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Modeling Gesture Use and Early Language Development in Autism Spectrum Disorder

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Abstract

Background—Nonverbal communication abilities, including gesture use, are impaired in autism spectrum disorder (ASD). However, little is known about how common gestures may influence or be influenced by other areas of development.

Aims—This study examined relationships among gesture, fine motor, and language in young children with ASD compared to a comparison group using multiple measures and methods in a structural equation modeling framework.

Methods & Procedures—Participants included 110 children with ASD and a non-ASD comparison group of 87 children (that included children with DD or TD), from 12 to 48 months of age. A construct of gesture use as measured by the Communication and Symbolic Behavior Scales–Developmental Profile Caregiver Questionnaire (CQ) and the Autism Diagnostic Observation Schedule (ADOS), as well fine motor from the Mullen Scales of Early Learning and Vineland Adaptive Behavior Scales-II (VABS-II) was examined using second-order confirmatory factor analysis (CFA). A series of structural equation models then examined concurrent relationships between the aforementioned latent gesture construct and expressive and receptive language. A series of hierarchical regression analyses was run in a subsample of 36 children with ASD with longitudinal data to determine how gesture factor scores predicted later language outcomes.

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Outcomes & Results—Across study groups, the gesture CFA model with indicators of gesture use from both the CQ (parent-reported) and ADOS (direct observation), and measures of fine motor provided good fit with all indicators significantly and strongly loading onto one gesture factor. This model of gesture use, controlling for age, was found to strongly correlate with concurrent expressive and receptive language. The correlations between gestures and concurrent language were similar in magnitude in both the ASD and the non-ASD group. In the longitudinal subsample of children with ASD, gestures at Time 1 predicted later receptive (but not expressive) language outcomes on the VABS-II, after controlling for nonverbal cognition, ASD severity, age, and Time 1 language.

Conclusions & Implications—This study extends research on the relationship of nonverbal communication and language by supporting the idea of an underlying construct of gesture use that includes fine motor ability and relates to language in young children with ASD. This further supports theories espousing developmental influences of motor and nonverbal communication strategies as important in early language learning.

Keywords

autism spectrum disorder; gesture; language development

Introduction

The emergence of language is a critical milestone in determining delay and as a functional outcome for children with disabilities. However, it is also critical to consider foundational prelinguistic communication skills that develop prior to and are predictive of spoken language (Rowe et al., 2008). In recent years, prelinguistic skills, and in particular gestures, have come to stand out as a strong predictor of language in young children, and are specifically impaired in children with autism spectrum disorder (ASD; e.g., Dimitrova et al., 2016, Ozcaliskan et al., 2015, Veness et al., 2012). Although much research has emerged on gesture deficits in young children with ASD, many studies have used only parent report (e.g., Luyster et al., 2007b, Mitchell et al., 2006) or investigated only a few specific gestures or variables related to gesture use, with particular emphasis on pointing and showing gestures (Camaioni et al., 2003, LeBarton and Iverson, 2016, Paparella et al., 2011).

Successful use of communicative gestures requires the integration of several developmental skills related to social, cognition, and motor abilities (Wray et al., 2016). Research is needed to examine how commonly measured gestures relate to and influence (or are influenced by) other areas of development. The purposes of this study were to 1) examine individual gestures obtained from multiple measures (i.e., parent report and observation), and 2) to form an underlying gesture use construct that includes consideration of fine motor skills, and examine the inter-relationships among gestures and other developmental domains in young children with ASD and a non-ASD comparison group. Improving understanding of the relationships among these skills in young children with ASD in comparison to children without ASD may help to inform clinical practices including differential diagnosis and early intervention strategies.

Relationship between Gesture and Language

Gestures play a critical role in the development of language in typically developing children (Rowe et al., 2008) as well as children with developmental delays, including ASD (e.g., Luyster et al., 2007b); however, less is known about how gestures relate to specific aspects of language in young children. In typical development, significant longitudinal relations have been observed between gesture use and receptive (Watt et al., 2006, Rowe et al., 2008) as well as spoken (Iverson et al., 2008) language. In comparison, cross sectional and longitudinal studies of toddlers with receptive and expressive language delay, primary delays in expressive language (i.e., later talkers), and Down Syndrome have found that receptive (but not expressive) language ability was positively correlated with gesture use (e.g., O'Neill and Chiat, 2015, Thal et al., 1991, Zampini and D'Odorico, 2009).

In ASD, early gesture use has been shown to be associated with both expressive and receptive language (e.g., Dimitrova et al., 2016, Luyster et al., 2008, Ozcaliskan et al., 2015), above and beyond nonverbal cognition (Charman et al., 2003). However, receptive language has been found to be more closely associated with gestures than expressive language in at least one study (Luyster et al., 2007a). Overall, this research suggests that continued work is needed to evaluate models examining the relationship between gesture and language in children with ASD compared to non-ASD in order to allow for more preciseness in determining the specificity of these relationships to ASD.

Relationship between Motor Abilities and Language

Aspects of motor development have been posited to play an important role in language development, and children with delayed or impaired language frequently demonstrate difficulties on a variety of motor tasks (Alcock and Krawczyk, 2010, Hill, 2001). Motor problems may include oral motor, gross motor, and fine motor difficulties, specifically the fine motor manual dexterity required for gestures. Early deficits in motor skills have also been found in young children later diagnosed with ASD, and both fine (LeBarton and Iverson, 2013) and gross (Bhat et al., 2012) motor delays have recently been linked with communication and expressive language skills.

Researchers have hypothesized a genetic basis for co-occurring motor and communication problems (Bishop, 2002), as well as a cascading developmental effect, such that early delays in motor skills may lead to difficulties beyond the motor domain in areas such as communication (Iverson, 2010) and cognition (Houwen et al., 2016). However, limited research has examined the specific relationship between fine motor ability and gesture and how these developmental domains may inter-relate and impact language in young children (see Iverson and Braddock, 2011), and more specifically in children with ASD compared to children with other developmental delays and typical development.

Relationship between Cognition, Symptom Severity, and Language

Nonverbal cognitive ability and severity of ASD symptoms are also important to consider as potential influencers of language in young children with ASD. Research has consistently found that nonverbal cognition is a robust predictor of language in ASD (e.g., Ellis Weismer and Kover, 2015). More recently, research has suggested that greater ASD symptom severity,

as measured by the Autism Diagnostic Observation Schedule Calibrated Severity Scores (Gotham et al., 2009), is related to lower language levels and less growth in language in children with ASD (Ellis Weismer and Kover, 2015); however, nonverbal cognition remains a stronger predictor of language development (Thurm et al., 2015). Nonverbal cognition and ASD symptom severity were recently found to influence the relationship between gross motor ability (onset of walking) and the rate of language development from 2 to 9 years of age in children with ASD (Bedford et al., 2015). Tasks that assess nonverbal cognition often require significant fine motor skill for success. Thus, one would expect nonverbal cognition by definition to relate to the development of other skills that require manual dexterity, such as gestures, and to language development (Houwen et al., 2016).

Study Purpose and Hypotheses

The purpose of the present study was to examine the relationship among gesture use, fine motor abilities, and language in children with and without ASD utilizing multiple measures and methods (parent report and direct observation). Utilizing multiple methods, including parent report and direct observation, to assess young children is vital to understanding a child's early development and the relationships between various abilities (Leonard and Hill, 2014). In addition to direct observational methods, easily administered parent report questionnaires and parent interviews are important to the assessment process and are needed to capture a young child's full repertoire of abilities. More information is needed about currently available methods and measures (Charman and Gotham, 2013). Thus, the present study utilized several assessment methods and tools to examine gesture use, fine motor abilities, and language.

This study extends previous research by comparing a group of children with ASD to a mixed non-ASD comparison group that includes children with typical development as well as developmental delays. This non-ASD comparison group includes children with similar nonverbal cognitive levels to those found in some children with ASD, in order to better examine the specificity of the relationships between gesture, fine motor, and language to ASD.

Additionally, a structural equation modeling framework was used in this study, which is a powerful method of analysis that captures the variability and covariance of individual components studied. Using a latent variable model to explore data from young children with ASD and a mixed comparison group, we hypothesized that gesture items from the CQ and ADOS, along with measurements of fine motor skills, would form a latent construct of gesture use. This was tested using a second-order confirmatory factor analyses (CFA), which reduces the influence of measurement error, and results in a more comprehensive approach. We hypothesized that gesture use would relate to concurrent language development. This model was analyzed across all participants, and then across groups (i.e., ASD and non-ASD) to see how the relationships differ for children with and without ASD. Lastly, for a subsample of the ASD group with longitudinal data, factor scores from the structural equation model were used to predict later language outcomes, again hypothesizing gesture use would predict receptive and expressive language.

Method

Participants

Children included in the current study were drawn from a larger natural history study in the Pediatrics and Developmental Neuroscience Branch of the National Institute of Health that recruited a group of children with autism spectrum disorder (ASD) and comparison groups of children with non-ASD developmental delays (DD) and typical development (TD). Although the larger study included children 12 months through 7 years, 11 months, the present study included 197 participants from 12 to 48 months (mean age=34.6; $SD=8.4$). Specifically, participants included 110 children with ASD, and a non-ASD comparison group of 87 children, which included 35 children with DD and 52 TD.

Inclusionary criteria for all groups included English as primary language and referral for one of the study groups. Exclusion criteria included a psychiatric or neurologic condition that prohibited the behavioral evaluation. Diagnostic procedures and criteria, as well as additional inclusion/exclusion criteria are described below. Most participants were from the local geographic area, with recruitment methods including referrals from medical providers, service and educational programs such as early intervention and preschool programs, as well as flyers posted throughout the community. Thus, as can be seen from the descriptives shown in Table 1, participants were generally representative of the population in the local geographic area.

A subsample of the ASD group ($n=36$; mean age at follow-up = 50.1 months) was reassessed 8-16 months after the initial evaluation (mean months to follow-up = 13.0 months); these children did not differ significantly from the full ASD group on age, gender, or nonverbal cognition. Participant demographics and characteristics are shown in Table 1. The groups had similar percentages of males, but the TD group was significantly younger than the other groups. The majority of the total sample had mothers with at least some college, although the TD group had a higher percentage of mothers with a graduate/professional degree than the ASD group. The ASD and DD groups had higher percentages of children who were African American than the TD group. As expected, scores obtained from the Mullen Scales of Early Learning (MSEL; Mullen, 1995) indicated that the ASD and DD groups performed significantly lower than the TD group in all areas. Standard scores on the Vineland Adaptive Behavior Scales, Second Edition (VABS-II; Sparrow et al., 2005) indicated the ASD group demonstrated significantly reduced adaptive behavior skills compared to DD and TD.

Mean weighted raw scores for the Communication and Symbolic Behavior Scales Developmental Profile Caregiver Questionnaire (CQ; Wetherby & Prizant, 2002) Social, Speech, and Symbolic Composites are also shown in Table 1. When controlling for nonverbal developmental level, the ASD group scored significantly lower than both the DD and TD groups on the Social Composite. Within the Social Composite, the DD and TD groups were reported to use a similar number of gestures, such that the two groups were not significantly different on the Gestures subscale score. In relation to the 10 individual gestures measured on the CQ, a significantly smaller percentage of children with ASD were

reported to use 6 of the 10 gestures (showing, waving, contact and distal pointing, and shaking and nodding head) compared to DD and TD (see Table 2).

Procedures

This research was approved by an Institutional Review Board at the National Institutes of Health and informed consent was obtained for all participants. All participants completed a diagnostic evaluation conducted by a doctoral-level clinician, including administration of the MSEL and Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000), the Autism Diagnostic Interview-Revised (ADI-R; Rutter, Le Couteur, & Lord, 2003), and the Vineland Adaptive Behavior Scales, Second Edition (VABS-II; Sparrow, Cicchetti, & Balla, 2005). In addition, parents completed the Communication and Symbolic Behavior Scales Developmental Profile Caregiver Questionnaire (CQ; Wetherby & Prizant, 2002) and the MacArthur-Bates Communicative Development Inventories, Second Edition (CDI; Fenson et al., 2006).

Eligibility for the ASD group was determined based on clinical judgment of an ASD diagnosis using DSM-IV-TR criteria for autistic disorder or pervasive developmental disorder, not otherwise specified and cutoff scores for ASD on research reliable administration of the ADOS and ADI-R. As described, children with DD and TD were combined to form a non-ASD comparison group. Within this group, the children with DD scored at least 1.5 standard deviations below the mean on either the overall cognitive standard score or the verbal standard score on the MSEL, and ASD was ruled out following administration of the ADOS and ADI-R. Some children in the DD subgroup were recruited specifically for inclusion in a DD group (as a comparison group for the ASD group); others were referred for possible diagnosis of ASD but were found to meet criteria for the DD group following the diagnostic evaluation. The remainder of the non-ASD group, who were considered typically developing, had combined verbal and nonverbal cognitive scores ≥ 78 . Children in the TD group were also administered the ADOS. Exclusion criteria for the TD group included a first degree relative with ASD or a history of receiving intervention services prior to study enrollment. This mixed comparison group included children with cognitive deficits similar to those seen in some children with ASD, allowing us to account in part for the effects of nonverbal cognition on other areas of development. Further, children with DD and TD were not significantly different on gesture use on the CQ, providing additional rationale for combining these groups.

Measures

Communication and Symbolic Behavior Scales Developmental Profile

Caregiver Questionnaire—The Communication and Symbolic Behavior Scales Developmental Profile Caregiver Questionnaire (CQ; Wetherby & Prizant, 2002) is a caregiver-report measure of prelinguistic communication that is part of a three-pronged tool with two well-validated components – the Infant-Toddler Checklist and the Behavior Sample. The CQ utilizes parent report in a recognition format, which has been shown to be a reliable and valid way to measure communication development in children with and without disabilities (Tek and Landa, 2012).

The CQ consists of 41 multiple-choice (not yet, rarely, and often) items that are categorized within three composites: Social, Speech, and Symbolic. The Gestures subscale falls within the Social composite. For this study, CQ items 19 and 20 were specifically examined, which correspond to the Gestures subscale. Item 19 asks caregivers to rate whether the child uses gestures that are easily understood by others on 3-point scale (not yet, sometimes, or often). Item 20 includes a list of 10 specific early developing gestures (see Table 2 for specific gestures), with caregivers marking whether or not the child uses each gesture.

Autism Diagnostic Observation Schedule—The Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) is a semi-structured observation of an individual's behavior in response to a variety of social presses, with different modules tailored to the language level and age. Children in this study received the following modules: Toddler ($n=23$, 11.7%), Module 1 ($n=123$, 62.4%), Module 2 ($n=46$, 23.4%), and Module 3 ($n=3$, 1.5%), no ADOS ($n=2$; 1%). We examined four gesture items from the ADOS: overall gesture use and pointing (from the Language and Communication Domain), and showing and giving (from the Reciprocal Social Interaction Domain). Overall gesture use is measured on all ADOS modules. Pointing and showing are measured on the Toddler Module and Modules 1 and 2. Giving is measured on the Toddler Module and Module 1. Gesture items were taken from the specific ADOS module each participant was administered in the study, such that some children (e.g., those that were administered Module 3; $n=3$) did not have all gesture items described above, but were estimated using Full Maximum Likelihood Estimation to use all available data. ADOS gesture item scores range from 0-3 and scores were used categorically in the present study. A lower score on an ADOS gesture item indicates more appropriate/purposeful use of the gesture, with a score of 0 indicating no observed abnormality of gestures across contexts and situations. Thus, lower ADOS scores indicate lower symptom severity and higher ADOS scores indicate greater symptom severity. In addition to gesture items, overall ADOS calibrated severity scores (ADOS-CSS; Gotham et al., 2009) were used as an indicator of ASD severity in Modules 1-3, encompassing both symptom domains of social-communication and restricted, repetitive behaviors.

Mullen Scales of Early Learning—The Mullen Scales of Early Learning (MSEL; (Mullen, 1995) is a standardized measure of nonverbal and verbal development in children birth through 68 months of age. Five developmental domains are assessed including gross motor, fine motor, visual reception, receptive language, and expressive language, and standard scores and age equivalents are provided. Age equivalent scores were used in the present study in order to control for the effects of age.

The visual reception domain provides a measure of nonverbal cognition, which we used as a covariate when modeling the relationship between gesture and language. The fine motor domain involves tasks examining the use of two hands together and finer coordination of movement (e.g., refined pincer grasp), unilateral hand patterning observed in the graded release and placement of small objects, unilateral and bilateral fine motor dexterity, and drawing and writing skills. As such, a range of fine motor abilities related to the use of hands and fingers and manual dexterity were measured. The receptive language domain

assesses understanding of verbal directions, memory for commands and general information, and auditory-spatial and auditory-quantitative concepts. The expressive language domain assesses vocalizations and utterances as well as verbal responses to tasks, including high-level concept formation.

Vineland Adaptive Behavior Scales, Second Edition—The Vineland Adaptive Behavior Scales, Second Edition (VABS-II; Sparrow et al., 2005) is a standardized measure of adaptive behavior for individuals from birth through 90 years of age, which is administered as a semi-structured interview with caregivers. The VABS-II measures adaptive behavior across four domains: communication (receptive and expressive), daily living skills, socialization, and motor skills (gross and fine). Age equivalent scores from the fine motor domain, and the receptive and expressive communication domains were used in the present study. The receptive communication domain measures how the child listens and what he/she understands. The expressive communication domain measures how the individual uses gestures, words, and sentences to gather and provide information. The fine motor domain surveys how the individual uses hands and fingers to manipulate objects (e.g., stacking blocks, turning pages in a book, holding a pencil, drawing, cutting with scissors).

MacArthur-Bates Communicative Development Inventories, Second Edition—The MacArthur-Bates Communicative Development Inventories, Second Edition (CDI; Fenson et al., 2006) is designed to inventory parent-reported information on language and communication development in infants and toddlers. The CDI Words and Gestures form was used in this study as a measure of child language (i.e., it was not used as a measure of gesture use). Specifically, raw scores of vocabulary comprehension (number of words understood) and production (number of words produced) were used in analyses.

Data Analysis

The ASD group was compared with a mixed comparison group (non-ASD) that included children with DD and TD. Two steps were required to examine the relationships between gestures (parent-reported and observational), fine motor, and language (Muthén and Muthén, 2010). The first step was to complete a series of bivariate correlations in SPSS to confirm the expected relationships among the variables used in this study (described above) to ensure the relevance of their inclusion in the final structural equation model (SEM). Variables included gesture items from the CQ and ADOS, expressive language (ratio scores* from the MSEL and VABS-II, CDI number of words produced), and receptive language (ratio scores from the MSEL and VABS-II, CDI number of words understood). Fine motor (age equivalents from the MSEL and VABS-II) was also examined in relation to gesture use. ASD severity (ADOS CSS) and nonverbal cognitive ability (visual reception age equivalent from the MSEL) were also included as potential confounds to the relation between gesture and language abilities.

In the second step, we conducted a second-order confirmatory factor analyses (CFA) in Mplus version 6.0. We hypothesized that gesture items from the CQ and ADOS, along with fine motor skills, would load onto one underlying gesture construct. Footnote: Ratio scores

were calculated by dividing a child's age equivalent score on a given domain by the child's chronological age and multiplied by 100.

A full structural equation model incorporated the second-order CFA to examine how overall gesture use predicted concurrent expressive and receptive language. In addition, we tested whether nonverbal cognitive ability and ASD symptom severity contributed to the final model. All analyses were first conducted across the whole sample, and then based on initial results, separately for children with ASD vs. non-ASD (DD and TD) to determine whether the fit of the models varied across diagnostic groups. It is of note that we attempted to examine these relationships in children with TD only by running a model that included the 52 children in the TD group; however, the model did not converge, likely due to the lack of variability in the TD sample, paired with reduced power.

Finally, hierarchical linear regressions were used to determine if the overall gesture use (i.e., derived from the CFA gesture factor score) from the initial evaluation (Time 1) predicted Time 2 (8-16 months post initial evaluation) language in a subsample of the ASD group.

Results

Bivariate Correlations

As expected, across the entire sample, results of bivariate correlations indicated that the gesture items from both the CQ and the ADOS were significantly correlated with fine motor. Additionally, the gesture items from the CQ and ADOS were significantly correlated with ASD severity and nonverbal cognitive ability, and all measures were significantly correlated with expressive and receptive language outcomes. Age was also significantly correlated with gesture items, and was thus added as a control variable in further analyses. Once age was added as a control variable, the correlations between gestures and language outcomes were similar in magnitude, although the correlations with the CDI were weak and not significant. Gesture items on the ADOS were all significantly negatively correlated with expressive and receptive language ratio scores (r s ranging from $-.38$ to $-.69$). Gesture items on the CQ were significantly positively correlated with language ratio scores (r s ranging from $.15$ to $.64$) with the exception of the correlation between "raise arms" and MSEL expressive language ($r = .07$, $p = .332$). Fine motor was significantly positively correlated with language ratio scores (r s ranging from $.52$ to $.76$). The correlation matrix, controlling for age, is presented in Table 3.

Confirmatory Factor Analyses

Descriptive statistics of indicators used in the CFAs are shown in Table 4. For the CFAs, goodness of fit (Hu & Bentler, 1999) was evaluated using the root-mean-square error of approximation (RMSEA), the comparative fit index (CFI), and Tucker Lewis Index (TLI). The RMSEA is a measure of lack of fit, whereby values below .08 indicate acceptable fit and values below .05 indicate excellent fit. CFI values above .95 indicate excellent fit. TLI values above .95 indicate excellent fit. A second-order CFA that included gesture items from the CQ and ADOS, and fine motor age equivalent scores, across all children yielded significant factor loadings onto each measure (CQ, ADOS, fine motor), and each measure

loaded significantly onto an underlying gesture construct. The fit indices revealed overall good fit, $\chi^2(101)=141.77$, $p<.05$, RMSEA=.05, CFI=.98, TLI=.98. When the model was run separately for the two groups, the fit indices were similar although the factor loadings onto the gesture construct were greater in magnitude in the ASD than the non-ASD group. An additional model to control for nonverbal cognition and ASD severity was also run, but a solution could not successfully converge.

Structural Equation Model: Concurrent Relationship between Gesture, Fine Motor, and Language

A series of structural equation models (SEM) was run to determine whether the underlying gesture score second-order CFA was related to concurrent expressive and receptive language. Ratio scores from the expressive and receptive language domains of the MSEL and VABS-II, in addition to the number of words produced and understood, were included as indicators of latent variables of expressive and receptive language. However, the SEM models revealed poor fit, and upon examination of the modification indices, removing the CDI from the model resulted in a substantial improvement of fit (Kline, 2011) for both models predicting expressive and receptive language.

The fit indices for each SEM model (that excluded CDI variables) are presented in Table 5. For expressive language, overall gestures, controlling for age, were significantly correlated with overall expressive language (as measured by MSEL and VABS-II) across the entire sample ($r=.92$, $p<.001$). When each group was analyzed separately, there was a large positive correlation between gesture and expressive language in both the ASD group ($r=.90$, $p<.001$) (see Figure 1) and the non-ASD group ($r=.88$, $p<.001$). We tested the difference between these correlations using Steiger's (1980) method and found that the correlation between gesture and expressive language was not significantly different in the ASD compared to the non-ASD group ($z=0.66$, $p=.509$). For receptive language, overall gestures, controlling for age, were significantly correlated with overall receptive language across the entire sample ($r=.98$, $p<.001$). This correlation was significant for both the ASD group ($r=.98$, $p<.001$) (see Figure 2) and the non-ASD group ($r=.98$, $p<.001$), $z=0$, $p=1.00$. Additionally, nonverbal cognition and ASD severity were added as controls to the SEM model, but a solution could not successfully converge.

Hierarchical Linear Regression: Longitudinal Relationship between Gesture, Fine Motor, and Later Language in ASD Subsample

Hierarchical linear regressions were run to examine how overall gesture use (including fine motor) at the initial evaluation (Time 1) predicted Time 2 (mean = 13.0 months post initial evaluation) language in a subsample of the ASD group. In Step 1, nonverbal cognition, ASD severity, and age were entered as controls. In Step 2, language ratio scores from Time 1 were entered into the model. And in Step 3, the overall gesture factor score from the second-order CFA model was added to predict Time 2 MSEL and VABS-II expressive and receptive language. As presented in Table 6, Time 1 gestures significantly predicted VABS-II, but not MSEL, receptive language, above and beyond nonverbal cognition, ASD severity, age, and Time 1 receptive language. Gestures at Time 1 did not predict Time 2 expressive language.

Discussion

This study extended previous research by testing how well commonly used parent report and direct observational methods of gesture and fine motor abilities form an underlying construct of gesture use in children with and without ASD. We then utilized a model that allowed us to evaluate the gesture construct in relation to specific aspects of both receptive and expressive language in a large sample of young children with ASD compared to a non-ASD group, and examined longitudinal data within a subsample of the ASD group.

Initial review of the gestures examined in this study indicated that gestures on the CQ (parent report) and ADOS (direct observation) were strongly correlated, suggesting that parents provide useful information when they report on the extent to which their child engages in specific communicative behaviors (e.g., Wetherby et al., 2002). Descriptive analyses from the CQ provide information on gestures that may be particularly useful in understanding ASD. Specifically, significantly fewer children in the ASD group were reported to use 6 of the 10 CQ gestures (showing, waving, contact and distal pointing, and shaking and nodding head) compared to non-ASD children (both DD and TD). These findings support and extend previous research indicating early gestures (those typically attained first) are reduced in children with ASD compared to typically developing children (Mitchell et al., 2006) and children with other developmental delays (Luyster et al., 2007a). Further, given that few studies have utilized the CQ in samples of children with ASD, these findings also provide evidence regarding the utility of the CQ as a measure of gesture use in children with ASD.

Gesture as a Latent Construct

The majority of previous research examining the relationships among gesture use, motor skills, and language abilities has relied on correlational analyses, which do not allow for the examination of underlying constructs of assessment tools commonly used with children with developmental disabilities. Thus, the current study aimed to use a more novel and robust statistical approach to examine the aforementioned relationship. Specifically, a second-order CFA, a technique that reduces the influence of measurement error on the resulting latent construct, was implemented to confirm that measures of individual gestures and fine motor abilities load onto one underlying gesture construct as hypothesized. Results indicated that the individual gesture items from each measure (CQ and ADOS) and fine motor abilities (MSEL and VABS-II) loaded onto a single, latent factor of gesture use. This factor form held across both the ASD and non-ASD groups but the factor loadings were greater in magnitude in the ASD group. The difference between groups may have been attributed to the restricted range in the “Gestures” item on the ADOS, such that the vast majority of children in the non-ASD group had either a score of 0 or 1, whereas the ASD group showed a full range of scores from 0-3.

Relationship between Gesture, Fine Motor, and Language in Children with ASD

Results of SEM conducted to determine whether the underlying second-order gesture construct related to concurrent language revealed significant correlations between gesture use and both expressive and receptive language for the whole sample and in both the ASD

and non-ASD groups separately. Overall, these findings support the idea of an underlying construct of gesture use, which includes fine motor abilities, influencing language.

We hypothesized that nonverbal cognitive ability and severity of ASD symptoms would be important variables to consider as confounds. Results of bivariate correlations indicated that gesture items from the CQ and ADOS were significantly correlated with ASD severity and nonverbal cognitive ability. Thus, a model controlling for these variables was run. However, as reported for the CFA model, when these variables were included in the model, a solution could not successfully converge. Similar to the CFA, it is likely that the high degree of multicollinearity between nonverbal cognition and ASD severity and each of the language measures contributed to the lack of convergence. In other words, the correlations among these variables may have been considered too strong or dependent on one another (Marsh and Bailey, 1991). It is also possible that the sample size became a limiting factor as we added more variables to the model, although we did meet the minimum sample size as suggested by prior research (Bentler and Chou, 1987).

Of note, indicators of expressive and receptive language were originally included from three assessment tools – the MSEL, VABS-II, and CDI. However, overall model fit with all three measures was poor. Results of analyses suggested that removing the CDI from the model would result in significant improvement of model fit. This finding may be related to several factors, such as differences in psychometric properties of the measures as well as sample size. Previous research has supported the use of the CDI Words and Gestures as a measure of vocabulary in children with and without developmental disabilities (e.g., Fenson et al., 2006, Luyster et al., 2008). However, while the CDI measures a range of vocabulary, it is possible that the limited range of language skills measured on the CDI (i.e., vocabulary: number of words understood and number of words produced) compared to the MSEL and VABS, which are more comprehensive measures of language, contributed to the poor fit of the model. In addition, we utilized the CDI Words and Gestures form in this study and it is possible that using the CDI Words and Sentences, which includes additional aspects of language such as grammar, would impact the model fit. Finally, only a subset of children in both the ASD ($n=80$) and non-ASD ($n=29$) groups had the CDI completed, so it is possible that missing data may have contributed to this finding.

In addition to finding relationships between gestures (and fine motor) and concurrent language, longitudinal relationships explored with regression analyses in a subsample of children with ASD indicated that early gesture use statistically predicted receptive language on the VABS-II (but not the MSEL) approximately 1 year later. This finding held even when controlling for nonverbal cognitive ability, ASD severity, age, and Time 1 receptive language. This finding of a specific relation between gesture use and receptive language on the VABS-II may be related to differences in how the VABS-II and the MSEL measure language. Specifically, the VABS-II is caregiver-report interview and focuses on adaptive functioning in the child's daily life, compared with the MSEL, which is an observational measure of language.

Previous research examining gesture and fine motor abilities in young children with ASD has traditionally analyzed the developmental domains of nonverbal communication and

motor abilities separately, finding impairments in both gesture and fine motor skills in ASD. Deficits in fine motor skills have been found as early as 6 months of age in young children later diagnosed with ASD (Landa and Garrett-Mayer, 2006, Libertus et al., 2014). Given that fine motor appears to be related to communication and expressive language skills early in development in children at-risk for ASD (Bhat et al., 2012), even when accounting for differences in nonverbal cognitive level (LeBarton and Iverson, 2013), we included fine motor abilities when modeling the relationship between gesture and language. These domains of language and fine motor are often targeted quite separately in treatment, but developmentally, it may be imperative to work on these skills in conjunction. This type of combined interaction may help bolster nonverbal communication skills that require motor planning, as gestures do, in order to be used for joint attention purposes that directly relate to word learning and verbal communication development.

Limitations and Future Directions

The primary focus of this study was on children with ASD. By including a non-ASD group, this study provided information regarding whether the relationships between constructs are specific to ASD. As has been done in previous studies (e.g., Hazlett et al., 2011, Jones et al., 2011, Lord et al., 2000), we included children with similar cognitive deficits to those found in some children with ASD in the comparison sample in order to enrich the non-ASD comparison group to allow for more preciseness in determining the specificity of the findings to ASD. However, future studies with larger comparison samples would allow for examination of these constructs in ways that would help further specify gesture – language relationships based on varying degrees of language development and specific chronological age groups (e.g., a narrower range of typically developing toddlers).

A strength of this study was the implementation of multiple measures and methods of data collection, including parent report and direct observation. However, it will be important for future studies to utilize measures of gesture that have a wider range of scores and involve more naturalistic assessments of child gesture. For example, contrived situations of interactive examiner observations in a clinic may create a bias on behaviors displayed (Shumway and Wetherby, 2009), with other types of sampling, such as parent-child play interactions, providing opportunities for more naturalistic observations. Further, this study utilized a descriptive, correlational design, with a relatively short developmental period examined, and cannot make claims about causal links between gesture and language. It will be important for future studies to longitudinally examine (over a longer period of time) the relationship between gesture, fine motor, and language, in larger samples of children with ASD and other neurodevelopmental disorders, and to determine other child characteristics as well as environmental variables that may relate to the development of language in young children.

Future research is also needed to continue attempting to quantify the extent to which increasing gesture use directly increases language abilities, to then understand the extent to which children with ASD or other developmental delays benefit from interventions aimed at increasing the frequency and types of gestures used (LeBarton et al., 2015) and the mechanisms by which these interventions work. In addition, research examining specific

gestures along with the combination of other features of nonverbal communication, such as function and form, will allow for more focused exploration of behaviors deficient in ASD that can be targets for language goals in interventions.

Summary and Conclusions

Taken together, findings from this study extend prior literature by examining gesture use as an underlying, latent construct using a structural equation modeling framework and combining it with fine motor skills to determine how language development is affected by these combined skills. Prior research has primarily examined these abilities separately and using an either/or approach – either parent report or direct observation. This study used multiple measures and methods, examining both parent report (CQ) and direct observation (ADOS). Examining the inter-relationships between developmental domains rather than analyzing each domain separately, and utilizing a combination of approaches (direct observation and parent report) and measures, provides invaluable information about early development. Overall, findings from this study support theories espousing developmental relationships of motor and nonverbal communication strategies as important in early language learning.

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What this paper adds?**What is known about the subject**

Gesture use is impaired in children with ASD and has been found to be related to language development. However gesture use requires the integration of several developmental skills and it is unclear how commonly measured gestures may influence or be influenced by other developmental domains.

What this study adds

As a result of this study, we now have empirical support for an underlying gesture use construct that includes fine motor ability that predicts concurrent receptive and expressive language in a sample of young children with ASD and a non-ASD comparison group, as well as later receptive language in children with ASD.

Clinical implications of this study

Results of this study provide further support for developmental influences of nonverbal communication strategies and fine motor skills as important for early language learning. These domains are often targeted quite separately in treatment, but developmentally, it may be imperative to work on these skills in conjunction.

Figure 1.

Structural Equation Model for Gestures Correlated with Concurrent Expressive Language Ratio Scores in Children with ASD.

Note: All parameter estimates in bold are significant at $p < .01$

Figure 2.

Structural Equation Model for Gestures Correlated with Concurrent Receptive Language Ratio Scores in Children with ASD.

Note: All parameter estimates in bold are significant at $p < .01$

Table 1
Summary of Participant Demographics and Characteristics

Characteristic	ASD	Non-ASD	
		DD	TD
Sample size	110	35	52
Age (<i>M, SD</i>)	35.6 _a (7.4)	36.6 _a (7.8)	30.0 _b (9.4)
Males (<i>n, %</i>)	96 (87.3%)	29 (82.9%)	37 (71.2%)
Race (%)			
Caucasian	61 _a	54 _a	81 _b
African American	24 _a	29 _a	8 _b
Asian	5 _a	9 _a	6 _a
Other/Unknown	10 _a	8 _a	5 _a
Mother's Education (%)			
Graduate/Professional Degree	32 _a	40 _{ab}	65 _b
Some College	55 _a	46 _{ab}	33 _b
High School Diploma	10 _a	6 _a	0 _a
< High School Diploma	1 _a	0 _a	2 _a
Unknown	2 _a	8 _a	0 _a
Mullen Scales of Early Learning (<i>M, SD</i>) ^a			
Nonverbal DQ	68.25 _a (14.34)	72.53 _a (16.53)	111.31 _b (13.13)
Verbal DQ	49.53 _a (21.07)	61.12 _b (15.58)	107.26 _c (14.69)
Vineland Adaptive Behavior Scales-II (<i>M, SD</i>)			
Communication	72.6 _a (12.6)	79.2 _b (9.0)	104.6 _c (8.3)
Daily Living Skills	75.1 _a (9.5)	82.5 _b (8.8)	101.0 _c (7.7)
Social	72.6 _a (8.0)	82.7 _b (8.0)	101.2 _c (7.1)
Motor	81.7 _a (9.9)	82.3 _a (11.0)	98.6 _b (8.4)
Adaptive Behavior Composite	72.3 _a (8.4)	78.5 _b (7.6)	101.3 _c (7.4)
Caregiver Questionnaire (Weighted Raw Scores <i>M, SD</i>)			
Social Composite (out of 48)	26.9 _a (8.0)	36.6 _b (8.2)	44.1 _b (2.5)
Emotion/EyeGaze (out of 16)	9.6 _a (2.6)	11.7 _b (2.9)	14.3 _c (1.2)
Communication (out of 20)	10.5 _a (3.9)	15.0 _b (4.2)	18.2 _b (1.8)
Gestures (out of 12)	6.8 _a (2.7)	10.0 _b (2.3)	11.7 _b (0.8)
Speech Composite (out of 40)	19.3 _a (12.9)	25.5 _a (10.1)	34.4 _a (8.6)
Symbolic Composite (out of 51)	26.0 _a (12.6)	35.9 _b (9.6)	44.2 _{ab} (7.8)
ADOS Social Affect CSS	6.6 _a (1.7)	2.2 _b (1.0)	1.3 _c (0.7)
Range	2.0-10.0	1.0-5.0	1.0-4.0
ADOS RRB CCS	8.2 _a (1.7)	5.3 _b (2.3)	3.0 _c (2.2)
Range	1.0-10.0	1.0-9.0	1.0-7.0

Note. Means in the same row with different subscripts differ significantly at $p < .05$ on Tukey's HSD post-hoc comparison.

^aBecause some children achieved the lowest possible standard score on the MSEL, Developmental Quotients (DQ), based on age equivalents divided by chronological age $\times 100$, were used to more fully characterize individual variation. Nonverbal DQ was calculated from the average of the Fine Motor and Visual Reception scales, and Verbal DQ from the average of the Receptive and Expressive Language scales.

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Table 2
Percentage of Children Reported to use Each Individual Gesture on the CQ

Gesture	ASD	DD	TD	χ^2	p-value	Post Hoc ^a
Giving	83.6	91.4	100	10.12	.006	ASD<TD
Showing	34.5	77.1	98.1	64.73	.000	ASD<DD<TD
Pushing Away	87.3	94.3	100	8.00	.018	ASD<TD
Raising Arms Up	84.5	91.4	100	9.36	.009	ASD<TD
Reaching	70.0	85.7	100	21.10	.000	ASD,DD<TD
Waving	61.8	97.1	98.1	36.07	.000	ASD<DD,TD
Pointing (contact)	53.6	80.0	96.2	32.33	.000	ASD<DD<TD
Pointing (distal)	41.8	82.9	100	58.46	.000	ASD<DD<TD
Shaking Head	59.1	85.7	94.2	25.62	.000	ASD<DD,TD
Nodding Head	15.5	51.4	82.7	69.23	.000	ASD<DD<TD

^a p<.005 on Bonferonni post-hoc comparison

Correlation Matrix Among Measures, Controlling for Age

ADOS																								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
Intellectual Language Communication CQ																								
(1) Gestures	--																							
(2) Picturing	.36*	--																						
(3) Stimming	.48*	.65*	--																					
(4) Circumscribing	.35*	.40*	.54*	--																				
Communication CQ																								
(5) Gestures	-.47*	-.48*	-.56*	-.43*	--																			
(6) Circumscribing	-.20*	-.19*	-.22*	-.29*	.48*	--																		
(7) Stimming	-.34*	-.39*	-.47*	-.35*	.61*	.42*	--																	
(8) Push Away	-.23*	-.08*	-.12*	-.19*	.32*	.50*	.32*	--																
(9) Raising Arms	-.27*	-.04*	-.14*	-.03*	.31*	.22*	.32*	.09*	--															
(10) Reaching	-.28*	-.28*	-.32*	-.14*	.34*	.21*	.40*	.19*	.19*	--														
(11) Draping	-.48*	-.35*	-.43*	-.35*	.50*	.37*	.47*	.33*	.24*	.30*	--													
(12) (contact)	-.35*	-.40*	-.35*	-.25*	.52*	.35*	.49*	.33*	.09*	.30*	.47*	--												
(13) (distal)	-.40*	-.48*	-.49*	-.35*	.61*	.23*	.54*	.17*	.23*	.32*	.42*	.57*	--											
(14) Shaking	-.15*	-.23*	-.29*	-.17*	.41*	.17*	.34*	.20*	.00*	.12*	.21*	.31*	.38*	--										
(15) Judding	-.38*	-.37*	-.40*	-.26*	.46*	.17*	.48*	.12*	.23*	.21*	.35*	.36*	.48*	.41*	--									
Fine Motor																								
(16) MSEL FM	-.44*	-.47*	-.56*	-.35*	.53*	.24*	.41*	.16*	.14*	.30*	.40*	.34*	.44*	.25*	.46*	--								
(17) VABS FM	-.30*	-.32*	-.44*	-.25*	.43*	.26*	.36*	.14*	.21*	.34*	.41*	.35*	.40*	.22*	.40*	.71*	--							
ADOS Severity																								
(18) ADOS CSS	.64*	.63*	.74*	.45*	-.63*	-.21*	-.50*	-.12*	-.17*	-.30*	-.40*	-.43*	-.49*	-.33*	-.55*	-.58*	-.36*	--						
Nonverbal Cognition																								
(19) MSEL VR	-.44*	-.51*	-.62*	-.36*	.49*	.21*	.43*	.12*	.11*	.26*	.33*	.30*	.43*	.25*	.45*	.84*	.61*	-.60*	--					
Expressive Language																								

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	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
(20) MSEL EL	-.39 *	-.60 *	-.65 *	-.43 *	.58 *	.27 *	.47 *	.15 *	.07	.35 *	.40 *	.45 *	.55 *	.33 *	.51 *	.76 *	.57 *	-.59 *	.76 *	--	--				
(21) VABS EL	-.41 *	-.58 *	-.65 *	-.43 *	.63 *	.32 *	.53 *	.23 *	.17 *	.38 *	.45 *	.49 *	.60 *	.37 *	.56 *	.73 *	.59 *	-.65 *	.77 *	.90 *	--				
(22) CDI WP	-.12	-.41 *	-.44 *	-.31 *	.28 *	.16	.35 *	.02	-.09	.22 *	.23 *	.35 *	.41 *	.26 *	.29 *	.60 *	.49 *	-.32 *	.64 *	.69 *	.74 *	--			
Receptive Language																									
(23) MSEL RL	-.48 *	-.66 *	-.69 *	-.43 *	.64 *	.32 *	.53 *	.24 *	.19 *	.33 *	.46 *	.45 *	.57 *	.35 *	.56 *	.70 *	.52 *	-.74 *	.78 *	.84 *	.84 *	.51 *	--		
(24) VABS RL	-.41 *	-.51 *	-.60 *	-.38 *	.60 *	.34 *	.51 *	.27 *	.25 *	.39 *	.41 *	.45 *	.51 *	.35 *	.54 *	.68 *	.58 *	-.66 *	.72 *	.76 *	.85 *	.53 *	.81 *	--	
(25) CDI WU	-.33 *	-.43 *	-.55 *	-.37 *	.45 *	.30 *	.44 *	.15	.04	.36 *	.34 *	.40 *	.47 *	.35 *	.36 *	.46 *	.48 *	-.47 *	.53 *	.57 *	.67 *	.77 *	.54 *	.62 *	--

*
p < .05

Table 4
Descriptive Statistics for all Variables Included in the Confirmatory Structural Equation Model

Variable	ASD			Non-ASD		
	<i>n</i>	% observed score of 0		<i>n</i>	% observed score of 0	
Gestures – Direct Observation (ADOS) ^a						
Gestures	108	18.5		84	70.2	
Pointing	108	8.3		84	60.7	
Showing	108	9.3		84	67.9	
Giving	96	9.4		50	46.0	
Gestures – Parent Report (CQ) ^b						
	<i>n</i>	% reported to use		<i>n</i>	% reported to use	
Gesture Use	110	72.7		87	97.3	
Giving	110	83.6		87	96.6	
Showing	110	34.5		87	89.7	
Pushing Away	110	87.3		87	97.7	
Raising Arms Up	110	84.5		87	96.6	
Reaching	110	70.0		87	94.3	
Waving	110	61.8		87	97.7	
Pointing (contact)	110	53.6		87	89.7	
Pointing (distal)	110	41.8		87	93.1	
Shaking Head	110	59.1		87	90.8	
Nodding Head	110	15.5		87	70.1	
Variable	<i>n</i>	<i>M</i>	<i>SD</i>	<i>n</i>	<i>M</i>	<i>SD</i>
Fine Motor						
MSEL AE	110	23.7	6.3	87	29.1	9.3
VABS-IIAE	110	25.1	7.4	87	28.2	9.2
ASD Severity						
ADOS Total CSS	105	7.2	1.9	72	1.7	1.0
Nonverbal Cognition						
MSEL Visual Reception AE	110	31.6	11.5	87	25.1	7.8
Expressive Language						

Variable	ASD		Non-ASD	
	<i>n</i>	% observed score of 0	<i>n</i>	% observed score of 0
MSEL Ratio Score	110	49.9	87	85.1
VABS-II Ratio Score	110	47.6	87	93.0
CDI Words Produced	80	52.2	29	88.6
Receptive Language				113.0
MSEL Ratio Score	110	50.1	87	92.6
VABS-II Ratio Score	110	47.4	87	100.3
CDI Words Understood	80	119.4	29	196.8
				121.8

Note. ASD=autism spectrum disorder; Non-ASD=developmental delay + typically developing. ADOS=Autism Diagnostic Observation Schedule; CQ=Communication and Symbolic Behavior Scales Caregiver Questionnaire; MSEL=Mullen Scales of Early Learning; VABS-II=Vineland Adaptive Behavior Scales, Second Edition; CDI=MacArthur-Bates Communicative Development Inventories. Ratio scores were calculated by dividing a child's age equivalent score on a given domain by the child's chronological age and multiplied by 100.

^aPercentage of Children Observed to use Each Individual Gesture Purposefully and Appropriately During ADOS (score of 0). ADOS gesture items measured according to Module: Gestures (all modules); Pointing and Showing (Toddler Module and Modules 1 and 2). Giving (Toddler Module and Module 1).

^bPercentage of Children Reported to use Each Individual Gesture on the CQ

Table 5
Fit Indices of Structural Equation Models Testing the Relation between Gesture and Concurrent Language Ratio Scores

Variable	χ^2	df	CFI	TLI	RMSEA	RMSEA (90% CI)	Correlation between Gesture & Lang. Ratio
Expressive Language							
All Participants	288.00 *	166	.97	.97	.06	.05-.07	.92 *
ASD	237.19 *	166	.92	.91	.06	.04-.08	.90 *
Non-ASD	201.34 *	166	.95	.95	.05	.02-.07	.88 *
Receptive Language							
All Participants	295.34 *	166	.98	.97	.06	.05-.07	.98 *
ASD	241.92 *	166	.91	.90	.06	.05-.08	.96 *
Non-ASD	199.55 *	166	.95	.95	.05	.01-.07	.98 *

* $p < .001$

Table 6
Longitudinal Results of Receptive Language for ASD with Follow-Up Data (N=36)

<i>Variables</i>	Receptive Language VABS-II Ratio Score (Time 2)		
	Model 1	Model 2	Model 3
	β	β	β
Nonverbal Cognition	.33 ⁺	.21	.16
Autism Severity	-.11	-.11	.02
Age	-.37 ⁺	-.35 ⁺	-.57 [*]
MSEL Ratio Score (Time 1)		-.11	-.25
VABS-II Ratio Score (Time 1)		.49 [*]	.27
Gestures Factor Score			.56 [*]
R^2	.15	.33	.43
R^2		.18 [*]	.10 [*]

⁺ $p < .10$,

^{*} $p < .05$

Note. Follow-up data were measured between 8-16 months (mean=13.0 months) post-initial evaluation.