J Autism Dev Disord (2015) 45:2218–2234
DOI 10.1007/s10803-015-2391-z

ORIGINAL PAPER

The Development of Coordinated Communication in Infants at Heightened Risk for Autism Spectrum Disorder

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Published online: 18 February 2015

Abstract This study evaluated the extent to which developmental change in coordination of social communication in early infancy differentiates children eventually diagnosed with ASD from those not likely to develop the disorder. A prospective longitudinal design was used to compare nine infants at heightened risk for ASD (HR) later diagnosed with ASD, to 13 HR infants with language delay, 28 HR infants with no diagnosis, and 30 low risk infants. Hierarchical linear modeling analyses revealed that ASD infants exhibited significantly slower growth in coordinations overall and in gestures coordinated with vocalizations, even relative to HR infants with language delay. Disruption in the development of gesture–vocalization coordinations may result in negative cascading effects that adversely impact later social and linguistic development.

Keywords Autism spectrum disorder · Development · Communication · Coordination · Gesture · Vocalizations

This article is based on a dissertation submitted to the University of Pittsburgh in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Portions of these data were presented at the 2011 Annual International Meeting for Autism Research, San Diego, CA; the 2012 Annual International Meeting for Autism Research, Toronto, ON, Canada; and the 2013 Society for Research in Child Development Biennial Meeting, Seattle, WA.

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Introduction

Infants with an older sibling who has a confirmed diagnosis of autism spectrum disorder (ASD) are at elevated risk for ASD and related social and communicative difficulties (e.g., Messinger et al. 2013; see Jones et al. 2014, for a review). These heightened-risk infants (HR) have an ASD recurrence risk of approximately 18.7 % (Ozonoff et al. 2011). Even those HR infants who do not later receive an ASD diagnosis are at significant risk for expressive language delay (e.g., Gamliel et al. 2007; Sullivan et al. 2007); and these delays are related to other difficulties in preverbal communication and social behavior (e.g., play; Thal et al. 1991). Therefore, the prospective study of HR infants during the first year of life may facilitate our understanding of broader developmental difficulties (e.g., expressive language delay) and also permit the delineation of subtle behavioral risk markers for later ASD. One potential locus for such risk markers can be found in the domain of social communicative behaviors, behaviors that lie at the heart of an ASD diagnosis (American Psychiatric Association 2013). Communicative behaviors take multiple forms (e.g., mutual eye gaze, facial expression, vocalization, and gesture) and can occur in isolation or combine to express communicative intentions (e.g., Parladé and Iverson 2011).

The ability to combine or coordinate communicative behaviors such as gestures and vocalizations into a single communicative act is a crucial component of communication and plays an important role in social interaction (e.g., Crais et al. 2009). However, very little work to date has examined coordinated social communication prospectively in HR infants. The current study was designed to describe the development of coordinated communication at regular and frequent intervals during a time in infancy when social communication typically emerges and begins to consolidate (i.e., 8–18 months). To address issues of sensitivity and specificity, developmental trajectories were modeled and compared in HR infants who develop ASD, those who do not receive an ASD diagnosis but may (or may not) experience other types of delays, and comparison infants with no family history of ASD. Identifying behavioral indicators of ASD that are both specific and unique to ASD will allow for earlier identification and initiation of more tailored treatment interventions. Moreover, this approach will offer a more comprehensive understanding of HR infants as a group (and developmental risk more generally).

Social Communication Behaviors in HR Infants

The extant literature on ASD has documented widespread social communication impairments in early childhood. However, research investigating early manifestations of these deficits in HR infants is just emerging. Much of this research has sought to characterize social communication in HR infants as a group in comparison to low-risk infants (LR) with no family history of ASD. With regard to gaze and affect expression during face-to-face interaction, Messinger and colleagues have reported a lower proportion of smiling and longer durations of gaze away from faces (i.e., non-face stimuli) at 6 months of age in HR relative to LR infants (Cassel et al. 2007; Ibanez et al. 2008; see also Yirmiya et al. 2006). With regard to gesture, several studies have now shown that relative to LR peers, HR infants as a group employ significantly fewer gestures (e.g., showing, pointing) to make behavioral requests and to initiate joint attention (Cassel et al. 2007; Goldberg et al. 2005; Yirmiya et al. 2006). And in the first research to assess the spontaneous production of communicative non-word vocalizations in very young HR and LR children, those in the HR group were found to produce communicative non-word vocalizations at lower rates than their LR peers at both 13 and 18 months (Winder et al. 2013).

Coordinated Communication in HR Infants

When typically-developing (TD) infants communicate, they not only do so through mutual eye gaze, facial expression, gesture, and vocalization, they do so by combining these communicative signals seamlessly into a single, multi-modal act. They initiate eye gaze and smile; they smile and vocalize; they vocalize and point; and, sometimes, they initiate eye gaze, smile, gesture, and point. As Bates (1976) demonstrated long ago, TD children are capable of frequently and flexibly coordinating multiple communicative behaviors across different modalities well before the first birthday. Indeed, coordinated communication—or the co-production of more than one communicative behavior in time—is a crowning achievement in the early development of social communication (e.g., Crais et al. 2009; Stone et al. 1997).

The relative importance of this emerging skill is evident from the fact that communicative coordinations have been shown to be powerful social stimuli with the potential to redirect caregiver attention (e.g., Goldin-Meadow et al. 2007; Martinsen and Smith 1989) and from the fact that young children's ability to coordinate behaviors is predictive of later language skill and social competence (e.g., Parladé et al. 2009; Rowe and Goldin-Meadow 2009). It is of particular note, therefore, that in ASD, the ability to combine communicative signals is known to be impaired, with children with ASD much more likely to rely on isolated communicative signals during social interactions (Shumway and Wetherby 2009; Stone et al. 1997).

Given the importance of communicative coordinations and their known impairment in ASD, it is surprising that this topic has remained relatively unexplored in research on social communication in HR infants. To date only three known studies have reported data on coordinated communication in this population (Gangi et al. 2014; Ozonoff et al. 2010; Winder et al. 2013). In the first, Ozonoff et al. limited their focus solely to HR infants later diagnosed with ASD. In the context of the Mullen Scales of Early Learning (MSEL; Mullen 1995) administered at 6, 12, 18, 24, and 36 months, they examined the frequencies of two types of "early emerging" coordinations: *social smiles* (i.e., co-occurrence of gaze to face and smiles) and *directed vocalizations* (i.e., co-occurrence of gaze to face and vocalizations).

Results indicated that in comparison to a gender-matched LR group, HR infants later diagnosed with ASD exhibited declining developmental trajectories in communicative coordinations. While frequencies of social smiles and directed vocalizations were highly comparable between groups at 6 months of age, HR infants produced relatively fewer directed vocalizations by 12 months and social smiles by 18 months. Because the study did not report data on HR infants without a later ASD diagnosis, it is difficult to know whether observed differences were specific to ASD or more generally characteristic of HR infants as a group. Furthermore, since data in this study were generated from infant-experimenter interaction during clinical administration of the MSEL, it is also unknown whether reduction in communicative coordinations in HR infants is characteristic of the child in the everyday environment.

In the second study of communicative coordination in HR infants, Winder et al. (2013) coded spontaneous communicative behaviors (i.e., gestures, communicative non-word vocalizations, words) and their coordinations as these were produced by HR and LR infants at both 13 and 18 months during in-home naturalistic interaction and semi-structured play with caregivers. Results indicated that as a group, HR infants (including 3 later diagnosed with ASD) combined gestures with communicative non-word vocalizations at a significantly lower rate than LR infants at 13 and 18 months of age and gestures with words at 18 but not 13 months. HR infants also demonstrated a more restricted repertoire of gesture-speech coordinations; specifically, HR infants produced significantly fewer vocal utterances (communicative non-word vocalizations and words) coordinated with point gestures.

Finally, and most recently, Gangi et al. (2014) compared the development of coordinated gaze and smiles within episodes of joint attention in a group of HR and LR infants. Within an examiner-led assessment designed to elicit acts of joint attention (i.e., the Early Social Communication Scales), the authors found that HR infants as a group produced lower rates of coordinated acts in which the smile precedes but overlaps in time with a gaze to face (i.e., anticipatory smiles; Parladé et al. 2009) than infants in the LR group. Group differences in the rate of anticipatory smiles remained similar from 8 to 12 months of age. Both groups, however exhibited similar rates of reactive smiles, or smiles that are coordinated with but produced slightly after the gaze to a social partner. Further, within the HR group there was no association between social smiles of either type at 8 months and later ASD symptomatology at 36 months. The authors reported that 12 HR siblings received a diagnosis of ASD at 36 months, and while they demonstrated that results were unchanged with and without the inclusion of the ASD infants, they did not specifically compare coordinated communication between subgroups of HR infants.

While the results of these studies are informative, they are limited in three significant ways. First, all three focused on a small subset of the communicative coordinations that infants can produce (Ozonoff et al. on smile and gaze, vocalization and gaze; Gangi et al. on smile and gaze; Winder et al. on gesture and communicative non-word vocalization, gesture and word). Second, none provided data from groups of HR infants differentiated in terms of outcome, i.e., those who received an eventual ASD diagnosis, those who received an eventual diagnosis of language delay but not ASD, and those who received no diagnosis. Finally, none assessed the growth of communicative coordinations over frequent and regularly spaced intervals in the naturalistic environment. While Ozonoff et al. (2010) observed infants at five time points from 6 to 36 months, they did so during administration of a standardized clinical assessment. Gangi et al. (2014) examined communication during an examiner-led assessment during a small window of time (8, 10, and 12 months); and although Winder et al. (2013) observed infants in the naturalistic environment, they did so only at two time points (i.e., 13 and 18 months; see Adolph et al. 2008, for a discussion of the importance of sampling at multiple time points). The present study was designed to transcend these limitations.

The Present Study

Determination of the degree to which differences in the development of early communicative coordinations is specific to ASD or a marker of general language delay requires differential assessment of coordinations in HR infants who eventually receive an ASD diagnosis, HR infants who receive a language delay (without ASD) diagnosis, HR infants who receive no eventual diagnosis, *and* comparison with LR infants at no known risk for ASD. Language and communication delays are one of the first concerns raised by parents of children with ASD (De Giacomo and Fombonne 1998), and many HR infants who do not develop ASD nevertheless experience early delays in communication (e.g., Yirmiya et al. 2006; Zwaigenbaum et al. 2007). Therefore, if early behavioral markers of ASD identified in HR samples are to be useful in guiding screening efforts for early diagnosis in the general population or in clinically referred samples, it is important to know not only whether these markers can distinguish ASD from typical development, but also whether they distinguish ASD from language delay (see Zwaigenbaum et al. 2007, for further discussion). The inclusion of a high risk group that develops non-ASD difficulties is necessary to begin to determine whether observed delays and/or deficits in social communication skills among ASD infants are both *sensitive* and *specific* to ASD.

Delineation of group differences in the growth of communicative coordinations among these various groups requires a longitudinal approach with frequent observations of both early emerging and developmentally advanced coordinations in familiar, everyday environments. With this in mind, the current study assessed developmental trajectories of communicative coordinations in HR and LR infants as these coordinations were spontaneously produced in the home. Naturalistic observation is a standard and reliable method that has been widely and successfully used in numerous studies of early communicative development (e.g., Iverson et al. 1994; Iverson and Goldin-Meadow 2005). There is also evidence that social communication behaviors (e.g., vocalizations, gestures, speech) are maximally likely to occur when infants are in familiar surroundings and engaged in familiar activities with familiar adults (Iverson et al. 1994; Lewedag et al. 1994; Thal and Tobias 1992). While many have advocated for the study of communication of children with ASD in natural, familiar settings (e.g., Tager-Flusberg et al. 2009; Wetherby 1986), very few studies have employed this approach. Further, to better characterize the shape of change in communicative coordination over time, observations took place at regular and frequent intervals from 8 to 18 months, the developmental period during which social communication emerges and becomes more varied and complex.

The purpose of this research was therefore to investigate developmental change in the coordination of infant communicative behaviors in early infancy (i.e., between 8 and 18 months) as assessed in a naturalistic home setting. We sought to address three primary research questions. First, do infants with and without risk for ASD demonstrate differences in developmental trajectories of coordinated communicative behaviors that are observable between 8 and 18 months? Second, to what extent do differences in the development of coordinated communication predict a later language delay or ASD outcome in HR infants, and do any such differences primarily represent delayed (i.e., slower) or deviant (i.e., atypical) development (see Satz et al. 1981, for further definition of delay versus deviance)? Third, is delay and/or deviance in coordinated communication specific and unique to ASD or a general marker of communicative delay?

Method

Participants

Two groups of infants participated in this study. The first consisted of 50 HR infants (22 males) with an older full biological sibling diagnosed with Autistic Disorder (AD; DSM-IV-TR; American Psychiatric Association 2000) verified using DSM-IV-TR criteria and scores above the Autism threshold on the Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord et al. 2000) administered prior to infant enrollment in the study. HR infants were recruited from western Pennsylvania by flyer, professional referral, and word of mouth through the Autism Research Program at the University of Pittsburgh, parent support groups, and local agencies and schools serving children with ASD. The second group consisted of 30 LR infants (14 males) with no family history of ASD followed longitudinally as part of a separate study of vocal-motor coordination in infancy (e.g., Iverson et al. 2007). LR infants were recruited through published birth announcements and word of mouth.

All infants were full-term, from uncomplicated pregnancies and deliveries with normal 5-min neonatal Apgar scores (9–10; Apgar 1953), and from monolingual, English-speaking homes. Demographic information is presented in Table 1. As is apparent, groups were similar in terms of ethnicity, parental age, education, and occupational prestige (Nakao and Treas 1994).

Procedure

Following informed consent procedures, all infants were observed at home at regular intervals with a primary caregiver. HR infants were seen monthly from 5 to 14 months, with 18-, 24-, and 36-month follow-up visits that included administration of standardized assessments of cognitive, social, behavioral, and communicative function. At 36 months, HR infants were also seen at the University of Pittsburgh Autism Research Program for final diagnostic assessment and classification by an experienced clinician blind to all previous study data. LR infants were followed bimonthly from 2 to 19 months of age; and while LR infants did not undergo formal evaluation to confirm typical development, no developmental concerns were noted by caregivers or research staff. The present study utilized data for both groups obtained at 8, 10, 12, 14, and 18 months and, for HR infants, from standardized assessments at 24 and 36 months. A summary of home visit procedures for the HR and LR groups is presented in Table 2.

Home visits occurred within 3 days of the monthly anniversary of the infant's birth at times when parents thought the infant would be alert and playful. Observations lasted approximately 25 min and were video- and audio-recorded. To enhance audio recording, infants wore a small wireless microphone housed in a cloth vest and clipped at shoulder level, and caregivers were asked to turn off the television. When siblings were at home, a sibling-minder was assigned to keep them occupied and out of the assessment room to ensure that infants had caregivers' undivided attention and that coders were blind to group membership.

At all sessions, observations included two segments in fixed order. The first consisted of 15 min of unstructured, naturalistic observation during which caregivers continued activities as usual for the time of day at which the visit took place. Infants typically played on the floor with the caregiver present but not specifically initiating involvement with the infant. The second segment consisted of 10 min of free play and social interaction between the caregiver and infant. During this segment, caregivers and infants were seated on the floor and asked to "play as you normally would;" otherwise, there was no attempt to structure this segment in any way.

Measures

MacArthur–Bates Communicative Development Inventory (CDI; Fenson et al. 2007)

At each session, parents were asked to complete the CDI, a parent report measure of language and communicative development that has been successfully used in studies of TD and atypically-developing children, including those with

Table 1 Demographic information for high risk and low risk groups

	HR (n = 50)	LR (n = 30)
Gender		
Female (%)	28 (56 %)	16 (53 %)
Male (%)	22 (44 %)	14 (47 %)
Racial or ethnic minority (%)	7 (14 %)	2 (7 %)
Birth order		
First born (%)	0 (0 %)	12 (40 %)
Second born (%)	24 (48 %)	14 (47 %)
Later than second born (%)	26 (52 %)	4 (13 %)
Multiplex family (%)	5 (10 %)	n/a
Mean age for mothers (SD)	34.10 (4.43)	31.77 (4.58)
Mean age for fathers (SD)	35.70 (4.30)	32.83 (4.21)
Maternal education		
Graduate or professional school (%)	15 (30 %)	16 (53 %)
Some college or college degree (%)	33 (66 %)	13 (43 %)
High school (%)	2 (4 %)	1 (3 %)
Paternal education		
Graduate or professional school (%)	18 (36 %)	12 (40 %)
Some college or college degree (%)	27 (54 %)	15 (50 %)
High school (%)	3 (6 %)	3 (10 %)
Mean paternal occupational prestige (SD)[a]	60.40 (14.96)	57.79 (12 %)

HR high risk, *LR* low risk

[a] Nakao–Treas occupational prestige score; not calculated for 5 fathers in HR group and 4 fathers in LR group

ASD (e.g., Charman et al. 2003; Mitchell et al. 2006). From 8 to 14 months, caregivers of HR and LR infants completed the Words and Gestures form of the CDI (CDI-WG). The CDI-WG consists of a 396-item vocabulary checklist and a list of early gestures (e.g., giving, showing, pointing) and actions (e.g., games and routines, pretend play). Parents are asked to check vocabulary items that their child only understands or both says and understands and to indicate those gestures and actions produced by the child.

At 18 months, depending on the child's language level, caregivers of HR infants completed either the CDI-WG or the CDI-WS (Word and Sentences). The CDI-WS is normed for children from 16 to 30 months and consists of a 680-word vocabulary checklist (parents indicate words that the child says) and a section on children's use of English morphology and syntax. If a child was producing relatively few words (as indicated by the primary caregiver and observed by the experimenter) and had no two-word combinations at 18 months, the CDI-WG was administered. If a child had a significant productive vocabulary and some word combinations, the CDI-WS was administered. At 24 months, all caregivers of HR infants were administered the CDI-WS; and at 36 months, the CDI-III. The CDI-III is normed for children aged 30–37 months and consists of a 100-item vocabulary checklist, 12 sentence pairs assessing grammatical complexity, and 12 yes/no questions concerning semantics, pragmatics, and comprehension. At the 18-month session, caregivers of LR infants were administered the CDI-WS; but because LR infants were followed as part of a separate study that concluded when infants were 19 months of age, no CDI data are available for LR infants at 24 or 36 months (see Table 2). All LR infants scored at or within the normal range (≥10th percentile) on the CDI as administered monthly from 8 to 19 months.

Mullen Scales of Early Learning (MSEL; Mullen 1995)

The MSEL was administered to all HR infants at 18, 24, and 36 months. The MSEL provides a measure of general cognitive functioning from 0 to 68 months. It consists of five subscales: Visual Reception, Receptive Language, Expressive Language, Fine Motor, and Gross Motor. Internal consistency ranges from 0.83 to 0.95. Items involve structured tasks, questions, and observation of the child's reaction to stimuli with verbal requirements ranging from none to one to three word responses to sentence repetition. The MSEL was not administered to LR infants (see Table 2).

Outcome Assessment and Classification

HR infants were classified into one of three outcome categories: (a) HR-ASD; (b) HR-LD (Language Delay no ASD); or (c) HR-ND (No Diagnosis). A diagnosis of *ASD* was given if infants met or exceeded ADOS algorithm cutoffs for ASD or AD *and* received a clinical best estimate diagnosis of ASD from a trained clinician using DSM-IV-TR criteria. To provide a continuous measure of ASD symptomatology, ADOS severity scores were calculated

Table 2 Summary and purpose of home visit procedures for high risk and low risk groups

	Schedule (infant age in months)		Purpose
	HR (n = 50)	LR (n = 30)	
Observational measures			
Videotaped observations	8	8	Observe frequency of gestures, vocalizations, eye contact, facial expressions, and Coordinated Bouts
	10	10	
	12	12	
	14	14	
	18	18	
Parent report instruments			
MacArthur–Bates Communicative Development Inventory (CDI)	8	8	Assess expressive and receptive vocabulary, use of early action schemes, gestures, and grammar
	10	10	
	12	12	
	14	14	
	18	18	
	24	–	
	36	–	
Standardized assessments			
Mullen Scales of Early Learning (MSEL)	18	–	Assess fine and gross motor, visuo-spatial, and language function
	24	–	
	36	–	
Autism Diagnostic Observation Schedule-Generic (ADOS-G)	24	–	Assess ASD symptomatology
	36	–	

HR high risk, *LR* low risk

for each child from ADOS scores based on Gotham et al. (2009) criteria. Calibrated severity scores ranged from 1 to 10 and accounted for the child's age and language level. Severity scores are presented for the HR subgroups at the bottom of Table 3. Nine HR infants (6 males) received a diagnosis of ASD at 36 months.[1] HR infants were assigned to the *LD* subgroup if they *did not* receive a diagnosis of ASD (many children classified with ASD also exhibited delayed language) *and* met one of the following criteria: (1) Standardized scores on the CDI-WS and CDI-III at or below the 10th percentile at *more than one* time point between 18 and 36 months (e.g., Ellis Weismer and Evans 2002; Heilmann et al. 2005) and/or (2) Standardized scores on the CDI-III at or below the 10th percentile *and* standardized scores on the Receptive and/or Expressive subscales of the MSEL equal to or greater than 1.5 standard deviations below the mean at 36 months (e.g., Landa and Garrett-Mayer 2006; Ozonoff et al. 2010). Thirteen HR infants (8 males) were classified as LD. The remaining 28 HR infants did not meet any of the above criteria for ASD or LD (9 males).[2]

Table 3 provides a characterization of the HR sample by presenting relevant CDI, MSEL and ADOS scores for the three HR groups at 18, 24, and 36 months. A series of Kruskal–Wallis one-way analyses of variance (ANOVA) revealed significant differences between HR outcome groups, with the HR-ASD group scoring significantly lower than the HR-ND group on all measures (see Table 3). Further, the HR-ASD group had significantly lower scores than the HR-LD group on MSEL Receptive Language, MSEL Expressive Language, and ADOS severity scores at 36 months. As expected, the HR-LD group also scored significantly lower than the HR-ND group on all language measures (i.e., CDI and MSEL). And while the HR-ASD

[1] The exception was for one HR-ASD infant who met clinical best estimate criteria for ASD at 36 months but his 36-month ADOS scores fell below the cutoff for ASD by one point (Severity score = 3, Cut-off $\geq$ 4). He was retained in the ASD category due to clinically significant ADOS scores and clinical best estimate at 24 months. 36-month ADOS scores for two additional HR infants were deemed invalid due to shyness and/or noncompliance; one child was classified as HR-ND and one as HR-LD.

[2] Two HR-ND infants demonstrated nonspecific developmental delays ("other delay") as indicated by MSEL standard scores at or below 1.5 SD from the mean on one or more non-language subscales (e.g., Fine Motor) and/or elevated scores (albeit below clinical cut-off) on the ADOS-G. Neither of these infants' parents reported concern, nor did they receive early intervention services. Further, visual inspection of the data suggested that communicative patterns for HR-ND "other delay" infants were not substantially different from other HR-ND infants; thus, the decision was made to retain them in this category.

Table 3 Mean (SD) standardized scores at 18, 24, and 36 months for the HR outcome groups

	HR-ND ($N = 28$)			HR-LD ($N = 13$)			HR-ASD ($N = 9$)			χ^2
	M	(SD)	n	M	(SD)	n	M	(SD)	n	
18 m CDI words Produced percentile	$38.33^{a,c}$	(26.24)	27	7.69^{c}	(8.07)	13	3.33^{a}	(5.00)	9	25.93***
24 m CDI words Produced percentile	$47.92^{a,c}$	(23.31)	24	18.85^{c}	(19.06)	13	6.11^{a}	(8.58)	9	23.59***
36 m CDI words Produced percentile	$32.00^{a,c}$	(27.42)	25	3.85^{c}	(4.63)	13	5.71^{a}	(9.76)	7	16.78***
36 m MSEL Receptive Language T-score	$54.14^{a,c}$	(9.08)	28	$44.23^{b,c}$	(8.80)	13	$24.00^{a,b}$	(9.80)	6	21.64***
36 m MSEL Expressive Language T-score	$58.35^{a,c}$	(9.05)	26	$48.54^{b,c}$	(8.89)	13	$31.50^{a,b}$	(11.90)	6	25.93***
36 m ADOS severity index	1.68^{a}	(1.36)	28	1.54^{b}	(0.97)	13	$6.22^{a,b}$	(2.99)	9	17.34***

HR-ND high risk-no diagnosis, *HR-LD* high risk-language delay, *HR-ASD* high risk-autism spectrum disorder, *CDI* MacArthur–Bates Communicative Development Inventory, *MSEL* Mullen Scales of Early Learning, *ADOS* Autism Diagnostic Observation Schedule. All children received either Module 1 ($n = 5$) or Module 2 ($n = 45$) based on their expressive language level at the time of the assessment

*** $p < .001$. Differing superscript letters show significant differences between groups as indicated by Mann–Whitney U tests

group performed lower than the HR-LD group on the MSEL language scales, they did not differ in expressive language as measured by the CDI at any age.

A clinical referral for further evaluation was made at 36 months if the child received an outcome classification of ASD or LD. In addition, HR infants were given a clinical referral at any time during the course of the study if parents indicated concern about the infant's development and asked for a referral, or the infant scored above diagnostic cutoffs on the Modified Checklist for Autism in Toddlers (M-CHAT; Robins et al. 2001) at either 18 or 24 months. Infants referred for evaluation and possible intervention were retained in the sample, and types and frequency of services were documented. Percentages of HR infants receiving services (HR-ASD = 77.78 %; HR-LD = 53.85 %; HR-ND = 66.67 %) and average numbers of services (HR-ASD: $M =$ 2.00; HR-LD: $M = 0.92$; HR-ND: $M = 1.17$) were roughly comparable among groups. None of the parents was systematically involved in a parent training regimen.

Observational Behavior Coding

All infant-initiated communicative behaviors (gestures, vocal utterances, eye gaze, and smiles) and temporally coordinated combinations of these behaviors were coded using a time-linked, computer-based video interface system (Noldus Observer Video-Pro version XT; Noldus 2000). Only behaviors that were truly spontaneous (i.e., not explicitly elicited by an adult[3]) were coded. Coding categories and definitions for communicative behaviors are presented below.

Gestures

Gesture was defined as a communicative hand movement accompanied by a clear effort to direct the caregiver's attention (e.g., through use of eye contact, vocalization, postural shift, or repetition; Iverson et al. 2008). Because the focus of this paper was on infant-initiated communicative behavior, hand movements that were part of a ritual act (e.g., blowing a kiss) or game (e.g., patty cake) produced in the context of play were not coded (e.g., Butcher et al. 1991; Iverson and Goldin-Meadow 2005). Also, with the exception of giving and showing (see below), hand movements that involved direct manipulation of a person or object (e.g., using the index finger to activate a button on a toy) were not coded as gestures. Gestures were classified into two main categories. *Deictic gestures* (pointing, reaching, giving, showing) express intent to request or declare (e.g., Bates et al. 1979) and *indicate* referents (i.e., object, location, event) in the immediate environment. Their meanings are thus context-bound. *Representational gestures* (e.g., nodding the head "yes;" raising the arms high for "tall") differ from deictic gestures in that they *represent* (rather than indicate) specific referents and their semantic content does not vary with context (e.g., Iverson et al. 1994).

Vocal Utterances

All vocal utterances were coded in a manner consistent with previous work examining infants' prelinguistic sounds (e.g., Gros-Louis et al. 2006). Vocal utterances were classified into two major categories: *words* and *non-word vocalizations*. *Words* involved use of the same sound pattern to refer to a specific referent on multiple occasions or in different contexts. They were either actual English words (e.g., "cat," "duck," "hot") or sound patterns that were consistently used by a particular child to refer to a specific object or event (e.g., using "bah" to refer to a bottle in a variety of different contexts). As indicated above, only spontaneously produced

[3] Elicited behaviors were those in which (a) the child was given explicit instructions that involve a specific directive (e.g., caregiver says "give me the ball" and child picks up the ball and hands it to her; caregiver says "Say ball" and child says "ball"), or (b) the child's behavior was directly prompted by physical movement or touching by the communicative partner (e.g., the caregiver tickles the child and the child smiles and laughs).

words were of interest here; words that were purely imitative (i.e., words repeated immediately after being spoken by another person) were not coded. All uninterpretable strings of speech sounds (with the exception of sneezing, coughing, breathing, and other vegetative noises) were coded as *non-word vocalizations* (*NWVs*). *NWVs* included vowel strings (e.g., [eeaa]), reduplicated babbling (e.g., [gaga]), and variegated babbling (e.g., [bama]).

Eye Gaze

Instances in which the infant's eye gaze was directed toward another person's face/eyes for at least one second were coded as *eye contact*. Extremely brief, or fleeting, glances toward another person were not coded as eye contact.

Smiles

Based on research examining infants' early attempts at nonverbal communication (e.g., Yale et al. 2003), facial expressions that involved the upward turning of the corners of the lips often accompanied by narrowed/crinkled eyes (i.e., eye constriction) and a widened mouth were classified as *smiles*. (Oster 2000).

Coordinated Bouts

In addition to coding individual vocal, gestural, affective, and eye gaze behaviors (i.e., those produced in isolation), instances in which communicative behaviors co-occurred in time were identified by coders with a single, unique code (i.e., *Coordinated Bout*; Parladé and Iverson 2010, 2011). A communicative act was coded as a *Coordinated Bout* when two (or more) behaviors overlapped temporally with one another (e.g., a child points at a car and holds the point while saying "car;" a child makes eye contact with his mother and vocalizes, "dadada"). Temporal co-occurrence was defined as when the duration of communicative behaviors overlapped at any point in time.

Coordinated Bouts were further described in terms of their composition (i.e., identifying individual behavioral forms appearing within a given coordination). *Developmentally-prior* bouts included Social Smiles and Directed Vocalizations. Social Smiles were defined as the co-occurrence of smiles and eye contact, while Directed Vocalizations were defined as the co-occurrence of NWVs and eye contact (see Ozonoff et al. 2010, for similar definitions). Three types of *developmentally-advanced* bouts were identified. These included gestures combined with smiles or eye contact (Gesture + Smile/EC), words combined with smiles or eye contact (Word + Smile/EC), and gestures combined with NWVs or words (Gesture + NWV/W).

Reliability

To assess intercoder reliability, 58 videotapes (15 % of the total; 29 HR, 29 LR) were chosen at random and independently scored by 3 raters blind to one another's codes. One rater (first author) had some knowledge of which group the tapes were from but was blind to diagnostic outcome classification. The second and third raters were blind to both group membership and outcome. Prior to coding, secondary coders were trained to at least 80 % agreement on all categories for three consecutive videos. Reliability meetings were held regularly to prevent coder drift and allow for estimation of reliabilities. Disagreements were resolved by joint viewing and discussion. Reliability data reflect the original codes. Intraclass correlation coefficients (ICCs) between the raw total counts of the three raters on each variable were calculated as an index of agreement (e.g., Drew et al. 2007). Using this procedure, ICCs were 0.78 for NWVs, 0.99 for words, 0.75 for gestures, 0.69 for eye contact, 0.74 for smiles, and 0.82 for Coordinated Bouts. For all variables, inter-rater reliability was good (>0.60) or excellent (>0.80).

Data Reduction and Analysis

This study was designed to explore developmental trajectories in the communicative coordination of gestures, vocalizations, words, smiles, or eye gaze in HR and LR infants. Although mean session lengths were highly similar across outcome groups (LR: $M = 25.00$, $SD = 1.05$; HR-ND: $M = 24.71$, $SD = 1.65$; HR-LD: $M = 24.77$, $SD = 1.52$; HR-ASD: $M = 25.08$, $SD = 0.38$), they sometimes varied slightly among participants. All frequency variables were therefore converted to rates per 10 min by dividing total frequency by length of observation in minutes, then multiplying by 10. Because of missing visits (e.g., infant not yet enrolled in study; visit missed due to illness or other unanticipated family events) and/or malfunction of equipment, 8-month data were available for $n = 74$, 10-month data for $n = 78$, 12-month data for $n = 77$, 14-month data for $n = 79$, and 18-month data for $n = 79$ infants.[4]

[4] There were 6 missing sessions at 8 months (all HR); 2 missing sessions at 10 months (both HR); 3 missing sessions at 12 months (2 HR, 1 LR); 1 missing session at 14 months (HR); and 1 missing session at 18 months (LR).

Analytic Approach

Hierarchical linear modeling (HLM; Bryk and Raudenbush 1992) was utilized to examine developmental trends with respect to the frequency, variety, and complexity with which communicative behaviors were produced in coordination during the 25-min naturalistic and toy play context over the observation period. Multilevel modeling techniques were chosen because of the nested, hierarchical nature of the data.[5]

In this study, analysis of five data points per infant permitted exploration of linear, quadratic, and cubic growth models. All models were estimated in HLM 6.08 using Full Information Maximum Likelihood estimation (FIML; Raudenbush et al. 2004). The data in this study contributed to a two-level hierarchical structure. The only predictor of Level 1 variance (within sessions) considered in this study was *TIME*. *TIME* was measured in months and was centered at the individual level at the initial data collection point (i.e., 8 months). The quadratic ($TIME^2$) and cubic ($TIME^3$) age variables were calculated by squaring and cubing the centered linear age variables, respectively. At Level 2 (between-child) were time-invariant predictors (i.e., a predictor that remained constant across observations for a given infant) which included outcome group (i.e., LR, HR-ND, HR-LD, and HR-ASD) and gender (MALE). The LR group was used as the comparison group, thus coefficients reflect deviations in initial level (i.e., intercept), slope, and/or acceleration from the average LR participant in the sample. As a result, these analyses explicitly examined differences in growth trajectories among outcome groups after controlling for infant gender.

For each analysis, a series of additional comparisons was conducted to examine potential differences between the HR-ND, HR-LD, and HR-ASD groups by systematically rotating the comparison group. Additional targeted analyses were performed by re-centering time so that the trajectories' anchor, or intercept, systematically varied by age (e.g., $age_{it}-10$, $age_{it}-12$, $age_{it}-14$, $age_{it}-18$). Centering improves the interpretability of the intercept (Singer and Willett 2003), particularly in cases where behavior is not expected to appear in typical development until after the point of initial data collection (e.g., gesture-speech combinations emerge between 8 and 12 months; e.g., Butcher and Goldin-Meadow 2000). This was also done to determine the point at which the divergence of developmental trajectories between outcome groups became statistically significant.

Although details of the modeling process differed slightly for each dependent variable (e.g., fixing the random Level 2 variation in intercept when no between-child differences were detected in Level 1), the same general procedure was used for all of the measures considered. The process began with an unconditional means model (without predictors). Model building continued with testing of functional form fit for unconditional growth models by computing linear, quadratic, and cubic growth models for each of the main variables. Further assumptions underlying statistical models were checked by assessing normality and homoscedasticity. In cases where homoscedasticity assumptions were violated, robust standard errors are reported instead. Finally, outliers were identified by inspecting the Mahalanobis distance plots. Extreme values were removed and models were fitted again. In all cases, normality improved but results remained unchanged (although significance levels may have attenuated or strengthened).

Results

The overarching goal of this study was to examine the developmental course of coordinated communication in infants at heightened risk for ASD. In order to address the primary research questions stated above, two sets of analyses regarding the nature of infants' multimodal communication patterns during the 8- to 18-month period were performed. The first focused on estimating growth in overall production of Coordinated Bouts over time; the second examined developmental changes in the specific composition of Coordinated Bouts (developmentally-prior vs. developmentally-advanced). For each variable, primary analyses were complemented by additional comparisons designed to evaluate differences in developmental trajectories between (a) the LR and HR groups; (b) the LR and HR-ASD groups; and (c) the HR-ASD and HR-LD groups.

Prior to conducting statistical analyses, potential effects of birth order and early intervention (EI) were examined by analyzing the mean rate of communicative attempts (i.e., a behavior produced alone or a single Coordinated Bout) and the mean rate of Coordinated Bouts (i.e., communicative utterances in which two or more behaviors overlapped in time). In light of prior research demonstrating differences between first- and second-born children in some aspects of language development (e.g., vocabulary, pronoun use; Hoff-Ginsberg 1998; Oshima-Takane et al. 1996), birth order was examined to ensure that any observed differences in communication between HR and LR infants were not due to the higher frequency of first born infants in the LR group. Mann–Whitney *U* tests revealed no effects of

[5] Nested, hierarchical data violate assumptions of independence required in traditional regression analyses. Violating assumptions of independence can result in downwardly biased (smaller) standard errors and alpha inflation. Thus, failure to account for nested and hierarchical levels can result in more frequent, incorrect, rejections of the null hypothesis and false positive results.

Table 4 Mean rate (per 10 min), standard deviations, and ranges of coordinated communicative behaviors for overall sample

Age	8 (n = 74)			10 (n = 78)			12 (n = 77)			14 (n = 79)			18 (n = 79)		
	M	(SD)	Range	M	(SD)	Range	M	(SD)	Range	M	(SD)	Range	M	(SD)	Range
Overall frequency															
Coordinated Bouts	2.96	(3.75)	22.92	6.35	(5.95)	23.11	3.65	(3.71)	15.51	8.77	(7.11)	40.35	9.62	(7.81)	37.22
Bout types															
Social Smiles	0.77	(1.55)	10.47	1.62	(2.68)	19.92	0.73	(1.39)	6.21	1.50	(2.06)	10.40	1.53	(2.37)	10.36
Directed Vocalization	1.96	(2.26)	9.97	3.60	(3.63)	14.80	1.86	(2.04)	8.03	4.09	(3.30)	12.82	2.70	(2.54)	11.88
Gesture + Smile/EC	0.03	(0.13)	0.80	0.41	(0.66)	3.61	0.25	(0.51)	3.20	0.74	(1.00)	4.38	0.81	(1.77)	13.21
Word + Smile/EC	0.00	(0.00)	0.00	0.01	(0.09)	0.80	0.03	(0.16)	1.20	0.19	(0.65)	4.39	0.52	(0.95)	4.00
Gesture + NWV/Word	0.08	(0.21)	0.80	0.61	(1.23)	6.80	0.69	(1.02)	4.80	2.05	(2.85)	17.20	3.84	(4.06)	19.60

EC eye contact, *NWV* non-word vocalization

birth order (first born vs. later born) or EI services (yes vs. no) on the rate of communicative acts or the rate of Coordinated Bouts at any age.

Developmental Trajectories

Descriptive data on rates of Coordinated Bout production and rates of occurrence of different types of Coordinated Bouts are presented in Table 4, and the final model summaries are presented in Table 5. As noted above, the LR group was entered into all models as a reference group; therefore, the coefficients generated for the HR-ND, HR-LD, and HR-ASD groups reflect deviations in intercept, slope and/or acceleration from the LR group.

Coordinated Bouts

To examine overall developmental change in coordination of communicative behaviors, growth models were estimated for the rate of production (per 10 min) of Coordinated Bouts. Preliminary analyses indicated that while the intercept term (i.e., starting point) was significantly different from zero, it did not vary significantly between children; all groups produced Coordinated Bouts at a similar rate at 8 months. The final HLM model included a fixed intercept term and significant random effects of linear age, and outcome group was included as a significant predictor ($\beta_{10} = 0.83$, $t(75) = 6.34$, $p < .001$; see Table 5).[6] While the rates of production of coordinated communication for the HR-ND and HR-LD groups were slightly lower than that estimated for the LR comparison group (0.83 bouts per 10 min, per month), differences were not statistically significant. However, relative to the LR comparison group, the HR-ASD group grew at a significantly slower rate ($\beta_{13} = -0.74$, $p < .001$). In fact, the slope term was close to zero, indicating that infants in the HR-ASD group showed almost no growth in the production of Coordinated Bouts between 8 and 18 months (see Fig. 1). The difference between the HR-ASD and LR group in the production of Coordinated Bouts became significant at 12 months of age ($p < .009$). By 18 months, the level of Coordinated Bouts in the HR-ASD group was almost 2 SD below that of the LR group.

To address the issue of specificity, additional analyses examining differences between HR-ASD infants and other HR outcome groups indicated that the growth rate in Coordinated Bouts for the HR-ASD group also differed from the HR-ND group ($p = .001$) and the HR-LD group ($p = .019$). While group differences between the HR-ASD and HR-ND groups were significant at 12 months ($p = .003$), significant differences between HR-ASD and HR-LD infants were not observed until 14 months ($p = .02$). There were no other significant between group differences in production of Coordinated Bouts.

Types of Coordinated Bouts

Next, the composition of Coordinated Bouts was examined across the 8- to 18-month period by classifying coordinations as developmentally-prior or developmentally-advanced based on the specific behaviors they included.

Descriptive statistics for each type of coordination for the overall sample are presented at the bottom of Table 4. These data indicate that infants produced Gesture + Smile/EC and Word + Smile/EC Bouts at very low frequencies

[6] Differences remained even after controlling for overall communicativeness. Further, variables of interest were calculated as proportion of total communicative acts and raw data was plotted. Visual inspection of the data suggested that proportion variables followed the same developmental patterns (in terms of both overall developmental pattern and group differences in trajectories) as those calculated as rates.

Table 5 Final growth models of gender and outcome group predicting growth trajectories for rate (per 10 min) of coordinated communicative behaviors

	All Coordinated Bouts[a]		Social Smiles		Directed Vocalizations		Gesture + NWV/W	
	Coefficient	*SE*	Coefficient	*SE*	Coefficient	*SE*	Coefficient	*SE*
Intercept								
Intercept (β_{00})	3.46***	0.47	0.98***	0.18	2.59***	0.26	0.08	0.07
Growth rate								
Linear time (β_{10})	0.83***	0.12	0.06	0.03	0.06	0.04	0.09	0.11
Male	−0.08	0.13					−0.22	0.13
HR-ND	−0.14	0.16					0.20	0.18
HR-LD	−0.32	0.18					−0.11	0.15
HR-ASD	−0.74***	0.13					0.00	0.11
Acceleration								
Quadratic time (β_{20})							0.04*	0.02
Male							0.02	0.02
HR-ND							−0.03	0.03
HR-LD							−0.02	0.02
HR-ASD							−0.05**	0.02
Variance components								
Var. in intercept (r_{0i})			0.29		0.71			
Var. in growth rate (r_{1i})	0.35***		0.02		0.01		0.47***	
Var. in acceleration (r_{2i})							0.07***	
Level-1 error (e_{ti})	5.61		3.99		8.36		1.34	
No. of parameters (FIML)	8		6		6		15	
Deviance (FIML)	2463.70		1663.97		1929.90		1552.05	

NWV non-word vocalizations, *HR-ND* high risk-no diagnosis, *HR-LD* high risk-language delay, *HR-ASD* high risk-autism spectrum disorder, *FIML* full information maximum likelihood

* $p < .05$; ** $p < .01$; *** $p < .001$

[a] Contained one outlier

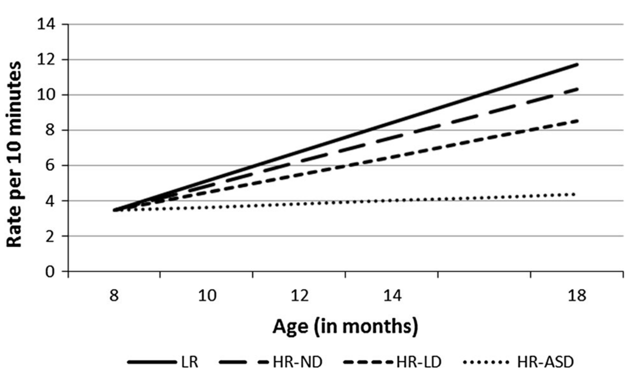

Fig. 1 Developmental trajectories of Coordinated Bouts by outcome group from 8 to 18 months of age

throughout the observation period. In fact, the mean rate of these types of bouts did not rise above 0.81 acts per 10 min across the 8- to 18-month age range. As a result, it was not possible to estimate reliable HLM models, even after data transformation methods were attempted (i.e., reliability estimates <.20).

Developmental change in the mean rates of Social Smiles and Directed Vocalizations was analyzed first. The initial rate of Social Smiles at 8 months was significantly different from zero ($\beta_{00} = 0.98$, $t(79) = 5.53$, $p < .001$), but did not vary significantly between groups, ($p > .10$). Further, little developmental change in this type of bout was indicated ($\beta_{10} = 0.06$, $t(79) = 1.71$, $p = .090$). This suggests that, as expected, Social Smiles are a part of infants' communicative repertoires at 8 months, regardless of diagnostic outcome, and remain so consistently over time.

The pattern of results was similar for Directed Vocalizations. While the initial rate of Directed Vocalizations was significantly different from zero ($\beta_{00} = 2.59$, $t(79) = 9.99$, $p < .001$), and higher than that observed for Social Smiles, no significant between-group differences were detected for initial rate or growth rate over time. The slope term was non-significant, indicating little change in these types of behaviors over time ($\beta_{10} = 0.06$, $t(79) = 1.40$, $p > .10$). Thus, it appears that Directed Vocalizations are a more prominent part of the communicative repertoire than Social Smiles, and that infants in all outcome groups

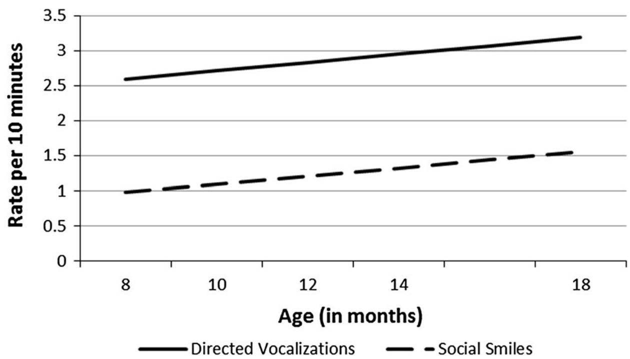

Fig. 2 Developmental trajectories of developmentally-prior Coordinated Bouts for all infants from 8 to 18 months of age

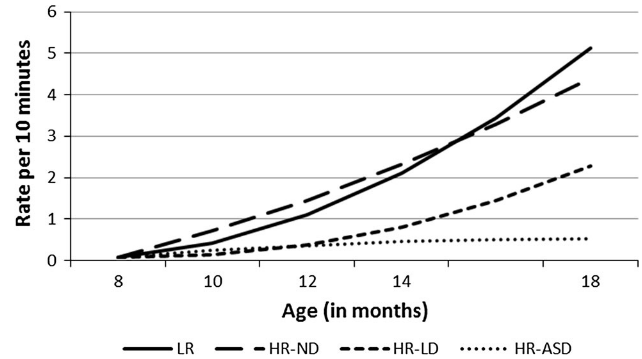

Fig. 3 Developmental trajectories of Gesture + NWV/W Bouts by outcome group from 8 to 18 months of age

produced both types of developmentally-prior coordinations at similar rates. Because between-child variation was not indicated in the unconditional analyses, Level 2 conditional models were not estimated for either type of bout. Overall, these results indicate that all four groups showed similar levels of Social Smiles and Directed Vocalizations at 8 months, and that levels of these behaviors did not change substantially with age (see Fig. 2).

Turning now to *developmentally-advanced* coordinations, the rate of Gesture + NWV/W coordinations was also low at 8 months but increased steadily with time (see Table 4) so that by 18 months, all infants taken as a group were producing, on average, 3.84 Gesture + NWV/W Bouts per 10 min. Preliminary growth models for Gesture + NWV/W Bouts revealed that the initial value (i.e., intercept at 8 months) was not significantly different from zero and variance components indicated that there were no significant between-group variation in intercept (i.e., level at 8 months). The final HLM model therefore included a fixed intercept and significant terms for linear and quadratic effect of time (i.e., age). While significant variation was detected in the linear term, group status was not a significant predictor of this variance. However, significant group differences were apparent in the quadratic effect of time for Gesture + NWV/W Bouts ($\beta_{20} = 0.04$, $t(75) = 2.66$, $p = .01$; see Table 5). This suggests that there were systematic differences between outcome groups in the acceleration (i.e., curvature) of Gesture + NWV/W coordinations.

Further analyses indicated that the LR, HR-ND, and HR-LD groups did not differ significantly in slope or acceleration, suggesting that the acquisition and development of Gesture + NWV/W coordinations is comparable for HR infants without a later diagnosis of ASD and LR infants. By contrast, infants who were later diagnosed with ASD exhibited significantly slower acceleration in this type of Coordinated Bout over time compared to the LR group, ($\beta_{23} = -0.04$, $t(75) = -2.87$, $p = .006$).[7] As is apparent in Fig. 3, the trajectory for the HR-ASD group remained fairly flat throughout the 8- to 18-month period, indicating little growth in this type of coordination over time. The difference between the trajectories of Gesture + NWV/W combinations for the HR-ASD and LR groups was significant as early as 12 months ($p = .002$) and remained significant through 18 months ($p = .002$). The HR-ASD group was not significantly different from the HR-ND or HR-LD groups in growth rate or acceleration.

Because visual inspection of the group trajectories depicted in Fig. 3 suggests that the HR-LD group began to diverge from the HR-ASD group around 12 months of age, a post hoc analysis was conducted with time re-centered at 12 months and the HR-LD group as the reference. Moreover, since gesture-speech combinations are a fairly low frequency behavior at 8 months, re-centering the starting point for the trajectory allowed us to improve the interpretability of the intercept (thereby detecting group differences when present), while still utilizing any data points prior to 8 months (Singer and Willett 2003).

This analysis resulted in a new set of intercept, slope, and acceleration parameters that reflected the mean frequency of Gesture + NWV/W Bouts at 12 (instead of 8) months of age. Figure 4 illustrates the group trajectories using the new parameters with time centered at 12 months. Comparison of these parameters indicated that the intercepts exhibited significant random variance and group status was a significant predictor of variation. HR-LD and ASD groups exhibited significantly lower intercepts than LR and HR-LD groups but did not differ from one another in rate of Gesture + NWV/W Bouts at 12 months. Importantly, however, the HR-ASD slope was significantly lower than that of the HR-LD group at 12 months ($\beta_1 = -0.09$, $t(75) = -1.94$, $p = .044$); there was also a non-significant trend for acceleration of growth ($\beta_2 = -0.03$, $t(75) = -1.73$, $p = .087$). When time was centered

[7] Results were identical when assessing for group differences in Gesture + NWV combinations alone. Gesture + Word combinations were not analyzed separately due to their low frequency.

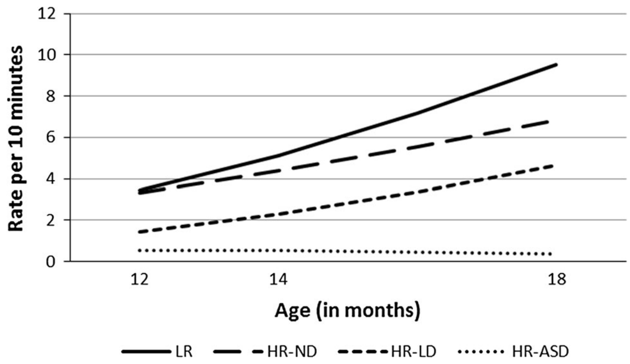

Fig. 4 Developmental trajectories of Gesture + NWV/W Bouts by outcome group from 8 to 18 months of age with time re-centered at 12 months

at 18 months, the group difference (at that specific point in time; i.e., intercept) between HR-ASD and HR-LD in the mean rate of production of Gesture + NWV/W Bouts reached statistical significance ($\beta_0 = -1.76$, $t(75) = -2.32$, $p = .023$). Thus, it appears that both HR-LD and HR-ASD infants demonstrated an initial delay in production of Gesture + NWV/W Bouts. However, by 12 months of age, Gesture + NWV/W Bouts began to emerge for HR-LD infants and then developed at a rate comparable to those for LR and HR-ND children (even though these types of bouts were still produced less frequently overall). By contrast, when examining the trajectory of these coordinations at multiple points from 8 to 18 months, the developmental course appeared deviant (i.e., atypical) for HR-ASD infants; this deficit in coordinating vocal utterances and gestures was most clearly evident by 18 months.

Discussion

The goals of this research were to examine developmental trajectories in coordination of social communicative behaviors from 8 to 18 months in HR and LR infants in order to: (a) describe the development of coordinated communication in HR infants and identify any group differences that might exist between HR and LR infants; (b) determine whether differences in developmental trajectories during early infancy may identify infants who receive a later diagnosis of ASD; and (c) examine whether delays and/or deviance in the development and coordination of communicative behaviors are specific to ASD rather than an index of general communicative delay. Overall, findings point to the value of a comprehensive approach that examines the communicative system as a whole by measuring both preverbal and verbal aspects of communication. They also underscore the importance of examining the course of developmental change over time.

What is the Nature of Coordinated Communication Development in HR Infants?

The current study extends previous findings on social communication in HR infants by examining a wider range of communicative behaviors, including the *coordination* of gesture, smiles, eye contact, NWVs, and words, spontaneously initiated by the child in everyday communication in the naturalistic environment of the home. One primary finding was that no differences were detected between LR and HR-ND groups in mean rates of Coordinated Bouts overall or in mean rates of either developmentally-prior or developmentally-advanced bouts. This stands in contrast to previous reports of significantly lower rates of communication among HR infants relative to LR peers (e.g., Cassel et al. 2007; Mitchell et al. 2006; Toth et al. 2007; Winder et al. 2013; Yoder et al. 2009). However, prior studies have adopted different approaches to characterizing HR infants. Some did not separate HR infants later diagnosed with ASD from those with no such diagnosis in their HR sample (e.g., Cassel et al. 2007). Others failed to distinguish HR infants with language delay but no ASD from those with no diagnosis (e.g., Toth et al. 2007; Winder et al. 2013; Yoder et al. 2009). The current study highlights the fact that a sizeable portion of HR infants (56 %) appear indistinguishable from their LR peers. For a majority of children, in other words, being at "heightened risk" (i.e., having an older brother or sister with ASD) is not synonymous with manifesting later delays or autism symptomatology (see also Messinger et al. 2013).

Can Differences in the Development of Coordinated Communication Identify Infants Later Diagnosed with ASD?

The present investigation contributes to a growing body of developmental research on early social communication skills by evaluating the extent to which delayed and/or atypical patterns of coordinated communicative behaviors can be used to identify children eventually diagnosed with ASD. By tracking development over time, it was possible to identify with greater accuracy the point in development where behavioral symptoms of ASD began to emerge. Developmental trajectories modeled across the 8- to 18-month period for the HR-ASD group deviated in significant ways from the HR-ND and LR groups for rates of Coordinated Bouts and Gesture + NWV/W Bouts. Specifically, relative to comparison groups, HR-ASD infants demonstrated virtually no growth in these behaviors over time. ASD growth trajectories diverged from the LR and HR-ND groups as early as 12 months of age (but not before), and became more discrepant over time.

This pattern of results is also consistent with previous work demonstrating that older children with ASD are often especially impaired in the coordination of communicative behaviors (Adrien et al. 1987; Buitelaar et al. 1991; Wetherby et al. 1989), and with more recent research with toddlers indicating that children later diagnosed with ASD demonstrate a lack of coordination of gaze, facial expressions, gesture, and vocalization relative to TD and developmentally delayed children (e.g., Shumway and Wetherby 2009; Wetherby et al. 2004).

Are Deficits in Social Communication Coordination Specific to ASD?

A unique aspect of the design of the current study was that it identified a subset of infants from the original HR group who did not receive an ASD diagnosis but met criteria for language delay (i.e., HR-LD). Specific comparison of infants and toddlers with LD versus ASD is important since language delay is often the first developmental disruption suspected by parents of children with ASD (Filipek et al. 1999). Not only were there significant differences between the HR-ASD and HR-LD groups in frequency of Coordinated Bouts overall; our data indicated specifically that Coordinated Bouts involving gestures and vocal utterances (NWV or words) distinguished infants with ASD from HR-LD infants. That is, Gesture + NWV/Words were the only coordinated communicative behavior studied for which HR-ASD infants also differed from HR-LD infants in developmental course. In comparison to LR and HR-ND infants, the HR-LD group demonstrated similar starting levels of these communicative behaviors at 8 months; and despite a slight delay at first, these infants exhibited increasing trajectories. By contrast, infants in the HR-ASD group displayed persistent delays. This finding suggests that infants with ASD have a specific and unique difficulty coordinating vocal utterances and gestures, particularly with one another. The coordination (i.e., temporal integration) of gesture with speech in older children with ASD has also been identified as a distinct feature of the disorder. Gesture-speech asynchrony is evident even when overall levels of gestures are similar to comparison groups and has been shown to negatively affect the perceived quality of social interactions (de Marchena and Eigsti 2010).

Early gesture-vocalization combinations may have important consequences for later social and linguistic development by more effectively establishing joint reference between an infant and his/her social partner (i.e., joint attention; Winder et al. 2013). Thus, an infant who not only points at something of desire or interest but vocalizes while doing so produces a powerful stimulus for parent behavior, a stimulus likely to bring about a state of joint attention. For example, a parent who is engaged in her own activities might very well fail to notice her infant silently pointing to a cat. But when the infant accompanies her point with a vocalization, the parent is much less likely to miss the gesture and may be more likely to shift attention to the object of infant desire or interest, possibly then providing a verbal label or comment about the object (e.g., "Yes, that's a kitty, look at the kitty, what a nice kitty").

Prior work has established the importance of NWVs for directing parental attention (e.g., Hsu and Fogel 2001; Gros-Louis et al. 2006). Moreover, research showing that mothers increase the length of their responses selectively to specific types of gesture-speech combinations suggests the value of coordinated NWVs for creating social learning opportunities (Goldin-Meadow et al. 2007). Thus, coordinated communication involving NWVs may serve to establish episodes of joint attention in which important input from a social partner may be elicited. Some evidence for this possibility is provided by a recent study examining maternal responses to coordinated communication produced by 12 HR and 15 LR infants during mother–child play at home when infants were 18 months old (Leezenbaum et al. 2014). Results indicated that mothers of HR and of LR infants almost always responded verbally to their infant's gestures produced alone as well as to gestures coordinated with NWVs. However, mothers in both groups were significantly more likely to respond with translations (i.e., verbally labeling a gesture referent) to infant gestures that were coordinated with NWVs than to gestures produced alone.

If infants later diagnosed with ASD demonstrate reduced frequency of gesture-vocalization combinations, they may also have fewer opportunities to establish shared states of attention during which linguistic and social learning occur. In other words, the deficit in coordinated communication exhibited by ASD infants in this study may have altered the input that these infants received from their environment. Caregivers may have been less likely to provide verbal labels and/or engage in episodes of shared reference (i.e., joint attention) as a result of ASD infants producing qualitatively less complex communicative bids. The absence of such experiences and loss of timely learning opportunities may negatively impact additional aspects of communication and social development (Mitchell et al. 2006; Yirmiya et al. 2006; Yirmiya and Ozonoff 2007).

In summary, findings from this study suggest three major conclusions. First, while a subset of non-ASD HR infants also experienced delays in language (HR-LD), the majority of HR infants demonstrated communication skills more comparable to those of LR infants. Second, behavioral symptoms of ASD within the social communication domain appear to emerge over time, beginning just after the first birthday and becoming more pronounced by

18 months. Finally, infants with ASD do not appear to have widespread difficulties in the production and coordination of all social communication behaviors; rather, they demonstrate a pronounced deficit in the coordination of more developmentally advanced behaviors. In particular, deviant trajectories indicating the absence of growth in coordinated vocalizations and gestures emerged as a unique predictor of ASD.

While more research with larger sample sizes, longer sampling of behavior, and additional clinical comparison groups (e.g., infants with cognitive delays but without ASD) are needed to replicate and clarify the full import of the findings presented here, these results underscore the importance of examining the multimodal coordination of communicative behaviors in naturalistic settings over time. By identifying patterns of communicative behaviors that are *specific* and *unique* to ASD (e.g., gesture-vocalization coordinations), we can begin to isolate early markers of the disorder. This will not only contribute to our understanding of how ASD unfolds in early infancy but may also be useful in refining and guiding more effective treatment interventions.

Acknowledgments This research was supported by an Autism Speaks Sir Dennis Weatherstone Predoctoral Fellowship, an American Psychological Association Dissertation Research Award, and an A. David Lazovik Research Award from the Department of Psychology at the University of Pittsburgh to Meaghan V. Parladé, and by Grants from Autism Speaks and the National Institutes of Health (R01 HD41607 and R01 HD054979) to Jana M. Iverson. Additional support was provided by HD35469 and HD055748 to Nancy J. Minshew. We would like to extend special thanks to the infants and their families without whose enthusiastic participation this research could not have been completed. We also thank the members of the Infant Communication Lab at the University of Pittsburgh for helping with data collection; Kaitlin Schuessler, Allison Rosenthal, and Nina Leezenbaum for assistance with coding and establishing reliability; and Celia Brownell, Susan Campbell, Michael Pogue-Geile, Elizabeth Votruba-Drzal, Diane Williams, Erin Koterba, and Eve Sauer LeBarton for their intellectual contributions throughout the project.

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