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Gesture Use in Toddlers with and without Autism Spectrum Disorder: Gestural Differences and Developmental Predictors

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This study examined the nature and predictors of parent-reported gesture use in a sample of toddlers (mean age: 15.6 months) who screened positive for Autism Spectrum Disorder (ASD). Gesture repertoire size, gesturing frequency, and content of gesture inventories were compared among 21 toddlers with ASD, 19 with Global Developmental Delay (GDD), 26 with Developmental Language Disorder (DLD), and 45 with typical development or no diagnosis (TD/ND). The relative contribution of developmental and demographic predictors to gesture production were examined. Children with ASD were reported to have significantly less gesture production than TD/ND peers, but not peers with GDD or DLD. Frequency in use of deictic gestures, as well as some conventional gestures primarily used in dyadic interaction, was significantly reduced in the ASD group compared to the TD/ND group. Receptive language skills (in particular, understanding of phrases), child's sex, and fine motor skills predicted gesture use in the whole sample, after accounting for all other factors. Parent-reported gesture use demonstrated concurrent validity with clinician gesture ratings, suggesting validity of use of parent measures to assess early gesture production in young toddlers at risk for ASD. Findings provide further support that gestural deficits in ASD are present early in development, within the first two years of life. Certain gesture types may better distinguish children with ASD from TD/ND peers, and may be important targets for autism screening and early intervention. Predictors of gesture use can begin to elucidate models regarding the emergence of atypical gesture production in ASD.

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Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by persistent impairments in reciprocal social interaction and verbal and nonverbal communication, as well as the presence of restricted and repetitive behaviors manifested early in childhood (American Psychiatric Association; APA, 2013). Deficits in the comprehension and use of gestures is a common nonverbal communicative weakness that hinders effective social communication in ASD.

Researchers are increasingly interested in investigating early atypical gesture use as a risk marker for ASD and other developmental disorders. Some suggest that reduced use of conventional gestures (i.e., hand and body movements with culturally specific forms and meanings, such as flipping hands while shrugging shoulders to convey “don’t know;” Özçalışkan, Adamson, & Dimitrova, 2016), as well as reduced use of gestures to share attention (e.g., pointing) are some of the core deficits of ASD in the second year that can serve as “red flags” for the disorder (Wetherby, Watt, Morgan, & Shumway, 2007). Veness and colleagues (2012) demonstrated that every decrease in the number of early communicative gestures used at 12 months doubled the odds of being diagnosed with ASD by age four, rather than a developmental delay (DD) or being typically developing (TD), and led to 1.5 greater odds of having ASD over language impairment. Gesture use at age two may be one of the strongest discriminating characteristics between ASD and not only TD peers, but also peers with other DD’s (Veness, et al., 2012; Wetherby et al., 2007).

While there is some research on gesture production delays in ASD during infancy and toddlerhood, less is known about the content of gesture inventories, particularly as reported by parents, who can offer information regarding a child’s typical gesture use in the home environment. There is even less research on what contributes to atypical gesture production in the ASD during the first years of life. In this study, we seek to address these gaps by examining the nature and predictors of gesture use in a sample of toddlers who screened positive for ASD.

Gesture use in typically developing infants and toddlers

Deictic gestures, or gestures used to refer to something in the environment, typically emerge at ten months. Infants first SHOW[1] (i.e., hold objects up to another person's line of sight for the purpose of sharing), then GIVE (i.e., show and release objects to another person), and then POINT to objects around them, reflecting a gradual distancing of the self from the object (Capone & McGregor, 2004). The onset of pointing reliably predicts the appearance of the first word (te Kaat- van den Os, Jongmans, Volman, & Lauteslager, 2015). REQUEST gestures (e.g., reaching with open-close grasping motion) also emerge between 9-13 months. Beginning at 12 months and continuing into the second and third years CONVENTIONAL gestures emerge, and are largely learned through interaction with objects and routines (e.g., imitated from songs; Capone & McGregor, 2004; LeBarton & Iverson., 2016). As toddlers gain more spoken words, they show a preference for either gestures or speech around 15-16 months but move to preferring spoken words around the second birthday (Capone & McGregor, 2004; Iverson, Capirci, & Caselli, 1994). Pointing also begins to take precedence over other deictic gestures around 16-20 months, and gesture-word combinations (e.g., POINT + "milk") that emerge at this time open the door for significant growth in vocabulary (Iverson & Goldin-Meadow, 2005; Lüke, Grimminger, Rohlfing, Liszkowski & Ritterfeld, 2017; Özçalışkan & Goldin-Meadow, 2005).

Gesture use in toddlers with language delay

Deficits in early communicative gestures, particularly declarative pointing (i.e., pointing to share attention) often emerge before speech delays in language-delayed children (Bello, Onofrio, Remi, & Caselli, 2018; Capone & McGregor, 2004; Goldin-Meadow et al., 2014). Gesture deficits may uniquely predict chronic language impairment. That is, "truly late talkers" diagnosed with specific language impairment can be differentiated from "late bloomers," or late-talking children who recover from language delays, by their decreased deictic and conventional gesture use at 18-29 months (Ellis & Thal, 2008; Tager-Flusberg, 2016). Late bloomers, in contrast, demonstrate *increased* gesture use that is

[1] Gesture types will be capitalized throughout the document.

thought to compensate for verbal language delays, and ultimately improve expressive language skills (Moyle, Stokes, & Klee, 2011).

Gesture use in toddlers with global developmental delays

Evidence about gesture development in children with global developmental delays has largely come from work with children with Down syndrome (DS), a large subgroup within the population of children with intellectual disability (te Kaat- van den Os et al., 2015). The same types of gestures emerge, but at a significantly delayed pace, in children with DS compared to age-matched TD peers (te Kaat- van den Os et al., 2015). Indeed, when compared to *mental age-matched* TD peers, young children with DS and other global delays of unknown etiology demonstrate strengths in gesture production (Galeote et al., 2011; Luyster, Lopez, & Lord, 2007; te Kaat- van den Os et al., 2015; Vandereet, Maes, Lembrechts, & Zink, 2011). While there is some evidence that gestural patterns are not significantly different between children with DS and children with intellectual disability of undetermined etiology (Calandrella & Wilcox 2000), it remains unclear if findings can be generalized from one group to the other.

Gesture use in infants and toddlers with ASD

Research with high risk (HR) baby siblings (i.e., children with an older sibling diagnosed with ASD) suggests that, when compared to peers with TD or DDs, infants and toddlers with ASD generally demonstrate stronger deficits in gesture production (LeBarton & Iverson, 2016). Deficits seem to emerge early and persist over the first two years of life. For example, Mitchell et al., (2006) found that HR siblings with ASD (HR-ASD) produced fewer gestures relative to HR siblings without ASD or low risk (LR) siblings starting at 12 months and persisting through 18 months. Iverson, et al. (2018) showed that HR-ASD children demonstrated the slowest growth in gesture repertoire size between 8 and 14 months, relative to HR siblings with language disorder (HR-LD), HR siblings with no diagnosis, or LR peers. While the HR-LD group gestured the least at eight months, they eventually “recovered” from initial delays, something not observed in the HR-ASD group. Recently, Franchini and colleagues (2018) found that from 9-24 months, HR-ASD siblings demonstrated an “intermediate” gesture acquisition trajectory (i.e., estimated 49 of 63 total gestures endorsed by 24 months of age on the *MacArthur-Bates Communicative Development Inventories;* CDI) or “low” trajectory (i.e., 32 of 63 gestures by 24 months). In contrast, HR peers without ASD and LR peers mostly demonstrated intermediate or “high” (i.e., 56 of 63 gestures by 24 months) trajectories.

A handful of studies have investigated gesture production in non-HR children with ASD (children without an older sibling with autism) during infancy and toddlerhood. Toddlers with ASD or Down syndrome (on average 30 months old) showed decreased gesture production relative to TD peers (on average 18 months old, matched on expressive vocabulary; Dimitrova, Özçalışkan, & Adamson, 2016; Özçalışkan, Adamson, Dimitrova & Baumann, 2018). Children later diagnosed with ASD had fewer gestures endorsed on the CDI at 12 and 24 months than peers with DD, LD, or TD (Veness et al., 2012, 2014). Deficits in early communicative gestures may uniquely differentiate high functioning children with ASD from peers with TD or DDs, when other language measures cannot (Luyster, et al., 2007).

There is some literature on which types of gestures in particular are reduced in children with ASD. Infants with ASD use fewer SHOW and POINT gestures than peers with DDs and TD, and fewer REQUEST gestures than TD peers (Clements & Chawarska, 2010; Parladé & Iverson, 2015; Watson, Crais, Baranek, Dykstra, & Wilson, 2013; Winder, Wozniak, Parladé, & Iverson, 2013). These differences persist into the second year, and toddlers with ASD also demonstrate reduced rates of CONVENTIONAL gestures (Watson et al., 2013). Weaknesses in deictic gesturing persist through the third year in children with ASD (Özçalışkan, et al., 2016; Özçalışkan et al., 2018), though these weaknesses are not necessarily unique to the disorder (e.g., also reduced in DS and LD; LeBarton & Iverson, 2016; Özçalışkan et al., 2018). In contrast to weaker deictic and conventional gestures, children with ASD may have relative strengths in producing later-developing gestures, particularly actions with objects (e.g., brush teeth; Charman, Drew, Baird, & Baird, 2003).

Developmental and Demographic Predictors of Gesture Use in ASD

While much of the extant research on gesture production in ASD during infancy and toddlerhood has focused on characterizing gesture use as well as understanding the consequences of early gestural deficits (e.g., on subsequent expressive language development; Iverson & Goldin-Meadow, 2005), little is known about what contributes to gesture atypicalities in ASD in the first place. Franchini and colleagues (2018) recently began to answer this question in their study of gesture acquisition trajectories in HR infants. They found that higher visual reception (measure of nonverbal ability; Carter et al., 2007), receptive language, gross motor, and fine motor skills on the Mullen Scales of Early Learning, as well as lower scores on a measure of early signs of ASD, were related to increased chances of being in the "high" gesture acquisition group rather than the "low" acquisition group. These data suggest that a range of developmental factors may impact early gestural ability.

Examining predictors of gesture production in infancy and toddlerhood can help elucidate theoretical perspectives on the etiology of a core symptom of ASD. As deficits in early communicative gestures have far-reaching consequences for the development of further functional communication (e.g., joint attention) and social interaction skills, identifying features of a child's development and environment that introduce risk for early gestural deficits can arm caregivers and providers with tools to use in developmental monitoring and early detection of ASD. Importantly, this research may be used to design early interventions that target enrichment in these developmental domains in order to remediate skills and prevent further gestural delays.

Research with typically and atypically developing populations suggests a variety of developmental factors that may contribute to early gesture development. Here we discuss several hypotheses regarding key contributing factors to the emergence and disruption of gesture use in ASD.

Social engagement. It may be the case that gestural deficits in ASD are best explained by the social deficits (i.e., social interest and engagement) characteristic of the disorder. This hypothesis would argue that gesture is best understood as a socially communicative act, and that what drives gesture use is a child's interest in others and desire to initiate and respond to social interaction using gesture. There is some evidence with school-aged children with ASD that gestural deficits, including pantomime of actions (e.g., ironing, toothbrushing) relate most strongly to severity of social and communicative impairments (Gizzonio et al., 2015; So et al., 2015). Some researchers suggest that rate of communicative acts, including gesturing, may be an index of intrinsic social motivation (Charman et al., 2003; Shumway & Wetherby, 2009). Others hypothesize that underlying social deficits lead to the profile of gestural weaknesses (e.g., reduced showing and pointing to share attention) and relative strengths (e.g., gestures involving use of objects, which are less socially involved, and gestures to regulate others' behaviors for a specific goal, such as requesting or protesting) observed in ASD (Charman et al., 2003; Clements and Charwarska, 2010; de Marchena & Eigsti, 2010; Mitchell et al., 2006; Shumway & Wetherby, 2009; Veness, et al., 2012; Watson et al., 2013). However, others have argued that gestural deficits emerge earlier than core social deficits in ASD (e.g., joint attention), and therefore are related to reduced spontaneous initiation of behavior regardless of social intent (Winder et al., 2013). Nevertheless, the role of social interest in gesturing has yet to be investigated in young toddlers with (or at risk for) ASD.

Cognitive capacity. Another hypothesis is that a child's gesture production is most related to the child's overall *capacity* for communication and gesturing (Bates et al, 1979); that is, it is their cognitive ability that best predicts gesture use. Researchers have highlighted the need to consider cognitive impairment and nonverbal ability in gesture delays in ASD (Colgan et al., 2006; LeBarton & Iverson, 2016). Charman et al. (2003) found that in children aged 1-7 years with ASD, gesture production increases with nonverbal mental age (NVMA), but not chronological age. Similarly, Luyster et al. (2007) found that infants and toddlers with ASD with a NVMA of 3-15 months had on average 3-4 First Communicative Gestures on the CDI, versus 4-8 gestures with a NVMA of 16-20 months. A child's inventory of conventional gestures prior to age two has also been found to correlate significantly with nonverbal ability (Wetherby et al., 2007). The argument for the role of cognitive capacity in gesture production aligns with research demonstrating that decreased mental age associates with higher severity of autism symptoms more broadly across childhood (Mayes, Calhoun, 2011; Hinnebusch, Miller, & Fein, 2017).

Motor functioning. Recent literature focusing on the key role that motor skills play in expressive language development in infants and toddlers with ASD paves the way to test yet another hypothesis – that gesture production is best explained by a child's capacity to perform motor movements during early childhood. Motor impairments are highly common in children with ASD (Dewey, Cantell, & Crawford, 2007), and motor atypicalities have been documented prior to age two in HR infants (Iverson et al., 2019; Landa & Garret-Mayer, 2006; Leonard et al., 2014; Ozonoff et al., 2010). Expressive language weaknesses in infants at risk and/or diagnosed with ASD have been linked to deficits in oral, fine, and gross motor skills (Bhat, Galloway, & Landa, 2012; Gernsbacher, Saeur, Geye, Schweigert, & Hill, 2008; LeBarton & Landa, 2019; Leonard et al. 2014). However, little is known about the relationship between early motor skills and gesture production during infancy and toddlerhood in ASD. To our knowledge, only one study has examined the relationship between fine motor skills and gesture production in toddlerhood (Franchini, et al., 2018), though not accounting for the relative contributions of other predictors of gesture use.

Some theoretical models based on research with adults and older children have articulated how motor skills may impact gesture use. For example, from a developmental neuropsychological framework, gestures themselves (termed as *praxis*; Mostofsky & Ewen, 2011) are defined as skilled motor acts that include sequences of purposeful motor movements as well as the ability to use tools (Dewey et al., 2007). Children with disrupted gesture production, as is observed in ASD, may be conceptualized as having a developmental dyspraxia (Dewey, 1995; Mostofsky & Ewen, 2011). According to this model, a child's gestural ability would be best explained by their ability to perform goal-directed motor movements. Impaired acquisition of earlier developing functions such as perceptual-motor skills would impact the capacity to develop more advanced praxis skills (Dewey, 1995). Some research suggests, however, that motor deficits cannot fully explain gestural impairments. For example, children with ASD show comparable levels of imperative pointing (i.e., to request, not to share) and use of objects that require intact fine motor ability (Charman et al., 2003; Sowden, Perkins, & Chegg, 2008). High functioning school-aged children with ASD continue to show significantly poorer praxis than TD peers after accounting for basic motor skills (e.g., speed of repetitive motor movements), suggesting that basic motor functioning cannot fully account for the form of dyspraxia observed in ASD (Dziuk et al., 2007). The relative contribution of motor functioning to gesture productions remains to be examined in ASD during infancy and toddlerhood, a time when motor and gestural functions are emerging.

Language comprehension. Lastly, researchers have also hypothesized that gestural deficits in ASD are better explained by deficits in language comprehension (LeBarton & Iverson, 2016; Iverson et al., 2018). School-aged children and adolescents with ASD make more gestural errors when responding to verbal commands (e.g., "Show me how you brush your teeth with a toothbrush") compared to when imitating a visual model (e.g., imitates examiner's gesture for brushing teeth; Dewey, et al., 2007). Dewey and colleagues suggest that gestural errors in ASD may reflect impairments in mechanisms translating language comprehension to action. Franchini et al. (2018) found that receptive language, but not expressive language, is one of the predictors of gesture growth in infants and toddlers with ASD. In contrast, expressive language, which generally follows gesture emergence in typical development, has been found to be strongly *predicted by* gesture ability in ASD and other developmental disorders (Iverson & Goldin-Meadow, 2005; Lüke, et al., 2017; Özçalışkan & Goldin-Meadow, 2005; Özçalışkan, et al., 2016; Özçalışkan, et al., 2018).

There is some evidence of a neuroanatomical basis for the link between language comprehension and gesture use (praxis). Early research characterizing apraxia (or loss of ability to perform skilled motor movements to command) in adult aphasic patients (i.e., patients who also lost the ability to understand or express speech) provide evidence that apraxia correlates most strongly with language comprehension deficits and severity of aphasia (Kertesz & Hooper, 1982). More contemporary models integrating findings from neuroimaging research on apraxic and aphasic patients suggests that both language and praxis are served by largely overlapping networks in the brain involving the superior temporal, rostral inferior parietal, and ventral premotor cortices, which in part serve language comprehension and production, social perception, and visual guidance of hand-arm movement functions (see Roby-Brami, Hermsdörfer, Roy & Jacobs, 2011 for review). Of course, models based on research with adults with acquired brain injuries may not necessarily apply to the form of dyspraxia found in a neurodevelopmental disorder like ASD (Dziuk et al., 2007), and it would be important to first establish the extent of the contribution of language comprehension skills to gesture use in this population early in development.

In addition to early developmental capacities, demographic factors (including a child's sex, as well as their social environment, including socioeconomic background and language exposure at home) may also play crucial roles in early gesture use in ASD.

Sex. In TD populations, there have been consistent findings that girls produce more communicative gestures than boys during infancy and toddlerhood. This was documented in the CDI norming study by Fenson and colleagues (2007), replicated in various other studies (Burglund et al., 2005; Eriksson & Berglund, 1999; Feldman, et al., 2000), and across language communities in Europe (Eriksson et al., 2012). Girls have also been found to advance in gesture-speech development (e.g., combining gestures and words) earlier than boys (Ozçalişkan & Goldin-Meadow, 2010). Research in this area is limited in ASD; a female advantage has been documented in one study with high functioning school-aged children with ASD where girls used more gestures than boys during two demonstration tasks on the Autism Diagnostic Observation Schedule (ADOS-2; Rynkiewicz et al., 2016).

Maternal education and socioeconomic status (SES). Compared to the often-replicated relationship between SES and vocabulary attainment in early childhood, there are mixed findings regarding the contribution of maternal education and SES to child gestural ability in TD populations. One study found small to moderate correlations between maternal education and pointing onset, with lower maternal education predicting later emergence of pointing (McGillion, et al., 2017). Another study found that children from lower SES families had lower gesture variety (e.g., used POINT to convey fewer meanings; e.g., point at dog = dog, point at cup = cup) at 14 months, even before the vocabulary by SES gap emerges (Rowe & Goldin-Meadow, 2009). However, other research has not found gesture repertoire size to vary by SES or maternal education (Berglund, Eriksson, & Westerlund, 2005; Feldman et al., 2000). Research on gesture use in ASD has largely controlled for sociodemographic factors in analyses. Therefore, it is unclear if there are specific effects of SES on gesture use in ASD.

Bi/multilingual exposure. There is some evidence in TD populations that bilingual children engage in more co-speech gesturing compared to monolingual children, perhaps in ways that facilitate speech formulation (Nicoladis, Pika, & Marentette, 2009; Yow, 2015). This finding has been partially replicated in ASD populations. Toddlers with ASD from bilingual homes are observed to use more point to request gestures than children with ASD from monolingual homes (Valicenti-McDermott et al., 2013). Another study found that while bilingual children with ASD had fewer total gestures on the CDI at 12-26 months compared to monolingual children, they demonstrated significantly greater gains in total gestures two years later following intervention (Zhou et al., 2017).

Motivation for the current study

It is perhaps more likely than not that early gesture use in ASD is impacted by a combination and/or interaction of the above developmental and demographic characteristics. Nonetheless, examining the relative contributions of these predictors to gesture use is an important step toward building a model for the emergence of gesturing in ASD, which has important clinical implications for early detection and intervention.

Overall, the literature suggests that children with ASD have poorer gesture production than peers without ASD in the first few years of life. Most of this research comes from work with HR siblings; general population-based research that compares early gesture use in ASD and other DDs (i.e., language disorder, global delay of undetermined etiology) is still limited. In addition, the literature is often unclear in distinguishing specific aspects that compose “poor gesture production” in ASD. That is, some studies measure gesture repertoire size (or number of different gestures a child uses), while others measure gesturing frequency within a discrete period of time. Examining both gesture repertoire size and gesturing frequency would allow us to investigate whether one or both aspects of gesture production are impaired in ASD, which can inform intervention goals (e.g., increase variety *and* frequency of gestures).

Furthermore, most of the research on gesture types in ASD come from coding gestures used during brief play sessions or dyadic interactions. This method provides a direct measure of gesture use; however, discrete periods of observation may not necessarily represent a child’s overall gesture ability in daily life for a variety of reasons (e.g., child and/or parent behaves differently when aware of being observed). In contrast, parent-report measures of gesture use (e.g., CDI) provide information about overall gesture use in day-to-day life. Despite potential for parental biases that come with any parent-report measure, the CDI has been found to be a valid and reliable measure of language development (Fenson et al., 2007). Parents may in fact more reliably report on how their child gestures (as opposed to what their child can understand), given the readily observable and discrete nature of early gestures (Feldman et al., 2000). To date, studies of gesture use in ASD using the CDI (Charman et al., 2003; Iverson et al., 2018; Mitchell et al., 2006; Parladé & Iverson, 2015; Veness et al., 2012, 2014) have measured only gesture repertoire size using total gesture scores.

The content of early gesture inventories in ASD based on parent report is also not well-studied. One study used item-level data on the CDI to examine the content of gesture inventories in a small sample of HR infants (Clements & Chawarska, 2010). The authors found that reduced SHOW gestures at 12 months significantly increased the odds of being diagnosed with ASD at 24 months over being diagnosed with a language disorder. However, the overall low gesturing frequency among the 9-12 month-old infants in this study did not allow for adequate characterization of gesture inventories. Examining gesture inventories during early toddlerhood, when more early communicative gestures have developed, allows for a more robust evaluation of gestural differences in children with and without ASD.

Finally, some researchers have raised concerns about whether parent report on the CDI accurately captures infant gesture use in ASD (Clements & Chawarska, 2010). Previous studies reporting concurrent validity of the CDI have focused on the CDI as a whole measure or on measures of vocabulary only (Deckers, Van Zaalen, Mens, Van Balkom, & Verhoeven, 2016; Luyster, et al., 2007). Limited research has specified concurrent validity of gesture scores on the CDI in correlation with behavioral measures of gesture use, and have provided mixed findings about the quality of concurrent validity (Fenson et al., 1994; Thal, O'Hanlon, Clemmons, & Fralin, 1999). Examining correlation of CDI Early Gesture scores with clinician ratings of gesture use at concurrent assessment will help inform us of the convergent validity of parent report of early gesture use in this population.

Current Study Aims

The current study seeks to address the following questions:

1. *How does a) gesture repertoire size and b) gesturing frequency differ among toddlers with ASD, global developmental delay (GDD), developmental language disorder (DLD), and typical development/no diagnosis (TD/ND)?* Can we replicate previous findings regarding early gesture differences between HR toddlers with and without ASD in a population-based sample of children who screened positive on autism screeners? This study would be the first to examine these questions in non-HR toddlers diagnosed with ASD or other developmental disorders prior to age two, which can inform us about early gesture development in ways that are more generalizable to non-HR populations. Based on existing literature, we expect that toddlers with TD/ND will gesture more than peers with delays (Özçalışkan et al., 2018). We expect children with ASD to have lower gesture production than children with GDD (Veness et al., 2012, 2014), and somewhat lower but more comparable gesture use than peers with DLD, given mixed findings on potential for "recovery" from gesture delays in DLD (Iverson et al. 2018; Tager-Flusberg, 2016). We expect similar group differences in both gesture repertoire size and gesturing frequency.
2. *Which types of gestures best differentiate children with ASD from children with GDD, DLD, and TD/ND?* Based on existing literature, we expect that all gesture types will differ between children with and without ASD. We hypothesize that SHOW, GIVE, and POINT gestures, relative to REQUEST and CONVENTIONAL gestures, will best distinguish children with ASD from peers in other groups (Watson et al., 2013; Gordon & Watson, 2015), but that the magnitude of difference would be less on POINT gesture use between the ASD and DLD groups (Bello et al., 2018).
3. *What is the relative contribution of functioning in various developmental domains (including social engagement, nonverbal ability, receptive and expressive language, fine motor skills) and demographic factors (maternal education, annual household income, bi/multi-lingual exposure, child's sex) in predicting a) gesture repertoire size, and b) gesturing frequency in toddlers with and without a developmental disorder?* Based on existing literature, we predict that lower performance on

all developmental domains except expressive language (with comparable impact) will predict a smaller gesture repertoire and lower gesturing frequency in our sample. We expect that girls will produce more gestures than boys in all groups, and children from bi/multilingual homes will produce more gestures than peers from monolingual homes. Given the mixed findings and relatively scarce literature in this area, we do not have specific hypotheses on whether gesture use will differ by maternal education or household income.

4. *Do parent ratings of gesture use on the CDI demonstrate convergent validity with clinician ratings of gesture use at evaluation?*

Methods

Participants

Participants were 108 children drawn from a large, multi-site investigation of the early detection of ASD. Children screened positive on one or more of the following autism/developmental screening measures: *Infant Toddler Checklist* (ITC; Wetherby & Prizant, 2001), *First Year Inventory, Lite* (FYI-L; Baranek et al., 2009; Appendix C), and *Modified Checklist for Autism in Toddlers – Revised with Follow-up* (M-CHAT-R/F; Robins, Fein, & Barton, 2009), or were "red-flagged" by their pediatrician for concern about autism. They also completed a developmental and diagnostic evaluation and had at least partial data on the *CDI Words and Gestures* form (i.e., completed at least one item on the Early Gestures section of the measure).

Sociodemographic characteristics of participants in the current sample were compared to children who were given the CDI Words and Gestures form but did not have useable data (see Table 1). Children with and without CDI data were comparable in sex, maternal education, and diagnostic group breakdown. Children without CDI data were significantly older. Examination of age frequencies showed that 26 out of 52 children (50%) without CDI data were 18 months old at the time of evaluation, whereas children with CDI data were generally younger (majority 13-14 months old). Racial/ethnic group breakdown differed between children with and without CDI data; in particular, a larger proportion of children without CDI data, compared to those with data, were Hispanic/Latinx. Two of 108 children with CDI data completed evaluations conducted in Spanish, and the remainder had evaluations conducted in English. Five of 52 children without CDI data had Spanish-language evaluations. For Spanish-language evaluations, the Spanish adaptation of the CDI Words and Gestures form (*Inventario del Desarrollo de Habilidades Comunicativas: Primeras Palabras y Gestos*; Jackson-Maldonado, Bates, & Thal, 2003) was given to parents to complete.

Annual household income and language exposure (i.e., one language versus more than one language) also differed between those with and without CDI data, although this was driven mostly by the proportion of children with missing data on these variables (i.e., more children without CDI data who also did not have data on annual income and language exposure). When analyses were rerun without children with missing data, group differences in annual income and language exposure no longer held.

Children in the current sample were classified into four groups based on their *International Statistical Classification of Diseases and Related Health Problems, 10th Revision* (ICD-10; World Health Organization, 2004) diagnosis at the evaluation: *Autism Spectrum Disorder* (*ASD;* ICD-10 Childhood Autism, or Atypical Autism; n = 21); *Global Developmental Delay* (*GDD;* ICD-10 Other Disorder of Psychological Development; n = 19); *Developmental Language Disorder* (*DLD;* ICD-10 Expressive Language Disorder, Mixed Receptive-Expressive Language Disorder, or Developmental Disorder of Speech and Language, Unspecified; n = 26); and *Typical Development/No Diagnosis* (*TD/ND;* n = 45). The TD/ND group is a combined group of children who were either within the normal range in all areas of development that were assessed (i.e., Typical Development; n = 28) or presented with sub-clinical symptoms not meeting full criteria for any ICD-10 developmental disorder (i.e., No Diagnosis; n = 17). The TD and ND groups were combined to reduce the overall number of comparison groups and enhance power of analyses. It is important to note that children in the TD group in our study nonetheless screened positive on an autism screener, and demonstrated some level of parent-reported developmental concern, which may differ from TD samples described in previous literature.

Children were excluded from the broader study if they did not enroll in the study between the age of 11 months, 15 days to 21 months, 30 days. Children were also excluded for reasons that would prohibit testing given our resources, including if their legal guardian did not speak English or Spanish, and if the child had a severe sensory or motor disability (e.g., blind, deaf). Children with an ASD diagnosis prior to initial enrollment in the study were screened but not evaluated. In addition, one child diagnosed with ICD-10 Specific Developmental Disorder of Motor Function and who had CDI data was excluded, as they could not be incorporated into an existing diagnostic group, and the motor disorder might affect gesture use in a way that was specific and unlike factors affecting gestures in other groups.

Participant characteristics of the whole sample and by diagnostic group are presented in Table 2. Participants ranged in age from 12 to 24 months, and were on average 15.6 months old at evaluation. The majority of participants were male, had mothers with a Bachelor's degree or higher, lived in households with a family annual income of at least $72,000, and were exposed to one language at home. Diagnostic groups did not differ in terms of age, sex, maternal education, household income, or language exposure. As a whole sample, participants reflected significant racial and ethnic diversity, with a majority of participants identifying as a race/ethnicity other than non-Hispanic/Latinx White. However, racial/ethnic group breakdown did differ significantly by diagnostic group. Specifically, while the TD/ND and DLD groups were composed of majority White toddlers, this was not the case in the ASD or GDD groups. The ASD group had equal proportions of White and Hispanic/Latinx children, and compared to the other groups, the GDD group had larger proportions of children who were Black or Bi/Multiracial.

Procedures

Depending on the screening schedule to which their pediatrician site was randomized (i.e., initial autism screening and participant enrollment at 12, 15, or 18 months), children were screened with the ITC and FYI-L if they enrolled at their 12-month well-child visit, the FYI-L and M-CHAT-R/F if enrolled at 15 months, and the M-CHAT-R/F if enrolled at 18 months. Screeners were mailed to and scored by research staff at the University of Connecticut, Drexel University, or Georgia State University. Children who screened positive on one or more screeners, or were "red-flagged" by their pediatrician as being at-risk for ASD, were invited for a free developmental/diagnostic evaluation. Three weeks prior to the evaluation, families were mailed and asked to complete various questionnaires, including the CDI and history form. Evaluations were conducted by a licensed clinician (clinical psychologist or developmental behavioral pediatrician) and a clinical psychology doctoral student or research assistant. Most evaluations took place at the research team's university clinics, and some evaluations took place at the participant's pediatrician site if the family did not have access to transportation. Clinical best estimate diagnoses were made based on data from observation, developmental history, and scores on measures of autism symptoms and developmental ability.

Measures

The *MacArthur-Bates Communicative Development Inventories (CDI;* Fenson et al., 2007) is a parent-report measure of child communication and language development and has been widely used to study language ability in children with TD and LD (LeBarton et al., 2016, Iverson et al., 2018). The current study uses the CDI Words and Gestures form (CDI-WG), which measures verbal comprehension, and verbal and gesture production in infants and toddlers. Part I of the measure presents parents with an inventory of 396 words and early phrases; parents are asked to indicate whether their child currently "understands" or "understands and says" each item. Total words understood, words produced, and phrases understood are each tallied up into raw scores. Part II presents parents with 63 actions and gestures in five sections. Section 1 asks parents to rate whether their child currently does "not yet," "sometimes," or "often" produces any of 12 First Communicative Gestures. A rating of "sometimes" or "often" suggests the gesture is part of the child's repertoire. In Section 2, parents endorse whether or not their child currently engages in any of six games and routines involving gesture use (e.g., playing "so big"). Sections 1 and 2 comprise "early gestures," while Sections 3-5 (i.e., actions with objects, pretending to be a parent, and imitating other adult actions) comprise "late gestures," based on their relative emergence in typical development. Given that the majority of our sample is developmentally delayed, we focused on examining early gestures in this study. Raw scores can be transformed into age-normed percentiles for children aged 8 to 18 months, although the CDI-WG has also been shown to be effective in examining language development even for preschoolers with ASD (Charman et al., 2003; Franchini et al., 2018). The

CDI has excellent internal consistency (*r*s = .95-.96), test-retest reliability (*r*s = .80-.90), and concurrent validity with clinician-rated measures (Iverson et al., 2018).

The *MacArthur Inventario del Desarrollo de Habilidades Comunicativas: Primeras Palabras y Gestos* (Jackson-Maldonado et al., 2003) is a Spanish adaptation of the CDI-WG, also meant for children 8-18 months old. It is scored similarly to the CDI-WG. "Early gestures" are similarly comprised of items on First Communicative Gestures (13 items, the first 12 identical to the English version) and Games and Routines (8 items regarding engagement in culturally-applicable gesturing songs and games). For participants who completed the Spanish adaptation, data from the first 12 items of the First Communicative Gestures section and first six items of the Games and Routines section were included in analyses. The Spanish adaption of the CDI demonstrates good to excellent internal consistency (*r*s = .89-.94), test-retest reliability (*r*s = .81-.97), and moderate concurrent validity with observed language skill (Jackson-Maldonado et al., 2003).

The *Mullen Scales of Early Learning (MSEL;* Mullen, 1995) is a clinician-administered standardized assessment of early development in children from birth to 68 months. T-scores from four subdomains are used in this study: Visual Reception (VR), Fine Motor (FM), Receptive Language (RL), and Expressive Language (EL). MSEL domain standard scores are internally consistent (*r*s = .75-.83) and inter-rater reliability is high (*r*s = .91-.99; Mullen, 1995).

The *Autism Diagnostic Observation Schedule-2, Toddler Module (ADOS-2;* Lord, et al., 2012*)* is a structured play session and clinician-rated measure used to diagnose ASD. The Toddler Module, meant for children under 30 months of age, was used to assess children in the current sample. Based on the child's responses to various activities designed to elicit social interaction, clinicians rate a series of items about the child's verbal and nonverbal language use, social reciprocity, play, and restricted and repetitive behaviors. Items have unique behavioral guidelines to inform ratings, but generally reflect the following: 0 = typically developing behavior, 1 = mildly atypical, 2 = moderately atypical, 3 = severely atypical. Item level scores from the ADOS were used to create two composite variables. One was a "social engagement" composite, which was the raw sum of scores on the following items: Unusual eye contact, Facial expressions directed toward others, Shared enjoyment in interaction, Ignore, Response to joint attention, Quality of social overtures, and Level of engagement (possible range of summed score is 0 – 21). Using a composite of individual items with the most face valid relevance to social engagement, rather than the ADOS's Social Affect score (which includes ratings of gesture use), allows us to isolate social engagement as a potential predictor of gestural ability. The seven items comprising the social engagement composite demonstrated good internal consistency (Cronbach's α = .88).

The second composite variable was "clinician gesture rating," which was the sum of scores on items directly assessing gesture use on the ADOS, including Pointing, Gestures, Giving, and Showing (possible range of summed score is 0 – 12, with lower scores indicating more typically developing gesture use). The four items comprising the clinician gesture rating composite demonstrated acceptable internal consistency (Cronbach's α = .72).

The *History Form* asks parents to provide information on their child's birth, medical, developmental, and education/intervention history, as well as family medical history and sociodemographic information. Parent reported maternal education, annual family income, child ethnicity, and language(s) spoken at home were used in this study.

Data Analytic Plan

For our first question, early gesture repertoire size was measured by the CDI Early Gestures raw score (possible range 0 to 18). Gesturing frequency was measured by a sum score of ratings on the 12 First Communicative Gestures items on the CDI, in which "not yet," "sometimes," and "often" are rated as 0, 1, and 2, respectively (possible range 0 to 24). For both gesture repertoire size and gesturing frequency, missing item-level data was counted as 0, and did not contribute to the total score. To examine group differences, diagnostic group was used to predict gesture repertoire size and gesturing frequency, separately, after accounting for age in linear regressions. Given a sample size of 108, and α = .05, post-hoc power analyses indicate 95% power to detect medium sized effects and 24% power to detect small effects.

For our second question, gesture profiles by diagnostic group were compared using a repeated-measures analysis of variance (ANOVA) with a between-subjects factor of diagnostic group (ASD, TD/ND, GDD, DLD), within-subjects factors of the 12 items on the CDI First Communicative Gestures section, and age at evaluation as covariate. Group differences at the individual item level were further explored to determine if certain gestures and gesture types distinguished children with ASD, TD/ND, GDD, and DLD from one another. A one-way analysis of covariance (ANCOVA) was conducted for each of the 12 First Communicative Gestures items, with diagnostic group as the between-subjects factor and age at evaluation as covariate. Post-hoc power analyses, with sample size of 103 (five participants had missing data on one or more First Communicative Gesture items, and were thus excluded from this set of analyses) and adjusted $\alpha = .0042$, indicate 74% power to detect large effects and 22% power to detect medium effects. Based on previous literature (LeBarton & Iverson, 2016; Özçalışkan et al., 2016), the CDI First Communicative Gestures were categorized into gesture types (see Table 3).

For our third question, we used a composite score on the ADOS to measure “social engagement.” MSEL VR and FM t-scores measured nonverbal ability and fine motor skills respectively. Parent-rated receptive language was measured by total words and total phrases understood on the CDI. Clinician-rated receptive language was measured by the MSEL RL t-score. Parent-rated expressive language was measured by total words produced on the CDI, and clinician-rated expressive language was measured by the MSEL EL t-score. Measures of demographic factors were taken from the History Form. Exploratory analyses with data from the whole sample used each developmental/demographic predictor individually to predict gesture repertoire size (and then gesturing frequency separately), accounting for age. Significant predictors from these exploratory regression analyses were then entered into multivariate regressions to explore relative contributions to gesture size repertoire and gesturing frequency. The latter analyses were performed on the sample as a whole, and then separately for the TD/ND group and a combined Developmental Disorder (DD) group, comprised of the ASD, GDD, and DLD groups. The DD group was formed to improve power to detect effects due to small sample sizes of individual diagnostic groups. Post-hoc power analyses indicated 78%, 30%, and 46% power to detect medium effects in the whole sample, TD/ND group, and DD group, respectively.

For our fourth question, early gesture repertoire size and gesturing frequency on the CDI were entered separately, with age at evaluation, in linear regressions to predict “clinician gesture rating” (as measured by the ADOS composite) in the whole sample. As ratings on individual ADOS items do not yet account for the impact of age on gesture behavior, age was controlled for in these analyses.

Results

Data were analyzed using an SPSS-PC package, version 25 (IBM Corp, 2017), after they were examined for entry errors, outliers, and distribution normality. Regression models were assessed for multicollinearity using the variance inflation factor (VIF) and tolerance statistics. A VIF of 4 or greater and a tolerance of .2 or less were used as criteria for concerns about multicollinearity among predictors.

Aim 1a: Gesture Repertoire Size by Diagnostic Group

Diagnostic group (ASD, TD/ND, GDD, DLD; dummy coded, with ASD as reference group) was used to predict gesture repertoire size, accounting for child’s age in a linear regression analysis. Results indicate that only the TD/ND group differed significantly from the ASD group in gesture repertoire size, with TD/ND children having on average approximately three more early gestures (out of a possible 18 gestures on the CDI) than children with ASD, accounting for age ($B = 3.94$, $t = 4.71$, $p < .001$). Neither the GDD group ($B = 1.05$, $t = 1.18$, $p = .241$) nor the DLD group ($B = 1.52$, $t = 1.79$, $p = .077$) differed significantly from the ASD group (see Figure 1). Gesture repertoire size of the GDD and DLD groups were also compared to the TD/ND group. Both the GDD ($B = -2.45$, $t = -3.19$, $p = .002$) and DLD ($B = -1.98$, $t = -2.75$, $p = .007$) groups had approximately two fewer gestures than TD/ND peers.

Aim 1b: Gesturing Frequency by Diagnostic Group

Diagnostic group (dummy coded, ASD as reference group) was used to predict gesturing frequency, accounting for child’s age using linear regression. Similar to gesture repertoire size, only the TD/ND group differed significantly in gesturing frequency compared to the ASD group, with the TD/ND group gesturing more (*B* = 5.72, *t* = 5.40, *p* < .001). The GDD group (*B* = 2.37, *t* = 1.87, *p* = .065) and the DLD group (*B* = 2.14, *t* = 1.77, *p* = .080) did not differ from the ASD group, but did differ from the TD/ND group (*B* = -3.35, *t* = -3.06, *p* = .003 and *B* = -3.58, *t* = -3.48, *p* = .001 for GDD and DLD respectively; see Figure 1).

Aim 2: Gesture Profiles and Item Level Differences by Diagnostic Group

To explore how item-level responses (i.e., gesture profiles) differed among diagnostic groups, a repeated-measures ANOVA was conducted with a between-subjects factor of diagnostic group, within-subjects factors of the 12 items on the CDI First Communicative Gestures section, and age at evaluation as covariate. Data from 103 participants were available for these analyses. Partial eta squared (η_p^2) was used as a measure of effect size. Values of .01, .06, and .14 are by convention interpreted as small, medium, and large effect sizes, respectively (Green & Salkind, 2003; Shumway & Wetherby, 2009). Accounting for age, scores differed significantly across CDI items ($F(11, 88) = 2.73$, $p = .004$, $\eta_p^2 = .254$). Across the whole sample, the most commonly used gesture was *raising arms to be picked up* (see Table 4 for mean gestural frequencies by item, ranked from highest to lowest). The least commonly used gesture was *placing finger to lip to 'hush'*.

As expected given Aim 1 results, average scores on CDI items differed among diagnostic groups ($F(3, 98) = 10.04$, $p < .001$, $\eta_p^2 = .235$). We did not find an item by diagnostic group interaction, suggesting that overall gesture profiles did not differ significantly among children with ASD, TD/ND, GDD, and DLD ($F(33, 270) = 1.41$, $p = .077$, $\eta_p^2 = .147$; see Figure 2). Nonetheless, we were interested based on visual examination of the data (Figure 2) in potential differences between groups on specific First Communicative Gestures items. An analysis of covariance (ANCOVA) was conducted for each of the 12 First Communicative Gestures, with diagnostic group as the between-subjects factor, and age at evaluation as covariate. Table 5 and Figure 3 present results of these analyses.

Compared to TD/ND peers, children with ASD were reported by their parents to demonstrate significantly less frequent use of the following gestures: SHOW (i.e., *extend arm to show object*), GIVE (i.e., *reach out to give object*), POINT (i.e., *point to object with arm and index finger extended*), and some

CONVENTIONAL gestures, including *waving "bye," blowing kisses,* and *smacking lips "yum."* Children with ASD differed from peers with GDD on only one gesture, using less frequently the CONVENTIONAL gesture of *smacking lips to indicate "yum."* Compared to peers with DLD, children with ASD only differed on the POINT gesture item, with the ASD group pointing significantly less frequently. In addition, children with GDD used the POINT gesture less frequently than TD/ND peers. There were no group differences on REQUEST gestures (i.e., *arms upward to be picked up, open/close hand with arm extended to request*) and some CONVENTIONAL gestures (i.e., *shakes head "no," nods head "yes," places finger to lips to "hush,"* and *shrugging "all gone" / "where'd it go"*).

Aim 3a: Predictors of Gesture Repertoire Size

Group differences on mean scores of developmental and demographic predictors are presented in Table 2. Mean MSEL VR t-scores were similar between the ASD and GDD groups, and both significantly lower than those in the TD/ND and DLD groups. Mean MSEL FM t-scores in the ASD group did not differ from GDD or DLD, but were significantly lower than TD/ND. GDD, but not DLD had significantly lower mean fine motor scores than TD/ND. MSEL RL and EL t-scores. CDI Words Produced in the ASD, GDD, and DLD groups were, on average, significantly lower than those in the TD/ND group, but not different from one another. Mean CDI Phrases Understood in the ASD group did not differ from GDD or DLD, but were significantly lower than TD/ND. The GDD and DLD groups had somewhat lower, but not significantly different, mean Phrases Understood compared to the TD/ND group. Finally, mean score on the ADOS social engagement composite was significantly higher (i.e., weaker social engagement skills) in the ASD group compared to all other groups. Mean social engagement scores in the TD/ND and DLD groups were also significantly lower (i.e., better social engagement) than that in the GDD group.

We first conducted exploratory analyses by using each developmental predictor (i.e., ADOS social engagement, MSEL VR, MSEL FM, CDI Words Understood, CDI Phrases Understood, MSEL RL, CDI Words Produced, and MSEL EL), and each demographic predictor (i.e., maternal education, annual household income, bi/multilingual exposure, and sex) individually to predict gesture repertoire size in the whole sample, accounting for age. An alpha of .05 was used to determine significance. The following variables significantly predicted gesture repertoire size, accounting for age: ADOS social engagement, MSEL FM, CDI Words Understood, CDI Phrases Understood, MSEL RL, CDI Words Produced, MSEL EL, and child's sex (i.e., being female; see Table 6). MSEL VR, maternal education, annual household income, and bi/multilingual exposure were not significant predictors, and were dropped from the next set of analyses.

We then proceeded to explore the *relative* contributions of the above eight significant predictors derived from exploratory analyses. The eight predictors were entered simultaneously into a multivariate linear regression, with age at evaluation, to predict gesture repertoire size in the whole sample, and then separately for the TD/ND and combined Developmental Disorder (DD) groups. Results are presented in Table 7. In the whole sample, CDI Phrases Understood and child's sex were significant predictors of gesture repertoire size, after accounting for age and other predictors. MSEL FM trended toward significance as a predictor. In the DD group, CDI Phrases Understood was the only significant predictor of gesture repertoire size, accounting for all other predictors. Child's sex and MSEL FM trended toward significance.

Diagnostic evaluation for each model included a check of model residuals. The multivariate model yielded results that raised concerns about the violation of normality and about potential inconsistencies in the estimates of scores across the full range of values. We attempted variable transformations of the dependent variable. A square transformation (i.e., gesture repertoire size^2) resolved concerns about model residuals. CDI Words Understood and child's sex significantly predicted gesture repertoire size, accounting for age and other predictors (see Table 7). We also checked for any issues of multicollinearity, and found that CDI Words Produced had a VIF of 4.2. In order to determine if this affected the interpretation of key variables, a model excluding CDI Words Produced was tested. No changes in the significance of any of the variables of interest were observed. As a result, interpreting our final model (in which CDI Words Produced was retained) is appropriate.

Aim 3b: Predictors of Gesturing Frequency

Aim 3a analyses were repeated to explore predictors of gesturing frequency. Results of Aim 3a were largely replicated. In addition to the eight variables that were significant predictors of gesture repertoire size in exploratory analyses, MSEL VR was also a significant predictor of gesturing frequency. In the whole sample, age at evaluation, CDI Phrases Understood, MSEL FM, and child's sex were significant predictors of gesturing frequency, after accounting for age and all other predictors. In the DD group, CDI Phrases Understood and child's sex were significant predictors, with MSEL FM trending toward significance. In the TD/ND, CDI Words Understood and child's sex were significant predictors.

Aim 4: Convergent Validity of Parent Gesture Ratings on the CDI

In the whole sample, parent rated gesture repertoire size and gesturing frequency on the CDI were used to predict (in separate linear regressions) a composite clinician gesture rating on the ADOS-2, accounting for child's age. Higher gesture repertoire size on the CDI significantly predicted lower (more typically developing) ADOS gesture ratings (β = -.39, t = -4.17, p < .001). Likewise, higher gesturing frequency on the CDI significantly predicted lower ADOS gesture ratings (β = -.48, t = -5.29, p < .001.

Discussion

The current study explored the nature and predictors of gestural differences in children with and without ASD during toddlerhood. Specifically, we compared parent-reported gesture repertoire size (i.e., total different gestures a child uses) and gesturing frequency (i.e., frequency with which a child uses gestures in daily life) among toddlers with ASD, GDD, DLD, and TD/ND, all of whom initially screened positive on an autism screener. We then examined gesture profiles to explore which types of gestures best distinguished toddlers with ASD from peers in other groups. Next, we investigated the relative contribution of developmental and demographic factors to early gesture use in this sample. Finally, we checked convergent validity of parent-reported gesture use on the CDI against clinician ratings of gesture use at concurrent assessment.

Aim 1: Gesture production in toddlers with and without ASD

We expected that toddlers with ASD, GDD, and DLD would have smaller gesture repertoires and would gesture less frequently than TD/ND peers, and that children with ASD would gesture less than GDD and DLD peers. Indeed, we found that toddlers with ASD were reported by their parents to have a significantly smaller gesture repertoire compared to TD/ND peers. This finding replicates results from various previous studies with high-risk siblings (e.g., LeBarton & Iverson, 2016) as well as low-risk children (e.g., Dimitrova, et al., 2016) showing a gesture production gap between children with ASD and TD peers. Importantly, the children in our TD/ND group are somewhat different than TD samples referenced in the literature, as all of the children in our sample screened positive on an autism screener, and were thus identified to have some developmental concern. Our study demonstrates that even when compared to these “at-risk” TD/ND peers, toddlers ultimately diagnosed with ASD show a demonstrable weakness in gesture production. Our study also adds to a literature that has mainly examined gesture production in the laboratory and/or within time-limited play sessions. Our data shows that parents of children with ASD are indeed noticing a gesturing deficit in their child’s daily communicative behaviors.

As expected, this gesturing weakness was not limited to toddlers with ASD, as children in the GDD and DLD groups also had significantly smaller gesture repertoires than TD/ND peers. We did not find, however, that children with ASD gestured less than peers with other developmental disorders, as has been shown in previous studies (e.g., LeBarton & Iverson, 2016; Veness, et al., 2012). It may be the case that, had there been differences among the ASD, GDD, and DLD groups, the effects would have been small and could be detected given a larger sample (e.g., Veness and colleagues (2012) examined a sample of 1911 children). Alternatively, it may be the case that, similar to findings reported by LeBarton & Iverson (2016), large individual differences in gesture production within diagnostic groups obscured between-group differences in our sample (as observed in Figure 1 standard error bars). Examination of MSEL VR scores by group (Table 2) also show that both the ASD and GDD groups had, on average, substantial delays in nonverbal skills, which may limit these children’s overall capacity to demonstrate much variation in gesture ability, though this does not fully explain the lack of group differences (the

DLD had average nonverbal ability but similarly reduced gesture use). Lastly, it may be more complex gestural acts (e.g., coordinating gesture with vocalization), rather than simply the number of gestures a toddler knows, that distinguishes children with ASD from children with other developmental disorders (Parladé & Iverson, 2015). If this were the case, our data would support the notion that having a restricted gesture repertoire is not an ASD-specific symptom.

Our study operationalized gesture production both in terms of gesture repertoire size and gesturing frequency, which offers clarity about which specific aspects of gesture production we are identifying as a weakness in ASD. As expected, group differences were also demonstrated in terms of gesturing frequency. Toddlers with ASD not only used fewer different gestures, but they were also using the gestures they knew less frequently and less consistently in daily life.

Aim 2: Content of gesture inventories in toddlers with and without ASD

We then examined item-level CDI Early Communicative Gestures data to explore the content of gesture inventories in our sample. These analyses allowed us to explicate gestural differences identified in our first question, and investigate which gesture types particularly discriminate children with ASD. Frequency scores on individual CDI First Communicative Gestures items in our whole sample provided a snapshot of what gesture production looks like in a sample of toddlers who screened positive for ASD (who are on average 15-16 months old). These children most frequently use deictic gestures, including REQUEST, GIVE, SHOW, and POINT gestures, as opposed to CONVENTIONAL gestures. This pattern of gesture use generally reflects what would be expected in typical development at around 15-16 months of age during which there is a relative mastery of deictic gestures that have emerged since 10 months of age, while conventional gestures are just starting to emerge shortly after the first birthday. Our data shows that *arms up "pick up"* was the most common gesture in this sample, and indeed within each diagnostic group as well. One could argue that, relative to the other First Communicative Gestures items on the CDI, this item reflects a child's request to seek comfort from a caregiver, rather than expression of social interest in a communication partner (as would be the case in *waving "bye"* or *extending arm to show*, for example), which might be unique to our sample of children "at-risk" for ASD.

We also found variability in the type of gesture used most often by children in different groups and certain gestures that better distinguished children with ASD from peers with TD/ND. As expected, deictic gestures (i.e., SHOW, GIVE, POINT) differentiated ASD from TD/ND children, with POINT gestures demonstrating the largest difference in frequency of use between ASD and TD/ND. Some, but not all, CONVENTIONAL gestures also distinguished ASD and TD/ND, including *wave "bye," smack lips "yum,"* and *blow kiss*. These gestures have been categorized in previous literature as "social interaction" gestures and are used to direct another person's attention to oneself during dyadic interactions (Watson et al., 2013). This is in contrast to other conventional gestures that were not different between ASD and TD/ND, such as *shaking head "no,"* which has been categorized as a "behavior regulation" gesture, or a gesture used to control another person's behavior (Watson et al., 2013). It is not surprising that children with ASD would show particular weaknesses in gestures that serve to initiate and involve others in social interaction. Other conventional gestures that were not different between ASD and TD/ND (i.e., *nod "yes," finger to lips "hush,"* and *shrug "where'd it go" / "all gone"*) were equally uncommon among toddlers with and without ASD, and are likely later developing conventional gestures.

Frequency of use of REQUEST gestures was also not different between children with ASD and TD/ND peers, which supported our hypothesis and previous literature (Gordon & Watson, 2015; Watson et al., 2013) that deictic gestures would be more discriminating between ASD and non-ASD peers than REQUEST or CONVENTIONAL gestures. This is in line with research suggesting that ASD is associated with weaknesses in communicative behaviors used to share attention (e.g., declarative pointing), rather than communicative behaviors used to request (e.g., imperative pointing; Charman et al., 2003). These findings suggest that children with ASD struggle, in particular, with producing gestures that are expected to emerge spontaneously during development and reflect a level of social interest (i.e., pointing, showing, giving), rather than gestures that are usually explicitly taught by caregivers (i.e., conventional and some request gestures).

Item level responses on the CDI First Communicative Gestures rarely distinguished the ASD group from the GDD or DLD groups. This was not surprising since overall gesturing frequency was not significantly different among the clinical groups. However, it does confirm that the types of gestures used less frequently by children with ASD are also seen less frequently in children with other developmental disorders, which aligns with overall trends in the literature showing limited differences in deictic gesture use between toddlers with ASD and peers with other developmental disorders (Manwaring, Stevens, Mowdood, & Lackey, 2018). One exception was the POINT gesture, in which children in both the ASD and GDD group, but not the DLD group, demonstrated weaknesses in pointing early in toddlerhood. It may be the case that our DLD group was comprised of more children who are "late bloomers" (late-talking children who recover from delays) and who used pointing as frequently as TD/ND peers to compensate for verbal delays (Moyle et al., 2011).

Aim 3: Predictors of gesture use during toddlerhood

Thus far, our findings have shown that gestural deficits emerge early in development in children with ASD and other developmental disorders. What might explain such early differences in gesture production? This study builds upon research that only recently began exploring predictors of gesture use in high and low-risk toddlers (Franchini, et al., 2018) by investigating the *relative* contributions of developmental and demographic predictors to explore which factors may be most relevant to gesture development. While it was not feasible – given our relatively small sample size and insufficient power to detect even large effects – to examine predictors in separate diagnostic groups, we were able to examine predictors within our whole sample of screen-positive children, as well as compare predictors between children with and without a developmental disorder. Given the similarities found among the ASD, GDD, and DLD groups in gesture repertoire size, frequency, and item profiles, we have some evidence that a predictive model of gesture use in the combined "Developmental Disorder" (DD) group could be informative for an ASD-specific model.

Several predictors emerged as "frontrunners" in all of our models (i.e., whole sample, TD/ND group-only, DD group-only). CDI Phrases Understood was a significant predictor of both gesture repertoire size and gesturing frequency in the whole sample, as well as in the DD group only, after accounting for age and all other predictors. This finding aligns with previous literature that suggests that receptive language is predictive of gesture production (LeBarton & Iverson, 2016; Iverson et al., 2018). One of the reasons that it is *phrases* understood, in particular, that predicts early gesture use may be that many of the items in the Phrases Understood section of the CDI serve as verbal commands or verbal representations of the First Communicative Gestures on the CDI. For example, the *"be quiet"* phrase relates to the *finger to lip "hush"* gesture, "*Do you want more?"* relates to *open/close hand request*, *"don't do that" / "stop"* relates to *shaking head "no," "give me a kiss"* relates to *blow kiss*, *"let's go 'bye bye'"* relates to *waving "bye,"* and *"give to Mommy"* relates to *reach out give*. In other words, the processes we are examining in the relationship between Phrases Understood and first communicative gestures use is 1) a child's gesture-to-command ability in some cases (e.g., *blowing a kiss* when asked to do so) and in other cases 2) a child's ability to imitate a gesture that might be paired with a verbal command (e.g., imitating a caregiver putting a *finger to lip to "hush"* when saying "be quiet"). A child who understands the meaning of a phrase is more likely to respond by producing the requested gesture.

In fact, our Aim 2 findings regarding item-level group differences on the CDI may offer further evidence that toddlers with ASD demonstrate particular gesturing weaknesses in gesture-to-command situations (e.g., *blow kiss* used less in ASD group relative to TD/ND) compared to gesture-to-imitation situations (e.g., no differences between groups on *finger to lip "hush"*). This aligns with previous research showing weaknesses in gesture-to-command skills in school-aged children and adolescents with ASD (Dewey et al., 2007), and highlights that intact receptive language is crucial for successful gesture production early in development for children with ASD and other developmental disorders.

CDI Words Understood, rather than Phrases Understood, was a significant predictor in the TD/ND group only. It may be the case that reduced variance in CDI Words Understood in the DD group obscured a significant relationship between words understood and gesture use that would otherwise be apparent. Indeed, in the whole sample, CDI Words Understood and Phrases Understood were significantly correlated (r = .64, p < .001). Clinician-rated receptive language on the MSEL was less correlated (but still significantly so) with parent-rated measures of receptive language (r = .34 and .35 for Words Understood and Phrases Understood, respectively; both p < .001). This suggests that the impact of the different measures of receptive language on gesture production is likely not substantial, but possibly reflective of method variance (parent versus clinician report). Instead, it is likely that receptive language, in general, predicts gesture production, even after accounting for other factors.

Another "frontrunning" predictor was child's sex, which significantly predicted gesture repertoire size in the whole sample and the TD/ND group, and gesturing frequency in the whole sample, DD, and TD/ND groups. After accounting for other factors, females demonstrated higher gesture use than males. Our findings replicate, in toddlers at-risk for ASD, a pattern that has been demonstrated in typically developing toddlers (e.g., Fenson et al., 2007) and school-aged children with ASD (Rynkiewicz et al., 2016). While empirical evidence about sex differences in language development is mixed, studies that do report sex differences show that girls acquire language more quickly than boys in early childhood (Barbu et al., 2015). Likewise, the literature is mixed on whether girls demonstrate fewer or comparable social deficits compared to boys (Harrop et al., 2015; Lai, Lombardo, Auyeung, Chakrabarti, & Baron-Cohen, 2015). It would be interesting to investigate whether sex differences in gesture production in ASD is mediated by potential female advantages in language and social skills. Our analyses demonstrate, however, that even accounting for language ability and social engagement, girls are gesturing more than boys, suggesting there may be other factors at play. For example, differences in the ways girls and boys are socialized (Lai et al., 2015) may already be impacting the way parents are demonstrating or eliciting gestures from girls versus boys at this early age.

Finally, fine motor skills significantly predicted gesturing frequency in the whole sample even after accounting for functioning in other developmental domains. Research over the past two decades has begun to build a conceptual model around the role of motor skills in expressive language development, particularly within ASD populations. Our data adds to this literature by exploring the contribution of fine motor skill to gestural communication, specifically, in toddlers at risk for ASD. Importantly, our measure of fine motor skills captures early motor planning and control abilities (rather than basic motor speed, as is the case in other studies; Dziuk et al., 2007), and these motor control abilities may in part explain gesturing frequency. Lowered gesture production may be related to reduced ability to carry out motor movements, though this may be more relevant to some gestures over others (e.g., less relevant to pointing, where children have been found to have intact imperative pointing; Charman et al., 2003). Overall, this finding aligns with a conceptualization of early gestural deficits as an early weakness in praxis, or the ability to perform purposeful motor movements.

There were several predictors that independently predicted gesture use, but did not emerge as significant predictors when other developmental and demographic factors were taken into account. One was social engagement; this suggests that a child's interest in social communication may not be as predictive of gesture production as is their language comprehension capacities. However, social engagement varied considerably within the combined DD group in our analyses, and it is possible that social engagement would have emerged as a stronger predictor in an ASD-only group. Further exploration of the social engagement-gesture relationship would be important in larger samples of children with ASD. Nonverbal ability also did not predict gesture use after accounting for other factors. Other studies have reported correlations between nonverbal mental age and gesture production (Luyster et al., 2007; Wetherby et al., 2007). Our data shows that relative to other factors, a child's overall developmental capacity may not better explain gesture use during toddlerhood, echoing similar findings from one study with school-aged children with ASD (Gizziono et al., 2015). Expressive language skills (as measured by parent and clinician ratings) did not predict gesture production when other factors were taken into account, supporting previous findings (Franchini et al., 2018).

Most demographic factors we explored (including household income, maternal education, and bi/multilingual exposure) did not relate to gesture production. Our findings suggest that socioeconomic background may not be as relevant to a child's gesture use (at least first communicative gestures) as it is to expressive vocabulary development. We did not find that children exposed to more than one language had larger variety or frequency of gesturing than peers exposed to one language, which contrasts with some research showing a potential advantage of bilingualism in gesture production (Valicenti-McDermott et al., 2013). It is important to note that most of our bi/multilingual families completed an English version of the CDI, which fails to capture gestures a child may use that are specific to their non-English language (particularly relevant for culture-specific games and routines involving gestures). This means we may have underestimated gesture use in bi/multilingual children. Future research should measure gestures used in all languages to which a child is exposed in order to get accurate estimates of gesture production.

Our findings provide preliminary evidence that gesture production during early toddlerhood in children at risk for ASD is best explained by language comprehension skills, sex, and possibly motor functioning (namely, early fine motor planning and control). It may be less well explained by overall cognitive capacity, social interest, and environmental factors such as socioeconomic background and language exposure, though findings should be replicated with larger samples rather than ruling out their contribution. Future research should explore whether neuroanatomical models of shared neural networks for language comprehension and praxis/gesture functions (and functional consequences of when these networks are disrupted) apply to infancy and toddlerhood, broadly for children with neurodevelopmental disorders and specifically within ASD.

Aim 4: Concurrent validity of parent report of early gestures

Lastly, our findings established convergent validity of parent-rated gesture repertoire size and gesturing frequency when correlated with clinician ratings of gesture use at concurrent assessment. This offers evidence that parent report on the CDI can accurately capture gesture use in young toddlers with or at-risk for ASD, and offer useful information regarding a child's gestural behaviors within the home environment.

Limitations and Future Research

Due to the relatively small sample size in this study, we had to be cautious in interpreting whether absence of significant effects in our analyses (e.g., differences among ASD, GDD, and DLD groups in gesture repertoire size and gesturing frequency) was reflective of true phenomena or low power issues. Future research should attempt to replicate our findings using larger samples in each diagnostic group. In particular, a larger ASD group could allow researchers to build an ASD-specific model testing predictors of gesture production, as well as effects of potential moderators and/or correlates (e.g., autism severity; Gordon & Watson, 2015).

In examining our participant characteristics, we found that a larger proportion of children without CDI data, compared to those with data, were Hispanic/Latinx. It is possible that a higher proportion of parents of Hispanic/Latinx children were bilingual, with Spanish as their preferred language. The CDI Words and Gestures form is an extensive questionnaire, and may feel cumbersome for parents to complete when not offered in their preferred language. Another possibility is that there is a higher proportion of Hispanic/Latinx children who are also exposed to more than one language at home. Their parents may not have found the English version of the CDI to be particularly relevant to their child, who is also learning another language. These parents may feel that the CDI English version underestimates their child's abilities, and are therefore less likely to complete the measure. For both reasons, it will be important in future studies to inquire what a caregiver's preferred language is, and if possible, offer versions of the CDI in relevant languages.

While our sample was racially and ethnically diverse, we did not have a large enough sample size to adequately explore the effects of cultural, and perhaps more importantly, linguistic differences on gesture production. Future research in this area should continue to emphasize cultural diversity in recruitment of participants in order to feasibly address these questions.

Given our findings regarding the relationship between language comprehension ability (specifically understanding of phrases) and gesture production, future research should explore whether increased understanding of a phrase leads to more spontaneous use of a related gesture when the gesture is not prompted or demonstrated. In addition, researchers should clarify whether general ability to understand phrases (i.e., commands *unrelated* to a gesture) also predicts gesture repertoire size and gesturing frequency.

If indeed the relationship between fine motor skills and gesture use can be replicated with other samples, this study raises a few questions yet to be explored in toddlers with ASD: 1) Do fine motor deficits differentially impact production of certain types of gestures? 2) How does gesture production fit into the relationship between fine motor skill and expressive vocabulary development? Given research in both TD and ASD populations showing that gesture use serves as a "stepping stone" for vocabulary development (e.g., Özçalışkan et al., 2016), does gesture use moderate or mediate the fine motor-expressive vocabulary relationship? 3) What, if any, is the role of motor imitation in how fine motor skills impact gesture production? To some extent, performance on fine motor tasks on the MSEL, as well as use of certain gestures require a level of ability to imitate adults engaging in a motor behavior. Finally, 4) What are the relationships among language comprehension, fine motor skill, and gesture production; that is, how are gesture-to-command abilities impacted by fine motor skills? Dewey and colleagues (2007) found that school-aged children with ASD had poor gesture-to-command abilities even after controlling for motor functioning. However, we have yet to understand how much fine motor ability impacts the translation of verbal command to action, and what this looks like in younger children.

As the current study focused on investigating the nature and predictors of gesture use as reported by parents, which offers a measure of a child's typical gesture use in their natural environment, we did not examine our questions with clinician ratings of gesture use. Our findings demonstrating convergent validity between parent and clinician ratings of gesture use in our sample suggests that we could likely replicate our findings with clinician ratings. Exploring gestural differences using clinician ratings of gestures, as well as video coding methods (e.g., raters blind to diagnosis coding gestures used at evaluation) would be important next steps.

Conclusions and Clinical Implications

Our findings provide further support that gestural deficits in ASD are present very early in development, within the first two years of life. Toddlers with ASD have significantly fewer gestures in their repertoire, and are using them inconsistently compared to typically developing peers. Longitudinal research has found that infants with ASD demonstrate early dampened gesture acquisition trajectories that continue through toddlerhood (Franchini et al., 2018; LeBarton et al., 2018). While our data provides a snapshot of gesture production during a point in toddlerhood (on average 15-16 months of age), it is likely that the gesture gap between children with and without ASD will widen with development. There is abundant research on the impact of early gesture use on further language outcomes early in development, including the development of vocabulary (e.g., Iverson & Goldin-Meadow, 2005). Early intervention efforts to remediate gesturing deficits, with a focus on both increasing the variety of gestures used as well as the frequency and flexibility in which gestures are used in daily life, could prevent further language difficulties.

Our study supports the notion that reduced gesture use may serve as a red flag for ASD, or at least a developmental disorder, prior to age 2. Importantly, this study offers information regarding specific gesture types that could better discriminate toddlers with ASD from TD peers. Screening for the presence of these early communicative gestures may be a useful part of autism screening (for example, as is done in the M-CHAT-(R/F) where parents are asked about their child's pointing, showing, and imitation of gestures such as waving "bye"). Our findings also offer insight into which kinds of gestures may require more intensive remediation (i.e., deictic gestures and conventional gestures used to moderate social interaction). For example, pointing, in particular was found to discriminate toddlers with ASD from not only TD/ND peers, but also peers with DLD. Previous work shows that a child's tendency to point is especially impactful for their language development, as it influences the likelihood their caregivers label referents (i.e., objects to which the child is pointing) and thereby produce opportunities for vocabulary development (Leezenbaum, Campbell, Butler, & Iverson, 2014).

Lastly, this study offers insight into the importance of receptive language skills and potentially fine motor skills for gesture production. It is hoped that this research can pave the way for further research into whether early intervention that targets language comprehension and fine motor skills leads to improved outcomes in gesture development.

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Table 1

Children with and without CDI Data

Variable	**With CDI Data (current sample; n=108)**	**Without CDI Data (n=52)**	***p***
Age in months [M (SD)]	15.56 (2.22)	16.75 (1.55)	<.001
Sex [N (%)]			0.756
Male	70 (64.8)	35 (67.3)	
Female	38 (35.2)	17 (32.7)	
Race/ethnicity (N (%)]			0.008
Non-Hispanic/Latinx White	51 (47.2)	14 (26.9)	
Hispanic/Latinx	19 (17.6)[a]	24 (46.2)	
Black	18 (16.7)	10 (19.2)	
Bi/Multiracial	9 (8.3)	1 (1.9)	
Asian	6 (5.6)	3 (5.8)	
Am. Indian/Alaskan Native	1 (0.9)	0 (0.0)	
Other	1 (0.9)	0 (0.0)	
Missing Data	3 (2.8)	0 (0.0)	
Maternal Education [N (%)]			0.061
≤ High school diploma/GED	19 (17.6)	16 (30.8)	
Some college/ Associate's/Vocational or technical	27 (25.0)	12 (23.1)	
Bachelor's degree	28 (25.9)	12 (23.1)	
Post-College	32 (29.6)	8 (15.4)	
Missing Data	2 (1.9)	4 (7.7)	
Annual Income			0.019
≤ $24,000	24 (22.2)	12 (23.1)	
$24,000-$48,000	15 (13.9)	6 (11.5)	
$48,000-$72,000	7 (6.5)	2 (3.8)	
$72,000-$96,000	6 (5.6)	3 (5.8)	
≥ $96,000	51 (47.2)	17 (32.7)	
Missing Data	5 (4.6)	12 (23.1)	
Language exposure at home			0.006
One language	79 (73.1)	30 (57.7)	
More than one language	29 (26.9)	18 (34.6)	
Missing Data	0 (0.0)	4 (7.7)	
Diagnostic Group			0.751
TD/ND	45 (41.7)	21 (40.4)	
ASD	21 (19.4)	13 (25.0)	
GDD	19 (17.6)	10 (19.2)	
DLD	23 (21.3)	8 (15.4)	

[a] Individuals in this group specified the following as their race: White (n=9), Bi/Multiracial (n=2), Black (n=1), Other (n=2), none specified (n=5).

Table 2

Participant Characteristics by Diagnostic Group

Variable	**ASD (n=21)**	**TD/ND (n=45)**	**GDD (n=19)**	**DLD (n=23)**	***p***
Age in months [M (SD)]	15.71 (2.61)	15.58 (2.31)	15.63 (2.11)	15.35 (1.85)	.955
Sex [N (%)]					.131
Male	16 (76.2)	24 (53.3)	12 (63.2)	18 (78.3)	
Female	5 (23.8)	21 (46.7)	7 (36.8)	5 (21.7)	
Race/ethnicity (N (%)]					.040
White	6 (28.6)	25 (55.6)	5 (26.3)	15 (65.2)	
Hispanic/Latinx	6 (28.6)	9 (20.0)	1 (5.3)	3 (13.0)	
Black	3 (14.3)	8 (17.8)	6 (31.6)	1 (4.3)	
Bi/Multiracial	2 (9.5)	1 (2.2)	3 (15.8)	3 (13.0)	
Asian	2 (9.5)	2 (4.4)	1 (5.3)	1 (4.3)	
Am. Indian/Alaskan Native	0 (0.0)	0 (0.0)	1 (5.3)	0 (0.0)	
Other	1 (4.8)	0 (0.0)	0 (0.0)	0 (0.0)	
Missing Data	1 (4.8)	0 (0.0)	2 (10.5)	0 (0.0)	
Maternal Education [N (%)]					.340
≤ High school diploma/GED	4 (19.0)	7 (15.9)	4 (21.1)	4 (18.2)	
Some college/Associate's/ Vocational or technical	9 (42.9)	13 (29.5)	3 (15.8)	2 (9.1)	
Bachelor's degree	3 (14.3)	14 (31.8)	6 (31.6)	5 (22.7)	
Post-College	5 (23.8)	10 (22.7)	6 (31.6)	11 (50.0)	
Missing Data	0 (0.0)	1 (0.9)	0 (0.0)	0 (0.0)	
Annual Income					.116
≤ $24,000	7 (33.3)	8 (17.8)	7 (36.8)	2 (8.7)	
$24,000-$48,000	3 (14.3)	8 (17.8)	3 (15.8)	1 (4.3)	
$48,000-$72,000	1 (4.8)	1 (2.2)	2 (10.5)	3 (13.0)	
$72,000-$96,000	2 (9.5)	3 (6.7)	1 (5.3)	0 (0.0)	
≥ $96,000	7 (33.3)	21 (46.7)	6 (31.6)	17 (73.9)	
Missing Data	1 (4.8)	4 (8.9)	0 (0.0)	0 (0.0)	
Language exposure at home					.174
One language	12 (57.1)	33 (73.3)	14 (73.7)	20 (87.0)	
More than one language	9 (42.9)	12 (26.7)	5 (26.3)	3 (13.0)	

Variable	**ASD (n=21)**	**TD/ND (n=45)**	**GDD (n=19)**	**DLD (n=23)**	***p***
MSEL VR T-score [M (SD)]	34.24 (12.96)$_{a}$	47.80 (8.09)$_{b}$	32.53 (5.15)$_{a}$	48.52 (7.68)$_{b}$	< .001
MSEL FM T-score [M (SD)]	43.62 (11.43)$_{ab}$	53.13 (7.70)$_{c}$	39.95 (13.26)$_{a}$	48.58 (8.77)$_{bc}$	< .001
MSEL RL T-score [M (SD)]	28.67 (9.58)$_{ab}$	41.69 (10.08)	30.16 (5.95)$_{ac}$	30.04 (6.55)$_{bc}$	< .001
MSEL EL T-score [M (SD)]	28.24 (7.27)$_{ab}$	45.49 (8.04)	29.89 (6.25)$_{ac}$	28.65 (6.73)$_{bc}$	< .001
CDI Words Understood [M (SD)]	71.33 (101.37)	102.89 (95.87)	44.79 (54.58)	53.65 (44.46)	.020ǂ
CDI Phrases Understood [M (SD)]	8.62 (7.83)$_{ab}$	15.11 (7.22)$_{cd}$	10.47 (6.76)$_{ace}$	11.04 (7.42)$_{bde}$	.005
CDI Words Produced [M (SD)]	2.29 (2.78)$_{ab}$	19.82 (27.17)	2.58 (2.74)$_{ac}$	5.57 (8.13)$_{bc}$	.001
ADOS Social Engagement Composite [M (SD)]	10.76 (4.19)	1.36 (1.55)$_{a}$	4.47 (3.61)	2.09 (2.15)$_{a}$	< .001

Note: Group means that do not differ based on $p < .05$ per post-hoc comparisons share a common subscript.

ǂ Post-hoc tests revealed no pairwise group differences on this variable.

Table 3

CDI-WG First Communicative Gestures by Gesture Type

Gesture Type	**CDI Item**
SHOW	#1. Extends arm to show you something he/she is holding
GIVE	#2. Reaches out and gives you a toy or object he/she is holding
POINT	#3. Points (with arm and index finger extended) at some interesting object or event
REQUEST	#5. Extends his/her arm upward to signal a wish to be picked up
	#9. Requests something by extending arm and opening and closing hand
CONVENTIONAL	#4. Waves bye-bye on his/her own when someone leaves
	#6. Shakes head "no"
	#7. Nods head "yes"
	#8. Gestures "hush" by placing finger to lips
	#10. Blows kisses from a distance
	#11. Smacks lip in a "yum" gesture to indicate that something tastes good
	#12. Shrugs to indicate "all gone" or "where'd it go"

Table 4

Mean Gesturing frequency by CDI First Communicative Gestures Items (Whole Sample)

CDI Item	**Gesture Type**	**Frequency[a] [M (SD)]**
Arms up "pick up"	REQUEST	1.74 (.48)
Reach out give	GIVE	1.45 (.67)
Extends arm show	SHOW	1.35 (.71)
Point	POINT	1.16 .(86)
Wave "bye"	CONVENTIONAL	1.11 (.83)
Shake head "no"	CONVENTIONAL	1.07 (.87)
Open/close hand request	REQUEST	0.90 (.76)
Smack lips "yum"	CONVENTIONAL	0.81 (.82)
Blow kiss	CONVENTIONAL	0.63 (.74)
Nod "yes"	CONVENTIONAL	0.45 (.76)
Shrug "all gone"/"where'd it go"	CONVENTIONAL	0.30 (.62)
Finger to lip "hush"	CONVENTIONAL	0.13 (.44)

[a] Estimated mean marginal frequency in which a gesture is used, where 0 = not yet, 1 = sometimes, and 2 = often. Gestures ranked from highest to lowest frequency.

Table 5

CDI First Communicative Gestures Item-Level ANCOVAs and Pairwise Comparisons

CDI Item [I vs. J]	***F*(3, 100-103)**	***p***	**η_p^2**	**Pairwise Comparison Adjusted Mean Difference (I-J)**	**Pairwise comparison *p***
Extend arm show	5.25*	.002	.133		
ASD vs. TD/ND*				-.61	.001
ASD vs. GDD				-.11	.593
ASD vs. DLD				-.37	.062
GDD vs. TD/ND*				-.50	.006
GDD vs. DLD				-.26	.200
DLD vs. TD/ND				-.24	.158
Reach out give	8.21*	< .001	.193		
ASD vs. TD/ND*				-.74	< .001
ASD vs. GDD				-.37	.048
ASD vs. DLD				-.33	.068
GDD vs. TD/ND				-.37	.024
GDD vs. DLD				.05	.805
DLD vs. TD/ND				-.41	.007
Point	9.37*	< .001	.214		
ASD vs. TD/ND*				-.93	< .001
ASD vs. GDD				-.22	.346
ASD vs. DLD*				-.75	.001
GDD vs. TD/ND*				-.70	.001
GDD vs. DLD				-.53	.023
DLD vs. TD/ND				-.17	.369
Wave “bye”	4.68*	.004	.122		
ASD vs. TD/ND*				-.70	< .001
ASD vs. GDD				-.29	.223
ASD vs. DLD				-.26	.257
GDD vs. TD/ND				-.41	.050
GDD vs. DLD				.03	.897
DLD vs. TD/ND				-.44	.027
Arms up “pick up”	1.67	.177	.047	--	--
Shake head “no”	1.32	.271	.037	--	--
Nod head “yes”	1.32	.274	.037	--	--
Finger to lip “hush”	3.04	.032	.081	--	--
Open/close hand request	.955	.417	.028	--	--

CDI Item [I vs. J]	***F*(3, 100-103)**	***p***	**η_p^2**	**Pairwise Comparison Adjusted Mean Difference (I-J)**	**Pairwise comparison *p***
Blow kiss	4.80*	.004	.124		
ASD vs. TD/ND*				-.58	.001
ASD vs. GDD				-.10	.630
ASD vs. DLD				-.46	.023
GDD vs. TD/ND				-.48	.011
GDD vs. DLD				-.36	.089
DLD vs. TD/ND				-.118	.485
Smack lips “yum”	5.64*	.001	.142		
ASD vs. TD/ND*				-.70	.001
ASD vs. GDD*				-.83	.001
ASD vs. DLD				-.30	.202
GDD vs. TD/ND				.127	.554
GDD vs. DLD				.529	.030
DLD vs. TD/ND				-.40	.043
Shrug “all gone” / “where’d it go?”	1.54	.209	.043	--	--

* Difference significant at α = .0042.

Table 6

Exploratory Analysis of Predictors of Gesture Repertoire Size and Gesturing Frequency

	Gesture Repertoire Size				Gesturing Frequency			
Predictor[a]	*B*	*t*	*p*	*β*	*B*	*t*	*p*	*β*
ADOS Social Engagement	-.23	-3.60	< .001	-.31	-.37	-4.05	< .001	-.34
MSEL Visual Reception	.05	1.96	.053	.18	.11	2.78	.006	.25
MSEL Fine Motor	.11	4.24	< .001	.37	.17	4.56	< .001	.39
CDI Words Understood	.02	4.32	< .001	.38	.02	4.09	< .001	.36
CDI Phrases Understood	.20	5.20	< .001	.47	.30	5.48	< .001	.48
MSEL Receptive Language	.10	3.79	< .001	.33	.16	4.13	< .001	.35
CDI Words Produced	.06	3.60	< .001	.37	.09	3.70	< .001	.36
MSEL Expressive Language	.11	4.14	< .001	.36	.17	4.44	< .001	.37
Child's Sex (Female)	1.67	2.70	.008	.27	2.41	2.66	.009	.24
Maternal Education (Bachelor's degree or above)	.17	.27	.786	.03	.15	.16	.871	.02
Household Income								
$24,000-96,000	.03	.03	.977	< .01	-.64	-.51	.613	-.06
> $96,000	.51	.65	.519	.08	.23	.21	.837	.02
Language Exposure (Bi/Multilingual)	.55	.81	.418	.08	1.12	1.13	.261	.10

[a] All regressions accounting for age at evaluation.

Table 7

Relative Contribution of Predictors to Gesture Repertoire Size

Predictor	***B***	***t***	***p***	***β***
Whole Sample				
Age at Evaluation	.25	1.65	.102	.17
ADOS Social Engagement	-.05	-.70	.483	-.06
MSEL Fine Motor	.05	1.90	.060	.17
CDI Words Understood	.01	1.61	.111	.17
CDI Phrases Understood	.11	2.42	.017	.26
MSEL Receptive Language	-.01	-.13	.898	-.01
CDI Words Produced	<.01	< -.01	.997	< .01
MSEL Expressive Language	.04	1.19	.238	.13
Child's Sex (Female)	1.45	2.58	.011	.21
DD				
Age at Evaluation	.16	.78	.439	.11
ADOS Social Engagement	-.01	-.07	.949	-.01
MSEL Fine Motor	.06	1.95	.057	.23
CDI Words Understood	-.01	-1.45	.153	-.21
CDI Phrases Understood	.22	3.45	.001	.51
MSEL Receptive Language	-.04	-.66	.513	-.09
CDI Words Produced	.09	1.11	.273	.16
MSEL Expressive Language	.02	.41	.681	.05
Child's Sex (Female)	1.64	1.96	.055	.23
TD/ND[a]				
Age at Evaluation	6.90	1.52	.139	.25
ADOS Social Engagement	4.98	1.13	.265	.12
MSEL Fine Motor	1.09	1.11	.274	.13
CDI Words Understood	.56	5.44	< .001	.84
CDI Phrases Understood	-.48	-.36	.718	-.05
MSEL Receptive Language	1.39	1.65	.109	.22
CDI Words Produced	-.69	-1.40	.172	-.29
MSEL Expressive Language	.03	.03	.978	< .01
Child's Sex (Female)	54.05	3.46	.001	.43

[a] Transformed dependent variable in analyses with TD/ND group is (gesture repertoire size)^2.

Table 8

Relative Contribution of Predictors to Gesturing Frequency

Predictor	***B***	***t***	***p***	***β***
Whole Sample				
Age at Evaluation	.54	2.49	.014	.25
ADOS Social Engagement	-.11	-1.13	.260	-.10
MSEL Visual Reception	-.03	-.68	.498	-.06
MSEL Fine Motor	.09	2.25	.027	.20
CDI Words Understood	< .01	1.12	.265	.12
CDI Phrases Understood	.19	2.79	.006	.29
MSEL Receptive Language	< .01	.16	.877	.02
CDI Words Produced	< -.01	-.23	.815	-.03
MSEL Expressive Language	.07	1.41	.162	.15
Child’s Sex (Female)	1.91	2.35	.021	.19
DD				
Age at Evaluation	.47	1.60	.116	.23
ADOS Social Engagement	-.12	-1.00	.321	-.14
MSEL Visual Reception	-.04	-.79	.436	-.10
MSEL Fine Motor	.09	1.91	.061	.24
CDI Words Understood	< -.01	-.97	.339	-.14
CDI Phrases Understood	.28	3.04	.004	.45
MSEL Receptive Language	-.07	-.90	.373	-.12
CDI Words Produced	-.03	-.23	.819	-.03
MSEL Expressive Language	.09	1.10	.277	.13
Child’s Sex (Female)	2.71	2.23	.030	.27
TD/ND				
Age at Evaluation	.68	1.96	.059	.36
ADOS Social Engagement	.31	.91	.368	.11
MSEL Visual Reception	.02	.30	.767	.04
MSEL Fine Motor	.09	1.17	.251	.16
CDI Words Understood	.03	3.45	.002	.61
CDI Phrases Understood	.08	.84	.407	.14
MSEL Receptive Language	.09	1.34	.190	.20
CDI Words Produced	-.05	-1.24	.224	-.29
MSEL Expressive Language	-.06	-.73	.468	-.11
Child’s Sex (Female)	3.00	2.52	.016	.35

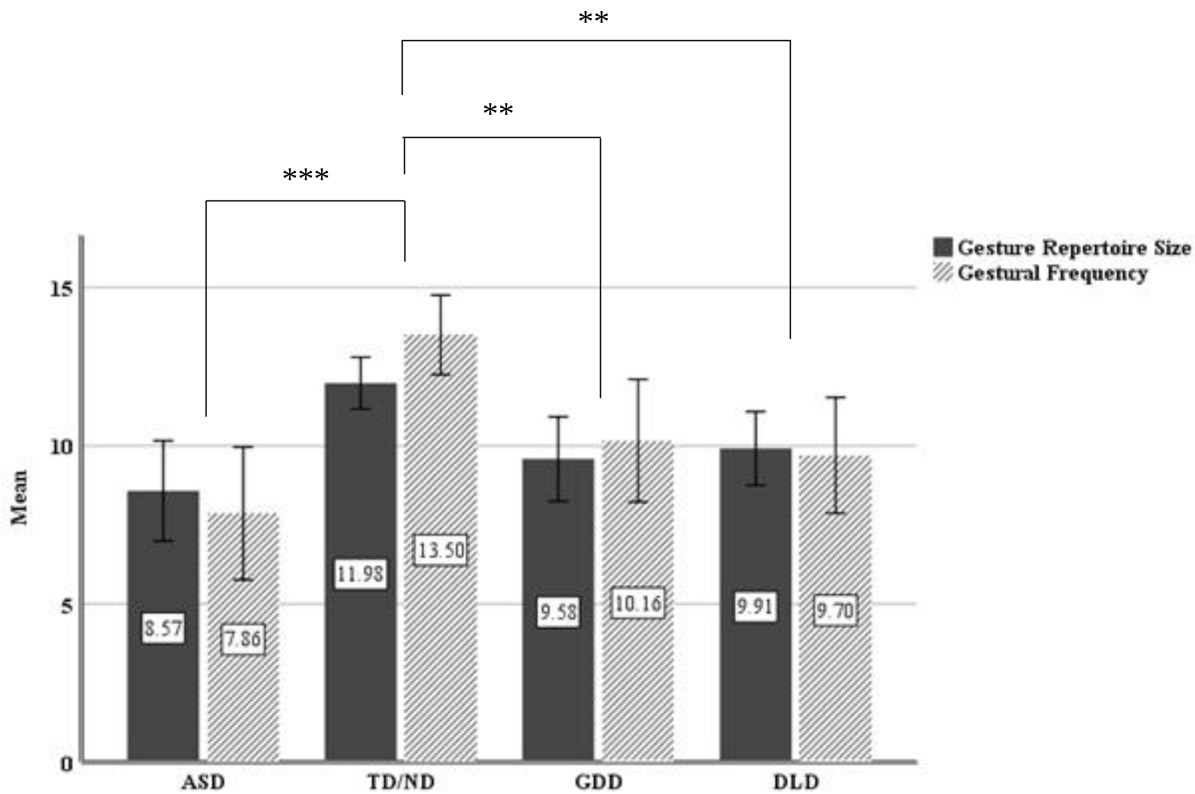

Figure 1. Mean gesture repertoire size and gesturing frequency by diagnostic group. Gesture repertoire size ranges from 0-18, and gesturing frequency ranges from 0-24. Means and standard errors bars displayed.
** $p < .01$; *** $p < .001$

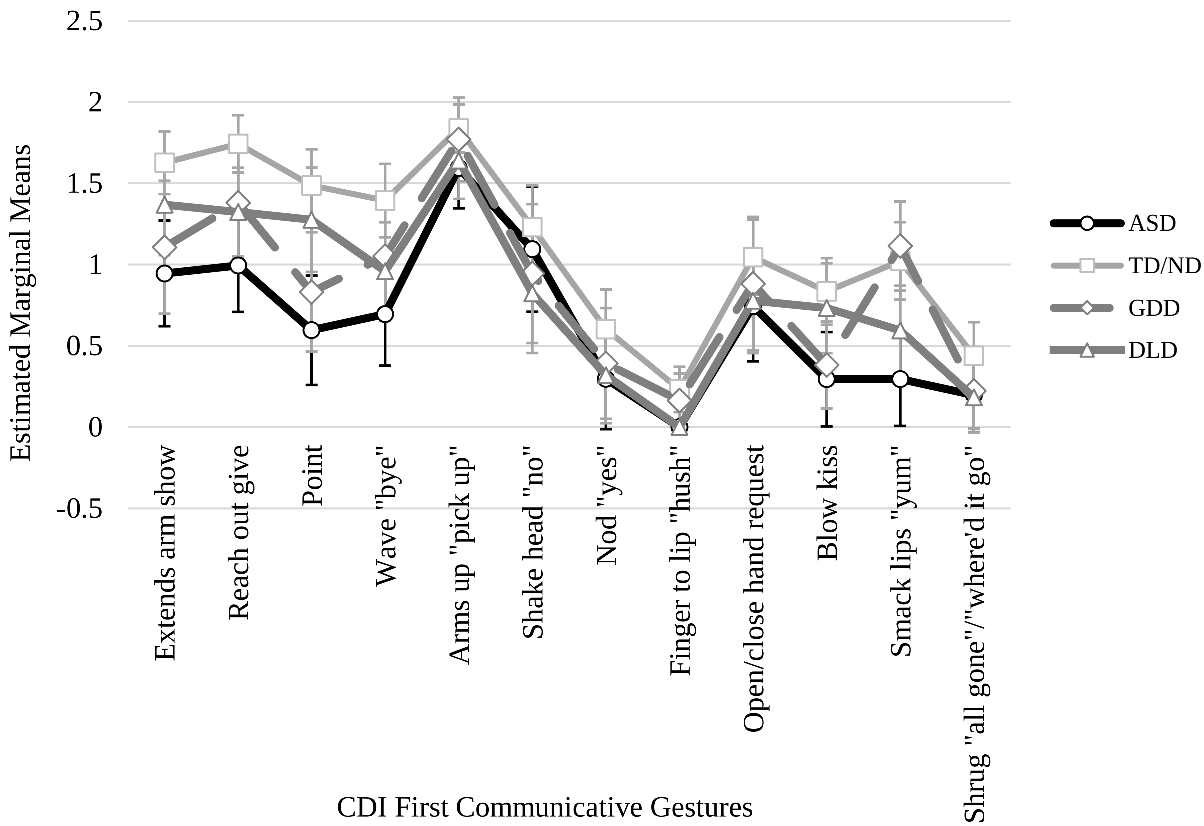

Figure 2. Estimated marginal means of CDI item gesturing frequency (0 = not yet, 1 = sometimes, 2 = often) by diagnostic group, accounting for age. Model evaluated at mean age at evaluation of 15.6 months. Standard error bars are presented.

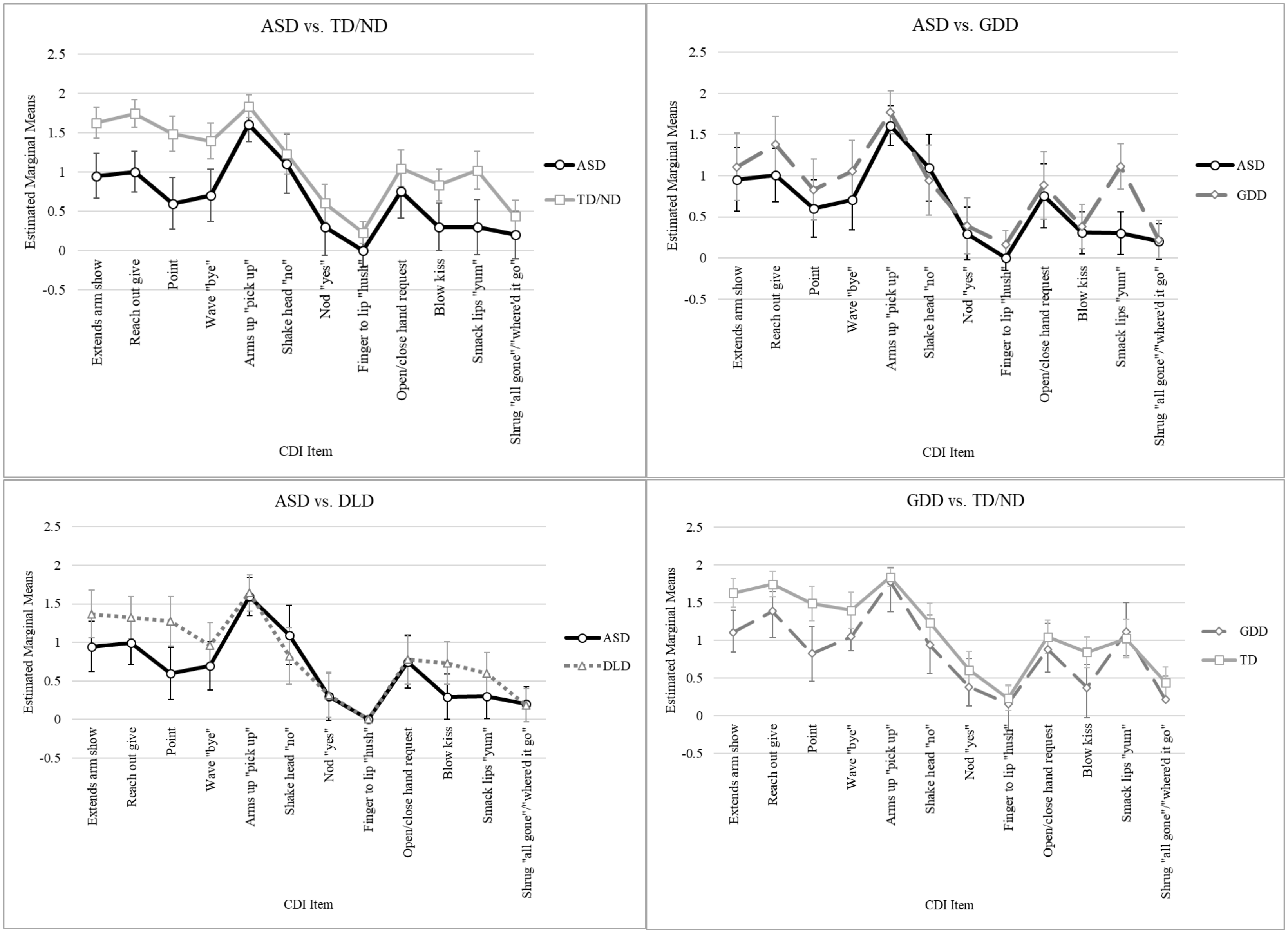

Figure 3. Estimated marginal means of CDI item gesturing frequency by diagnostic group in pairwise comparisons, accounting for age. Model evaluated at mean age at evaluation of 15.6 months. Standard error bars are presented.