RESEARCH ARTICLE

Conversational Gestures in Autism Spectrum Disorders: Asynchrony but not Decreased Frequency

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Conversational or "co-speech" gestures play an important role in communication, facilitating turntaking, providing visuospatial information, clarifying subtleties of emphasis, and other pragmatic cues. Consistent with other pragmatic language deficits, individuals with autism spectrum disorders (ASD) are said to produce fewer conversational gestures, as specified in many diagnostic measures. Surprisingly, while research shows fewer deictic gestures in young children with ASD, there is a little empirical evidence addressing other forms of gesture. The discrepancy between clinical and empirical observations may reflect impairments unrelated to frequency, such as gesture quality or integration with speech. Adolescents with high-functioning ASD ($n = 15$), matched on age, gender, and IQ to 15 typically developing (TD) adolescents, completed a narrative task to assess the spontaneous production of speech and gesture. Naïve observers rated the stories for communicative quality. Overall, the ASD group's stories were rated as less clear and engaging. Although utterance and gesture rates were comparable, the ASD group's gestures were less closely synchronized with the co-occurring speech, relative to control participants. This gesture–speech synchrony specifically impacted communicative quality across participants. Furthermore, while story ratings were associated with gesture count in TD adolescents, no such relationship was observed in adolescents with ASD, suggesting that gestures do not amplify communication in this population. Quality ratings were, however, correlated with ASD symptom severity scores, such that participants with fewer ASD symptoms were rated as telling higher quality stories. Implications of these findings are discussed in terms of communication and neuropsychological functioning in ASD.

Keywords: conversational gestures; autism; synchrony; communication; narratives

Introduction

Individuals with autism spectrum disorders (ASD) exhibit striking impairments in socialization and communication. In many language-disordered populations, affected individuals compensate for decreased verbal output via nonverbal communication; thus, increased rates of gesturing are observed in adults with acquired aphasia [Buck & Duffy, 1980] and children with expressive language delay [Thal & Tobias, 1992] and Down syndrome [Stefanini, Caselli, Nusbaum, & Small, 2007]. These data suggest a speech-specific origin of communicative impairments in these populations: communicative intent appears relatively intact despite decreased verbal output. In contrast, communicative impairments in ASD are characterized as more global. Clinicians have long reported abnormalities in *both* verbal and nonverbal forms of communication [e.g., Kanner, 1943]. For example, the original account of Asperger syndrome described the "large," "clumsy," and "inappropriate" nature of gestures [Asperger, 1944, from Wing, 1981]. Early clinicians described the atypical composition of gestures, their poor integration with speech, and a general decrease in gesture quantity. A precise characterization of nonverbal communication impairments in ASD, including conversational gestures, is essential to our broader understanding of communication in ASD. In the current study, we characterize communicative gestures produced by high-functioning adolescents with ASD, link this characterization to broader ASD symptomatology, and suggest that gesture is primarily affected in ASD via its synchrony with speech, as opposed to simple measures of gesture frequency.

Gesture is studied within the fields of neuropsychology and psycholinguistics. Within neuropsychology, gesture (or praxis) is conceptualized as a motor rather than a communicative process, and is defined as the ability to perform purposeful motor movements with or without objects [Heilman & Gonzalez Rothi, 2003]. In contrast, psycholinguists define gestures as spontaneous *communicative* hand movements that *accompany* speech [McNeill, 1992]. Co-speech gestures, in this latter sense, are the focus of this study. Specifically, we focus on *iconic* gestures, termed "descriptive gestures" on the Autism Diagnostic Observation Schedule [ADOS; Lord, Rutter, DiLavore, & Risi, 2002]. Iconic gestures depict physical

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properties of referents, often giving information that complements co-occurring speech (for example, a throwing motion complements, "he threw the coconut").

The presence of communicative gesture deficits in ASD is widely asserted in the clinical literature. Impairments in gesture are codified on gold-standard ASD diagnostic measures and screeners such as the ADOS [Lord et al., 2002], the Autism Diagnostic Interview [ADI; Lord, Rutter, & LeCouteur, 1994], and the M-CHAT [Robins, Fein, Barton, & Green, 2001]; on these measures, the absence or infrequency of gesture is rated as symptomatic. Scoring criteria for these diagnostic measures suggest that individuals with ASD use *all* gestures less than their typically developing (TD) peers; however, this assertion has not been demonstrated in the empirical literature. Protodeclarative pointing (i.e., pointing to share attention), but not instrumental pointing (i.e., pointing to request), is found to be reliably reduced in frequency in ASD [Bono, Daley, & Sigman, 2004; Camaioni, Perucchini, Muratori, & Milone, 1997; Loveland & Landry, 1986; Mundy, Sigman, Ungerer, & Sherman, 1986; Mundy, Sigman, & Kasari, 1990], a finding which highlights that the *social* aspects of these gestures likely contribute to their delayed production [Baron-Cohen, 1989; Klin, Jones, Schultz, Volkmar, & Cohen, 2002]. However, the literature on non-pointing gestures in ASD is sparser and less conclusive; specifically, reductions in gesture frequency are not well replicated. It may be that children with ASD simply *appear* to gesture less due to overall reductions in communicative acts. For example, early studies found reduced rates of gesture in children with ASD [Bartak, Rutter, & Cox, 1975], and more recent studies have observed gesture delays [Charman, Drew, & Baird, 2003; Luyster, Lopez, & Lord, 2007]. However, others have failed to find group differences in gesture frequency after controlling for overall amount of speech [Attwood, Frith, & Hermelin, 1988; Capps, Kehres, & Sigman, 1998]. In fact, some have found iconic gestures to be a relative communicative strength for children with ASD, perhaps because enacting experiences is more accessible than verbalizing them [Capps et al., 1998], and consistent with gesture use in other speech-disordered populations (described above). Children with ASD also show a reduced variety of gestures [Colgan et al., 2006; Wetherby & Prutting, 1984], which may strengthen the impression of fewer gestures.

In addition to reductions in overall communicativeness, clinicians may be sensitive to gesture *quality*, a less-studied aspect of nonverbal communication in ASD. Studies of adults with ASD show few differences in the frequency or duration of nonverbal communication directed at conversational partners [García-Pérez, Lee, & Hobson, 2007; Tantam, Holmes, & Cordess, 1993]; however, ASD groups differ in more subjective ratings, such as "conversational flow" [García-Pérez et al., 2007]. Qualitative differences in gestures, such as "odd" greeting waves, have been noted [Hobson & Lee, 1998]. In fact, unusual quality, in addition to quantity, of gestures has long been central to clinical accounts of ASD [e.g., Asperger, 1944; Wing, 1981]. Qualitative aspects of conversational gestures (e.g., "exaggerated" gestures), as well as the integration of distinct forms of verbal and nonverbal communication, including gesture, are coded on ADOS modules intended for individuals with fluent speech. One study of adults with ASD examined the co-occurrence of speech and nonverbal communication during conversation [Tantam et al., 1993]; this study measured the co-occurrence of speech and gesture within half-second intervals. Co-occurrence of these behaviors was found in both the ASD group and controls, though co-occurrence was reduced in the ASD group; unfortunately this observation was not addressed statistically. In addition, since the behaviors were coded in half-second intervals (a fairly low resolution for speech and gesture), the *degree* of asynchrony could not be determined. The authors suggested that gesture and speech might be less synchronous in ASD, but did not quantify this asynchrony.

In TD children and adults, gesture accompanies and amplifies information conveyed in speech [McNeill, 1992]. Conversational partners are sensitive to gestural content, and will incorporate information provided only in gesture into speech [Cassell, McNeill, & McCullough, 1998]. The main motion (stroke phase) of a gesture reliably occurs in synchrony, and is exquisitely well-timed, with its semantically related speech [Chui, 2005; Levelt, Richardson, & La Heij, 1985; McNeill, 1992; Nobe, 2000]. Although gesture can communicate information that is not found in speech, its communicative power is reduced in the absence of speech [Krauss, Morrel-Samuels, & Colasante, 1991], suggesting that it is the *integration* of gestures with speech that provides communicative power. In typical adults, gesture–speech comprehension is dependent on timing [Habets, Kita, Shao, Özyurek, & Hagoort, 2010]; thus, when gestures are poorly synchronized with speech, their communicative power may be diminished. The integration of gesture and speech—the coordinated timing of these behaviors—is the focus of this study. Impairments in gesture–speech coordination by individuals with ASD may account for discrepancies in the clinical and empirical literatures. Specifically, gestures produced by individuals with ASD may be poorly integrated with speech, thereby reducing communicative power. Thus, *while gestures may be equally present in ASD* (consistent with the empirical literature), *their effectiveness in communication may be reduced* (consistent with the clinical literature).

Gesture–speech synchrony requires the efficient coordination of distinct behaviors. There is a growing literature demonstrating impairments in behavioral timing in ASD. Specifically, electrophysiological studies have shown delayed responses to social stimuli by children

with ASD, as compared to typical peers [McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; Webb, Dawson, Bernier, & Panagiotides, 2006]. A recent electromyography study of facial mimicry showed that children with ASD differed from typical peers only in terms of their latency to mimic, but not in the amount and appropriateness of mimicry [Oberman, Winkielman, & Ramachandran, 2009]. These findings suggest that deficits in interpersonal synchrony may reflect inefficient *timing*, rather than *execution*. Timing impairments may also be present in non-social cognitive processes [Sears, Finn, & Steinmetz, 1994].

Abilities in ASD appear to be more normalized in conditions of high structure and explicit attention, relative to spontaneous production. This phenomenon applies to gesture: when children with ASD are specifically instructed to gesture, their gestures appear more typical [Bartak et al., 1975]. Research on how gesture, as a communicative tool, is limited in ASD, should thus begin with spontaneous, rather than prompted, communication. The current study used a narrative task from the ADOS [Lord et al., 2002] to elicit speech and gesture. This task prompts participants to tell a story based on six picture cards, allowing for a high degree of spontaneity; participants were not instructed to gesture. This task thus provides a spontaneous communication sample that is structured enough to allow comparisons between groups and individuals. We use this task to assess verbal and gestural communication, and to measure the degree of synchrony between these two modalities. These data provide quantitative information on gesture production, its integration with speech, and the degree to which gestures are related to autistic symptomatology.

Method

Participants

Participants were 20 adolescents with ASD and 16 adolescents with TD matched on chronological age, gender, and full-scale IQ [Stanford-Binet, Fifth edition; Roid, 2003]. Table I provides demographic information by group. Diagnoses, based on DSM-IV [APA, 2000] criteria, were confirmed in the ASD group and ruled out in the TD group using the ADOS [Lord et al., 2002], the Social Communication Questionnaire [Rutter, Bailey, & Lord, 2003], and clinical judgment. Nine participants met criteria for Autistic Disorder, five for PDD-NOS, and one for Asperger's Disorder.

Participants with ASD were not excluded for comorbid learning or psychiatric disorders. Likewise, participants

Table I. Demographic Information for Participants with ASD and TD Control Participants

	Group				
	ASD *M* (SD) Range	TD *M* (SD) Range	χ^2 or *F*	*P*	η_p^2
N	15	15			
Gender (M:F)	13:2	14:1	0.37	0.54	
Chronological age (years)	15.0 (1.5)	15.0 (1.5)	0.01	0.93	<0.01
	12.4–17.3	12.8–17.6			
Stanford-Binet					
Nonverbal	10 (1.6)	11 (2.0)	2.68	0.11	0.09
	7–12	6–13			
Verbal	11 (2.6)	10 (1.6)	1.63	0.21	0.06
	6–16	7–13			
Full-scale IQ	103 (9.9)	103 (8.9)	0.003	0.95	<0.01
	85–118	82–115			
ADOS					
Communication (C)	2.7 (1.0)	0.3 (1.0)	68.60	<0.001	0.71
	1–4	0–1			
SR	7.3 (1.9)	0.3 (0.6)	184.19	<0.001	0.87
	2–10	0–2			
C+SR[a]	9.9 (2.6)	0.6 (0.6)	185.66	<0.001	0.87
	3–13	0–2			
SCQ (total score)[b]	20.6 (6.8)	1.9 (2.9)	88.09	<0.001	0.78
	10–29	0–9			

ASD, autism spectrum disorder; TD, typically developing; ADOS, Autism Diagnostic Observation Schedule; SR, social reciprocity; SCQ, Social Communication Questionnaire.

[a]On the ADOS, 7 is the cutoff for a diagnosis on the autism spectrum, 10 is the cutoff for autism. All ASD participants in the final sample, except one, were above the cutoff for an ASD diagnosis on the ADOS; this participant had a high SCQ score (20) and was judged to carry an ASD diagnosis by clinicians on the study.

[b]When used as a screening instrument, a cutoff score of 15 is recommended as an indication of a possible ASD [Rutter et al., 2003].

with TD were not excluded for non-ASD learning or psychiatric disorders, to avoid obtaining a "hypernormal" comparison group. Participants with TD were excluded, however, if they had any first-degree relatives with ASD or any history of neurological problems.

Five participants from the ASD group were excluded for the following reasons: ASD diagnosis not confirmed ($n = 1$), IQ below 80 ($n = 3$), and failed digital recording ($n = 1$); these individuals are not included in subsequent analyses. One participant with TD was excluded because he had a mild form of cerebral palsy. The final sample consisted of 15 adolescents with ASD and 15 adolescents with TD, all of whom had IQ scores within the average range.

This study was approved by the University of Connecticut Institutional Review Board. Written consent or assent was obtained from parents and participants.

Measures

Autism Diagnostic Observation Schedule [ADOS; Lord et al., 2002]. The ADOS is a semistructured assessment for the diagnosis of pervasive developmental disorders. Participants completed either Module 3 or Module 4, depending on their maturity level. Six participants from each group completed Module 3, and nine participants from each group completed Module 4. Modules 3 and 4 provide comparable scores, so scores for the two modules were collapsed; data are presented in Table I. The cartoons task from the ADOS is an optional task designed to assess gestural communication and the integration of verbal and nonverbal communication. This task (hereafter, the *narrative task*) served as the primary experimental measure of gesture and speech production.

Social Communication Questionnaire [SCQ; Rutter et al., 2003]. The SCQ is a 40-item parent questionnaire for the screening of ASD symptoms in children, based on the ADI-R [Lord et al., 1994], a major tool used for diagnosing ASD. Parents of 27 participants across both groups completed this questionnaire; three parents (one from the TD sample, and two from the ASD sample) were unable to complete and return the measure.

Stanford-Binet Intelligence Scale: Fifth Edition [Roid, 2003]. The Stanford-Binet is a factor-analytic measure of intellectual functioning. Participants completed the vocabulary and matrices subtests, providing a reliable estimate of verbal and nonverbal cognitive functioning.

Experimental Task

Procedures. All participants were tested in a quiet room at the University of Connecticut, in their homes, or at school. Measures included in this study were collected as part of a larger battery lasting approximately 4 hr over one or two sessions.

Stimuli for the narrative task were six (7 by 8.5 in) cards containing black-and-white line drawings depicting the story of two monkeys.[1] Participants were instructed to examine the cards and then they would be asked to tell the story to the experimenter. Participants viewed the cards one at a time; the cards were then removed and the participant was asked to stand up and tell the story. Participants who began speaking with their hands in their pockets were asked to remove them. No further instructions were given, and participants were never explicitly instructed to gesture. Narrations were recorded on digital video for transcription, gesture coding, and synchrony analyses.

Behavioral coding. The narrative task was used to assess the frequency and types of gestures used spontaneously during storytelling, naïve listeners' perceptions of story quality, and the temporal synchrony between gestures and speech. All coders and story raters were trained research assistants (RAs) naïve to study hypotheses and participant diagnosis.

Speech transcription. Speech was transcribed from digital recordings using CLAN [Computerized Language Analysis Software; MacWhinney, 2000]. All words and pauses were transcribed, and speech was broken into separate utterances based on a combination of linguistic and suprasegmental cues.

Identifying and coding gesture categories. All gestures produced during narrations were identified and categorized according to McNeill's [1992] taxonomy. Gesture coding quantified the number and types of gestures produced during narrations.[2] Movements that were determined to be gestures were classified as either: (1) iconic gestures ("descriptive" gestures on the ADOS, which depict the physical properties of objects or actions), (2) metaphoric gestures (i.e., gestures with abstract referents), (3) deictic gestures (i.e., pointing), (4) beat gestures (i.e., gestures with minimal semantic content that are timed with speech prosody), or (5)

[1]The six cards depict the following story: (1) A monkey (Monkey A) is up in a tree picking coconuts. (2) A second monkey (Monkey B) is leaning against a tree and a coconut lands in front of him; he appears surprised. (3) Monkey B picks up the coconut. (4) Monkey A looks down to where the coconut was and appears confused. We also see Monkey B running off with the coconut. (5) Monkey A drops a second coconut from the tree, and we see Monkey B running back to retrieve it. (6) Monkey B leans over to take the new coconut, as Monkey A throws a coconut and hits Monkey B in the head.

[2]One challenge of gesture coding is differentiating simple movements from gestures. Adolescents with ASD might make movements that are more erratic and difficult to interpret. If coding is relatively more difficult or unreliable for gestures produced by the ASD group, this introduces a potential confound. To address this challenge, prior to beginning gesture coding, videos were watched in their entirety with a focus on the participant's movements and mannerisms. Then, once coders began gesture coding, it was easier to differentiate gestures from non-communicative movements, as the coder already had a sense of the participant's movements.

emblems ("conventional" gestures on the ADOS, such as an "ok" sign).

Ratings of story quality. RAs ($n = 10$) rated each story on two 7-point scales. These RAs had not participated in prior speech or gesture coding. Each story was rated according to two questions: (1) How well were you able to follow this story? and (2) How engaged were you during this story? To determine the relative contributions of verbal and nonverbal communication to story ratings, raters were instructed to listen to half of the stories without the accompanying video (*radio* condition) and watch the other half with both audio and video (*TV* condition). Condition and group were counterbalanced across raters.

Gesture–speech synchrony. Synchrony coding entails determining the start and endpoint of a gesture and its semantically related speech. Coders must be confident about what speech co-occurs with a given gesture. It is more difficult to determine the semantically related speech for gestures with ambiguous meanings. This might be especially confounding if gesture clarity is reliably lower for one group. To address this issue, only iconic gestures were included, as these gestures were produced frequently by participants across groups, and because the intended meaning of these gestures is the most transparent. Gesture–speech synchrony was coded for all participants who produced at least one iconic gesture during their narration. For each iconic gesture, the co-occurring speech was determined in two stages. First, based on the form and motion of the gesture, the gesture meaning was determined (e.g., *throwing*); coders also rated their confidence in the gesture's meaning. There was no difference in confidence between groups, $F(1,24) = 0.81$, $P = 0.38$, with ratings of M (SD) of 3.66 (0.68) and 3.83 (0.25) out of five for the TD and ASD groups, respectively, suggesting that coders could confidently identify gesture meanings. Second, the coder selected one or two words from the speech transcription that contained most of the information present in the gesture meaning (e.g., "threw"). In one case, the exact meaning of the gesture was not present in the (TD) adolescent's speech (the utterance, "picked it up," and the gesture, glossed as "a coconut", contained distinct information); in this case, the word ("picked") that complemented the gesture's meaning was selected.

After selecting the gesture–speech pair, the start and endpoints of the speech and gesture were coded in Noldus Observer [Noldus, Trienes, Hendriksen, Jansen, & Jansen, 2000]. The audio portion of the video was replayed at half-speed until the beginning of the first phoneme and the end of the last phoneme in the target word could be identified. During speech coding, the video display was hidden; hence, coders would not be biased by participants' movements.

Once speech was coded, coders muted the audio signal while coding gestures, so that speech would not bias gesture coding. For gesture coding, videos were first watched in real time to determine the *stroke* phase of the gesture. In most accounts, the stroke carries most of the gesture's information [McNeill, 1992]. The stroke was defined as the middle of three gesture phases (i.e., preparation, stroke, and retraction), and was the phase that included the major motion of the gesture. Once the stroke was identified, the picture was advanced frame-by-frame to code its onset and offset.

As an additional measure of gesture quality, coders rated their own confidence about the onset and offset of each gesture, from 1 (uncertain) to 5 (very confident). There was a significant group difference in coder confidence, $F(1,24) = 5.61$, $P = 0.03$, with the TD group gesture endpoints rated more confidently than the ASD group, with group means (SD) of 4.58 (0.67) and 3.93 (0.73), respectively. The groups shared a similar range of confidence ratings (from 3–5 in each group), and for both groups, mean confidence was greater than 3, the midpoint of the scale (anchored with the word "confident"). Thus, while RAs felt more confident coding the TD group, both groups were seen as reliably "codable," an impression consistent with the high inter-rater reliability for this analysis (reported below).

Reliability. Story quality ratings were analyzed for inter-rater reliability. Because these ratings were entirely subjective, and raters were given only limited scoring instructions, there was a concern that raters would be unreliable. In fact, inter-rater reliability was high. Chronbach's alpha (collapsed across diagnosis) was 0.93 when raters were asked how well they could follow the story and 0.91 when asked how engaged they were. Collapsed across question, Chronbach's alpha was 0.87 for the TD group and 0.91 for the ASD group. Thus, although the ratings were subjective in nature, raters generally agreed on the communicative quality of the stories, for both diagnostic groups.

Three aspects of speech coding were assessed for reliability: utterance count, co-gesture speech, and the timing of speech onset. To determine the reliability of speech transcription, two coders independently transcribed nine narratives (four by adolescents with ASD). The intraclass correlation coefficient (ICC) for utterance count per narrative was 0.95. Co-gesture speech was independently coded by two coders for ten narrations (four by adolescents with ASD). Percent agreement for the words that best captured the meaning of the co-occurring iconic gesture was 0.90. ICC for the timing of speech onset was 0.99.

Three aspects of gesture coding were analyzed for reliability by two independent coders: gesture count, gesture type (iconic vs. other), and gesture timing. Coding nine participants (seven with ASD), percent agreement was 0.90 and ICC was 0.98 for the number of gestures per narration. Kappa for gesture type (iconic vs. other) was 0.86. ICC was 0.99 for gesture onsets.

Results

The narrative task provided information about how adolescents with ASD gesture spontaneously during storytelling. To investigate overall rates of verbal and nonverbal communication, a one-way multivariate ANOVA was conducted with diagnostic group as the independent variable, and utterance count, gesture count, and gesture rate (gestures per utterance) as dependent variables. Group differences were nonsignificant, $F(3,26) = 0.36$, $P = 0.78$, $\eta_p^2 = 0.04$, suggesting that on this task, participants with ASD spoke *and gestured* with the same frequency as participants with TD. Data are presented in Table II. Interestingly, gesture rate varied dramatically within groups, from as many as two gestures per utterance (both groups) to as few as two gestures in total (ASD group) or no gestures at all (TD group).

One possibility is that individuals with ASD may gesture with similar frequency as their typical peers, but use different types of gesture. We tested this hypothesis by looking at the distribution of gesture types used during narrations in the two groups. All gestures were categorized as iconics, deictics, beats, and "other" (a category which included metaphoric gestures and emblems, both of which were very infrequent). While deictics, iconics, and others were normally distributed, beat gestures violated this assumption; as such, non-parametric Kolmogorov–Smirnov (KS) tests were used to probe for group differences in this category of gestures. Analyses indicated no significant group differences in the frequency of different categories of gesture, all P's > 0.13. While beat gestures appeared to be produced more frequently in the TD group (4.7 vs. 1.7 per narration), this difference was not significant, KS $(28) = 0.91$, $P = 0.38$.

Several subsequent analyses focused on iconic gestures. Participants who produced sufficient iconic gestures included 14 adolescents with ASD and 12 adolescents with TD. The number of iconic gestures produced during narratives was similar in across groups, $t(25) = -1.46$, $P = 0.16$, Cohen's $d = 0.58$; see Table II. A multivariate ANOVA revealed no group differences in the length of gesture stroke phases or co-occurring speech, $F(2,23) = 0.64$, $P = 0.54$, $\eta_p^2 = 0.05$; see Table III. This further suggests that gestures produced by the ASD and TD groups did not differ in raw *quantity* or *duration*.[3]

In contrast to the similar rates of communicative events for the ASD and TD groups, sharp differences were observed in narrative *quality*. Naïve listeners rated these stories while watching and listening to them (TV condition) or only listening to them (radio condition). Stories produced by the ASD group were rated across conditions as significantly harder to follow, $F(1,28) = 12.71$, $P = 0.001$, $\eta_p^2 = 0.31$, and less engaging, $F(1,28) = 5.02$, $P = 0.03$, $\eta_p^2 = 0.15$; data are presented in Table IV. Correlational analyses supported the validity of the story quality ratings. For the ASD group only, ratings of "how engaged were you during this story?" were significantly negatively correlated with ADOS social reciprocity scores, $r(15) = -0.57$, $P = 0.03$; adolescents whose stories were more engaging exhibited fewer social symptoms. There was also a trend, in the expected direction, for these ratings to be correlated with ADOS communication scores in the ASD group, $r(15) = -0.40$, $P = 0.15$, although this effect failed to reach significance.

Correlational analyses within groups also indicated that, for the TD group, gesture count was positively and significantly correlated with ratings of communicative quality in the TV condition, $r(15) = 0.69$, $P = 0.005$. In contrast, for the ASD group, gesture count was unrelated to communicative quality, $r(15) = -0.06$, $P = 0.83$. The strength of these correlations differed significantly between ASD and TD groups, $z = -2.48$,

Table II. Utterance and Gesture Count, by Group

	Group				
	ASD *M* (SD) Range	TD *M* (SD) Range	χ^2 or *F*	*P*	η_p^2
Number of utterances	10.5 (3.3) 6–16	11.1 (5.7) 5–29	0.12	0.73	<0.01
Number of gestures (total)	9.7 (6.5) 2–23	8.2 (8.2) 0–25	0.30	0.59	0.01
Number of iconic gestures	6.9 (5.4) 0–19	3.9 (4.7) 0–16	2.52	0.12	0.08
Gesture rate[a]	0.98 (0.76) 0.25–2.86	0.72 (0.65) 0.00–2.00	1.01	0.32	0.04

ASD, autism spectrum disorder; TD, typically developing.
[a]Gesture rate computed as number of gestures (total) divided by number of utterances.

Table III. Length of Gesture Stroke Phase and Co-occurring Speech by Group

	Group				
	ASD *M* (SD) Range	TD *M* (SD) Range	χ^2 or *F*	*P*	η_p^2
Gesture length (ms)	690 (510) 170–2310	780 (560) 30–2070	0.01	0.95	<0.01
Speech length (ms)	350 (110) 70–350	300 (120) 50–300	1.29	0.27	0.05

ASD, autism spectrum disorder; TD, typically developing.

[3]In addition, coding examined whether participant consistently linked story characters with a particular hand or location. Results indicated that gestures were predominantly produced by the right hand, *M*(SD) of 80% (34%) and 67% (44%), for the ASD and TD groups, respectively, and produced in a similar location (center of body) across groups. Both analyses were non-significant, with $P > 0.39$. While more fine-grained analyses may provide more detail, these preliminary results suggest no group differences in the ability to mark characters via hand or location.

Table IV. Listener Ratings of Story Quality (on a 1–7 scale), Averaged Across Ten Different Raters

Group				
ASD *M* (SD) Range	TD *M* (SD) Range	χ^2 or *F*	*P*	η_p^2
"How well were you able to follow this story?" (1 = somewhat; 7 = very well)				
3.3 (1.5)	5.0 (1.0)	12.71	<0.01	0.31
1.4–5.8	3.4–6.4			
"How engaged were you during this story?" (1 = somewhat engaged; 7 = very engaged)				
3.6 (1.1)	4.6 (1.3)	5.03	0.03	0.15
1.6–5.3	2.7–6.5			

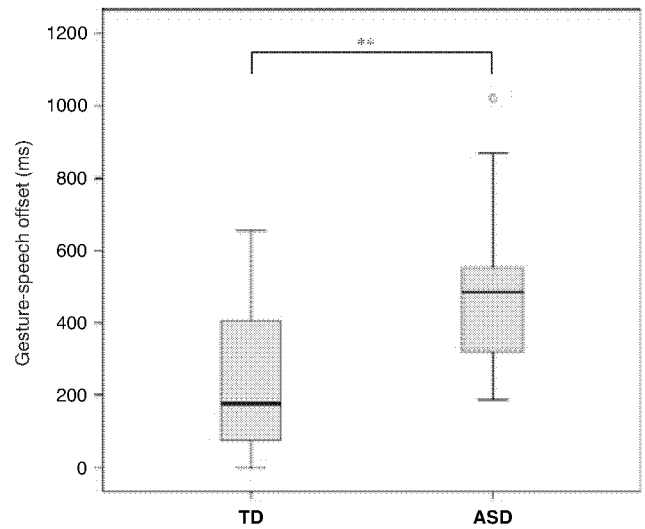
ASD, autism spectrum disorder; TD, typically developing.

$P = 0.007$. This finding is consistent with the hypothesis that gestures augment communicative quality for TD participants, but not for participants with ASD.

In addition to gesture and speech production, and narrative quality, we investigated the temporal dynamics of gesture–speech pairs for iconic gestures. The onset times of each gesture and its co-occurring speech were marked; the absolute value of the difference in onset times was taken as a measure of gesture–speech synchrony. Gesture–speech pairs that begin simultaneously have a value of zero; larger values indicate less synchrony. One adolescent with ASD, whose mean asynchrony was more than four standard deviations above the ASD group mean, was excluded from this analysis as an outlier. Gesture–speech onsets differed by 490 (SD = 250) ms in the ASD group and by 240 (SD = 200) ms in the TD group, a difference that was significant with a large effect size, $t(23) = -2.72$, $P = 0.01$, Cohen's $d = -1.13$. Data (excluding the outlier participant) are shown in Figure 1. Adolescents with ASD produced gestures that were strikingly less synchronized with speech, compared to TD adolescents.

In the gesture literature, gestures typically anticipate the related item in speech by 100 ms [Morrel-Samuels & Krauss, 1992]. In the current data set, gestures sometimes preceded and sometimes followed the related speech, and the ASD and TD groups did not differ in this dimension; 58.3% of gestures produced by the ASD group and 57.1% of gestures produced by the TD group started prior to the co-occurring speech, a difference that was not significant, $\chi^2(1,n = 26) = 0.95$, $P = 1.0$. In the TD group, gesture strokes preceded as much as 460 ms in advance of the speech, or lagged by as much as 280 ms, and in the ASD group, preceded and lagged by as much as 2,770 and 930 ms, respectively. Thus, the relative onsets of gesture and speech did not vary by group; rather, it was the absolute synchrony of gesture and speech onset that distinguished them.

A linear regression analysis was conducted to investigate the contribution of gesture–speech synchrony to communicative quality. Communicative quality is multiply



** $p = 0.01$

Figure 1. Synchrony of iconic gestures and co-occurring speech, by diagnostic group (**$P = 0.01$).

determined; it is influenced by (at least) language skills, the ability to consider a listener's perspective, and experience with the narrative form. To control for some of these additional factors, a regression was conducted with communicative quality ratings as the dependent variable. Full-scale IQ was entered at the first step, and gesture–speech asynchrony values at the second step; diagnostic status and the interaction of diagnosis with asynchrony were entered in the final step, to test whether the effect of asynchrony on story quality was more or less pronounced for the ASD group. Results indicated that IQ scores accounted for a nearly significant 13% of the variance in communicative quality ratings, $F(1,24) = 3.49$, $P = 0.07$. Controlling for full-scale IQ, gesture–speech asynchrony accounted for an additional significant 20% of the variance in communicative quality, $F(1,23) = 6.65$, $P = 0.02$. Finally, testing for group effects, the addition of diagnostic status contributed to an additional significant 26% of the variance, $F(2,21) = 6.43$, $P = 0.007$. Unsurprisingly, given the significant group differences in asynchrony, adding diagnostic status to the regression model meant that asynchrony no longer accounted for specific significant variance, $\beta = -0.188$, $t = -1.16$, $P = 0.26$; diagnostic status was a significant contributor to the model, $\beta = 0.672$, $t = 3.13$, $P = 0.005$. The interaction of asynchrony with diagnostic status did *not* account for significant independent variance, $\beta = -0.176$, $t = -0.885$, $P = 0.39$. Those individuals with less coordination between their speech and gestures produced stories that were harder to understand, indicating that gesture–speech asynchrony had a specific negative impact on communication across groups; furthermore, this relationship was consistent across groups.

Discussion

Although clinicians, and the diagnostic literature, have often described lifelong gestural impairments in ASD, to date there has been little empirical work to quantify how gesture is used in combination with fluent speech in older (i.e., beyond preschool) individuals with ASD. The data presented here contribute to our understanding of how adolescents with ASD spontaneously use gesture and speech to communicate, and how these distinct communicative modalities are integrated.

Using a structured narrative task in which participants were not instructed or prompted to gesture, we found that adolescents with ASD and TD spontaneously produced the same number of utterances and gestures in their narratives. While inconsistent with some prior work [e.g., Bartak et al., 1975], this finding is consistent with studies showing comparable gesture rates for ASD and other populations [e.g., Attwood et al., 1988; Capps et al., 1998; Tantam et al., 1993], and suggests that raw quantities of gestures cannot account for group differences. In addition, we found the iconic gestures produced by the two samples to be equally interpretable by trained coders, suggesting that the gestures produced by teens with ASD were communicative. However, despite similarities in gesture and speech frequency between groups, results indicated that naïve listeners rated the stories produced by adolescents with ASD as significantly harder to follow, and less engaging, than stories produced by adolescents with TD. This finding is consistent with the literature on narratives in ASD, which suggests that narratives are less coherent in this population [Baron-Cohen, Leslie, & Frith, 1986; Diehl, Bennetto, & Young, 2006]. Although differences in communicative quality were apparent, as suggested by listener ratings, these differences could not be reduced simply to differences in the frequency of communicative acts. Interestingly, for the adolescents with TD, communicative quality was related to increased gesture rates, such that participants who produced more gestures were rated as telling stories that were more engaging and easier to follow. However, in the ASD group, there was no relationship between gesture production and listener ratings, suggesting that gestures, while present, did *not* contribute to story quality. Furthermore, higher quality ratings given by naïve listeners were associated with fewer autism symptoms, suggesting the relevance of this task to real-world communication abilities.

Our most robust finding was that gesture and its semantically related speech were less synchronized in adolescents with ASD than adolescents with TD. This effect was highly reliable despite our relatively small sample size and relatively small number of iconic gestures produced, and points to the strength of integration impairments in this population. Integration of verbal and nonverbal communication is clinically relevant in ASD (e.g., on diagnostic tools). Empirically, children and adolescents with ASD exhibit difficulties integrating audio and visual information from linguistic stimuli [Bebko, Weiss, Demark, & Gomez, 2006; Smith & Bennetto, 2007]. In fact, one of the only studies to look at gesture comprehension in ASD [Silverman, Bennetto, Campana, & Tanenhaus, 2010] found that adolescents with ASD were slower to select a picture matching a spoken sentence when that sentence was accompanied by an informative gesture; TD participants were faster when the gesture was present. This suggests that adolescents with ASD could not integrate information from speech and gesture, and in fact may have found this information distracting. Given the parallels between language comprehension and production, it stands to reason that integration impairments in communicative production should be expected in ASD. However, the specific nature of integration impairments has not been well described to date.

Our findings provide evidence that the integration of verbal and nonverbal communication is impaired in ASD, even given comparable baseline rates of communication. Further, the degree of gesture–speech coordination was associated with communicative quality ratings by naïve listeners. These findings are consistent with recent work on interpersonal synchrony, which has shown differences in timing but not in quantity of facial mimicry [Oberman et al., 2009], and on ERP studies of social responsiveness [McPartland et al., 2004; Webb et al., 2006], as reviewed in the Introduction; this work suggests differences in interpersonal synchrony in ASD, with negative social and communicative consequences.

Our study differs from this prior work in its focus on synchrony of behaviors within an individual. There is no a priori reason to believe that a single modality would be *delayed* in the ASD sample, as some gesture theorists propose that gesture and speech arise out of a single semantic origin [e.g., "growth points," McNeill, 2005]. Other theorists have proposed that gesture and speech arise out of separate, but parallel processes that are highly coordinated during production [Chu & Kita, 2008; Kita, 2000; Kita & Özyürek, 2003]. If either of these proposals is true, instead of a specific impairment in a single modality (gesture vs. speech), one might expect decreased overall synchrony, consistent with current findings. In addition to group differences in gesture–speech synchrony, results indicated that the individual degree of gesture–speech synchrony played a significant role in listener ratings of story quality, over and above the contribution of IQ, further supporting the hypothesis that gesture–speech integration contributes to communication.

The study of gesture–speech synchrony informs our understanding of communicative strengths and

weaknesses in ASD. It also provides support for specific theories of brain function in this population. Although our data cannot distinguish between these theories, they do lend support to several current proposals regarding brain function in ASD. The integration of speech with gestures, which are often produced bilaterally, should require communication between multiple cortical regions and across hemispheres [McNeill, 2005]. Further, if gesture and speech represent separate but parallel processes [Chu & Kita, 2008; Kita, 2000; Kita & Özyürek, 2003], then their integration should require connectivity between distinct neural areas. Connectivity between distant brain regions is reduced in ASD [Just, Cherkassky, Keller, & Minshew, 2004; Kana, Keller, Cherkassky, Minshew, & Just, 2006]. Our finding of decreased synchrony between speech and gesture provides support for theories of reduced connectivity.

The impaired coordination of speech and gesture reported here may also suggest the involvement of Broca's area, which is involved in the retrieval of semantic information [Gough, Nobre, & Devlin, 2005] and action production [Nishitani, Schurmann, Amunts, & Hari, 2005]. In fact, Broca's area appears to be involved in *integrating* information acquired from both speech and gesture and generating semantic representations [Skipper, Goldin-Meadow, Nusbaum, & Small, 2007]. Functional neuroimaging studies have suggested that Broca's area functions atypically during language tasks in ASD, although some studies report increased activation [Knaus, Silver, Lindgren, Hadjikhani, & Tager-Flusberg, 2008] and others report decreases [Harris et al., 2006]. The iconic gestures evaluated in this study are rich in semantic information; differences in Broca's area function could contribute to decreased integration of semantic information from speech and gestural modalities [McNeill, 1992, 2005].

Although it has yet to be investigated, gesture–speech synchrony likely involves the cerebellum. Atypicalities of the cerebellum have been found in individuals with ASD in multiple studies [Chugani, Sundram, Beham, Lee, & Moore, 1999; Courchesne, Yeung-Courchesne, Press, Hesselink, & Jernigan, 1988; Fatemi et al., 2002; Otsuka, Harada, Hisaoka, & Nishitani, 1999; Ritvo et al., 1986]. The cerebellum has been shown to be involved in tool use [Higuchi, Imamizu, & Kawato, 2007] and tool-use gestures [Choi et al., 2001]. Further, the cerebellum is involved in the timing and integration of behaviors. Eyeblink conditioning, mediated by the cerebellum [McCormick & Thompson, 1984], requires rapid and precise timing, and is inefficient in ASD [cf. a study of eyeblink conditioning in ASD which demonstrated intact learning but poorly coordinated timing of eyeblinks; Sears et al., 1994]. The cerebellum also controls the timing of behaviors that have both a cognitive and a motor component [Glickstein, 2006], and that require close synchrony [Katz & Steinmetz, 2002], such as speech production [Ackermann, Mathiak, & Ivry, 2004]. Gesture is not only timed closely with speech, but is also part of a larger suite of behaviors that are rhythmically coordinated [Loehr, 2007]. Although our data are purely behavioral, the finding that gesture and speech are asynchronous in ASD is consistent with atypical cerebellar development in this population [Allen, 2005].

There are several limitations to this work, many of which motivate future studies. This study did not include a measure of gesture form. Gestures may be poorly formed in ASD, which may negatively impact their communicative power. Ongoing research in our laboratory will include a standardized praxis assessment to disentangle the role of fine motor control in gesture production. Another limitation of this study is that we used subjective ratings of story quality as a measure of communicative skill. While there are certain limitations to using a relatively short seven-point scale as an outcome measure, we believe that it is important to obtain holistic ratings of how listeners interpret communicative exchanges, rather than simply reducing them to their component parts. Finally, the gesture production tasks used in this study involve communication produced in a "monologue" format. That is, although an experimenter was present and responded nonverbally throughout, participants told their stories uninterrupted. Beattie and Aboudan [1994] found that typical adults produce more gestures during conversations than monologues. The distinction between conversation and monologue will be particularly important to address in adolescents with ASD, who struggle with conversational skills. Although we found that adolescents with ASD produced the same quantity of gestures as adolescents with TD, it is certainly possible that in conversation these adolescents might produce fewer gestures, consistent with clinical impressions [though cf. Tantam et al., 1993, which failed to find differences in the frequency of nonverbal communication during conversations].

A major advantage of this study is the use of spontaneous communication samples to study gesture–speech synchrony. Individuals with ASD often perform more similarly to controls when given explicit instructions, relative to their spontaneous behaviors [Charlop, Schreibman, & Thibodeau, 1985]. For example, the timing of spontaneous but *not* explicitly instructed facial mimicry is delayed in ASD samples relative to controls [Oberman et al., 2009], suggesting that the timing of behaviors in ASD may be affected by explicit instruction, and providing further support for the study of spontaneous over prompted behaviors. To truly understand the constraints on how individuals with ASD communicate, we must investigate how communicative behaviors, such as speech and gesture, occur spontaneously. Future work on the integration of communicative modalities should

address how these distinct systems come together during spontaneous communication.

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