Gesture and Motor Skill in Relation to Language in Children With Language Impairment

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Purpose: To examine gesture and motor abilities in relation to language in children with language impairment (LI).

Method: Eleven children with LI (aged 2;7 to 6;1 [years;months]) and 16 typically developing (TD) children of similar chronological ages completed 2 picture narration tasks, and their language (rate of verbal utterances, mean length of utterance, and number of different words) and gestures (coded for type, co-occurrence with language, and informational relationship to language) were examined. Fine and gross motor items from the Battelle Developmental Screening Inventory (J. Newborg, J. R. Stock, L. Wneck, J. Guidubaldi, & J. Suinick, 1994) and the Child Development Inventory (H. R. Ireton, 1992) were administered.

Results: Relative to TD peers, children with LI used gestures at a higher rate and produced greater proportions of gesture-only communications, conventional gestures, and gestures that added unique information to co-occurring language. However, they performed more poorly on measures of fine and gross motor abilities. Regression analyses indicated that within the LI but not the TD group, poorer expressive language was related to more frequent gesture production.

Conclusions: When language is impaired, difficulties are also apparent in motor abilities, but gesture assumes a compensatory role. These findings underscore the utility of including spontaneous gesture and motor abilities in clinical assessment of and intervention for preschool children with language concerns.

KEY WORDS: gestural communication, language disorders, children

In this study, we explored gesture and motor ability and their relationships to language in children with language impairment (LI) in the absence of hearing loss, neurological deficits, social–emotional disorders, or other known factors. We examined measures of gesture and motor skill in children with LI and same-age typically developing children (TD) and the extent to which they independently contribute to the prediction of expressive language abilities. The motivation for this work stems from the recent surge of interest in links between language and action, which has rekindled a long-standing theoretical debate regarding the nature of the relationship between cognition and action.

Embodiment and LI

Traditionally, cognition and action, and consequently language and action, have been studied separately and treated theoretically as distinct domains of psychological functioning (e.g., Fodor, 1983). By contrast, the body of work indicating close relations between language and action has provided a solid empirical basis for an embodied view of cognition, one

that highlights the centrality of bodily action in cognitive process (e.g., Clark, 1997; Varela, Thompson, & Rosch, 1991; M. Wilson, 2002; see also Gibson, 1966; Merleau-Ponty, 1945/1962; Piaget & Inhelder, 1966/1969). According to this view, cognition depends crucially on having a body with particular perceptual and motor capabilities and the types of experiences that such a body affords. In other words, cognition and cognitive processes are strongly influenced by the body and the ways in which it moves through and interacts with the world.

There is a growing body of neurophysiological and behavioral evidence that is consistent with this perspective. At the neurophysiological level, a close link between language and action is supported by two broad sets of converging results from work with adults. First, areas of the brain implicated in language functions (e.g., Broca's area) are also involved in motor tasks. For example, in addition to the activation expected during language tasks, Broca's area is also active during motor tasks (e.g., the execution, imagination, imitation, and observation of finger movements; Heiser, Iacoboni, Maeda, Marcus, & Mazziotta, 2003; Iacoboni et al., 1999). Second, activation of motor structures is observed during language tasks; for example, areas of the motor cortex are activated when adults listen to speech sounds (e.g., S. M. Wilson, Saygin, Sereno, & Iacoboni, 2004) or silently read action verbs (e.g., Hauk, Johnsrude, & Pulvermuller, 2004; see Willems & Hagoort, 2007, for a review). This pattern of activity may be attributed in part to common neural mechanisms supporting language production and motor sequencing (Ojemann, 1984) and to the representation of the hands, arms, and vocal tract in neighboring brain regions (e.g., Fried et al., 1991).

At the behavioral level, one instantiation of the broader relation between language and action is the link between language and gesture. In adults and children, gestures co-occur with language in spontaneous production, and this co-occurrence is characterized by tight temporal and semantic relations between the two modalities (e.g., Goldin-Meadow & Iverson, 2010; McNeill, 1992). Thus, the active phase of the gesture is typically executed just as co-expressive meaning is expressed verbally, resulting in a temporally synchronous, semantically coherent message. These relationships are apparent relatively early in development; even one-word speakers produce tightly timed gesture–word combinations in which the two elements convey related information about a referent (see Capone & McGregor, 2004, for a review).

Debate regarding the nature of the relationship between language and action is currently alive and well in research on developmental language disorders, in particular specific language impairment (SLI). On the one hand, because SLI is defined as a significant limitation in language in the absence of hearing impairment, low nonverbal intelligence test scores, and neurological damage (e.g., Leonard, 1998), and because much of the existing research on SLI has focused on characterizing the nature of the language deficits, SLI is widely viewed as a disorder *specific* to language. On the other hand, a number of studies have revealed that children with SLI also have difficulties in nonlinguistic cognition (e.g., attention, perceptual processing, procedural memory; see Bishop, 1992; Hill, 2001; Leonard, 1998; Ullman & Pierpont, 2005). Such findings run counter to the view that language impairment is an isolated disorder, suggesting instead that although language appears to be the primary area of impairment in SLI, the disorder also involves difficulties in a range of domains beyond language.

The suggestion that the difficulties observed in children with language disorders may not be specific to language, coupled with the growing body of evidence documenting links between language and action in general, has stimulated interest in examining the language–action relationship in children with language impairment. Researchers have taken two approaches to this issue, one focused on detailing the relation between language and motor skill and the other on examining the relation between language and gesture. The general logic underlying both approaches has been to explore whether and to what extent there is variation in the nature of these relationships when language is impaired versus developing typically.

Motor abilities and language. With regard to the relationship between language and motor skill, the general finding is one of relatively high rates of co-occurrence between impairments in motor coordination and language in children clinically referred for language concerns (see Hill, 2001, for a review). Thus, for example, Hill (1998; see also Webster et al., 2006) found that 11 of 19 children with SLI obtained scores on the Movement Assessment Battery for Children (Henderson & Sugden, 1992) that fell within the range for children with developmental coordination disorder, a neurodevelopmental condition characterized by movement difficulties disproportionate to the child's general developmental level and in the absence of any medical condition (e.g., cerebral palsy) or identifiable neurological disease. This rate is nearly 10 times that of the general population. Hill also reported significantly worse performance in children with SLI than in age-matched peers on an experimental representational gesture imitation task requiring production of coordinated sequences of movement. Indeed, children with SLI—even those who scored within the normal range on the Movement Assessment Battery for Children—performed more like children with developmental coordination disorder on this task. Hill interpreted these findings as an indication of underlying neurological immaturity that manifests in both the motor and the language systems (see also Bishop & Edmundson, 1987).

Gesture and language. Studies of spontaneous gesture production in older children with LI suggest that gesture may play a compensatory role in the face of difficulties with expressive language. Evans, Alibali, and McNeil (2001; see also Mainela-Arnold, Evans, & Alibali, 2006) analyzed the gestures and language produced by 7- to 9-year-old children with a diagnosis of SLI and phonological working memory deficits as they reasoned through a series of Piagetian conservation tasks. They found that the proportion of gestures used by children with SLI to convey information disjoints between language and gesture (i.e., gesture-conveyed information that was not present in oral language) was twice that of a group of TD children matched on overall conservation performance.

Blake, Myszczyszyn, Jokel, and Bebiroglu (2008) asked 5- to 10-year-old children with SLI to narrate a short cartoon from memory and to describe their classrooms. Analyses of gestures revealed that in both tasks, children with SLI tended to produce more iconic gestures and to use them to replace words more frequently than age- and language-matched comparison children. The findings from these two studies suggest that although gesture production clearly involves fine motor abilities, it also makes use of other cognitive and communicative abilities (e.g., communicative intent, symbolization). This raises the possibility that gesture may make an independent contribution to the prediction of language.

Because previous work has examined relationships between language and gesture and between language and motor abilities separately in different groups of children with LI and TD comparison children, it leaves open the question of whether gesture, motor skill, or both make independent contributions to the prediction of children's language abilities. We also do not know whether the relationship of gesture and motor skill to language differs between children with LI and their TD peers.

From a practical perspective, understanding the extent to which gesture and motor abilities contribute uniquely to the prediction of language may provide useful information regarding their value as potential predictors of future language outcomes. Much of the available work that has examined motor–language and gesture–language relations in children with LI has focused on school-age children, for whom language difficulties are presumed to be relatively stable. Although it is generally acknowledged that early language delay is a transient phenomenon for many toddlers (e.g., see Thal & Katich, 1996, for a review), work by Bishop and Edmundson (1987) suggests that spontaneous recovery from delay can also occur during the preschool years: In their longitudinal study of 87 four-year-olds clinically referred for concerns about delayed language, by age 5½ just under half of the sample (44%) was indistinguishable from comparison children with typical language on a battery of language measures.

We therefore designed the present study to examine gesture and motor skill in relation to language in preschool-age children clinically referred for LI and same-age TD comparison children. We explored whether variation in aspects of co-speech gesture and in motor skill may be related to severity of language difficulties. Although the research described here involves assessment of these abilities at a single time point, observation of systematic variability in gesture and motor skill in relation to measures of language would, in principle, be suggestive of their utility as potential prognostic indicators in longitudinal work.

The study had the three main goals. The first goal was to characterize spontaneous gesture production and its relation to language in preschoolers clinically referred for LI and age-matched TD comparison children. Children's language and gesture were sampled during a pair of picture narration tasks, and we examined several measures of gesture use, focusing not only on frequency of gesture production but also on co-occurrence with language, gesture types, and the informational relationship between gesture and language. In line with previous research on older children with SLI, we expected to find evidence of enhanced gesture use in children with LI relative to comparison children, specifically in the more frequent use of gestures to replace speech (i.e., gesture alone; Blake et al., 2008) and to add unique information to co-occurring language (Evans et al., 2001).

The second goal was to examine fine and gross motor skills in children with LI and TD children. We administered fine and gross motor items from two widely used screening instruments: (a) the Battelle Developmental Screening Inventory (BDSI; Newborg, Stock, Wneck, Guidubaldi, Suinick, 1994) and (b) the Child Development Inventory (CDI; Ireton, 1992). We expected that children with LI would exhibit poorer fine and gross motor abilities compared with same-age peers (e.g., Hill, 1998).

The third goal was to examine the extent to which these two measures of gesture and motor skill contribute to the prediction of expressive language. Given the opposite directions of the respective relationships of motor skill and gesture with language (impairment in one instance, compensatory enhancement in the other), motor skill and gesture production should make independent contributions to the prediction of language level in children with SLI but not in TD comparison children.

Method
Participants

Participants were 11 preschool-age children who had been referred to regional speech clinics by parents or pediatricians because of concerns about language learning

difficulties with no apparent cause (the LI group) and 16 children with typical language (the TD group). This general sampling approach was adopted in preference to one based on narrowly defined standardized score criteria of the sort commonly used in studies of older children diagnosed with SLI (e.g., Leonard, 1998), for three reasons.

First, because a goal of this study was to examine the extent to which variability in gesture use and motor skill is related to variability in language in the preschool years, we needed a sample of children who exemplified such variability.

Second, Fey, Long, and Cleave (1994) pointed out that although many studies of children with LI exclude those within the borderline range of intelligence (i.e., nonverbal IQ between 70 and 85), such a criterion is problematic for two reasons: (a) It does not take standard error of measurement into consideration, and (b) because there is no upper limit set on the IQ score range, exclusion of children at the lower end of the distribution may result in the creation of an artificial group. In support of their argument, Fey et al. presented data indicating that the language scores of children with LI and performance IQ scores between 70 and 85 did not differ significantly from those of children with SLI who met traditional IQ criteria (i.e., scores above 85).

Third and finally, because in previous research approximately 40% of 4-year-olds who were clinically referred for concerns about LI and who had nonverbal abilities within the normal range "recovered" from these earlier difficulties (i.e., were indistinguishable from TD children with no history of language concerns by age 5½ years; Bishop & Edmundson, 1987), it is unclear whether adoption of a minimum IQ criterion for children in the preschool age range would result in a sample of children who would ultimately be classified as children with SLI.

The 11 children with LI (eight males and three females) were identified through regional speech clinics located in and around a small midwestern city and referred for study participation by a certified speech-language pathologist. Their mean age was 3;11 (years; months; range: 2;8–6;1), and all were from monolingual, English-speaking homes. Characteristics of the LI group are presented in Table 1. As is evident, all of the children with LI scored at least 1.25 SD below the mean on one ($n = 4$) or both ($n = 7$) of the Preschool Language Scales—3 (PLS–3; Zimmerman, Steiner, & Pond, 1992) subtests. Leiter International Performance Scale—Revised Brief IQ Screen (LBIQ; Roid & Miller, 1997) scores were within the normal range for seven of the nine children who completed the assessment; scores could not be computed for the remaining two children because they did not complete the assessment.

Sixteen TD children (13 males and three females) comparable to the LI children in chronological age were recruited from area preschool programs (mean age = 3;9, range: 2;7–5;10). A Mann–Whitney test confirmed that the two groups did not differ significantly in age, $U = 80$ (ns). There were no parent or experimenter concerns about language or cognitive development for any of the children in the TD group. The standardized cognitive and language measures were not administered to TD children.

Procedure

Children with LI were seen for two visits (scheduled no more than 1 week apart) at their homes or preschools. The communication and motor observations were

Table 1. Characteristics of participants with language impairment (LI).

Participant	Age (months)	PLS–VE[a]	PLS–AC[a]	LBIQ[a]	BDSI–FM[b]	BDSI–GM[b]	CDI–FM[b]	CDI–GM[b]
1	47	79	88	103	29	42	38	38
2	37	70	103	121	26	29	27	27
3	59	52	65	87	29	29	34	34
4	73	52	63	71	26	29	25	25
5	32	86	80	117	26	29	36	36
6	49	69	60	89	34	29	27	27
7	54	68	73	85	49	42	51	51
8	54	50	50	80	29	29	36	36
9	42	73	88	107	28	35	30	30
10	37	62	58		23	29	24	24
11	37	62	56		23	29	24	24

Note. PLS-VE = Preschool Language Scales–Verbal Expression; PLS-AC = PLS–Auditory Comprehension; LBIQ – Leiter Brief IQ Screen; BDSI-FM = Battelle Developmental Screening Inventory–fine motor; BDSI-GM = BDSI–gross motor; CDI-FM = Child Development Inventory–fine motor; CDI-GM = CDI–gross motor.

[a]Standard score. [b]Age equivalent (months).

completed at the first visit, and the standardized language and cognitive measures were administered at the second visit. TD children were seen for one visit in their homes to complete the communication and motor observations.

Communication observation. Although studies of TD children younger than 3½ years typically sample communication during free play with a familiar adult (e.g., Nicoladis, Mayberry, & Genesee, 1999), pilot work indicated that many children (especially children with LI) produce very few utterances in this setting. In addition, tasks used in previous studies of gesture use by older children with SLI (e.g., Piagetian conservation, cartoon retelling from memory, classroom description) are not developmentally appropriate for preschoolers. We therefore needed a task that was more structured than free play, compatible with in-home observations, and maximally likely to elicit communication. In light of these considerations, we selected two narrative tasks that involved telling a story from a series of pictures. Creating narratives is a common occurrence in the daily lives of preschoolers (e.g., P. J. Miller & Sperry, 1988), and narrative tasks have been successfully used in numerous studies of children in this age range (e.g., Berman & Slobin, 1994; Reilly, 1992). Thus, in the communication observation, which lasted approximately 10 min, children and caregivers were asked to engage in cartoon sequence and picture book narration tasks.

The cartoon sequence narration was adapted from the Autism Diagnostic Observation Schedule (Lord, Rutter, DiLavore, & Risi, 1999); we selected it for use in the present study because it is specifically designed as a press for gesture use in the original instrument. This item is typically administered by an experimenter who tells the child the story depicted by the pictures; the pictures are then removed from sight and the child is asked to retell the story from memory. However, we introduced several modifications to reduce memory demands and make the task appropriate for young children. The sequence of six individual black-and-white drawings was placed in front of the child and caregiver, and caregivers were instructed to look at the pictures and talk with the child about what was happening in them. Children were then asked to provide a narrative of the cartoon sequence while looking at the pictures. An Elmo doll was introduced, and children were encouraged to "Tell Elmo the story." Caregivers were permitted to provide visual and verbal prompts as needed.

The picture book narration involved the wordless picture book *Frog, Where Are You?* (Mayer, 1980), which has been extensively studied in numerous investigations involving a wide range of ages (from 3 years through adulthood) and populations with typical and atypical language (e.g., see Berman & Slobin, 1994). As in the cartoon sequence task, caregivers and children first looked at the book together, and children were then asked to provide a narrative of the story while looking at the pictures using the Elmo toy and prompts from caregivers as needed.

Motor skill observation. The motor skill observation, which lasted approximately 30 min, was conducted after completion of the communication observation. During this segment of the visit, the experimenter administered fine and gross motor items from the BDSI while caregivers completed the fine and gross motor sections of the CDI.

The BDSI is a general developmental screening instrument used to identify preschool- and kindergarten-age children's developmental strengths and weaknesses. It contains 11 fine and nine gross motor items. Gross motor items for the age range of the children in the present study assess general balance and coordination (e.g., jumps forward on both feet, hops on one foot for 10 ft). Fine motor items tap manual dexterity, bimanual coordination, and eye–hand coordination (e.g., opens door by turning knob, uses scissors to cut paper, folds piece of paper horizontally and vertically, copies triangle). Scores were computed on the basis of the administration manual.

The CDI is a parent report instrument consisting of yes/no questions about the developmental status of children in a variety of domains and can be used with children between the ages of 1 and 6 years. The 30 gross motor items examine walking, running, climbing, jumping, riding, balance, and coordination (e.g., runs, hops on one foot, does cartwheels), and the 30 fine motor items assess eye–hand coordination, drawing, and cutting (e.g., draws recognizable pictures, colors within lines).

Although the BDSI and CDI are relatively general developmental screening tools, many items are similar to tasks that have been used in previous studies of motor skill in children with LI. These instruments have two additional advantages. First, because the CDI is completed by parent report and the BDSI is observational, taken together they may provide a more reliable and valid index of children's motor abilities. Second, they are widely available in clinical settings; require relatively little time to administer; and, unlike experimental tasks, do not require either a controlled setting or complex and time-intensive coding.

Standardized language and cognitive measures. Children with LI were seen for a second 1-hr session at home or at the clinic from which they were recruited. At this session, children were given the Auditory Comprehension and Expressive Communication subscales of the PLS–3, followed by the LBIQ. This order of administration was fixed across all children.

The PLS–3 is a standardized language assessment designed to assess language precursors, semantics, language structure, and integrative thinking skill. It is a

norm-referenced test for children functioning at birth to 6-year levels.

The LBIQ comprises four subtests (Figure Ground, Form Completion, Sequential Order, and Repeated Patterns) from the Visualization and Reasoning Battery. It assesses nonverbal abilities with pictures, figural illustrations, and coded symbols, and all instructions to the child are adapted to a nonverbal format. The Brief IQ Screen can be used as a rapid estimate of global intellectual level in persons between the ages of 2 and 20 years.

Coding

All of the children's verbal and gestured communications were transcribed from the videotaped cartoon and wordless book narrations. A *communication* was defined as any sequence of words and/or gestures (that may or may not be grammatically structured) that was preceded and followed by a pause. Language was transcribed verbatim and coded using a standard procedure for analyzing free-speech samples (J. F. Miller, 1985). Children's gestures were transcribed following conventions used in adult research (e.g., McNeill, 1992) and adapted in previous work with very young children (e.g., Nicoladis et al., 1999; Őzçalişkan & Goldin-Meadow, 2005). A *gesture* began when the moving hand entered the "gesture space" in front of the child's body and ended either when the hand was retracted into neutral space or changed trajectory or location following a hold or pause in movement (e.g., if a child pointed to a toy on her left, then pointed to another toy on her right without dropping the hand in between, two gestures would be coded). Although the vast majority of gestures involved the hands, some gestures involved movements of the head (e.g., head nod "yes") or the whole body (e.g., the child bounces the torso up and down while talking about the frog "jumping away"). All communications were then classified into one of three categories: (a) *gesture only* (communications in which gestures were produced without accompanying language), (b) *language only* (communications consisting of language without coproduced gesture), and (c) *language with gesture* (communications in which a gesture was produced along with language).

Analysis of language. We computed three measures of language for each child: (a) number of verbal utterances per minute (i.e., total number of verbal utterances divided by length of observation in minutes), (b) number of different words, and (c) mean length of utterance in morphemes (MLU_m; i.e., total number of morphemes divided by the total number of utterances). We selected number of different words and MLU_m as measures of language complexity because they have been used in previous studies of gesture in young children in this age range (e.g., Nicoladis et al., 1999; Őzçalişkan & Goldin-Meadow, 2005),

and a study of kindergarten-age children with and without SLI reported group differences on both measures (Hewitt, Hammer, Yont, & Tomblin, 2005).

Analysis of gesture. Following criteria described in previous work with TD children of this age and general language level, we classified gestures by type into one of four categories Őzçalişkan & Goldin-Meadow, 2005). *Deictic gestures* indicated referents in the immediate environment, either by pointing at an object or person or holding up an object for another to see. *Conventional gestures* had meanings that are recognizable by others even in the absence of accompanying language (e.g., waving "bye-bye," nodding the head "yes"). *Representational gestures* depicted a characteristic of or action performed by a referent (e.g., flapping the arms to refer to a bird in flight). Consistent with standard procedures for coding gesture in narrative tasks (e.g., McNeill, 1992), we determined the meaning of these gestures through reference to the language with which they were coproduced. When representational gestures occurred alone, we tentatively determined meaning by examining the verbal portion of communications that immediately preceded and followed the gesture (e.g., if a child said "frog in jar," then produced a gesture consisting of a *C*-shaped hand following a pause, the meaning of the gesture was glossed as "jar"). These procedures are standard for coding gesture in spontaneous narration tasks (e.g., McNeill, 1992; Nicoladis et al., 1999). Finally, *beat gestures* were formless movements of the hands and arms that followed the rhythm of accompanying language, highlighting aspects of discourse structure but conveying no semantic information (e.g., flicking the hand up and down or back and forth; McNeill, 1992).

Informational relationship between language and gesture. We grouped all communications containing intelligible, meaningful language with gesture into one of three categories on the basis of the relation between the information conveyed in gesture and language (see also Őzçalişkan & Goldin-Meadow, 2005). A *reinforcing* relation was coded when gesture emphasized or conveyed the same information as the verbal portion of the communication. Included in this category were communications with a beat gesture, communications containing a conventional gesture and its verbal equivalent (e.g., head nod + "yes"), and communications in which a referent was indicated with a deictic gesture (showing or pointing) and labeled verbally (e.g., showing an apple + "apple"). A *disambiguating* relation was coded when gesture clarified the precise referent of the spoken portion of the utterance, which was generally a demonstrative or locative expression (e.g., "This," "That," "Here," "There"), personal or possessive pronoun (e.g., *your, yours*), or attention-directing expressions (e.g., "Look!", "See!"). An *add* relation was coded when gesture provided semantic information that was not explicitly conveyed in

oral language. In a majority of instances in this category, the gestured portion of the communication (usually a deictic gesture) identified the referent, and the spoken portion described an attribute of the referent (e.g., point to a picture of a cat watching fishermen unload fish from a boat + "watching 'em").

Reliability

To assess intercoder reliability, we randomly selected four of the 27 observation segments (two per group) for independent transcription and coding by a second trained coder. Mean intercoder agreement for language measures was .94 for identifying utterances ($N = 544$), .93 ($N = 518$) for number of different root words, .88 ($N = 544$) for classifying utterances as intelligible, and .88 ($N = 230$) for morpheme identification. For gesture measures, mean intercoder agreement was .92 ($N = 228$) for gesture occurrence, .93 ($N = 212$) for classifying gestures by type, and .86 ($N = 107$) for classifying the informational relationship between gesture and language.

Results

This study was designed to examine relationships among language, gesture, and motor abilities in preschool children with LI and age-matched TD children. We begin by presenting data on language and gesture production, followed by analyses of gesture types and the informational relationship between gesture and language in coproduced communications. Next, we describe gross and fine motor abilities in the two groups of children. In the final section, we investigate gesture production and motor skill as predictors of expressive language abilities in children with LI and TD children and explore the extent to which relationships among language, gesture, and motor skill may differ between the two groups. Unless otherwise indicated, all statistical comparisons were two-tailed.

We conducted preliminary analyses to determine whether communication profiles differed between children with average versus below average (or missing) IQ scores (see Table 1). A series of Mann–Whitney U tests revealed a single statistically significant difference: Children with average IQs produced a significantly greater number of verbal utterances per minute ($U = 3$, $p = .042$). There were no differences on any other measure of language or gesture.

Language and Gesture Production

Language. We examined children's language from the communication observation by calculating the number of verbal utterances per minute, number of different words, and MLU_m for each child and averaging them across children in the two groups. These data are presented in Table 2, along with the results of statistical comparisons (using Mann–Whitney U tests) and Cohen's d as a measure of effect size. As expected, there were significant group differences on all of these measures. In comparison to TD children, children with LI produced fewer utterances per minute, fewer different words, and had shorter MLU_ms.

Gesture. To evaluate the prediction that children with LI rely more extensively on gesture for communicative purposes, we examined gesture production in terms of frequency of production, gesture type, and the informational relationship between gesture and language in coproduced utterances.

In light of the group differences in overall communication during the session, we used the number of gestures per communication (i.e., number of gestures divided by the total number of communications) as our measure of gesture production. We computed this ratio for each child and averaged across children in the two groups (see Table 2). Although the difference just missed conventional cutoffs for statistical significance ($p = .08$), on average children with LI produced gestures at a rate nearly one and a half times that of TD peers.

Because inspection of the group distributions indicated significant skewing and substantial individual variability at the high end, especially among children with LI, we decided to evaluate differences in gesture rate further by comparing distributional patterns between groups. We computed a Fisher's Exact test on the distributions of children with LI whose gesture rates fell above versus at or below the median for the TD group (and vice versa). This difference was highly significant ($p = .002$): Eight of 11 children with LI produced gesture at a rate above the median for the TD group, whereas only two TD children gestured at a rate higher than the LI group median.

We next examined proportions of communications in language only, in language with gesture, and in gesture only. We calculated these proportions by totaling the number of communications in each of these categories and dividing them by the total number of communications produced during the language–gesture observation. These data are presented in Figure 1.

Not surprisingly, a majority of communications for both groups of children occurred in language only, followed by language with gesture, and gesture only, in that order. Examination of the relative proportions of communications within the three categories, however, indicated that, relative to their TD peers, children with LI produced a significantly higher proportion of communications in gesture only ($M_{LI} = .23$, $SD = .18$; $M_{TD} = .09$,

Table 2. Means (and *SD*s, in parentheses) for LI and typically developing (TD) groups on measures of language, gesture, and motor skill.

Language	LI M (SD)	TD M (SD)	U	p	d
Verbal utterances per minute	4.73 (4.41)	8.66 (3.56)	23.5	.001	1.96
No. different words	40.82 (40.12)	92.69 (29.86)	21.0	.000	8.76
MLU$_m$	1.69 (0.67)	3.30 (0.82)	9.0	.000	1.86
Gesture production					
Gestures per communication	0.51 (0.24)	0.35 (0.18)	51.0	.08	0.35
Gesture type					
Deictic	0.49 (0.22)	0.61 (0.20)	60.0	ns	
Conventional	0.36 (0.20)	0.23 (0.22)	57.5	ns	
Representational	0.04 (0.05)	0.05 (0.05)			
Beat	0.11 (0.11)	0.11 (0.11)			
Informational relationship					
Reinforce	0.46 (0.34)	0.47 (0.18)			
Disambiguate	0.35 (0.34)	0.39 (0.26)			
Add	0.20 (0.17)	0.14 (0.15)			
Motor skill					
CDI-FM	19.36 (4.72)	25.31 (4.33)	30.5	.003	2.80
BDSI-FM	11.73 (1.68)	14.00 (2.99)	40.0	.017	1.49
CDI-GM	23.00 (4.43)	26.13 (1.89)	35.5	.008	1.76
BDSI-GM	10.36 (0.81)	11.69 (2.21)	53.5	.089	1.08

Note. MLU$_m$ = mean length of utterance in morphemes.

SD = .08; $U = 48$, $p = .05$, $d = 1.40$). A Fisher's Exact test indicated that this difference was highly robust across individual children in the LI group. For eight of 11 children with LI, the proportion of gesture-only communications fell above the median for the TD group, and proportions for only two TD children were greater than the LI group median ($p = .006$).

As described earlier, gestures were classified as deictic (pointing or showing), conventional (e.g., head nod "yes," shoulder shrug "I don't know"), representational (e.g., circling hand movement to indicate bees flying around), or beat (e.g., upward/downward flick of the hand). The mean proportions of gestures in each of these categories are presented in the middle of Table 2. As is

Figure 1. Mean proportions of utterances in language only, language with gesture, and gesture only produced by children in the LI and TD groups. Error bars represent standard errors.
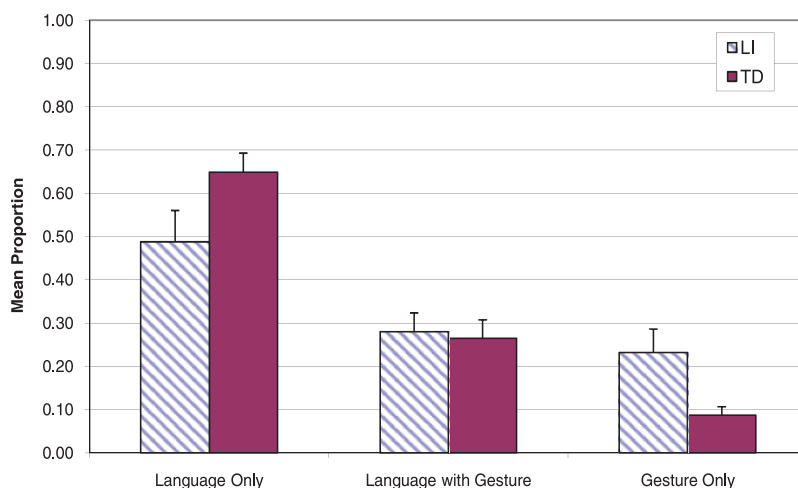
apparent in the table, the overall distribution of gestures across categories was relatively similar for both groups. Over half of the gestures produced were deictic, followed by conventional, beat, and representational gestures, in that order. Despite the general absence of average group differences, however, there was a difference in the distributions for conventional gestures. Proportions for nine children with LI fell above the TD group median, and those for five TD children exceeded the LI group median ($p = .026$, Fisher's Exact test).

Informational relationship between gesture and language. We next examined the extent to which children with LI used gestures to add unique information to a verbal message by computing the mean proportions of communications containing language and gesture classified as *reinforcing* (e.g., shaking the head while saying "There's no frog there!"), *disambiguate* (e.g., pointing to picture of the boy and then to the picture of the frog while saying "The boy has a frog"), or *add* (e.g., making a circling movement with the hand to depict bees swarming while saying "Bees there!"), respectively. Although no average group differences were observed for either measure (see Table 2), inspection of the distributions indicated that although the proportions of add utterances for seven of 11 children with LI fell above the TD group median, they exceeded the LI group median for only three of the 16 TD children ($p = .048$, Fisher's Exact test).

Motor Abilities in Children With LI and TD Children

On the basis of previous research (e.g., Hill, 1998), we predicted that children with LI would exhibit deficits in motor functioning. To assess this prediction, we computed standard scores separately for each child on the fine and gross motor sections of the BDSI and the CDI according to test manual guidelines. The mean standard scores and standard deviations for each of these measures are presented at the bottom of Table 2.

As is evident in Table 2, substantial group differences were obtained on all four measures, with children with LI consistently performing more poorly than their same-age TD counterparts. Thus, relative to their same-age TD peers, children with LI obtained significantly lower fine motor scores on both the BDSI and CDI. In addition, the distributions of scores in the two groups on each measure were almost nonoverlapping. On the BDSI, only two children with LI scored above the median for the TD group, whereas all 16 TD children scored above the LI group median ($p = .001$, Fisher's Exact test). Scores from the CDI revealed a similar pattern: Two children from the LI group, but 15 TD children, scored above the comparison group's median ($p = .0001$).

Gross motor scores for children with LI were also lower than those for TD children; the difference was statistically reliable on the CDI but only approached significance on the BDSI. Once again, however, the distributions of scores in the two groups on each measure were almost nonoverlapping. On the BDSI, two children with LI scored above the median for the TD group, whereas all 16 TD children scored above the LI group median ($p = .001$, Fisher's Exact test). Scores on the CDI revealed a similar pattern: One child from the LI group, but all 16 TD children, scored above the comparison group's median ($p = .001$).

Gesture Production and Motor Skill as Predictors of Language

Thus far, we have presented group data to address predictions regarding gesture use and motor skill in children with LI. However, as described earlier, the children with LI in the present study were sampled so as to reflect the variability in language abilities typical in a clinic-referred population. In this section, we present two sets of analyses designed to examine whether gesture and motor abilities are related to individual differences in language abilities.

Before conducting these analyses, we created a language composite and a fine motor composite score for each child. We created the language composite score using three of the language measures from the communication observation: (a) verbal utterances per minute, (b) number of different words, and (c) MLU_m. We chose these measures because reliable group differences were observed on each and because all three are tied to gesture production (e.g., McNeill, 1992, 2005). Scores on each of these measures were standardized and then averaged to yield the language composite score. Similarly, we created the fine motor composite score by standardizing each child's raw scores on the fine motor sections of the BDSI and CDI and averaging the two scores. We focused on fine motor skills in these analyses in light of the literature indicating particularly close links between language and fine motor abilities in children (e.g., Bishop, 2002; see also Iverson & Thelen, 1999). Level of internal consistency for both composites was more than adequate (Cronbach's αs = .91 and .83 for the language and motor composites, respectively).

Using language composite score as the dependent variable and rate of gesture production (i.e., gestures per utterance, added at Step 1) and fine motor composite score (added at Step 2) as separate predictor variables, we then ran a hierarchical regression analysis. This procedure allowed us to examine the extent to which gesture and fine motor abilities made independent contributions to the prediction of language. The results of this analysis are presented in Table 3.

Table 3. Expressive language hierarchical regression models.

Variable	Full model		LI group		TD group	
	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2
Gesture production B (SE)	−1.86* (0.762)	−1.044 (0.645)	−1.553 (1.009)	−1.124 (0.803)	−0.265 (0.954)	−0.042 (0.911)
Fine motor composite B (SE)		0.587** (0.151)		0.754* (0.289)		0.303 (0.184)
R2	.192	.504	.209	.573	.005	.177
F	5.951*	15.063**	2.371	6.83*	0.077	2.704

*$p < .05$. **$p \leq .001$.

As is evident in the table, there was a significant negative relation between gesture production and language composite scores. A one-unit increase in gesture production was associated with a 1.860-point decline (2.04 *SD*) in the language composite score. When fine motor composite score was introduced at Step 2, the gesture coefficient decreased by about 20%, suggesting that the effect of gesture was partially mediated by the fine motor composite. The relation between language and fine motor ability was also significant, though positive in direction. A one-unit increase in fine motor composite score was associated with a 0.587-point (0.64-*SD*) increase in language composite score.

To examine whether the relationship just described varied in relation to group status, we conducted a Chow test (Chow, 1960). This analysis allowed us to test whether regression coefficients differed significantly between the LI and TD groups. The results indicated that the difference between the two sets of regression coefficients approached significance, $F(3, 21) = 2.72$, $p = .07$. This difference may be partially explained by the fact that although the fine motor coefficients were moderately positive for both groups, the gesture coefficient for the LI group was more strongly negative ($\beta = -.33$) than that for the TD group, which approached zero ($\beta = -.012$). Thus, for the LI group (but not the TD group), increases in gesture production were associated with reductions in the language composite scores.

Discussion

Previous research that has examined motor–language and gesture–language relationships in children with LI has reported two main findings. The first is that children with language difficulties exhibit impairments in motor skill (e.g., see Hill, 2001, for a review). This (and similar findings from populations with other disorders; see Iverson & Thelen, 1999, for a review) has formed the basis for the view that the co-occurrence of language and motor impairments in populations with language and/or motor disorders reflects the tight links that exist between the two systems. The second finding is that children with

LI make more extensive use of gesture than TD peers, presumably as a means of expressing ideas that cannot be conveyed in language (e.g., Evans et al., 2001).

Because these results derive from different studies and different samples, the question arises whether this same pattern would be found in children whose language, gesture, and motor abilities were all examined simultaneously in the same study and, if they were, whether this pattern might be impacted when one (language) is impaired. The goal of this study was therefore to bring these two previously distinct lines of work together into a single study by examining language, gesture, motor abilities, and relationships among them in preschool-age children with LI and age-matched TD children. Consistent with prior work on language–motor relations, the preschool-age children with LI in our sample performed more poorly on measures of fine and gross motor abilities and, consistent with previous investigations of language–gesture links, the children with LI made enhanced use of gesture, presumably as a means to compensate for poor oral language. After discussing these two sets of findings, we examine the implications of our findings for the clinical evaluation of children with language difficulties.

Motor Deficits in Children With LI

In line with previous research (e.g., Hill, 1998; Webster et al., 2006), and consistent with the view that LI may be only one component in a broader spectrum of delays and difficulties for children with LI, the children with LI in our sample lagged significantly behind their TD age-mates in both fine and gross motor skills. This result is in line with a growing body of work indicating that motor and language systems are closely linked in the brain from very early in development and that when language is impaired, some level of motor difficulty is generally apparent (cf. Bates & Dick, 2002; Iverson & Thelen, 1999).

That children with LI often exhibit motor difficulties is not a novel finding (e.g., Bishop & Edmundson, 1987; Powell & Bishop, 1992), but the nature of the mechanism underlying their coexistence is still unclear. One view is that because speech production and the kind of motor

tasks that are typically used in these studies (e.g., finger tapping) both involve precise timing of movements, the observed motor difficulties are more a reflection of difficulties with precise timing than problems with the motor system per se (e.g., Wolff, Melngailis, Obregon, & Bedrosian, 1995; but see Zelaznik & Goffman, 2010, for some recent counterevidence).

Although this explanation is consistent with what is known about the nature of the neural mechanisms supporting language production and motor sequencing (see Ojemann, 1984), it cannot account for the pattern of results described here. Neither the BDSI nor the CDI items administered as part of this study required precise timing of movements. Nonetheless, young children with LI performed relatively poorly on these tasks (cutting paper with scissors, balancing on one foot; see Powell & Bishop, 1992, for similar results with older children).

Findings of this sort have led Bishop (2002) to point out that co-occurring motor and language difficulties may have an underlying genetic basis, with genes that put a child at risk for communicative impairment also affecting motor development. This view is supported by data from prospective studies of infants at heightened biological risk for a variety of communication disorders, including autism spectrum disorders (Iverson & Wozniak, 2007) and dyslexia (Viholainen et al., 2002, 2006), for whom attainment of early motor milestones (e.g., independent sitting) lags behind that of no-risk comparison infants.

Clearly these two views are not mutually exclusive—neither are they the only possible accounts (e.g., see Ullman & Pierpont, 2005)—and further work is needed to ascertain the extent to which difficulties with precise timing versus disruptions in the motor system in general are linked to speech and LI. There is also an additional possibility, however, namely that the acquisition and refinement of motor skills in infancy and early childhood impacts developing language indirectly. Put simply, new ways of acting in the environment that are a consequence of advances in motor skill provide opportunities for practicing and refining skills that are crucial for language and for increasingly complex learning about speech sounds and meaning-making (see Iverson, 2010, for a discussion of this issue). An implication of this view is that delays or deficits in motor skills may constrain the learning that takes place during these everyday activities. Disruptions in early-emerging motor skills (e.g., independent sitting, object mouthing) may have cascading developmental effects and lead to disturbances that extend beyond the motor domain (e.g., delayed consonant production; Iverson, 2010; see also Thelen, 2004). It is important to note, however, that regardless of the precise details of the mechanisms underlying the language–motor link, it is a relationship that is not likely to be simple and directional but rather to be complex and multifaceted.

Relationship Between Language and Gesture in Children With LI

Despite the co-occurrence of language and motor difficulties among the children with LI, there was no indication that this influenced their production of gestures either quantitatively or qualitatively. Indeed, many of the children with LI produced gestures at a rate above the median for the TD comparison group, and regression analyses that examined the relative contributions of gesture to language skill indicated that the relationship between language and gesture differed between the LI and TD groups. Although the regression coefficient for gesture rate for the LI group was moderate in size and negative in direction, that for the TD group approached zero. Within the LI but not the TD group, in other words, *poorer* expressive language was related to *more frequent* gesture production.

In light of what is known about the nature of movement coordination disorders, and given previous data indicating that the gestures produced by children with SLI more closely resemble those of younger children, we might have expected to find similar qualitative differences in this study. However, with the exception of conventional gestures (discussed later in this section), there were no differences in distributions of gesture types, even those that are more complex motorically (i.e., representational gestures; see Blake et al., 2008, for a similar finding with older children with SLI). However, studies that have reported qualitative differences in the gestures produced by children with LI have used imitation tasks in which children are asked to reproduce familiar actions (e.g., brushing their teeth; e.g., Hill, Bishop, & Nimmo-Smith, 1998). Imitated gestures are produced on the spot following a verbal command or exposure to a model, and there is a target form of the gesture with which a given child's production can be compared. By contrast, spontaneous gestures have no standards of well-formedness and are idiosyncratic to the speaker (McNeill, 1992), and even when speakers produce spontaneous gestures in response to the same stimulus there is substantial variation in the nature and form of those gestures (e.g., McNeill, 2005).

That children with LI (in particular those with poorer oral language abilities) made more frequent use of gestures than their TD peers is consistent with the claim that they may in fact be using gestures to compensate for difficulties with spoken language (see also Evans et al., 2001). Enhanced gesture use in children with LI could, in principle, emerge in a variety of different ways beyond sheer frequency of production. Compensation could, for example, be evident in the relative co-occurrence of gestures with language (i.e., greater production of gestures without speech), in the use of specific

gesture types (i.e., more extensive use of gestures that convey specific, concrete information, e.g., conventional or representational gestures), and/or in the informational relationship between gesture and language (i.e., more frequent use of gestures that add unique information to a verbal utterance). We found evidence for compensation on all three of these measures. Relative to TD age-mates, children with LI produced greater proportions of gesture-only communications, conventional gestures, and utterances in which gesture added information to language.

Why did children with LI use gestures in this compensatory fashion? One explanation involves the possibility that mental representations may be weak or imprecise in children with LI (e.g., Bishop, 2000) and the now well-established fact that gestures are especially likely to appear when representations are still developing and therefore fragile. As Goldin-Meadow (2003) suggested, there are at least three reasons why gestures may be particularly well suited for conveying information when representations are relatively weak or fragile (see also Capone, 2007), and each of these has implications for our understanding of gesture compensation in children with LI. First, in contrast to speech, which is linear and segmented and requires the hierarchical organization of smaller units into larger constituents that combine to create a larger meaning, gestures are global and synthetic. Meaning is conveyed simultaneously by the gesture as a whole, and a single gesture can convey multiple elements of meaning (see McNeill, 1992). Thus, for children with LI, the formulation of a verbal utterance may place greater demands on memory and planning, and these demands may be especially taxing when a mental representation is weak.

Second, gesturing may free resources for other cognitive processes by externalizing an idea in a visual form or drawing attention to it. Using a cognitive load paradigm, Goldin-Meadow, Nusbaum, Kelly, and Wagner (2001) demonstrated that memory for a word list (the secondary task) was improved when speakers gestured while explaining solutions to math problems (the primary task). They interpreted this finding as indicating that gesturing reduces the cognitive demands imposed by explanation, thereby freeing resources that can be used for the secondary memory task. In the present study, children were asked to narrate a series of pictures, a task that required both the establishment of attention to aspects of the pictures and the construction of a description or narration of those elements. Because the pictures were relatively complex and included different characters and scenery, children had to isolate the aspect of the picture on which they wished to focus and then draw the caregiver's attention to that feature while communicating about it. For the children with LI in particular, gestures may have provided a means for accomplishing part of this task. Instead of using words to reinforce their own

attention to the picture and to establish joint attention with their listener, children with LI may have relied more on gestures for this purpose and used their more limited language to provide descriptions of the characters or events depicted in the picture. This interpretation is consistent with the finding that children with LI produced a higher proportion of utterances in which gesture added information to speech (e.g., child points to the beehive in the picture while saying "buzzing around").

Finally, gestures are readily interpreted by listeners, and it may be that children with LI are more successful in conveying messages via gestures than through oral language. Thus, for example, our data indicate that, relative to TD peers, children with LI produced a higher proportion of conventional gestures, which can be understood by a listener even in the absence of accompanying speech. This may be due to the differing motor demands associated with speech versus gesture production. Whereas speech requires, among other things, the coordination of respiratory, phonatory, and articulation movements, gesture production requires coordinated movements of the hands and arms, and it has been proposed that because control over the manual system develops more rapidly than for the oral articulators, gesture may be a more efficient means of communication for children for whom speech is effortful and relatively unintelligible (e.g., Acredolo & Goodwyn, 1988).

Moreover, because the narration tasks used in this study often involved a conversation between children and their caregivers, children with LI may have used gestures, rather than language, as a strategy for turn-taking. In other words, conventional gestures may have provided a means for children to take their turn in the narrative conversation, thereby maintaining the flow of interaction while perhaps also gaining a little extra time to plan and sequence their next utterance.

Limitations of the Study

Although this study has added to our understanding of the relationship among gesture, language, and motor skill in preschoolers with LI, a note of caution regarding the interpretation of the findings is in order. First, because there is a relative dearth of research on the gesture–language relationship in preschool-age TD children, we included a comparison group of children matched on the basis of age to gather some initial normative data. Because the normative development of gesture and motor skill in relation to language is poorly understood, there is a clear need for additional work with TD children to address this gap in our knowledge. Future work should also include a comparison group of children matched to those with LI on the basis of expressive language to examine the extent to which the differences described here

may be a function of language ability. Second, the LBIQ and PLS–3 were not administered to the TD children. Although there were no parent, teacher, or experimenter concerns about their language or cognitive development, the absence of these data makes it difficult to exclude the possibility that our data reflect group differences in cognitive ability in particular. Third, the motor measures used in this study were primarily screening tools; future work should incorporate more detailed assessments and analyses of children's motor abilities. Finally, the sample sizes were relatively small, and the findings clearly merit replication with larger groups of children.

Clinical Implications

There is now growing evidence that children's gestures can affect their learning environments (e.g., see Goldin-Meadow, 2003, for a recent review); specifically, children's gestures often elicit input from a responsive listener, and this input can create timely opportunities for language enrichment and learning. The implications for intervention are clear. Caregivers and interventionists must recognize gestures as communicative acts and provide a response that translates the child's gesture into language. Thus, for example, when a child points to a picture of a sleeping bird and says "nap," an attentive listener might respond with "Yes, the bird is taking a nap." Such a response is timely because it provides a spoken language model that is specifically targeted to the child's focus of attention (which is critical for language learning; e.g., Tomasello & Farrar, 1986). Translations of this sort have been tied to advances in language in young TD children (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007), suggesting their utility for children with language difficulties.

With regard to motor abilities, delays in motor development have traditionally been conceptualized as indexes of "delayed maturation" or "neurological soft signs," particularly when they co-occur with language difficulties, and they are typically not included in assessments or interventions for children with LI, which focus on language and language-related skills. The fact remains, however, that motor difficulties are evident in a substantial proportion of these children, and motor difficulties can have significant negative consequences for children's school performance (e.g., writing, coloring, drawing) and their ability to participate in physical activities and games with their peers (e.g., ball games, climbing playground equipment). Children with LI and motor difficulties may therefore be at additional risk for social isolation and lowered self-esteem (see Webster et al., 2006, for additional discussion). This suggests that motor skills should also be assessed in children referred for language concerns and intervention provided for children who evidence motor problems. In light of the substantial evidence for the existence of broad common mechanisms underlying language and motor function, such intervention could potentially support improvements in language, but even if it does not address the primary language symptoms it can target additional areas of difficulty that are not the focus of language services (e.g., gripping a pencil, throwing a ball) but that can give rise to social difficulties and feelings of exclusion.

In sum, we have found that when language is impaired, difficulties are also apparent in motor abilities. Gesture, however, takes on a compensatory role, conveying information that may be difficult for the speaker to encode or express in oral language. Our results are consistent with the growing body of evidence indicating that language difficulties may be only one component in a broader spectrum of developmental impairment for children with LI. They also suggest not only that motor abilities and gesture have differing relationships to language, highlighting the tight link between language and motor systems, but also that gesture is an interface between language and action and, as such, is a product of a unique constellation of motor, symbolic, cognitive, and linguistic abilities.

Acknowledgments

References

Acredolo, L. P., & Goodwyn, S. W. (1988). Symbolic gesturing in normal infants. *Child Development, 59,* 450–466.

Bates, E., & Dick, F. (2002). Language, gesture, and the developing brain. *Developmental Psychobiology, 40,* 293–310.

Berman, R. A., & Slobin, D. I. (1994). *Relating events in narrative: A crosslinguistic developmental study.* Hillsdale, NJ: Erlbaum.

Bishop, D. V. M. (1992). The underlying nature of specific language impairment. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 33,* 3–66.

Bishop, D. V. M. (2000). How does the brain learn language? Insights from the study of children with and without language

impairment. *Developmental Medicine & Child Neurology, 42,* 133–142.

Bishop, D. V. M. (2002). Motor immaturity and specific speech and language impairment: Evidence for a common genetic basis. *American Journal of Medical Genetics (Neuropsychiatric Genetics), 114,* 56–63.

Bishop, D. V. M., & Edmundson, A. (1987). Specific language impairment as a maturational lag: Evidence from longitudinal data on language and motor development. *Developmental Medicine & Child Neurology, 29,* 442–459.

Blake, J., Myszczyszn, D., Jokel, A., & Bebiroglu, N. (2008). Gestures accompanying speech in specifically language-impaired children and their timing with speech. *First Language, 28,* 237–253.

Capone, N. (2007). Tapping toddlers' evolving semantic representations via gesture. *Journal of Speech, Language, and Hearing Research, 50,* 732–745.

Capone, N., & McGregor, K. K. (2004). Gesture development: A review for clinical and research practices. *Journal of Speech, Language, and Hearing Research, 47,* 173–186.

Chow, G. C. (1960). Tests of equality between sets of coefficients in two linear regressions. *Econometrica, 28,* 591–605.

Clark, A. (1997). *Being there: Putting body, brain, and world together again.* Cambridge, MA: MIT Press.

Evans, J. L., Alibali, M. W., & McNeil, N. M. (2001). Divergence of embodied knowledge and verbal expression: Evidence from speech and gesture in children with specific language impairment. *Language and Cognitive Processes, 16,* 309–331.

Fey, M. E., Long, S. H., & Cleave, P. L. (1994). Reconsideration of IQ criteria in the definition of specific language impairment. In R. V. Watkins & M. L. Rice (Eds.), *Specific language impairments in children* (pp. 161–178). Baltimore, MD: Brookes.

Fodor, J. (1983). *The modularity of mind.* Cambridge, MA: MIT Press.

Fried, I., Katz, A., McCarthy, G., Sass, K. J., Williamson, P., Spencer, S. S., & Spencer, D. D. (1991). Functional organization of human supplementary motor cortex studied by electrical stimulation. *Journal of Neuroscience, 11,* 3656–3666.

Gibson, J. J. (1966). *The senses considered as perceptual systems.* Boston, MA: Houghton-Mifflin.

Goldin-Meadow, S. (2003). *Hearing gesture: How our hands help us think.* Cambridge, MA: Harvard University Press.

Goldin-Meadow, S., Goodrich, W., Sauer, E., & Iverson, J. M. (2007). Young children use their hands to tell their mothers what to say. *Developmental Science, 10,* 778–785.

Goldin-Meadow, S., & Iverson, J. M. (2010). Gesturing across the lifespan. In R. Lerner & W. Overton (Eds.), *Handbook of lifespan development: Vol. 1. Cognition, biology, and methods across the lifespan* (pp. 36–55). Hoboken, NJ: Wiley.

Goldin-Meadow, S., Nusbaum, H., Kelly, S. D., & Wagner, S. (2001). Explaining math: Gesturing lightens the load. *Psychological Science, 12,* 516–522.

Hauk, O., Johnsrude, I., & Pulvermuller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron, 41,* 301–307.

Heiser, M., Iacoboni, M., Maeda, F., Marcus, J., & Mazziotta, J. M. (2003). The essential role of Broca's area in imitation. *European Journal of Neuroscience, 17,* 1123–1128.

Henderson, S. E., & Sugden, D. A. (1992). *Movement Assessment Battery for Children.* Sidcup, Kent, UK: The Psychological Corporation.

Hewitt, L. E., Hammer, C. S., Yont, K. M., & Tomblin, J. B. (2005). Language sampling for kindergarten children with and without SLI: Mean length of utterance, IPSYN, and NDW. *Journal of Communication Disorders, 38,* 197–213.

Hill, E. L. (1998). A dyspraxic deficit in specific language impairment and developmental coordination disorder? Evidence from hand and arm movements. *Developmental Medicine & Child Neurology, 40,* 388–395.

Hill, E. L. (2001). Non-specific nature of specific language impairment: A review of the literature with regard to concomitant motor impairments. *International Journal of Language & Communication Disorders, 36,* 149–171.

Hill, E. L., Bishop, D. V. M., & Nimmo-Smith, I. (1998). Representational gestures in developmental coordination disorder and specific language impairment: Error-types and the reliability of ratings. *Human Movement Science, 17,* 655–678.

Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C., & Rizzolatti, G. (1999, December 24). Cortical mechanisms of human imitation. *Science, 286,* 2526–2528.

Ireton, H. R. (1992). *Child Development Inventory.* Minneapolis, MN: Behavior Science Systems.

Iverson, J. M. (2010). Developing language in a developing body: The relationship between motor development and language development. *Journal of Child Language, 37,* 229–261.

Iverson, J. M., & Thelen, E. (1999). Hand, mouth, and brain: The dynamic emergence of speech and gesture. *Journal of Consciousness Studies, 6,* 19–40.

Iverson, J. M., & Wozniak, R. H. (2007). Variation in vocal-motor development in infant siblings of children with autism. *Journal of Autism and Developmental Disorders, 37,* 158–170.

Leonard, L. B. (1998). *Children with specific language impairment.* Cambridge, MA: MIT Press.

Lord, C., Rutter, M., DiLavore, P. C., & Risi, S. (1999). *Autism Diagnostic Observation Schedule—WPS Edition.* Los Angeles, CA: Western Psychological Services.

Mainela-Arnold, E., Evans, J. L., & Alibali, M. W. (2006). Understanding conservation delays in children with specific language impairment: Task representations revealed in speech and gesture. *Journal of Speech, Language, and Hearing Research, 49,* 1267–1279.

Mayer, M. (1980). *Frog, where are you?* New York, NY: Dial Books for Young Readers.

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought.* Chicago, IL: University of Chicago Press.

McNeill, D. (2005). *Gesture and thought.* Chicago, IL: University of Chicago Press.

Merleau-Ponty, M. (1962). *Phenomenology of perception.* London, UK: Routledge & Kegan Paul. (Original work published 1945)

Miller, J. F. (1985). *Assessing language production in children: Experimental procedures*. Baltimore, MD: University Park Press.

Miller, P. J., & Sperry, L. L. (1988). Early talk about the past: The origins of conversational stories of personal experience. *Journal of Child Language, 15,* 293–315.

Newborg, J., Stock, J. R., Wneck, L., Guidubaldi, J., & Suinick, J. (1994). *Battelle Developmental Screening Inventory*. Itasca, IL: Riverside.

Nicoladis, E., Mayberry, R. I., & Genesee, F. (1999). Gesture and early bilingual development. *Developmental Psychology, 35,* 514–546.

Ojemann, G. A. (1984). Common cortical and thalamic mechanisms for language and motor functions. *American Journal of Physiology (Regulatory, Integrative, and Comparative Physiology), 246,* R901–R903.

Őzçalişkan, S., & Goldin-Meadow, S. (2005). Gesture is at the cutting edge of early language development. *Cognition, 96,* B101–B113.

Piaget, J., & Inhelder, B. (1969). *The psychology of the child*. London, UK: Routledge & Kegan Paul. (Original work published 1966)

Powell, R. P., & Bishop, D. V. M. (1992). Clumsiness and perceptual problems in children with specific language impairment. *Developmental Medicine & Child Neurology, 34,* 755–765.

Reilly, J. S. (1992). How to tell a good story: The intersection of language and affect in children's narratives. *Journal of Narrative and Life History, 2,* 355–377.

Roid, G., & Miller, L. (1997). *Leiter International Performance Scale—Revised*. Wood Dale, IL: Stoetling.

Thal, D. J., & Katich, J. (1996). Predicaments in the early identification of specific language impairment: Does the early bird always catch the worm? In K. Cole, P. Dale, & D. Thal (Eds.), *Assessment of communication and language* (pp. 1–28). Baltimore, MD: Brookes.

Thelen, E. (2004). The central role of action in typical and atypical development: A dynamic systems perspective. In I. J. Stockman (Ed.), *Movement and action in learning and development: Clinical implications for pervasive developmental disorders* (pp. 49–73). San Diego, CA: Elsevier Academic Press.

Tomasello, M., & Farrar, M. J. (1986). Joint attention and early language. *Child Development, 57,* 1454–1463.

Ullman, M. T., & Pierpont, E. I. (2005). Specific language impairment is not specific to language: The procedural deficit hypothesis. *Cortex, 41,* 399–433.

Varela, F., Thompson, E., & Rosch, E. (1991). *The embodied mind*. Cambridge, MA: MIT Press.

Viholainen, H., Ahonen, T., Cantell, M., Lyytinen, P., & Lyytinen, H. (2002). Development of early motor skills and language in children at risk for familial dyslexia. *Developmental Medicine & Child Neurology, 44,* 761–769.

Viholainen, H., Ahonen, T., Lyytinen, P., Cantell, M., Tolvanen, A., & Lyytinen, H. (2006). Early motor development and later language and reading skills in children at risk of familial dyslexia. *Developmental Medicine & Child Neurology, 48,* 367–373.

Webster, R. I., Erdos, C., Evans, K., Majnemer, A., Kehayia, E., Thordardottir, E., ... Shevell, M. I. (2006). The clinical spectrum of developmental language impairment in school-aged children: Language, cognitive, and motor findings. *Pediatrics, 118,* 1541–1549.

Willems, R. M., & Hagoort, P. (2007). Neural evidence for the interplay between language, gesture, and action: A review. *Brain and Language, 101,* 287–298.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9,* 625–636.

Wilson, S. M., Saygin, A. P., Sereno, M. I., & Iacoboni, M. (2004). Listening to speech activates motor areas involved in speech production. *Nature Neuroscience, 7,* 701–702.

Wolff, P. H., Melngailis, I., Obregon, M., & Bedrosian, M. (1995). Family patterns of developmental dyslexia: II. Behavioral phenotypes. *American Journal of Medical Genetics (Neuropsychiatric Genetics), 60,* 494–505.

Zelaznik, H., & Goffman, L. (2010). Generalized motor abilities and timing behavior in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 53,* 383–393.

Zimmerman, I. L., Steiner, V. G., & Pond, R. E. (1992). *Preschool Language Scale—3: Examiner's manual*. San Antonio, TX: The Psychological Corporation.