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Infant and toddler oral- and manual-motor skills predict later speech fluency in autism

Morton Ann Gernsbacher,[1] Eve A. Sauer,[2] Heather M. Geye,[1] Emily K. Schweigert,[1] and H. Hill Goldsmith[1]

[1]University of Wisconsin–Madison, USA; [2]University of Chicago, USA

Background: Spoken and gestural communication proficiency varies greatly among autistic individuals. Three studies examined the role of oral- and manual-motor skill in predicting autistic children's speech development. **Methods:** Study 1 investigated whether infant and toddler oral- and manual-motor skills predict middle childhood and teenage speech fluency; Study 2 verified those early infant and toddler predictions with historical home video; and Study 3 assessed the relation between autistic children's current-day oral-motor skill and their speech fluency. **Results:** Infant and toddler oral-motor and manual-motor skills inter-correlated significantly, distinguished autistic children ($N = 115$) from typically developing children ($N = 44$), and distinguished autistic children whose current-day speech was minimally fluent ($N = 33$), moderately fluent ($N = 39$), and highly fluent ($N = 39$). These results were corroborated by analysis of historical home video ($N = 32$) and verified with current-day assessment ($N = 40$). **Conclusions:** The prominent associations among early oral- and manual-motor skills and later speech fluency bear implications for understanding communication in autism. For instance, these associations challenge the common assumption (made even in diagnostic criteria) that manual modes of communication are available to autistic individuals – if simply they choose to use them. These associations also highlight a potential confound from manual-motor skills when assessing autistic cognition, receptive language, and 'nonverbal' social communication. **Keywords:** Early motor development, autism, communication, dyspraxia, motor skills. **Abbreviations:** ADOS: Autism Diagnostic Observation Schedule.

Autism is characterized by atypical communication, social interaction, interest focus and body movements. One dimension that varies greatly among autistic[1] individuals is that of communication, spoken and gestural. Although by diagnostic definition, all children with autistic disorder are characterized by a delay in developing spoken language, some autistic children develop fluent speech, whereas others develop only minimally fluent speech. This research explores a basis for both the phenotypic marker of delayed speech and its within-phenotype variability.

Autistic children's delay and, for some, continued impairment in speech are typically ascribed to intellectual impairments or social affiliation deficits. Indeed, autistic children whose speech does not develop to fluency are often referred to as 'low functioning,' and are sure to be disadvantaged on speech-based measures of intelligence. However, when assessed without demand on their speech production, minimally fluent autistic children excel on the pre-eminent test of fluid intelligence, the Raven's Progressive Matrices (Dawson, Soulières, Gernsbacher, & Mottron, 2007). Similarly, although theoretical speculations continue to misperceive autism as an attachment disorder (Bartz & Hollander, 2006; Lim & Young, 2006), all empirical studies of autistic children's socio-emotional attachment unambiguously demonstrate that autistic children are as securely attached to their primary caregivers as their peers (Gernsbacher et al., 2005).

In contrast to socio-emotional or intellectual attributions for autistic children's speech delay and the variation among autistic children in their speech delay, the focus of the current investigation is oral- and manual-motor development. Whereas language is the mental representation of concepts and their relations, speech is – literally – the articulation of language (Gernsbacher, 2004), and speaking fluently requires 'an intricate orchestration' of oral-motor mechanisms (Gracco, 1994, p. 4).

During typical development, oral-motor skills are strongly associated with speech fluency. For example, typically developing toddlers' ability to lick food from their lips is strongly associated with the size of their spoken vocabulary and the length of their spoken sentences (Alcock, 2006). During typical development, oral-motor skills are also strongly associated with manual-motor (hand and finger) skills (Corbetta & Thelen, 1996; Iverson & Thelen, 1999). For example, during middle-childhood, fluency in repeating sentences and nonwords is associated with fluency in pegboard tasks (Bishop, 2002), and during infancy, rhythmicity in shaking rattles is associated with facility in reduplicated babbling (Iverson & Fagan, 2004).

Conflict of interest statement: No conflicts declared.

[1]See Sinclair (1999; http://web.syr.edu/~jisincla/person_first.htm) to appreciate our respectful use of the term 'autistic' rather than 'person with autism.'

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A scattering of findings demonstrates similar associations during autistic development. Preschool autistic children's oral-motor skills, such as their ability to protrude their tongues and pucker their lips, are associated with their speech fluency (Amato & Slavin, 1998). Middle-childhood and teenage autistic children's oral-motor skills, such as their ability to wiggle their tongues and blow whistles, are associated with their manual-motor skill, such as their ability to manipulate puzzle pieces and pencils, but not their ability to run or jump (Page & Boucher, 1998). During middle-childhood, both oral-motor skills (Adamson, 1998) and manual-motor skills (Jones & Prior, 1985) distinguish autistic children from chronological- and mental-age matched children. Most strikingly, autistic toddlers' oral-motor skills (Thurm, Lord, Lee & Newschaffer, 2007) and their manual-motor skills (Stone & Yoder, 2001) are more predictive of their preschool speech fluency than are measures of social cognition, such as joint attention.

In the research reported here, Study 1 investigated whether early infant and toddler oral- and manual-motor skills distinguish autistic children from typically developing children and predict autistic children's speech fluency in later childhood; Study 2 verified those early infant and toddler predictions with historical home video; and Study 3 assessed current-day associations between autistic children's oral-motor skill and their speech fluency.

Study 1: Caregiver landmark-based interview

Caregiver interview is a prominent means for collecting phenotypic data, particularly about very early development (e.g., the Diagnostic Interview Schedule for Children; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). In fact, one of the 'gold standard' diagnostic instruments for autism relies solely on caregivers' recall of their children's early developmental skills (Lord, Rutter, & LeCouteur, 1994). Cautious of the potential fallibility of retrospective recall, we employed a landmark-based interview to buttress caregivers' accurate recollection of their children's early oral- and manual-motor skills.

Method

Participant recruitment and matching. One-hundred seventy-two primary caregivers from Dane County, Wisconsin, who reported a child (under age 18) with an autism diagnosis were recruited. To obtain a representative sample, a variety of recruitment methods were employed (e.g., flyers posted in community venues such as recreation centers and swimming pools, announcements with autism organizations, in newsletters, and in newspapers, contact via service providers). The sample captured approximately 80% of the county's autistic children as identified by the Wisconsin Department of Public Instruction. The children's mean age at the time of their caregiver's interview was 95.03 months ($SD =$ 44.86; range = 28–227 months), with 55% younger than 8 years and 15% between 12 and 18 years. The male to female ratio was 4.04:1.

Forty-four primary caregivers of typically developing children (33 male, 11 female) were also recruited via birth announcement. The mean age of the typically developing children at the time of their caregivers' interview was 98.05 months ($SD = 45.77$; range = 30–210 months). Autistic participants were stratified into narrow age bands by gender, and groups of three to four adjacent-in-age autistic children were matched with a typically developing child of the same gender. All participating caregivers provided informed consent.

Exclusionary criteria. All children in the autistic sample had a credible diagnosis as reported by the primary caregivers and as verified through medical and educational records by research staff. Stringent criteria were imposed to exclude medical complications and impairments that might suggest non-idiopathic autism or confound oral-motor or manual-motor development, including the following: (1) any chromosomal anomaly (e.g., Down syndrome, Fragile X) or known genetic syndrome (e.g., Prader-Willi); (2) any history of a seizure disorder or cerebral palsy; (3) major illnesses, surgeries, or diagnoses involving cardiac or CNS function; (4) immunological or autoimmune disorders; (5) major sensory (e.g., blindness) or motor (primary wheelchair use) impairment; (6) extreme pregnancy or early infancy outcomes (e.g., fetal alcohol syndrome); and (7) other diagnosed medical syndromes.

Thirty-three percent of the autistic children (46 male, 11 female) were characterized by an exclusionary medical complication, and those children's data were excluded from further analysis. The data from one additional autistic child with an unusual history of family rearing was excluded due to the likely unreliability of the information provided in the interview. Additional exclusionary criteria were imposed on the typically developing sample: Neither the typically developing child nor any of his or her siblings could be diagnosed with attention deficit hyperactivity disorder, antisocial personality disorder, anxiety disorder, autistic disorder, bipolar disorder, conduct disorder, depression, obsessive compulsive disorder, or oppositional defiance disorder, any language delay or speech/language impairment, dyslexia/reading impairment, learning disability, any severe chronic medical condition, heart disorder, or kidney disorder.

Landmark-based interview. Primary caregivers were interviewed with a landmark-based instrument designed for this study (available from the first author). The landmark-based questions were intended to aid the primary caregiver's recollection by clearly establishing a memorable, temporal reference period (a 'landmark,' Loftus & Marburger, 1983). For each target age (6, 12, 18, 24, and 36 months), the primary caregiver was prompted to recall in detail a salient event that occurred during that month (e.g., Interviewer: 'Your son John would have been six months old in September, 1996. What salient event happened during that month?' Caregiver: 'Let's see. Well, at the end of that September, the entire family went to visit my parents in Montana.' Interviewer:

'How long was your visit?' Caregiver: 'About five days.' Interviewer: 'Did you stay overnight in your parents' house or did you stay in a hotel or somewhere else?' Caregiver: 'We all stayed with my parents. They have a couple of guest rooms.' Interviewer: 'What types of activities did you and your family do during this visit?' etc.).

After a specific event had been recalled thoroughly, the primary caregiver was asked specific questions regarding the child's attainment of a targeted motor skill (e.g., 'When you and your family were visiting your parents in Montana during that week toward the end of September of 1996, was John crawling? Did he, for instance, crawl around at his grandparents' house? Do you remember him crawling in the living room? In the kitchen? Did anyone take any pictures or home video of John crawling around his grandparents' house?').

Ten oral-motor and 21 manual-motor skills were assayed. The majority of the questions required a simple 'yes' or 'no' response, and the skills were selected to be primarily non-social. For example, 'blowing kisses,' 'reaching arms to be lifted up,' 'waving bye-bye,' and 'playing patty cake' were avoided, and comparable skills were assayed (e.g., 'blowing bubbles' rather than 'blowing kisses'). In addition, traditional motor milestones (sitting, crawling, and walking) were assayed as a check for more general motor delay, and 'alerts to name' at 12 months, a popular item in early identification screening assessments (e.g., Robins, Fein, Barton, & Green, 2001), based on Osterling and Dawson's (1994) classic, historical home video analysis of autistic versus typically developing children, was included for comparison.

Each autistic child's current-day speech fluency, relative to age, was classified by two researchers working collaboratively and kept naïve to the children's early motor skills. Three categories, highly fluent ($N = 39$), moderately fluent ($N = 39$), and minimally fluent ($N = 33$), were formed, based on three sources of information. Initial classification was based on each child's current speech as described by the child's primary caregiver at the end of the interview. For one fourth of the autistic sample, a collaborating pediatric speech-language pathologist (with a practice comprising autistic children) made a follow-up phone call with the caregiver or a direct observation of the child. Additionally, one third of the autistic sample was assessed directly in current day in Study 3.

The highly fluent category comprised children whose parents reported that their speech, as assessed by school or other professional personnel, was within one year of age level and was rarely unintelligible to persons unfamiliar with the child. The moderately fluent category comprised children whose speech, as assessed by school or other professional personnel, was between one and three years below age level; included noticeable mispronunciations, atypicalities in rate, pitch, or volume, and occasional echolalia; and was sometimes unintelligible to persons unfamiliar with the child. The minimally fluent category comprised children whose speech was severely delayed (e.g., unable to produce utterances longer than three-word phrases after six years of age or unable to produce recognizable words at any age).

Results

How related are early oral-motor and manual-motor skills? The autistic children's scores for the early oral-motor and manual-motor skills were correlated to determine associations within the oral- and manual-domains. Within each domain, virtually all correlations were positive. For example, within the oral-motor domain, producing animal sounds at 18 months was significantly correlated with blowing raspberries at 6 months ($r(105) = .25$), with sticking out one's tongue on request at 24 months ($r(109) = .45$), with puffing cheeks on request at 24 months ($r(106) = .37$), and with blowing bubbles with a straw or bubble wand at 24 months ($r(110) = .25$, all ps < .01). Within the manual-motor domain, pointing distally on request at 18 months was significantly correlated with grabbing dangling toys at 6 months ($r(100) = .28$), clapping at 12 months ($r(105) = .32$), stacking blocks at 12 months ($r(103) = .40$), pointing to indicate wants at 18 months ($r(105) = .44$), liking to play with Duplos/connecting blocks at 24 months ($r(103) = .48$), liking to assemble puzzles at 24 months ($r(103) = .36$), and turning round door knobs at 24 months ($r(99) = .36$, all ps < .01).

Because virtually all the within-domain correlations were positive, we formed a composite for each domain. Using as the principal criterion whether an item could be eliminated without lowering its composite's internal consistency (alpha), we excluded 2 of the original 10 oral-motor skills, yielding an oral-motor composite of 8 skills with an alpha of .80, and we excluded 7 of the original 21 manual-motor skills, yielding a manual-motor composite of 14 skills with an alpha of .83. Three of the manual-motor skills excluded were the only skills assayed at 36 months; therefore, the resulting two composites were restricted to 6 to 24 months. The two composites and their component skills are listed in Table 1.

The oral-motor and manual-motor composites were significantly correlated for the autistic children ($r(113) = .61$, $p < .001$), as well as for the less variable, typically developing children ($r(44) = .35$, $p < .05$). For the autistic children, 52% of the 112 correlations between the 8 oral-motor skills and the 14 manual-motor skills were significant ($p < .05$). For example, blowing raspberries at 6 months and banging on a high chair at 12 months ($r(106) = .41$), producing animal sounds at 18 months and pointing distally on request at 18 months ($r(105) = .46$), and puffing cheeks via imitation at 24 months and turning round door knobs at 24 months ($r(93) = .45$), were all significantly correlated (all ps < .001).

Do early oral- and manual-motor skills distinguish autistic from typically developing children? The autistic children were distinguished from the typically developing children by their scores on both the oral-motor composite ($F(1,155) = 119.49$, $p < .001$) and the manual-motor composite ($F(1,155) = 109.01$, $p < .001$). Box-and-whisker plots, shown in Figure 1, display these differences, with each box depicting the middle two quartiles (bifurcated by the bold, horizontal line representing the median) and each whisker (extending vertically beyond each box) depicting scores within 1.5 box lengths from either end of the box.

Table 1 Early oral- and manual-motor skills: group comparisons

	Autistic children versus typically developing children			Autistic children only: currently minimally versus highly fluent		
	Percentage of autistic children	Percentage of typically developing	χ^2 (df)	Minimally fluent autistic children	Highly fluent autistic children	χ^2 (df)
Oral-motor skills						
6 mos – blows raspberries	35	62	8.57 (1)**	13	51	11.14 (1)**
18 mos – makes animal sounds	32	86	36.73 (1)***	12	49	11.01 (1)**
24 mos – blows bubbles through straw or wand	35	86	32.58 (1)***	21	42	3.52 (1)
24 mos – sticks out tongue on request	35	93	42.69 (1)***	3	66	29.97 (1)***
24 mos – sticks out tongue in imitation	59	100	25.64 (1)***	23	83	23.92 (1)***
24 mos – puffs cheeks on request	22	83	46.69 (1)***	0	40	16.12 (1)***
24 mos – puffs cheeks in imitation	43	98	35.77 (1)***	7	72	25.75 (1)***
24 mos – blows nose into tissue on request	15	66	38.19 (1)***	11	21	1.00 (1)
Manual-motor skills						
6 mos – grabs dangling toy	69	98	14.40 (1)***	63	89	6.66 (1)**
6 mos – grabs dangling earrings	47	76	9.87 (1)**	38	60	3.09 (1)
6 mos – grabs glasses off another's face	49	79	10.42 (1)**	42	58	1.79 (1)
12 mos – reaches into one-year birthday cake	74	95	8.57 (1)***	74	79	.24 (1)
12 mos – claps	54	98	27.46 (1)***	48	72	4.09 (1)*
12 mos – stacks blocks	39	81	21.72 (1)***	33	43	.72 (1)
12 mos – scribbles	27	67	20.71 (1)***	23	30	.44(1)
12 mos – bangs on high chair tray	64	93	13.42 (1)***	58	77	3.08 (1)
18 mos – points to indicate wants	36	89	35.40 (1)***	21	51	6.90 (1)**
18 mos – points proximally on request	33	98	52.78 (1)***	12	59	16.11 (1)***
18 mos – points distally on request consistently	25	93	61.40 (3)***	9	44	15.98 (3)**
24 mos – likes to play with duplos/connecting blocks	28	84	38.23 (1)***	24	43	2.80 (1)
24 mos – likes to assemble puzzles	44	79	15.92 (1)***	37	45	.38 (1)
24 mos – turns round door knobs	43	84	20.56 (1)***	27	54	5.11 (1)*

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

Outliers, represented by circles, indicate scores between 1.5 and 3 box lengths from the end of the box, and extremes, represented by asterisks, indicate scores greater than 3 box lengths from the end of the box.

Receiver operator characteristics analyses, with equal weight placed on sensitivity and specificity, suggested that the optimal cutting score for the oral-motor composite was 5 (i.e., children who attained fewer than 5 early oral-motor skills were predicted to be autistic). At this cut-point, sensitivity was 83%, and specificity was 93%. The optimal cutting point for the manual-motor composite was 10.7, with sensitivity of 89% and specificity of 86%.

Each of the 8 oral-motor and 14 manual-motor skills reliably distinguished autistic children from typically developing children, as the chi-square statistics in Table 1 demonstrate. These oral- and manual-motor skills distinguished autistic children from typically developing children better than the traditional motor milestone of crawling at 6 months ($\chi^2(1) = 2.79$, $p > .05$) or 12 months ($\chi^2(1) = .98$, $p > .05$), and the majority of the oral- and manual-motor skills distinguished autistic children from typically developing children better than the classic early identification marker of 'alerts to name' at 12 months ($x^2(1) = 10.06$, $p < .01$).

Do early oral- and manual-motor markers predict autistic children's current-day speech fluency?
The autistic children whose current-day speech was minimally fluent ($N = 33$), moderately fluent ($N = 39$), and highly fluent ($N = 39$) varied significantly on both the composite of early oral-motor skills ($F(2,108) = 24.04$, $p < .001$) and the composite of early manual-motor skills ($F(2,108) = 8.66$, $p < .001$). Box-and-whisker plots, shown in Figure 2, display these variations and illustrate that the early oral-motor skills composite differentiated among all three levels of current-day speech fluency, while the early manual-motor skills composite differentiated minimally fluent from highly fluent and moderately fluent from highly fluent, but not minimally fluent from moderately fluent. As the chi-square statistics in Table 1 also illustrate, most of the early oral-motor and manual-motor skills reliably distinguished autistic children with minimally fluent current-day speech from autistic children with highly fluent current-day speech.

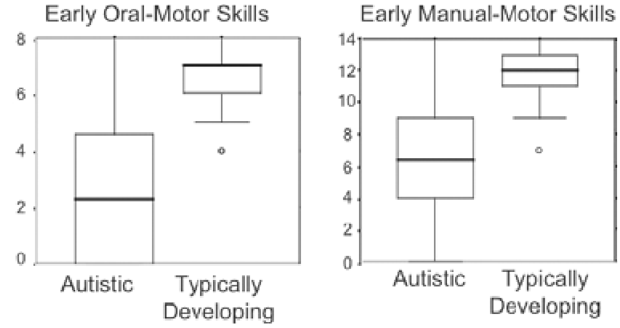

Figure 1 Box-and-whisker plots of early oral- and manual-motor skills

Figure 2 Box-and-whisker plots of early oral- and manual-motor skills

Study 2: Historical home video

Historical home video has provided a rich data source for identifying early indicators of the autistic phenotype (Adrien et al., 1992, 1993; Baranek, 1999). In this study, we used historical home video to assess the accuracy of the early oral- and manual-motor data obtained in the caregivers' landmark-based interview of Study 1.

Method

Sample. Families of 32 autistic children (28 male; 4 female) who participated in Study 1 (and whose data were not excluded due to medical complications) provided home video recorded when their children were between the ages of 5.5 and 24.5 months. The children's mean age was 7.81 years ($SD = 2.75$) at the time the historical home videos were provided. All participating families provided informed consent.

Coding and scoring. The average amount of historical home video provided was 231 minutes ($SD = 185$, range 15–780). All home video in which the child was present was coded. Two researchers, working independently and kept naïve to the caregivers' landmark-based interview, coded the presence of each of the 8 oral-motor and 14 manual-motor skills listed in Table 1. For each skill, video was coded within one month of the target age. For each target age, video was available for over half the children. A wide set of early oral- and manual-motor skills, including those of high population frequency (e.g., reaching into the first-year birthday cake and clapping at 12 months) as well as those of very low population frequency (e.g., blowing nose with a tissue at 24 months), was available in the home video. The two coders achieved 98% concordance.

A third researcher, working independently of the two researchers who coded the home video, calculated the concordance between the home video data and the landmark-based interview data.

Results

In all but one of the 32 observations, the data coded from the home video corroborated the data obtained from the caregivers' interview. In the one non-corroborated instance, the child was reported during the interview to not bang on his high chair tray at 12 months; however, that early manual-motor skill was observed in the child's home video. Thus, the historical home video strongly corroborated the caregivers' landmark-based interviews (i.e., 97% concordance).

Study 3: Current-day oral-motor assessment

In this study, we observed in current day one third of the autistic sample whose infant and toddler oral- and manual-motor skills were assessed in Study 1 via caregiver interview. Using an extreme group design (Kelley, 1939), we assessed directly the oral-motor skills of minimally fluent versus highly fluent autistic children.

Method

Participants. Twenty minimally fluent autistic children (18 male, 2 female) were recruited whose primary caregiver had previously participated in the early oral- and manual-motor interview (Study 1). The minimally fluent autistic children's mean age at the current-day oral-motor assessment was 88.3 months ($SD = 32.6$; range 50–169). According to their primary caregivers' interviews (Study 1), these minimally fluent autistic children had achieved an average .4 early oral-motor skills ($SD = .68$; range 0–2) and an average 4.4 early manual-motor skills ($SD = 3.2$; range 0–11). Twenty highly fluent autistic children (16 male, 4 female) were also recruited; their mean age at the current-day oral-motor assessment was 99.6 months ($SD = 37.6$, range 43–161). According to their primary caregivers' interviews (Study 1), these highly fluent autistic children had achieved an average 5.0 early oral-motor skills ($SD = 1.4$; range 3–8) and 9.0 early manual-motor skills ($SD = 2.9$; range 5–13).

Thus, as infants and toddlers, the 20 minimally fluent autistic children had achieved significantly fewer early oral- and manual-motor skills than the 20 highly fluent autistic children ($t(39) = 11.8$ and 6.1, respectively, both ps < .001), although all children had experienced an early speech delay. According to the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000), 45% of the minimally fluent and 40% of the highly fluent autistic children met criteria for autism (with the remaining, 55% and 60%, respectively, meeting criteria for the autism spectrum). Thus, the two groups did not differ significantly according to ADOS diagnostic classification, $\chi^2(1) = .12$, $p > .70$; it should be noted, however, that most of the minimally fluent autistic children were assessed with Module 1 of the ADOS, whereas most of the highly fluent autistic children were assessed with Module 3.

Historical home videos had been provided for 60% of the minimally fluent children and 75% of the highly fluent autistic children, and no discrepancies were observed between the caregivers' interview (Study 1) and the coded home video (Study 2). All caregivers provided informed consent for their children to participate in the current study.

Assessment and scoring. For the current-day oral-motor assessment, all children were tested in their homes, in a location that provided each child the most comfort and fewest distractions. The assessment comprised Part 1 (Oral-Motor Assessment) of the Kaufman Speech Praxis Test for Children (Kaufman, 1995). The items, listed in Figure 3, overlapped considerably with the 'volitional nonverbal oral abilities' items of the Pre-School Oral Motor Examination (Sheppard, 1990) used by Amato and Slavin (1998) to assess autistic children.

All items were administered by both request (e.g., 'let's open our mouths like this') and demonstration, with the exception of 'control saliva pooling,' which was assessed by natural observation. For all other items, the examiner made multiple requests and demonstrations (with plentiful time in between) until the child made some oral movement. Each assessment was scored independently by two coders, who achieved 94.6% reliability. The standard coding protocol for Part 1 of the Kaufman Speech Praxis Test for Children delineates scores of 'able' (skill is performed without error), 'unable' (child was unable to make any movement whatsoever), 'awkward,' 'oral groping,' 'reduced,' 'isolate,' or 'other.' Because of the relatively small sample (20 per group), our analysis was restricted to only percent able.

Results

On average, the minimally fluent autistic children were less able to perform the oral-motor skills than the highly fluent autistic children ($F(1,38) = 27.9$, $p < .001$). As shown in Figure 3, the minimally fluent autistic children were distinguished from the highly fluent autistic children by all but three items: producing any vocalization, puckering lips, and controlling saliva pooling (all three Fs < 1). For each of the other items, the minimally fluent autistic children were less able to perform the oral-motor skills than the highly fluent autistic children (all ps < .03).

While one could speculate why the minimally fluent and highly fluent children did not differ in their ability to pucker lips (both groups showed relatively low performance) or their ability to produce any vocalization (both groups showed relatively high performance), the minimally fluent children's relatively high performance on the latter item suggests that their lower performance

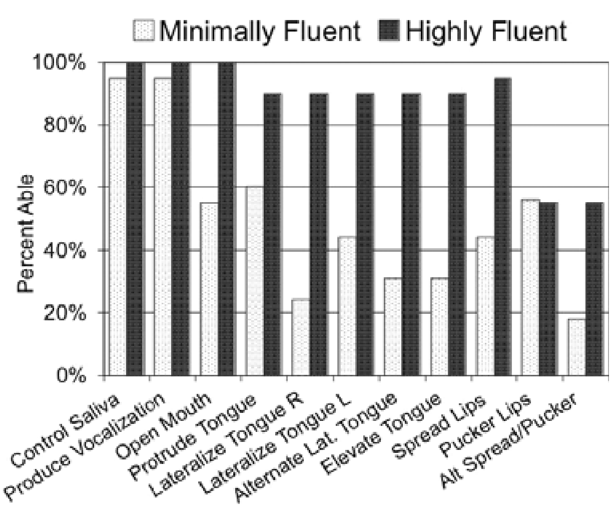

Figure 3 Percent able on current-day oral-motor assessment

on other items was not a general function of failure to understand the tasks or a lack of 'compliance.'

General discussion

The prominent associations among early oral- and manual-motor skills and later speech fluency demonstrated in the data reported here bear important implications for understanding communication in autism. For example, the associations between oral-motor skill and speech fluency illuminate minimally fluent autistic children's phonetic repertoires. Like typically developing children during early stages of speech development, minimally fluent autistic children are more likely to produce vowels than consonants (Wetherby, Yonclas, & Bryan, 1989), voiced consonants (e.g., /d/) as opposed to voiceless consonants (e.g., /t/), and voiced bilabial plosive (e.g., /b/) rather than fricative (e.g., /f/) or sibilant (e.g., /s/) consonants (McCleery, Tully, Sleve, & Schreibman, 2006). Thus, minimally fluent autistic children's phonetic repertoires are in perfect sync with their oral-motor skill (e.g., vowels are notoriously easier to produce than consonants; voiced consonants require less orchestration of the speech-motor apparatus than do voiceless consonants, and so forth).

The data reported here also bear important implications for understanding nonverbal, 'social' communication. Manual-motor skill underlies the three pre-eminent measures of early social communication (Mundy et al., 2003): nonverbal requesting (e.g., reaching for a toy); initiating joint attention (e.g., pointing to a toy), and responding to joint attention (turning one's head in a solicited direction). Indeed, motor skill correlates significantly with these three measures of social communication (Mundy, Kasari, Sigman, & Ruskin, 1995) – with the same magnitude, as reported here, that grabbing toys, stacking blocks, liking to play with Duplos or puzzles, and turning round door knobs correlates with pointing to indicate wants and needs or pointing distally on request.

Shadmehr and Wise (2005) remind us of the complex motor demands of reaching and pointing with the admonition that 'understanding reaching and pointing requires knowledge of physics, biology, mathematics, robotics, and computer science' (p. 1). Furthermore, although some developmentalists have distinguished between pointing proto-imperatively (to indicate wants) and pointing proto-declaratively (to indicate interests), with the latter assumed to assay 'theory of mind,' in Baron-Cohen et al.'s (1996) large-scale study, 90% of the autistic toddlers who were unable to point proto-declaratively were also unable to point proto-imperatively, a finding that 'was not predicted from current theories, although this has been noted clinically' (p. 162). Thus, it is likely that manual-motor skill also underlies this popularly used metric of 'theory of mind.'

Manual-motor skills can also confound the assessment of receptive language. In one study of typically developing infants and toddlers, motor skill accounted for almost three fourths of the variance in receptive language development (Mundy et al., 1995). Why? The assessment was made via the Reynell Developmental Language Scales (1977), which assesses comprehension by requiring children to point to and manually manipulate objects, pictures, or figurines.

Thus, oral-motor and manual-motor skill underlie standard forms of spoken and 'non-verbal' communication. Current DSM-IV-TR (APA, 2000) criteria for autistic disorder specify a 'delay in, or total lack of, the development of spoken language (not accompanied by an attempt to compensate through alternative modes of communication such as gesture or mime),' implying that manual modes of communication are available to autistic individuals – if simply they choose to use them. The data presented here challenge this assumption by demonstrating the tight coupling between the hands and the mouth (Corbetta & Thelen, 1996; Iverson & Thelen, 1999).

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Correspondence to

Morton Ann Gernsbacher, 1202 W. Johnson Street, Madison, WI 53706, USA; Email: MAGernsb@wisc.edu

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