they underscore the need for greater statistical power and more refined measurement in future studies. The second exploratory analysis examined whether CCS score at the initial visit, representing a static snapshot of communicative functioning, predicted later language

acquisition. Unlike gesture frequency, higher initial CCS scores were significantly associated with higher receptive and expressive language levels at age three. This finding suggests that early communication complexity, as measured at a single time point, may reflect differences in language development. In other words, toddlers with ASD who demonstrate more advanced coordinated communication skills early on are more likely to attain higher levels of language ability, regardless of how much change occurs over time. These results are consistent with prior work emphasizing the value of early symbolic and presymbolic skills in forecasting later developmental outcomes (e.g., Bopp & Mirenda, 2011; Calandrella & Wilcox, 2000). Together, these exploratory findings offer important context for interpreting the primary results. They reinforce the idea that both developmental rate (linear slope) and initial capacity (Time 1 CCS) hold predictive value, but that gesture use alone, particularly when measured without functional detail, may be insufficient as a standalone indicator of later language ability. Moreover, the interaction analysis illustrates the complexity of modeling overlapping predictors in small samples, suggesting caution in interpreting nonsignificant effects when statistical power is limited.

4.1 Implications

The findings from this study underscore the importance of adopting a developmental framework that captures how early coordinated communication unfolds over time, rather than relying on isolated behaviors or static assessments. The results highlight the value of modeling individual trajectories, such as rates of growth in coordinated communication, as a way to identify children with ASD who may be on stronger developmental paths toward language acquisition. For researchers and clinicians, this suggests a shift away from asking whether a child gestures or uses communicative acts at a single point in time, and toward examining how these

behaviors change, accumulate, and evolve across early development. These results also speak to the limitations of assessing early language predictors in isolation. A dynamic assessment approach, one that considers both initial ability and rate of change, could improve early identification of language trajectories and allow for more personalized intervention strategies. Tracking communication complexity longitudinally may offer a more reliable window into emerging language abilities than static metrics alone. Ultimately, these findings support a broader move toward individualized, longitudinal models of developmental assessment in autism research and practice. By prioritizing growth-informed frameworks over fixed benchmarks, we can better align assessment tools and interventions with the complex nature of language development in children with ASD.

4.2 Alternative Explanations, Limitations, and Future Directions

Several factors may have contributed to the pattern of significant findings observed. The significant predictive effects of the linear slope and initial CCS sores may reflect meaningful developmental processes. Specifically, the predictive value of the linear growth component, even among children with more complex, nonlinear trajectories, suggests that the underlying direction and magnitude of communication change genuinely matter for language acquisition. Rather than simply capturing steady growth, the linear component may represent each child's cumulative developmental momentum – the net progress they made over time. From a developmental standpoint, this makes intuitive sense. Children whose overall communicative complexity increased more substantially, even if unevenly, may have experienced richer and more frequent opportunities for language learning through enhanced social interactions and communicative practice. Likewise, the significant relationship between initial CCS scores and later language outcomes reflects early differences in foundational communication skills. Early symbolic and

coordinated communication behaviors measured by the CCS are foundational to later receptive and expressive language development. These initial competencies may signal underlying strengths in social engagement, intentionality, and symbolic understanding, which are well-established precursors to language learning in young children with ASD.

Several factors may have contributed to the pattern of null findings observed. One possible factor was the variability in assessment intervals. While visits were intended to occur every three months, actual intervals varied significantly (approximately 2-5 months), potentially impacting the accuracy and representativeness of growth trajectory assessments. Children's performance on measures like CCS and Mullen may have also fluctuated and not always been reflective of maximum abilities due to transient factors such as mood, motivation, fatigue, or comfort levels. Another important factor was the influence of an outlier. One participant, whose CCS scores were at ceiling from the first visit, had to be excluded due to a lack of measurable growth. This participant also exerted a strong influence on the overall statistical model. When analyses were run including this outlier, the results shifted considerably: gesture frequency became a significant predictor. This emphasizes how a single influential case can alter model interpretation. Although excluding the outlier was statistically justified, its presence raises questions about the stability and sensitivity of the models used.

Several limitations in this study must be acknowledged. While the actual sample included 22 participants, a power analysis conducted using G*Power indicated that 36 participants would be ideal to achieve sufficient statistical power. Due to missing data and the exclusion of one outlier, the final analytic sample was reduced to 20 participants. This small sample size limited the study's statistical power, reducing the ability to detect small or moderate effects. Recruitment was constrained by the available participant pool from the Georgia Tech Child Study Lab, and

the sample was further limited by time constraints, as only children who had completed their 3-year-old assessment by February 2025 could be included. Future studies with larger samples and fewer timing restrictions will be important for increasing power and strengthening conclusions regarding the relationships explored in this study. Additionally, variability in assessment intervals and the inherent limitations of my measurement instruments introduced potential limitations. The CCS, while reliable and validated, has a ceiling that limits its sensitivity for children already demonstrating more advanced communicative abilities. Participants who were performing at or near ceiling early in the study had limited room to demonstrate growth, possibly limiting the variability needed to adequately capture growth trajectories over time.

The present findings suggest promising directions for future research. Rather than relying on single assessments of gesture frequency, subsequent studies should consider repeated measures of gesture frequency to capture its trajectory over time. Examining gesture use dynamically could provide insights into developmental patterns that static snapshots cannot capture. Additionally, future work should move beyond frequency counts to consider the communicative quality and coordination of gestures, including whether gestures are accompanied by gaze, vocalizations, or clear social intent. These features may be more closely tied to language acquisition and could help clarify inconsistencies in the literature. Coding for intentionality and multimodal coordination would offer a more precise understanding of how gestures contribute to early communication development. Given the limitations of the CCS ceiling, alternative measures offering continuous scaling of early coordinated communication behaviors could better capture growth beyond early developmental stages. Future research might explore instruments that avoid these ceiling constraints, thereby providing more detailed insights into children's developmental trajectories.

This study contributes important insights into the complex nature of early coordinated communication trajectories in toddlers with ASD and their implications for later language outcomes. The predictive power of linear slope and initial communication complexity underscores the value of both dynamic and static assessments, suggesting complementary roles for tracking developmental progress and measuring early communication capacities. Future studies addressing measurement limitations, enhancing sample size, and incorporating functionally coded assessments of gesture use could further clarify developmental predictors and strengthen implications for intervention planning and early identification of language trajectories in autism. Ultimately, this work advocates for a more flexible, integrative understanding of how communication develops in the earliest years of life and how these early patterns can inform more effective, individualized interventions moving forward.

REFERENCES

Blume, J., Wittke, K., Naigles, L., & Mastergeorge, A. M. (2021). Language growth in young children with autism: Interactions between language production and social communication. *Journal of Autism and Developmental Disorders, 51*(2), 644-665.

Bopp K. D., Mirenda P. (2011). Prelinguistic predictors of language development in children with autism spectrum disorders over four-five years. *Journal of Child Language, 38*(3), 485–503.

Brady, N. C., Fleming, K., Swinburne Romine, R., Holbrook, A., Muller, K., & Kasari, C. (2018). Concurrent validity and reliability for the Communication Complexity Scale. *American Journal of Speech-Language Pathology, 27*(1), 237–246.

Brady, N. C., Fleming, K., Thiemann-Bourque, K., Olswang, L., Dowden, P., Saunders, M. D., & Marquis, J. (2012). Development of the Communication Complexity Scale. *American Journal of Speech-Language Pathology, 21*(1), 16–28. https://doi.org/10.1044/1058-0360(2011/10-0099)

Brady, N. C., Romine, R. E. S., Holbrook, A., Fleming, K. K., & Kasari, C. (2020). Measuring Change in the Communication Skills of Children with Autism Spectrum Disorder Using the Communication Complexity Scale. *American Journal on Intellectual and Developmental Disabilities, 125*(6), 481–492. https://doi.org/10.1352/1944-7558-125.6.481

Bradley-Johnson, S. (1997). Mullen Scales of Early Learning [Review of *Mullen Scales of Early Learning*]. *Psychology in the Schools, 34*(4), 379–382. Wiley Subscription Services, Inc., A Wiley Company. https://doi.org/10.1002/(SICI)1520-6807(199710)34:4<379::AID-PITS14>3.0.CO;2-E

Calandrella, A. M., & Wilcox, M. J. (2000). Predicting language outcomes for young prelinguistic children with developmental delay. *Journal of Speech, Language, and Hearing Research, 43*(5), 1061-1071.

Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Drew, A., & Cox, A. (2003). Predicting language outcome in infants with autism and pervasive developmental disorder. *International Journal of Language & Communication Disorders, 38*(3), 265-285.

Crais, E. R., Watson, L. R., & Baranek, G. T. (2009). Use of gesture development in profiling children's prelinguistic communication skills.

Cui, M., Ni, Q., & Wang, Q. (2023). Review of intervention methods for language and communication disorders in children with autism spectrum disorders. *PeerJ, 11*, e15735.

Drew, A., Baird, G., Taylor, E., Milne, E., & Charman, T. (2007). The Social Communication Assessment for Toddlers with Autism (SCATA): An instrument to measure the frequency, form and function of communication in toddlers with autism spectrum disorder. *Journal of autism and developmental disorders, 37,* 648-666.

Kjelgaard, M.M., & Tager-Flusberg, H. (2001). An investigation of language impairment in autism: Implications for genetic subgroups. *Language and Cognitive Processes, 16*, 287–308.

Landa, R. (2007). Early communication development and intervention for children with autism. *Mental Retardation and Developmental Disabilities Research Reviews, 13*(1), 16–25. https://doi.org/10.1002/mrdd.20134

Landa, R. J., Holman, K. C., & Garrett-Mayer, E. (2007). Social and communication development in toddlers with early and later diagnosis of autism spectrum disorders. *Archives of general psychiatry, 64*(7), 853-864.

Latrèche, K., Godel, M., Franchini, M., Journal, F., Kojovic, N., & Schaer, M. (2024). Early trajectories and moderators of autistic language profiles: A longitudinal study in preschoolers. *Autism*, 13623613241253015.

Lord, C., Risi, S., & Pickles, A. (2004). Trajectory of language development in autistic spectrum disorders. *In Developmental language disorders* (pp. 18-41). Psychology Press.

Mayo, J., Chlebowski, C., Fein, D. A., & Eigsti, I. M. (2013). Age of first words predicts cognitive ability and adaptive skills in children with ASD. *Journal of autism and developmental disorders, 43*(2), 253–264. https://doi.org/10.1007/s10803-012-1558-0

Miranda, A., Berenguer, C., Baixauli, I., & Roselló, B. (2023). Childhood language skills as predictors of social, adaptive and behavior outcomes of adolescents with autism spectrum disorder. *Research in Autism Spectrum Disorders, 103*, 102143.

Mullen, E. M. (1995). *Mullen scales of early learning*. AGS Publishing.

Norrelgen, F., Fernell, E., Eriksson, M., Hedvall, Å., Persson, C., Sjölin, M., Gillberg, C., & Kjellmer, L. (2015). Children with autism spectrum disorders who do not develop phrase speech in the preschool years. *Autism, 19*(8), 934-943.

Parladé, M. V., & Iverson, J. M. (2015). The development of coordinated communication in infants at heightened risk for autism spectrum disorder. *Journal of autism and developmental disorders, 45*, 2218-2234.

Ramos-Cabo, S., Vulchanov, V., & Vulchanova, M. (2019). Gesture and Language Trajectories in Early Development: An Overview From the Autism Spectrum Disorder Perspective. *Frontiers in Psychology, 10*, 1211–1211. https://doi.org/10.3389/fpsyg.2019.01211

Rose, V., Trembath, D., Keen, D., & Paynter, J. (2016). The proportion of minimally verbal children with autism spectrum disorder in a community-based early intervention programme. *Journal of Intellectual Disability Research, 60*(5), 464-477.

Rowland, C. (2011). Using the communication matrix to assess expressive skills in early communicators. *Communication Disorders Quarterly, 32*(3), 190–201.

Salley, B., Brady, N. C., Hoffman, L., & Fleming, K. (2020). Preverbal communication complexity in infants. *Infancy, 25*(1), 4-21.

Shank, L. (2011). Mullen scales of early learning. *Encyclopedia of clinical neuropsychology,* 1669-1671.

Sigman, M., & McGovern, C. W. (2005). Improvement in Cognitive and Language Skills from Preschool to Adolescence in Autism. *Journal of Autism and Developmental Disorders, 35*(1), 15–23. https://doi.org/10.1007/s10803-004-1027-5

Sparrow, S. S., Cicchetti, D. V., & Balla, D. A. (2005). *Vineland Adaptive Behavior Scales (Vineland-II)*. Circle Pines, MN: American Guidance Service.

Stone, W. L., Ousley, O. Y., Yoder, P. J., Hogan, K. L., & Hepburn, S. L. (1997). Nonverbal communication in two-and three-year-old children with autism. *Journal of autism and developmental disorders, 27*, 677-696.

Tager-Flusberg, H., & Kasari, C. (2013). Minimally verbal school-aged children with autism spectrum disorder: The neglected end of the spectrum. *Autism Research: Official Journal of the International Society for Autism Research, 6*(6), 468–478.

Tager-Flusberg, H., Paul, R., & Lord, C. (2005). Language and communication in autism. *Handbook of autism and pervasive developmental disorders, 1*, 335-364.

Talbott, M. R., Young, G. S., Munson, J., Estes, A., Vismara, L. A., & Rogers, S. J. (2020). The developmental sequence and relations between gesture and spoken language in toddlers with autism spectrum disorder. *Child development, 91*(3), 743-753.

Thiemann-Bourque, K. S., Brady, N., & Hoffman, L. (2019). Application of the communication complexity scale in peer and adult assessment contexts for preschoolers with autism spectrum disorders. *American Journal of Speech-Language Pathology, 28*(1), 29-42.

Toth, K., Munson, J., N. Meltzoff, A., & Dawson, G. (2006). Early predictors of communication development in young children with autism spectrum disorder: Joint attention, imitation, and toy play. *Journal of autism and developmental disorders, 36*, 993-1005.

Venker C. E., Ray-Subramanian C. E., Bolt D. M., Ellis Weismer S. (2014). Trajectories of autism severity in early childhood. *Journal of Autism and Developmental Disorders, 44*(3), 546 563.

Venter, A., Lord, C., & Schopler, E. (1992). A follow-up study of high-functioning autistic children. *Journal of child psychology and psychiatry, 33*(3), 489-597.

Wetherby, A. M., Watt, N., Morgan, L., & Shumway, S. (2007). Social communication profiles of children with autism spectrum disorders late in the second year of life. *Journal of autism and developmental disorders, 37,* 960-975.

Yoder, P., Watson, L. R., & Lambert, W. (2015). Value-added predictors of expressive and receptive language growth in initially nonverbal preschoolers with autism spectrum disorders. *Journal of autism and developmental disorders, 45*, 1254-1270.