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How children make language out of gesture: Morphological structure in gesture systems developed by American and Chinese deaf children ☆

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Abstract

When children learn language, they apply their language-learning skills to the linguistic input they receive. But what happens if children are not exposed to input from a conventional language? Do they engage their language-learning skills nonetheless, applying them to whatever unconventional input they have? We address this question by examining gesture systems created by four American and four Chinese deaf children. The children's profound hearing losses prevented them from learning spoken language, and their hearing parents had not exposed them to sign language. Nevertheless, the children in both cultures invented gesture systems that were structured at the morphological/word level. Interestingly, the differences between the children's systems were no bigger *across* cultures than *within* cultures. The children's morphemes could *not* be traced to their hearing mothers' gestures; however, they were built out of forms and meanings shared with their mothers. The findings suggest that children construct morphological structure out of the input that is handed to them, even if that input is not linguistic in form.

Keywords: Gestures; Homesign; Sign language; Linguistic input; Morphology; Classifiers; Deafness; Embodiment; Haptic knowledge; China; Frequency boosting; Probability matching

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1. Introduction

In a sense, all language-learning children go beyond the linguistic input to which they are exposed. Children are presented with particular sentences, but learn patterns or rules. Moreover, the language children learn is in many ways underdetermined by the input they receive (Chomsky, 1965, 1981), suggesting that children come to language-learning biased to interpret their input in particular ways. But what are those biases and how can we best discover them?

Observing children at the earliest stages of language-learning could, in principle, give us a glimpse of the biases that children bring to language-learning. However, in many respects, children look like native-speakers of their language from the very beginning (Berman & Slobin, 1994; Choi & Bowerman, 1991). In other words, the linguistic input to which children are exposed has an immediate effect on their earliest productions, making it difficult for us to discover the child's contribution to the process. To get a clearer picture of children's language-learning skills, we need to turn to situations where children are exposed to input that is imperfect. These conditions both require and allow the children to contribute in a more positive way to the language they are developing.

Take, as an example, the deaf child studied by Singleton and Newport (2004; see also Ross and Newport, 1996). Deafness alone does not impair a child's language-learning skills. When deaf children are exposed to an intact model of a sign language, they acquire that language naturally achieving the same developmental milestones as hearing children exposed to spoken language (Lillo-Martin, 1999; Newport & Meier, 1985). But many deaf children are not exposed to intact models of a conventional sign language. The deaf child in Singleton and Newport's study was forced to apply his language-learning skills to a less-than-perfect model of American Sign Language (ASL). Both of the child's parents were deaf and had learned ASL late in life. As a result, they had an incomplete knowledge of ASL morphological structure (Newport, 1991). As one example, the parents used a much larger variety of handshape forms to convey a single meaning than is permissible in ASL. The child, who had only his parents' signs as input at the time he was observed, nonetheless improved upon the impoverished model of ASL morphology that he received, and did so using a process that Singleton and Newport dubbed "frequency boosting." Although the child's parents used a variety of forms for a given meaning, they typically used one form for that meaning more often than any of the others. The child adopted that form as the *only* form he used for the meaning, thus "boosting the frequency" of the form and introducing greater systematicity into his own signs than he found in his parents' signs.

The question we ask in this paper is what happens when the input that children receive is reduced even further to the point that it in no way resembles a conventional language. Will children in such circumstances engage their language-learning skills nonetheless, applying them to the non-linguistic input they receive? We have studied children in just such a situation. Deaf children with severe to profound hearing losses are unable to make use of the spoken language that surrounds them. In addition, if those children are born to hearing parents who choose not to expose them to sign language, the children will not have access to any usable language model. It turns out that deaf children in such circumstances do communicate despite their lack of linguistic input, and use gestures, called "homesigns," to do so (Padden & Humphries, 1988; Tervoort, 1961). Moreover, these homemade gesture systems turn out to be structured in language-like ways (Goldin-Meadow, 2003a), suggesting that a child's language-learning skills can be engaged even when that child is not exposed to a language model.

Although deprived of linguistic input, these deaf children are not developing their gesture systems in a vacuum. They are surrounded by hearing speakers who move their hands as they talk—they gesture. The children have input that is accessible to them, but this input is structured differently from language (Goldin-Meadow, 2003b; McNeill, 1992). As a result, these children provide us with an ideal case to explore what happens when a child's language-learning skills are applied to non-language input. Will children boost whatever forms they find in their hearing parents' gestures? Or does a mechanism like frequency boosting require at least a certain amount of conventional linguistic input in order to be engaged?

We focus in this paper on structure at the word level, that is, on morphology. Human languages are distinct from other animal communication systems in having a set of elements (words) that combine systematically to form potentially novel larger units (sentences). What further distinguishes human language is the fact this combinatorial feature is found at the word-level as well. In all human languages, the words that combine to form sentences are themselves composed of parts (morphemes). Although there is great variability in how much within-word structure a given language has, it is nevertheless difficult to find a language that has no structure at the word level (be it the result of inflectional processes or stem-formation processes, including derivational morphology, compounding, or incorporation, cf. Anderson, 1985). Indeed, in her review of the Perkins (1980) sample of 50 languages chosen to represent the languages of the world and to minimize genetic or areal bias, Bybee (1985) found that all of the languages in the sample had at least some morphologically complex words.

Our previous work has shown that deaf children lacking access to a usable model of a conventional language develop gesture systems that exhibit some structure at the morphological level (Goldin-Meadow, Mylander, & Butcher, 1995). The children's gestures are composed of a limited set of handshape and motion forms, each associated with a particular meaning or set of meanings. These form-meaning pairings function like morphemes in that they combine to create gestures, and the meanings of those gestures are predictable from the meanings of their component parts. Although the children in the study displayed morphological systems that varied in detail, each child developed sets of discrete handshape and motion categories that participated in a combinatorial system.

Our goal in this paper is to explore how the language-learning skills that deaf children bring to communication interact with the gestural input they receive from their hearing parents to create morphological structure. We reasoned that it would be easier to abstract the child's language-learning skills from the process if we could observe children exposed to a variety of gestural inputs. If children see different kinds of gestures and end up producing the same morphological structures, we can begin to identify the skills children bring to the task of communication that allow them to arrive at common structures despite varied gestural input. If, on the other hand, children in different gesture environments end up producing different morphological structures, we can begin to see how gestural input influences the language creation process.

To extend the range of variation in gestural input, we observed deaf children of hearing parents in two distinct cultures, a Chinese culture and an American culture. We know that Chinese mothers behave differently from American mothers when they interact with their children (e.g., Chen & Uttal, 1988; Lin & Fu, 1990; Wu, 1985) and, in fact, are much more likely to gesture when they talk to their children, deaf or hearing, than American mothers (Goldin-Meadow & Saltzman, 2000). In our previous work on homesign, we found few differences between the gesture systems created by Chinese and American deaf children at the *syntactic* level (Goldin-Meadow & Mylander, 1998). However, the fact that there is within-culture variability in the American deaf children's gesture systems at the *morphological* level leaves open the possibility that there may also be across-culture variability at this level—and that whatever morphologic variability there is within- and across-cultures might be related to the gestural input the deaf children receive from their hearing parents.

We therefore begin by examining morphological structure in the four Chinese deaf children of hearing parents observed by Goldin-Meadow and Mylander (1998), and comparing the children's morphological systems to those developed by four American deaf children (Goldin-Meadow et al., 1995). We then look in detail at the gestures used by the hearing mothers of each of these eight children, comparing them to their children's gestures. Our goal is to identify skills that the deaf children bring to the task of language development and to determine, in particular, whether a process such as frequency boosting can account for the morphological systems that the children develop.

2. Methods

2.1. Participants

Deaf children born to deaf parents and exposed from birth to a conventional sign language acquire that language naturally; that is, these children progress through stages in acquiring a sign language similar to those of hearing children acquiring a spoken language (Lillo-Martin, 1999; Newport & Meier, 1985). However, 90% of deaf children are not born to deaf parents who could provide early exposure to a conventional sign language. Rather, they are born to hearing parents who, quite naturally, tend to expose their children to speech (Hoffmeister & Wilbur, 1980). Unfortunately, it is extremely uncommon for deaf children with severe to profound hearing losses to acquire the spoken language of their hearing parents naturally—that is, without intensive and specialized instruction. Even with instruction, deaf children's acquisition of speech is markedly delayed when compared either to the acquisition of speech by hearing children of hearing parents, or to the acquisition of sign by deaf children of deaf parents. By age 5 or 6, and despite intensive early training programs, the average profoundly deaf child has only limited linguistic skills in speech (Conrad, 1979; Mayberry, 1992; Meadow, 1968). Moreover, although some hearing parents of deaf children send their children to schools that teach signed systems modeled after spoken languages (e.g., Signed English, Signed Mandarin), other hearing parents send their deaf children to "oral" schools in which sign systems are neither taught nor encouraged. Thus, these deaf children are not likely to receive input in a conventional sign system, nor be able to use conventional oral input.

The children we studied are severely (70–90 dB bilateral hearing loss) to profoundly (>90 dB bilateral hearing loss) deaf, and their hearing parents chose to educate them using an oral method. At the time of our observations, the children had made little progress in oral language, occasionally producing single words but never combining those words into sentences. In addition, at the time of our observations, the children had not been exposed to a conventional sign system of any sort.

We examined morphological structure in four deaf children of hearing parents living in Taipei, Taiwan, whose gesture systems have previously been shown to have syntactic structure (Goldin-Meadow & Mylander, 1998), story structure (Phillips, Goldin-Meadow, & Miller, 2001), a coherent system for expressing motion events (Zheng & Goldin-Meadow, 2002) and generic nouns (Goldin-Meadow, Gelman, & Mylander, 2005). We compared the Chinese deaf children's data to comparable data from four deaf children of hearing parents living either in Philadelphia or the greater Chicago area (Goldin-Meadow et al., 1995). The Chinese children were each observed two or three times between the ages of 3;8 and 4;9 (see Goldin-Meadow & Mylander, 1998); the American children were observed seven times between the ages of 2;10 and 4;11 (see Goldin-Meadow et al., 1995). In addition, we analyzed the gestures produced by each of the eight children's hearing parents (the child's primary caregiver, the mother in every case) as they interacted with their child.

2.2. Procedure

The children were videotaped at home during spontaneous play with either their mother or an experimenter using a standardized set of toys, books and puzzles (see Goldin-Meadow, 1979). Table 1 presents the number of sessions, the age range, and the total amount of time during which each child was observed.

2.3. Coding

2.3.1. Identifying a gesture in the stream of motor behavior

We coded all of the gestures that the children and their mothers produced during the sessions. Table 1 presents the mean number of gesture utterances that each child and mother produced per hour. Our criteria for isolating gestures grew out of a concern that the gestures meet the minimal requirements for a communicative symbol and were as follows (see Feldman, Goldin-Meadow, & Gleitman, 1978, & Goldin-Meadow & Mylander, 1984, for discussion): (1) The gesture must be directed to another individual (i.e., it must be communicative); in particular, we required that the child establish eye contact with a communication partner in order for the child's act to be considered a gesture. (2) The gesture

Table 1
Descriptive information on the Chinese and American dyads

	Number of sessions child observed	Age of child during observations (years; months)	Total amount of time child observed (in hours)	Mean number of gesture utterances produced per hour	
				Child	Mother
Chinese dyads					
Qing	3	4;02–4;09	5.5	423	381
Bao	2	3;10–4;05	4.0	300	269
Ling	2	3;08–4;08	3.8	198	304
Fen	2	4;00–4;05	3.0	113	258
American dyads					
David	7	2;10–4;10	12.1	389	341
Marvin	7	2;11–4;06	10.4	183	225
Kathy	7	3;01–4;09	10.4	113	115
Abe	7	2;10–4;11	14.9	139	135

must not itself be a direct manipulation of some relevant person or object (i.e., it must be empty-handed, cf. Petitto, 1988); all acts performed on objects were excluded[1] except for instances where a child held up an object to bring it to another's attention, an act that serves the same function as pointing. (3) The gesture must not be part of a ritual act (e.g., to blow a kiss as someone leaves the house) or a game (e.g., patty-cake).[2]

Particularly because the deaf children's gesture systems were not conventional systems shared by a community of users, our interpretations of the children's gestures necessarily remain tentative and represent our best guesses at their intended meaning. Context played a central role in shaping these interpretations, including as part of context any responses the interlocutor made to the children's gestures and the children's reactions to those responses. On occasion, the interlocutor responded in several different ways until a response was finally accepted by the child. Gesture interpretation was also facilitated by the fact that we were familiar with the toys and the activities that typically occurred during the taping sessions, and by the fact that the parents frequently shared their intimate knowledge of the child's world with us during the taping sessions. Not only did we bring the same set of toys to each taping session, but this set was accessible to the coders when they transcribed the tapes, a procedure that allowed the coders to verify, for example, that a particular toy did indeed have buttons or that the cowboy in a particular picture was in fact riding a horse. In addition, the parents were familiar with the child's own toys and activities outside the taping session and if we were puzzled by a child's gestures, we asked the parents during the session what they thought the child was looking for, commenting on, etc. The parents' comments, as well as our own, were therefore on tape and were accessible even to coders who were not at the original taping session. Thus context, bolstered by the parents' and our own knowledge of the child's world, constrained the possible interpretations of the child's gestures and helped to disambiguate the meanings of those gestures.

We used the same criteria for identifying gestures in the mothers' communications and used the same techniques for interpreting those gestures. In other words, we did *not* use the speech that the mothers produced along with their gestures to help constrain our interpretations of those gestures. We were interested in how the mothers' gestures function as input to their deaf children's gesture systems and thus made every attempt to interpret those gestures from the deaf child's point of view—that is, without speech.

2.3.2. Classifying gestures

We classified the gestures that the children and their mothers produced into three categories: (1) *Deictic gestures* indicate objects, people, and locations in the immediate environment

[1] We did allow gestures in which the child held an object that was not related to the meaning of the gesture (e.g., the child happened to be holding a toy horn and, while still holding the horn, jabbed his hand at his mouth to produce an *eat* gesture). Of course, in these cases, we could analyze only the motion of the gesture, as the handshape was determined by the shape of the object that was being held. We eliminated gestures produced directly on an object (e.g., a twisting motion done on the jar itself) because we could not be certain that the child was not actually trying to twist open the jar. The children produced very few of these gestures, usually no more than one per session.

[2] It is worth noting that our criteria for a gesture are different from and somewhat more stringent than those often used to isolate gestures in hearing children during the early stages of spoken language acquisition. For example, in their studies of gesture in hearing children, Bates, Benigni, Bretherton, Camaioni, and Volterra (1979) did not require a gesture to be communicative, nor did they require a gesture to be divorced from the actual manipulation of an object (but see Acredolo & Goodwyn, 1988 & Petitto, 1988, whose studies of gesture in hearing children are based on criteria that are very close to those used here).

and their meanings are context-bound. The children and their mothers produced two types of deictic gestures—hold-ups in which the gesturer holds up an object in the partner's line of sight, and points in which the gesturer extends a finger or palm toward an object. (2) *Conventional* gestures included hand and body movements that were conventional in form and that were associated with conventional meanings in the child's hearing community, e.g., extending an open palm as though to request an object (*give*); placing an open palm on the side of the head and tilting the head (*sleep*); nodding the head (*yes*), turning and raising the palms upward (*do not know*). (3) *Iconic gestures* depicted actions or attributes of concrete or abstract referents via hand or body movements (e.g., moving the index finger in circles to indicate the movements of a rolling ball, or placing two vertical palms on the head to indicate the shape of a rabbit's ears). Iconic gestures form the data for our morphological analyses.[3]

Our search for morphological structure in the deaf children's gesture systems was guided by descriptions of morphology in conventional sign languages such as American Sign Language (ASL). The signs of ASL are composed of combinations of a limited set of discrete morphemes, as are all spoken languages. In fact, ASL appears to be comparable to those spoken languages that are morphologically quite complex, with word-stems that are themselves composed of parts. The relevant research has focused on signs that are productive (as contrasted with the "frozen" signs of ASL listed in dictionaries as single-morpheme stems) and that tend to be transparent in form. These so-called "mimetic" signs are constructed from discrete sets of morphemes and include in the stem, at a minimum, a motion morpheme combined with a handshape morpheme (McDonald, 1982; Newport, 1981; Schick, 1987, 1990; Supalla, 1982). As in spoken languages, morphemes in ASL can be organized into frameworks or matrices of oppositions, referred to as "paradigms" (cf. Matthews, 1974). For example, the motion form 'linear path' (representing movement along a straight path) can be combined with a number of hand forms representing the moving object (e.g., index finger held with the fingertip up = a person; thumb + two fingers held sideways = a vehicle, used for cars, motorcycles, trains, etc.; index finger, pinky and thumb extended = airplane; Wilbur, 1987). These combinations create a set of stems whose meanings are predictable from the meanings of the individual motion and handshape elements (i.e., a human moves along a straight path, a car moves along a straight path, an airplane moves along a straight path). When combined with a different motion (e.g., 'circular path,' representing movement in a circle), these handshapes form a set of stems whose meanings are again systematic combinations of their component parts (e.g., a person moves in a circle, a car moves in a circle, an airplane moves in a circle). In addition to motion and handshape morphemes, stems in ASL can contain a variety of other morphemes, for example, morphemes capturing the manner, direction, or orientation of the motion (Supalla, 1982). In our analyses of the gestures produced by the deaf children in our study, we focused exclusively on handshape and motion, coding form and meaning for each component.

2.3.3. Coding handshape and motion form in iconic gestures

Table 2 presents the dimensions along which handshape (2A) and motion (2B) form were coded. Handshapes were described in terms of three parameters—(1) whether the

[3] Hearing speakers also produce *beat gestures*, formless hand movements that convey no semantic information but move in rhythmic relationship to speech to highlight aspects of discourse structure (e.g., flick of the hand or the fingers up and down or back and forth; McNeill, 1992). However, mothers rarely produce beat gestures when they interact with young children (Ozcaliskan & Goldin-Meadow, 2005) and the hearing mothers of the children in our study were no exception. Beat gestures are thus not included in our study.

Table 2
Parameters along which handshape and motion forms were coded

A. Handshape form parameters

Placement of thumb relative to fingers	Palm shape	Hand breadth
Thumb opposition	Curved	Narrow
Thumb touch fingers	Angled	Neutral
Thumb small distance from fingers	Straight	Broad
Thumb medium distance from fingers		
Thumb large distance from fingers		
No thumb opposition		

B. Motion form parameters

Type of movement	Joint involved in movement	Length	Direction
Crossing space	Shoulder	1 in. increments	Unidirectional
Straight trajectory	Elbow		Bidirectional
Arc trajectory	Wrist		
Irregular trajectory	Hand		
Circle trajectory	Finger		
Within hand			
Revolve			
Open/close			
Bend			
Wiggle			
Hold			
No motion			

thumb was held in opposition to the fingers and, if so, the distance between thumb and fingers; (2) the shape of the palm; and (3) the breadth of the hand (for O and C forms, 1 or 2 fingers opposing the thumb [Narrow] vs. 4 fingers [Neutral], and for Palm and V forms, no spread between the fingers [Neutral] vs. spread [Broad]). Motions were described in terms of four parameters—(1) the type of motion (shape of trajectory for crossing-space motions, or hand movement for within-hand motions); (2) the joint involved in the movement (shoulder, elbow, etc.); (3) the length of the movement (coded in 1 in. increments only for crossing-space motions); and (4) whether the movement was unidirectional or bidirectional.

2.3.4. Coding handshape and motion meaning in iconic gestures

The children used their handshapes in three distinct ways: (1) to represent a hand as it *Handles* an object, (2) to represent the *Object* itself, or (3) to *Trace* the path of motion without representing any aspect of the object involved.

Handle and *Object* handshapes in the deaf children's gestures are reminiscent of handle classifiers and semantic or size-and-shape classifiers, respectively, in ASL (cf. Emmorey, 2003; McDonald, 1982; Schick, 1987). As an example of a *Handle* handshape, to describe a cap, one child produced a Fist handshape (with an arced movement toward the head) which mirrors a person's hand placing a cap on a head. In contrast, to again describe the cap, the same child produced in a separate sentence a Palm handshape held perpendicular to the head (with the same arced movement toward the head), mirroring the flat shape of the cap itself and therefore meeting the criterion for an

Table 3
Parameters along which handshape and motion meanings were coded

A. Handshape meaning parameters

Handle handshapes			Object handshapes	Trace handshapes
Diameter of handled object (in.)	Length of handled object (in.)	Shape of handled object	Type of object	(No object information)
<1	<1	Curved	Animate object	
1–2	1–2	Straight	Bulky object	
2–3	2–3	Angled	Curved object (Wide, Skinny)	
3–5	3–5		Individuated objects	
>5	5–10		L-shaped object	
Many small surfaces	>10		Round object	
			Small object	
			Straight object (Wide, Skinny)	
			Surface of angled object	
			Surface of curved object	
			Surface of round object	
			Two straight skinny objects	
			Vehicle	
			Y-shaped Object	

B. Motion meaning parameters

Change location	Change orientation	Change shape	No change
Move along path to an endpoint	Reposition to reorient	Open/close	Hold
Move along path with no endpoint	Reposition to affect object	Expand/contract	Exist in place
	Reposition by moving back & forth	Bend at joint	
	Move in circle	Wiggle back and forth	
	Rotate around an axis		

Object handshape. The same handshape could be used to represent either a *Handle* or an *Object* morpheme in a child's system. For example, on one occasion, a child used a C handshape to represent handling a large horn—where the handshape mirrored the handgrip around the horn [*Handle*]. At another time, the child used the same C handshape to represent the shape of a cowboy's curved legs as the cowboy sits astride a horse [*Object*].[4]

Table 3A presents the meaning parameters used to code the children's and mothers' handshapes. *Handle* handshapes were coded in terms of characteristics of the manipulated object—its diameter, its length, and its shape. *Object* handshapes were coded in terms of the type of object, either its semantic category or size/shape. *Trace* handshapes were generally

[4] Orientation of the hand with respect to the motion was crucial in determining whether the hand represented a *Handle* handshape or an *Object* handshape. In the cowboy example in the text where the C was used as an *Object* handshape, the fingers and palm of the C handshape point downward as the motion descends, mirroring the shape of the toy cowboy's legs as they go around the horse. If, however, the C were perpendicular to the motion (oriented as a person's hand would be if it were placing the toy cowboy on the horse), the handshape would have been considered a *Handle* handshape rather than an *Object* handshape. There were, of course, instances where it was impossible to tell whether the hand was a *Handle* or an *Object* handshape. These cases, which were quite rare, were considered ambiguous and excluded from the analyses of handshape.

points (although some were O handshapes or Palms) and were typically oriented at right angles to the path of motion, resembling a pencil "drawing" the path; they encoded no object information.

Table 3B presents the meaning parameters used to code the children's and mothers' motions. Motions conveying change of location were coded as describing an open *path* with an endpoint or without one. Motions conveying change of orientation were coded in terms of the repositioning motion (reposition to *reorient*, reposition to *affect an object*, reposition by *moving back-and-forth*, move in a *circle, rotate* around an axis). Motions conveying change of shape were coded in terms of the type of change (*open/close*, *expand/contract*, *bend*, *wiggle*). Motions involving no-change were coded as representing a hand holding an object in place (*hold*) or as an object located in space (*exist in place*).

The manual modality permits a gesturer to vary the shape and motion of the hand to exactly mimic the particular characteristics of each object and action described. For example, in theory a child could subtly vary the diameter of his hand to capture the relatively small differences between holding an object that is 1/2 in. in diameter vs. one that is 3/4 in. in diameter. If we were to code this child's handshape forms in 1-in. increments, we would miss the potential analog mapping between handshape form and meaning. In other words, if we use form coding categories that are bigger than the smallest meaning distinction that the child makes in his gestures, we are in danger of creating a categorical system where there is none. We avoided this pitfall in our previous study of morphological systems in the American deaf children (Goldin-Meadow et al., 1995) by analyzing each child's gestures to determine whether the units we used to code form in the child's gestures were smaller than the meaning distinctions that the child actually made. For example, David, one of our American deaf children, used two different handshapes (one in which his thumb *touched* his fingers, and one in which his thumb was a *small* distance from his fingers) to represent handling objects <2 in. in diameter. David could have used the *touch* handshape to represent grasping objects <1 in. in diameter and the *small* handshape to represent grasping objects between 1 and 2 in. in diameter. However, he did not use the forms in this way—he used both forms for both meanings. Thus, in his gestures, David did not use the handshapes that he would have used to actually grasp objects of this size. He used hand forms categorically to map onto meanings and, importantly, those categories were *not* dictated by the level at which we coded either forms or meanings (i.e., we distinguished between the *touch* and *small* forms but the form category that captured the meaning distinction in David's system was the broader category *touch* + *small*). We used the procedures described in Goldin-Meadow et al. (1995) to address this concern in the Chinese deaf children's gestures. In every case, we found that the units described in Tables 2 and 3 were small enough to capture, but not force, categories in the child's gesture system.

2.3.5. Reliability

A second coder transcribed and coded a 2 hour session of a Chinese deaf child and her mother. Agreement between coders was 87% for identifying gestures in the stream of behavior, and ranged from 77% to 93% for classifying handshape and motion forms in iconic gestures using the parameters described in Table 2, and from 78% to 100% for classifying handshape and motion meanings in iconic gestures using the parameters described in Table 3.

3. Results

All of the deaf children and their mothers in both cultures produced iconic gestures during our observations.[5] On average, the Chinese children produced 290 iconic gestures (SD = 163, range from 139 to 450) and the American children produced 390 (SD = 91, range from 266 to 484). Both the Chinese and American mothers produced somewhat fewer iconic gestures than their children (185, SD = 54, range from 140 to 251, Chinese mothers; 221, SD = 125, range from 112 to 381, American mothers).[6]

Almost all of the children's iconic gestures were interpretable: Only 8% of the Chinese children's iconic gestures (SD = 5%, range from 4% to 13%) and 11% of the American children's iconic gestures (SD = 3%, range from 8% to 15%) were coded as ambiguous.[7] The Chinese mothers produced slightly more ambiguous gestures than their children (13%, SD = 5%, range from 8% to 19%) and the American mothers produced many more ambiguous gestures than their children (36%, SD = 6%, range from 27% to 40%). In an ANOVA analysis of the ambiguous gestures using culture (Chinese, American) as a between-subjects factor and member of the dyad (child, mother) as a within-subjects factor, we found that the mothers produced significantly more ambiguous gestures than their children ($F(1,6) = 52.63$, $p < .0001$); however, there was an effect of culture ($F(1,6) = 22.53$, $p < .01$) and an interaction between factors ($F(1,6) = 23.56$, $p < .01$): The American mothers produced significantly more ambiguous gestures than each of the other three groups ($p < .001$, Newman–Keuls). We took as the data for the rest of our analyses only the gestures that were interpretable. Consequently, the descriptions that follow account for a greater proportion of the children's gestures than their mothers' gestures, particularly for the American dyads.

3.1. The handshape and motion forms produced by the deaf children and their hearing mothers

Table 4 lists the types of handshape and motion forms that the children and their mothers actually produced in their gestures. As can be seen in Table 4A, the O and the C handshapes varied in all of the parameters shown in Table 2A: (1) in the distance between the thumb and the fingers (for the O, the fingers *touched* the thumb, or the distance was *small* with less than 1 in. between the fingers and thumb; for the C, the distance was *medium* with 1–3 in. between the fingers and thumb, or *large* with greater than 3 in. between the fingers and thumb); (2) in shape (with the palm and fingers *curved* or

[5] As in Goldin-Meadow et al. (1995), we excluded from the analyses gestures made with the entire body and gestures that traced the outline or extent of an object (a mean number of 99 for the Chinese children, 98 for the American children, 44 for the Chinese mothers, and 34 for the American mothers). Although gestures that trace the outline of an object are reminiscent of size-and-shape classifiers in conventional sign languages, we excluded this type of trace from our analyses because almost all of them used the point handshape (i.e., there was no variation in handshape form and thus nothing to analyze with respect to handshape) and because 89% of these gestures traced the outline of an actual object rather than tracing a shape in the air, as signs in ASL do (i.e., the motion did not vary freely but was dictated by the outline of the traced object).

[6] Recall that the Chinese dyads were observed for fewer sessions than the American dyads.

[7] Coders used the ambiguous category when they were unable to determine the meaning of a gesture; "ambiguous" was one of the categories included in our analysis of reliability.

Table 4
Observed hand and motion forms

A. Hand forms produced by the deaf children and their hearing mothers

Basic handshape form		Thumb-finger distance	Palm shape	Hand breadth
Thumb-finger opposition				
1	O_1	Touch	Curved	Narrow
2	O_2	Touch	Curved	Neutral
3	O_3	Touch	Angled	Narrow
4	O_4	Touch	Angled	Neutral
5	O_5	Small	Curved	Narrow
6	O_6	Small	Curved	Neutral
7	O_7	Small	Angled	Narrow
8	O_8	Small	Angled	Neutral
9	C_1	Medium	Curved	Narrow
10	C_2	Medium	Curved	Neutral
11	C_3	Medium	Angled	Narrow
12	C_4	Medium	Angled	Neutral
13	C_5	Large	Curved	Narrow
14	C_6	Large	Curved	Neutral
15	C_7	Large	Angled	Narrow
16	C_8	Large	Angled	Neutral
No opposition				
17	$Palm_1$		Curved	Neutral
18	$Palm_2$		Curved	Broad
19	$Palm_3$		Angled	Neutral
20	$Palm_4$		Angled	Broad
21	$Palm_5$		Straight	Neutral
22	$Palm_6$		Straight	Broad
23	V_1		Curved	Neutral
24	V_2		Curved	Broad
25	V_3		Straight	Neutral
26	V_4		Straight	Broad
27	$Point_1$		Curved	
28	$Point_2$		Straight	
29	Fist			
30	L			
31	Y			
32	Thumb			

B. Motion forms produced by the deaf children and their hearing mothers

Basic motion form		Joint involved in motion	Length	Direction
Crossing space motions				
1	$Straight_1$	Wrist/elbow/shoulder	Short	Unidirectional
2	$Straight_2$	Wrist/elbow/shoulder	Short	Bidirectional
3	$Straight_3$	Wrist/elbow/shoulder	Medium	Unidirectional
4	$Straight_4$	Wrist/elbow/shoulder	Medium	Bidirectional
5	$Straight_5$	Wrist/elbow/shoulder	Long	Unidirectional
6	$Straight_6$	Wrist/elbow/shoulder	Long	Bidirectional
7	Arc_1	Wrist/elbow/shoulder	Short	Unidirectional
8	Arc_2	Wrist/elbow/shoulder	Short	Bidirectional
9	Arc_3	Wrist/elbow/shoulder	Medium	Unidirectional
10	Arc_4	Wrist/elbow/shoulder	Medium	Bidirectional
11	Arc_5	Wrist/elbow/shoulder	Long	Unidirectional

Table 4 (*continued*)

B. Motion forms produced by the deaf children and their hearing mothers

Basic motion form		Joint involved in motion	Length	Direction
12	Arc_6	Wrist/elbow/shoulder	Long	Bidirectional
13	$Irregular_1$	Wrist/elbow/shoulder	Short	Unidirectional
14	$Irregular_2$	Wrist/elbow/shoulder	Short	Bidirectional
15	$Irregular_3$	Wrist/elbow/shoulder	Medium	Unidirectional
16	$Irregular_4$	Wrist/elbow/shoulder	Long	Unidirectional
17	$Circle_1$	Wrist/elbow/shoulder	Short	Unidirectional
18	$Circle_2$	Wrist/elbow/shoulder	Medium	Unidirectional
19	$Circle_3$	Wrist/elbow/shoulder	Long	Unidirectional
Within hand motions				
20	$Revolve_1$	Wrist		
21	$Revolve_2$	Fingers		
22	$Open/Close_1$	Hand		Unidirectional (open)
23	$Open/Close_2$	Hand		Unidirectional (closed)
24	$Open/Close_3$	Hand		Bidirectional
25	$Open/Close_4$	Fingers		Unidirectional (closed)
26	$Open/Close_5$	Fingers		Bidirectional
27	$Bend_1$	Hand		
28	$Bend_2$	Fingers		
29	Wiggle	Fingers		
Hold				
30	No motion			

angled); and (3) in the number of fingers extended (*neutral* with 4 fingers extended, or *narrow* with 1 or 2 fingers extended). Thus, there were 8 variants of the O handshape, and 8 of the C handshape. The Palm varied in two of these three parameters: in shape (with the palm *curved*, *angled*, or *straight*) and in spread between the fingers (*broad* with spread, or *neutral* without spread). There were thus 6 variants of the Palm handshape. The V also varied in shape (with the two extended fingers *curved* or *straight*) and in spread (*broad* or *neutral*), creating 4 variants of the V handshape. The Point varied in only one parameter, shape (with the index finger either *curved* or *straight*), thus resulting in 2 variants of this handshape. Including the four handshapes that had no variations (Fist, L, Y, Thumb), we found a total of 32 different handshape forms in the children's and mothers' gestures.

In terms of motions, as seen in Table 4B, the children and their mothers moved *wrist*, *elbow*, and/or *shoulder* to create different trajectories traced by the hand in crossing-space motions —*straight*, *arc*, *irregular* or *circle*. These forms also varied in terms of directionality (*unidirectional* vs. *bidirectional*) and length of path (*short* = less than 5 in., *medium* = between 5 and 10 in., *long* = greater than 10 in.; we used these particular size categories because they were the smallest divisions that we could code reliably on our videotapes). Motions created by movement of the *wrist*, *hand*, or *fingers* were coded as *revolve*, *open/close*, *bend* or *wiggle*. Open/Close forms were further distinguished in terms of directionality. Including a No-Motion form in which the hand was held in place without movement, we found a total of 30 motion forms in the children's and mothers' gestures.

The two columns on the left of Table 6 (see page 101) present the mean number of different types of handshape and motion forms that the Chinese and American deaf children and their mothers produced. On average, the children in both cultures used between 21 and 22 of the 32 handshape forms and between 20 and 23 of the 30 motion forms. The Chinese mothers used approximately as many different forms as their children, but the American mothers used fewer. In an ANOVA analysis of handshape and motion forms using culture (Chinese, American) as a between-subjects factor and member of the dyad (child, mother) as a within-subjects factor, we found no effect of culture ($F(1,6) = 0.396$, ns, handshape; $F(1,6) = 0.0$, ns, motion), an effect of dyad member ($F(1,6) = 37.38$, $p < .001$, handshape; $F(1,6) = 16.35$, $p < .01$, motion), and an interaction between factors ($F(1,6) = 16.6$, $p < .01$ handshape; $F(1,6) = 16.35$, $p < .01$, motion). The interaction was due to the American mothers who produced significantly fewer handshape types than all of the other three groups ($p \leqslant .001$, Newman–Keuls), and significantly fewer motion types than the American ($p = .005$) and Chinese ($p = .03$) children and marginally fewer than the Chinese mothers ($p = .06$).

Table 5
Observed hand and motion meanings produced by the deaf children and their hearing mothers[a]

Handle meanings	Object meanings	Motion meanings
1. Handle an object <1 in. W, <1 in. L	1. Animate object	1. Change location to an endpoint
2. Handle an object <1 in. W, 1–2 in. L	2. Bulky object	2. Change location with no endpoint
3. Handle an object <1 in. W, 2–3 in. L	3. Curved skinny object	3. Reposition to reorient
4. Handle an object <1 in. W, 3–5 in. L	4. Curved wide object	4. Reposition to affect object
5. Handle an object <1 in. W, 5–10 in. L	5. Individuated objects	5. Reposition by moving back & forth
6. Handle an object <1 in. W, >10 in. L	6. L-shaped object	6. Move in circle
7. Handle an object 1–2 in. W, 1–2 in. L	7. Round object	7. Rotate around an axis
8. Handle an object 1–2 in. W, 2–3 in. L	8. Small object	8. Open/close
9. Handle an object 1–2 in. W, 3–5 in. L	9. Straight skinny object	9. Expand/contract
10. Handle an object 1–2 in. W, 5–10 in. L	10. Straight wide object	10. Bend
11. Handle an object 1–2 in. W, >10 in. L	11. Surface of angled object	11. Wiggle back & forth
12. Handle an object 2–3 in. W, 1–2 in. L	12. Surface of curved object	12. Hold
13. Handle an object 2–3 in. W, 2–3 in. L	13. Surface of round object	13. Exist in place
14. Handle an object 2–3 in. W, 3–5 in. L	14. Two straight skinny objects	
15. Handle an object 2–3 in. W, 5–10 in. L	15. Vehicle	
16. Handle an object 2–3 in. W, >10 in. L	16. Y-shaped object	
17. Handle an object 3–5 in. W, <1 in. L	17. Trace (no object information)	
18. Handle an object 3–5 in. W, 1–2 in. L		
19. Handle an object 3–5 in. W, 2–3 in. L		
20. Handle an object 3–5 in. W, 3–5 in. L		
21. Handle an object 3–5 in. W, 5–10 in. L		
22. Handle an object 3–5 in. W, >10 in. L		
23. Handle an object >5 in. W, 1–2 in. L		
24. Handle an object >5 in. W, 2–3 in. L		
25. Handle an object >5 in. W, 3–5 in. L		
26. Handle an object >5 in. W, 5–10 in. L		
27. Handle an object >5 in. W, >10 in. L		
28. Handle many small surfaces		

[a] W = width, L = Length.

Table 6
Number of different forms used and the types of meanings they conveyed

	Mean number of different types of forms produced[a]		Proportion of forms produced conveying handshape or motion meanings								
	Handshape	Motion	Handshape			Mean Number produced	Motion				Mean number produced
			Handle	Object	Trace		Change location	Change orientation	Change shape	No change	
Children											
Chinese	21.2 (5.1)	20.0 (2.6)	0.40	0.49	0.11	231.5	0.19	0.54	0.06	0.21	266.3
American	22.5 (2.1)	23.2 (1.0)	0.52	0.31	0.17	319.0	0.20	0.56	0.07	0.17	345.3
Mothers											
Chinese	19.7 (5.2)	20.0 (2.4)	0.54	0.33	0.14	151.5	0.18	0.62	0.07	0.13	168.0
American	15.0 (2.9)	16.7 (1.7)	0.33	0.31	0.36	127.3	0.18	0.67	0.07	0.09	136.5

[a] The number in parentheses is the Standard deviation.

3.2. The meanings that the deaf children and their hearing mothers conveyed with their handshape and motion forms

We turn next to the meanings that the children and their mothers conveyed with their gesture forms. Table 5 (see page 100) presents the list of meanings that the children and their mothers conveyed with their handshapes, both *Handle* and *Object*, and with their motions. Table 6 (the 9 columns on the right) presents the proportion of handshape forms that the children and mothers in both cultures used to convey *Handle, Object, and Trace* meanings and the proportion of motion forms that they used to convey *Change of Location*, *Change of Orientation*, *Change of Shape*, *and No Change* meanings.

Focusing first on handshape meanings, we found that all four groups used their handshapes for *Handle*, *Object*, and *Trace* meanings but produced different proportions of some of the types. We subjected each handshape type to an ANOVA analysis, using culture (Chinese, American) as a between-subjects factor and member of the dyad (child, mother) as a within-subjects factor. For *Handle* handshapes, we found no effect of culture ($F(1, 6) = .37$, *ns*), no effect of dyad member ($F(1,6) = .59$, *ns*, handshape), but an interaction between factors ($F(1,6) = 21.8$, $p < .005$). The interaction was due to the fact that the Chinese children produced fewer *Handle* handshapes than the American children ($p = .05$) and the Chinese mothers produced more *Handle* handshapes than the American mothers ($p = .02$). The Chinese children also produced marginally fewer *Handle* handshapes than their mothers ($p = .06$) and the American children produced significantly more than their mothers ($p = .02$). Although the Chinese children produced more *Object* handshapes than the other three groups, none of the differences was reliable ($F(1,6) = 2.89$, *ns*, culture; $F(1,6) = 3.92$, *ns*, dyad member; $F(1,6) = 3.63$, *ns*, interaction). There were, however, reliable differences in how the four groups used *Trace* handshapes ($F(1,6) = 5.80$, $p = .05$, culture; $F(1,6) = 11.32$, $p = .015$, dyad member; $F(1,6) = 6.85$, $p = .04$, interaction). The interaction was due to the American mothers who produced significantly more *Trace* handshapes than all of the other three groups ($p < .006$). Recall that the *Trace* handshape contains no object information and is, in a sense, an empty category. More than one-third of the American mothers' handshapes fell into this information-less type. Overall, although there are differences in how often the different types of handshapes were used, there were no recognizable patterns across the cultures, nor were there patterns shared between mothers and children within a culture.

In terms of motion meanings, we found again that all four groups used their motions to convey all four meaning types. However, in contrast to handshape, the groups displayed few differences. We found no significant differences for Change of Location ($F(1,6) = 0.0004$, ns, culture; $F(1,6) = 0.23$, ns, dyad member; $F(1,6) = 0.07$, ns, interaction), Change of Orientation ($F(1,6) = 0.48$, ns, culture; $F(1,6) = 4.25$, ns, dyad member; $F(1,6) = 0.14$, ns, interaction), and Change of Shape ($F(1,6) = 0.03$, ns, culture; $F(1,6) = 0.009$, ns, dyad member; $F(1,6) = 0.002$, ns, interaction). There was no effect of culture for No Change ($F(1,6) = 3.15$, ns) but there was an effect of dyad ($F(1,6) = 16.3$, $p = .007$) and no interaction ($F(1,6) = 0.05$, ns)—the children, both Chinese and American, used proportionally more No Change motions than their mothers.

Thus, children and mothers in both cultures used their handshape and motion forms for essentially the same types of meanings. Interestingly, there was more variability in how the various groups used handshapes than motions. This pattern is reminiscent of conventional sign languages, which display more variability in handshapes than they do in motions (Brentari, 1998; Liddell & Johnson, 1989; Sandler, 1989).

3.3. Identifying morphemes in the gestures: An example from Qing's handshapes

The next step is to determine whether a particular form was used to convey a particular meaning. Recall from Table 2 that we coded every handshape along 3 parameters: Thumb-finger distance, Palm shape, Hand breadth. We had found in previous work that the American deaf children made use of different parameters when constructing *Handle* vs. *Object* morphemes. The children used Thumb-finger distance as the basis for their *Handle* categories—we found a systematic pairing between form and meaning for *Handle* handshapes *only if* we organized the hand forms around the Thumb-finger dimension, for example, O_{1-4} (OTouch), O_{5-8} (OSmall), C_{1-4} (CMedium), C_{5-8} (CLarge) (see Table 4 for descriptions of these gesture forms). In contrast, the children used Palm shape as the basis for their *Object* categories—we found systematic form-meaning pairings for *Object* handshapes *only if* we organized the hand forms around the Palm Shape dimension, for example, $O_{1-2,\ 5-6}$ (OCurved), $O_{3-4,\ 7-8}$ (OAngled), $C_{1-2,\ 5-6}$ (CCurved), $C_{3-4,\ 7-8}$ (CAngled). Before conducting our analyses of the Chinese children's gestures, we verified for each child that Thumb-Finger distance was the relevant parameter for *Handle* handshapes and Palm shape was the relevant parameter for *Object* handshapes.

We illustrate the procedure we followed to identify morphemes using handshape data from one of the Chinese deaf children, Qing, beginning with her *Handle* handshapes (Table 7A). The left side of the grid displays Qing's handshape forms organized in terms of thumb-finger distance. Across the top of the grid, we listed object widths, the meaning dimension found to be relevant to *Handle* handshapes (width was defined as the portion of the object that would be grasped between the fingers and thumb if that object were actually held). The numbers enclosed in boxes in the table represent the consistent pairings of forms and meanings in Qing's *Handle* handshapes, that is, her *Handle* morphemes.

We used the following procedure to identify morphemes in Qing's and in all of the children's handshapes (and motions). To determine whether a particular hand form was used consistently for a particular meaning (e.g., whether the Fist form was used to represent grasping objects <1 in. in width consistently enough for this particular form-meaning pairing to be considered part of Qing's morphological system), we first determined the two most frequent forms used for each meaning (e.g., for grasping objects <1 in. in width, the most frequently used forms were OTouch and Fist, in that order). We then determined the two most frequent meanings conveyed by each form (e.g., for the Fist, the most frequent meanings were grasping objects 1–2 in. in width and grasping objects <1 in. in width, in that order).[8] The final step was to survey the grid and isolate those cells that contained *both* a frequent form and a frequent meaning (e.g., the Fist was a frequent form for the <1 in. wide meaning, and vice versa). These cells were considered consistent form-meaning pairings for that child. In other words, the cells in which the most frequent forms *intersected* with the

[8] We identified the top two forms for a given meaning unless the most frequent form accounted for 85% or more of the times that meaning was conveyed. If so, a second form was *not* marked for that meaning; that is, there was only one frequent form for that cell, as opposed to two. Similarly, if the most frequent meaning accounted for 85% of a particular form, a second meaning was not marked for that form.

Table 7
Form-meaning pairings in Qing's Handle and Object handshapes[a]

A. Qing's Handle Handshapes

Qing's Handle forms	Qing's Handle meanings				
	Grasp an object <1 in. wide	Grasp an object 1–2 in. wide	Grasp an object 2–3 in. wide	Grasp an object 3–5 in. wide	Contact an object >5 in. wide
Fist	17	28[b]	1		1
O Touch	36	1	2		
O Small	3				
C Medium	3		4	1[b]	
C Large	2		8	1	
Palm	3	3			11[b]

B. Qing's Object Handshapes

Qing's Object forms	Qing's Object meanings											
	Bulky object	Surface of a round object	Surface of an angled object	Curved wide object	Straight wide object	Animate object	Individuated points or lines	Curved skinny object	Straight skinny object	Two straight skinny objects	L-Shaped object	Y-Shaped object
Fist	14											
O Angled		3	2									
C Angled			2									
Palm curved neutral				1								
Palm curved broad					4	1	11					
Palm straight broad				2	55	6	22					
Palm straight neutral					20							
Point curved								2	1			
Point straight					1	2			21			
V										23		
L											8	
Y												3

[a] The boxed cells are the form-meaning combinations meeting the 85% criterion for a morpheme.

[b] These 3 Handle morphemes are also specified for length; the Fist handshape represents grasping an object >5″ in length, the C Medium and C Large handshapes represent grasping an object >3″ in length, and the Palm handshape represents contacting an object >3″ in length.

most frequent meanings were classified as consistent form-meaning pairings. We followed this procedure for all of the cells in a child's grid.[9] Note that Qing did not distinguish between the OTouch and OSmall handshapes—both were used to represent grasping objects <1 in. diameter. We therefore considered the two handshapes to be allomorphs of a single morpheme. In addition to examining whether Qing systematically captured the manipulated object's diameter with her gestures, we also explored whether she captured the object's length. We found, in fact, that Qing had a further restriction on her Fist handshape—she used it only for handling objects that were greater than 5 in. in length (e.g., a whip, produced at age 4;2; noted in footnote b in the table).

We used the same procedure to identify form-meaning pairings in Qing's *Object* handshapes (Table 7B). Again, the numbers enclosed in the boxes represent the consistent pairings of forms and meanings. Note that Qing used a single handshape form to represent a single meaning for bulky objects (e.g., a rock, 4;9), the surface of round objects (e.g., a flower bud, 4;2), curved wide objects (e.g., a clay cup, 4;6), curved skinny objects (e.g., eyebrows, 4;9), straight skinny objects (e.g., a clay snake, 4;9), two straight skinny objects (e.g., rabbit ears, 4;2), and L- and Y-shaped objects (e.g., a gun, 4;2, and a telephone, 4;2). But she used two forms of angled handshapes—with the thumb close to the fingers (O handshapes) or further from the fingers (C handshapes) – to represent the surface of angled objects (e.g., a dog's mouth, 4;2). She also used all variants of the Palm handshape (curved or straight, neutral or broad) to represent straight wide objects (e.g., the lid of a playdough container, 4;6), but only broad Palms (curved or straight) to represent animate objects (e.g., a baby, 4;6) and individuated points or lines (e.g., a tiger's claws, 4;6).

We used the same procedure to identify form-meaning mappings in the *Handle* and *Object* handshapes and the motions that each of the four Chinese deaf children produced in their gestures. This procedure may appear to be arbitrary. In conducting our original work on morphological structure in American deaf children (Goldin-Meadow et al., 1995), we felt the need for a procedure to ensure that we were applying the same standard to each child's gestures. Rather than decide on an intuitive basis that a particular form was associated with a particular meaning, we chose to make the decision on the basis of a clear-cut procedure that could help us filter out the noise of infrequent associations between a form and a meaning. Importantly, the procedure we used resulted in form-meaning pairings that resembled those generated by a more intuitive process (cf. Goldin-Meadow & Mylander, 1990) and thus has face validity. Moreover,

[9] In a very small number of cases, the procedure failed to identify any meaning for a form that the child did use or, conversely, failed to identify any form for a meaning that the child used. For example, <1 in. in Table 7A is the most frequent meaning for the OSmall form (indeed, it's the only meaning for this form), but OSmall is *not* one of the top two forms used for this meaning (Fist and OTouch are). The OSmall/<1 in. cell is marked as a frequent meaning but not a frequent form and therefore is not a cell in which the most frequent forms intersect with the most frequent meanings; that is, it does not meet our criterion for consistent use. However, since this leaves the OSmall with no associated meaning, we arbitrarily assigned the OSmall its most frequent meaning (<1 in.) and added the pairing to the list of Qing's morphemes. In general, when our procedure resulted in a form being associated with no meaning at all, we assigned that form its most frequent meaning (assuming the form was used a number of times); similarly, when our procedure resulted in a meaning being associated with no form, we assigned that meaning its most frequent form (again, assuming the meaning was used a number of times). It is important to note that only a small number of morphemes were added to each child's list on the basis of this relatively ad hoc assignment procedure. Moreover, the procedure had the virtue of insuring that when a child used a form (or meaning) a small but countable number of times, it would be assigned a meaning (or form) in the child's system.

when we analyzed the data with more and less stringent criteria, although the details of the analyses changed, we found essentially the same phenomenon—that the children's gestures formed coherent systems that differed from their mothers'. Finally, by using the same procedure on the Chinese and American children's data (and on their mothers' data), we ensured that morphemes were identified in precisely the same way across the two cultures (and across mother and child).

It is important to note that the procedure we used for identifying morphemes does not force *coherent* form-meaning pairings on the data if they are not there (as we will see when we examine the mothers' data). The crucial test in determining whether each child's handshapes and motions form a morphological system is two-fold: (1) whether, using our procedure, we arrive at coherent form-meaning pairings for the handshapes and motions of each child and (2) whether a sizeable number of the gestures each child produces fits the form-meanings we devised for that child.

3.4. Hand and motion morphemes in the Chinese deaf children's gestures: Is there within-culture variability

Table 8 presents the form-meaning pairings for the *Handle* morphemes for each of the four Chinese children. The hand forms are listed on the left side of the table and the particular meaning associated with each form is described in the corresponding column for each child (along with an example). The first number in each entry represents the number of different types of objects for which that handshape was used, and the number in parentheses represents the total number of times the handshape was used for that meaning (i.e., the number of tokens). Note that the set of morphemes described for each of the children is both systematic and coherent, with particular hand forms mapping in a categorical fashion onto particular meanings. In general, the Fist and O handshapes were used for objects with small widths, the C handshapes were used for objects with larger widths, and the Palm handshape was used for objects with the largest widths.

The fact that smaller handshapes were used for objects of smaller widths and larger handshapes were used for objects of larger widths might be taken to suggest that the deaf children were mapping handshapes onto meanings in an analog rather than a discrete fashion. However, even in ASL, a language which quite clearly is based on categorical rather than analog representation (cf. Newport, 1981), there is an apparently continuous mapping of small forms to small meaning categories and large forms to large meaning categories (see, for example, Fig. 4-3 in Wilbur, 1987). What is crucial in both ASL and in the deaf children's gesture systems is that *within each category* there is no systematic relationship between form and meaning (see Supalla, 1982, p. 126, for discussion of this point with respect to ASL).

Table 9 presents the form-meaning pairings for the *Object* morphemes for each of the four Chinese children, and Table 10 presents comparable data for motion. The set of handshape and motion morphemes described for each of the children is, in general, systematic and coherent. Moreover, the morphemes described in these three tables accounts for over three-quarters of the gestures that each of the children produced. The bottom row in Tables 8–10 presents the proportion of each child's gestures that fits the system displayed for that child (calculated in terms of tokens). The fits for each child, although not perfect, are in general quite high, suggesting that the system described for each child is a good reflection of that child's use of handshapes and motions.

Table 8
Chinese children's Handle morphemes*

Forms	Qing's meanings	Bao's meanings	Ling's meanings	Fen's meanings
Thumb		Contact an object <1 in. wide and <1 in. long e.g., helicoptor button 4(10)		
Point			Contact an object <1 in. wide and <1 in. long e.g., toy button 1(2)	Contact an object <1 in. wide and <1 in. long e.g., sticker 1(1)
Fist	Grasp an object <2 in. wide and >5 in. long e.g., bag handle 14(42)	Grasp an object 1–2 in.wide and >3 in. long e.g., banana 6(17)	Grasp an object <2 in. wide and >5 in. long e.g., steering wheel 5(6)	Grasp an object 2–5 in. wide and >5 in. long e.g., tree branch 2(5)
O Touch	Grasp an object <1 in. wide e.g., button 22(39)	Grasp an object <1 in. wide e.g., popcorn piece 38(92)	Grasp an object <1 in. wide e.g., crayon 7(9)	Grasp an object <2 in.wide e.g., helicopter toy 8(12)
O Small		Grasp an object <1 in. wide and <2 in. long e.g., cup handle 3(3)		Grasp an object 1–2 in. wide and 1–2 in. long e.g., toy cowboy hat 2(4)
C Medium	Grasp an object 2–5 in. wide and >3 in. long e.g., cup 4(14)	Grasp an object 2–5 in. wide e.g., apple 6(14)	Grasp an object 1–3 in. wide e.g., ice cream cone 2(3)	
C Large				Grasp an object 2–3 in. wide and 2–3 in. long e.g., jar lid 1(3)
Palm	Contact a surface >5 in. wide and >3 in. long e.g., stomach 7(12)	Contact a surface >5 in. wide e.g., book page 6(7)	Contact a surface >1 in. wide and >1 in. long e.g., face 5(6)	Contact a surface of any size e.g., doll on skate board 4(5)
Proportion of gestures fitting the system	0.85 ($N = 126$)	0.80 ($N = 178$)	0.81 ($N = 32$)	0.94 ($N = 32$)

* The first number in each entry represents the number of different types of objects for which the handshape was used, and the number in parentheses represents the total number of times the handshape was used for that meaning (i.e., the number of tokens).

Table 9
Chinese children's Object morphemes*

Forms	Qing's meanings	Bao's meanings	Ling's meanings	Fen's meanings
Fist	Bulky object e.g., rock 5(14)	Bulky object e.g., frog 2(2)		
O Curved		1. Surface of round object e.g. cherry 2(2) 2. Surface of angled object e.g. display case 1(1)	Surface of round object e.g. tiger eyes 1(1)	Surface of round object e.g., tree ornament 1(1)
O Angled	Surface of round object e.g. flower bud 2(3)			
Angled (O or C)	Surface of angled object e.g., head of fish 2(4)			
C (angled or curved)		Surface of curved object e.g., popcorn lid 2(8)		
O or C (any variant)				Surface of curved object e.g., skater doll toy 2(5)
Palm curved broad		Curved wide object e.g., dish 2(2)	Vehicle e.g., airplane 1(3)	1.Curved wide object e.g., bird toy 1(2) 2. Individuated lines or points e.g., stickers 1(1)
Palm curved (neutral or broad)			Curved wide object e.g., frog 5(8)	
Palm straight broad	Curved wide object e.g., clay cup 1(2)	Animate object e.g., parrot 1(2)	Bulky object e.g., mallet 2(2)	
Palm broad (straight or curved)	1. Animate object e.g., baby 3(7) 2. Individuated lines or points e.g., rain 5(33)	Individuated lines or points e.g., antlers 9(16)	Individuated lines or points e.g., comb 3(4)	1. Straight wide object e.g., knife blade 8(25) 2. Animate object e.g., brother 5(7)

Palm straight (neutral or broad)		Straight wide object e.g., kite 23(42)		
Palm (any variant)	Straight wide object e.g., airplane wings 28(80)		Straight Wide Object e.g., wings 9(12)	
Point curved	Curved skinny object e.g., eyebrows 2(2)			
Point straight	Straight skinny object e.g., clay snake 11(21)	Small object e.g., sticker 1(4)	Animate object e.g., dog toy 3(3)	1. Straight skinny object e.g., crayon 2(3) 2. Small object e.g., sticker 1(1)
Point (straight or curved)		Straight skinny object e.g., zoo key 9(29)	Round object e.g., golf ball 2(2)	Vehicle e.g., helicopter 1(2)
V	Two straight skinny objects e.g., rabbit ears 4 (23)	Two straight skinny objects e.g., animal ears 4(14)	Two straight skinny objects e.g., rabbit ears 1(2)	Two straight skinny objects e.g., scissors 1(2)
L	L-shaped object e.g., gun 2(8)	L-shaped object e.g., gun 1(3)		
Y	Y-shaped object e.g., telephone 1(3)			
Proportion of gestures Fitting the system	0.97 ($N = 206$)	0.93 ($N = 135$)	0.88 ($N = 42$)	0.92 ($N = 53$)

* The first number in each entry represents the number of different types of objects for which the handshape was used, and the number in parentheses represents the total number of times the handshape was used for that meaning (i.e., the number of tokens).

Table 10
Chinese children's Motion Morphemes*

Forms	Qing's meanings	Bao's meanings	Ling's meanings	Fen's meanings
Linear path	Change location by moving in a path without an endpoint e.g., glide-forward 6(7)	1. Change location by moving in a path without an endpoint e.g., go 3(5) 2. Reposition to affect an object e.g., plane wood 7(9)	Change location by moving in a path with an endpoint e.g., go to 7(11)	1. Change location by moving in a path without an endpoint e.g., go 2(2) 2. Reposition to affect an object e.g., fall-over 1(1)
Linear path/long arc			Reposition to affect an object e.g., hit 11(16)	
Long arc	Reposition to reorient e.g., pick-up 11(21)		Change location by moving in a path without an endpoint e.g., go 2(3)	Reposition to reorient e.g., pull apart 5(9)
Long/medium arc	Change location by moving in a path with an endpoint e.g., jump forward 8(29)	Change location by moving in a path with an endpoint e.g., move to 6(20)		Change location by moving in a path with an endpoint e.g., move to 9(16)
Medium arc			Change location by moving in a path with or without an endpoint e.g., dive 6(13)	
Medium/short arc		Reposition to reorient e.g., turn over 26(77)		
Short arc	Reposition to affect an object e.g., comb 4(11)	Reposition to affect an object e.g., dab 11(23)	Reposition to reorient e.g., put down 5(8)	Reposition to reorient e.g., put down 12(22)
Arc to and fro	1. Reposition by moving back and forth e.g., flap 26(79) 2. Reposition to reorient e.g., crash together 7(17)	Reposition by moving back and forth e.g., brush 22 (50)	Reposition by moving back and forth e.g., rock 12(18)	Reposition by moving back and forth e.g., draw 9(13)

Circle	Reposition by moving in a circle e.g., stir 10(16)	Reposition by moving in a circle e.g., stir 1(1)	Reposition by moving in a circle e.g., wash 2(2)	
Circle/revolve		Rotate around an axis e.g., screw 6(24)		Rotate around an axis e.g., twist 3(11)
Revolve	Rotate around an axis e.g., twist 8(12)		Rotate around an axis e.g., twist 1(6)	
Open and close	1. Open/close e.g., claw 7(27) 2. Expand/contract e.g., bloom 1(4)	1. Open/close e.g., grasp 7(19) 2. Expand/contract e.g., bloom 2(2)	Open/close e.g., squeeze 5(6)	Open/close e.g., scissor cut 2(3)
Bend	Bend e.g., swim like fish 1(7)			
Wiggle	Wiggle back and forth e.g., play fife 5(6)		Wiggle back and forth e.g., press many keys 1(1)	
No motion	1. Hold an object 6(24) 2. Exist in place 18 (42)	1. Hold an object 13(47) 2. Exist in place 12(46)	1. Hold an object 1(1) 2. Exist in place 7(33)	1. Hold an object 5(15) 2. Exist in place 6(10)
Proportion of gestures Fitting the system	0.76 ($N = 398$)	0.83 ($N = 387$)	0.82 ($N = 144$)	0.77 ($N = 133$)

* The first number in each entry represents the number of different types of motions for which the form was used, and the number in parentheses represents the total number of times the form was used for that meaning (i.e., the number of tokens).

Although the Chinese children's morphemes resembled one another at a general level, they did differ in detail. For example, as can be seen in Table 8, the OTouch handshape was used for objects narrow in diameter by all four of the children; however, the precise boundary for a narrow object differed across the children: for Qing, Bao and Ling, the boundary for this handshape was 1 in. (i.e., they used the OTouch for objects <1 in. in width, e.g., crayons, Bao 3;10) whereas, for Fen, the boundary was 2 in. (she used the OTouch for objects <2 in. in width, e.g., crayons as well as a small helicopter toy, Fen 4;5). In addition, the relationship of particular morphemes to other morphemes in the system differed across the children. For example, in Bao's and Fen's systems, OTouch was a category unto itself and was distinct in meaning from the other forms they used. In contrast, in Qing's and Ling's systems, OTouch was not distinguished from OSmall and the two forms thus formed a single morpheme for these children. Overall, only three *Handle* morphemes were found in more than one child's system (Point = contact a object <1 in. wide and <1 in. long [e.g., a sticker, Fen 4;5] for Ling and Fen; Fist = grasp an object <2 in. wide and >5 in. long [e.g., a bag handle, Qing 4;9] for Qing and Ling; OTouch/Small = grasp an object <1 in.wide [e.g., a button, Qing 4;2] for Qing and Ling).

In contrast, the children produced a number of identical *Object* morphemes (Table 9): 10 *Object* morphemes could be found in more than one child's system, 8 shared by two children, 1 shared by three children, and 1 (V = two straight skinny objects [e.g., rabbit ears]) shared by all four children. In general, the children tended to use variants of the O and C forms to represent the surface of round (e.g., a flower bud, Qing 4;2), curved (e.g., a doll toy, Fen 4;5) and angled (e.g., a display case, Bao 3;10) objects; variants of the Palm handshape to represent animate objects (e.g., parrot, Bao 4;5), vehicles (e.g., an airplane, Ling 4;8), straight (e.g., a picture card, Bao 4;5) or curved wide (e.g., a gorilla arm, Ling 4;8) objects; and individuated lines or points (e.g., rain, Qing 4;6); and variants of the Point handshape to represent skinny and small objects (e.g., a sticker, Fen 4;5).

The children also produced a number of identical motion morphemes (Table 10): 15 motion morphemes could be found in more than one child's system (8 shared by two children, 3 shared by three children, and 4 shared by all four children) (Arc To and Fro = reposition by moving back and forth [e.g., to draw]; Open and Close = open/close [e.g., to grasp]; No Motion = hold an object; No motion = exist in place). In general, the children tended to use Linear Path and the longer Arcs to represent change of location by moving in a path (either with or without an endpoint, e.g., to go up, Qing 4;2), and the shorter Arcs to represent repositioning to affect an object (e.g., to dab, Bao 3;10) or to reorient (e.g., to put down, Fen 4;5). However, two children used both a short and a long form for one repositioning meaning (reposition to affect an object for Bao, and reposition to reorient for Fen). All four children used some combination of Circle and Revolve to represent repositioning by moving in a circle (e.g., to stir) and/or rotating around an axis (e.g., to twist), Open and Close to represent opening/closing (e.g., to squeeze) and/or expanding/contracting (e.g., to bloom) and No Motion to represent holding an object or existing in place. Bend and Wiggle were used by one or two of the children to represent bending (e.g., to swim like a fish, Ling 4;9) or wiggling (e.g., to wiggle fingers while playing a fife, Ling 4;6).

The similarities across the children's systems are not surprising given that the systems had to be relatively transparent in order to be understood by the hearing individuals who communicated with the deaf children. However, the differences across the systems do suggest that, within the general constraint of iconicity, the children were able to introduce relatively arbitrary and idiosyncratic distinctions into their gesture systems.

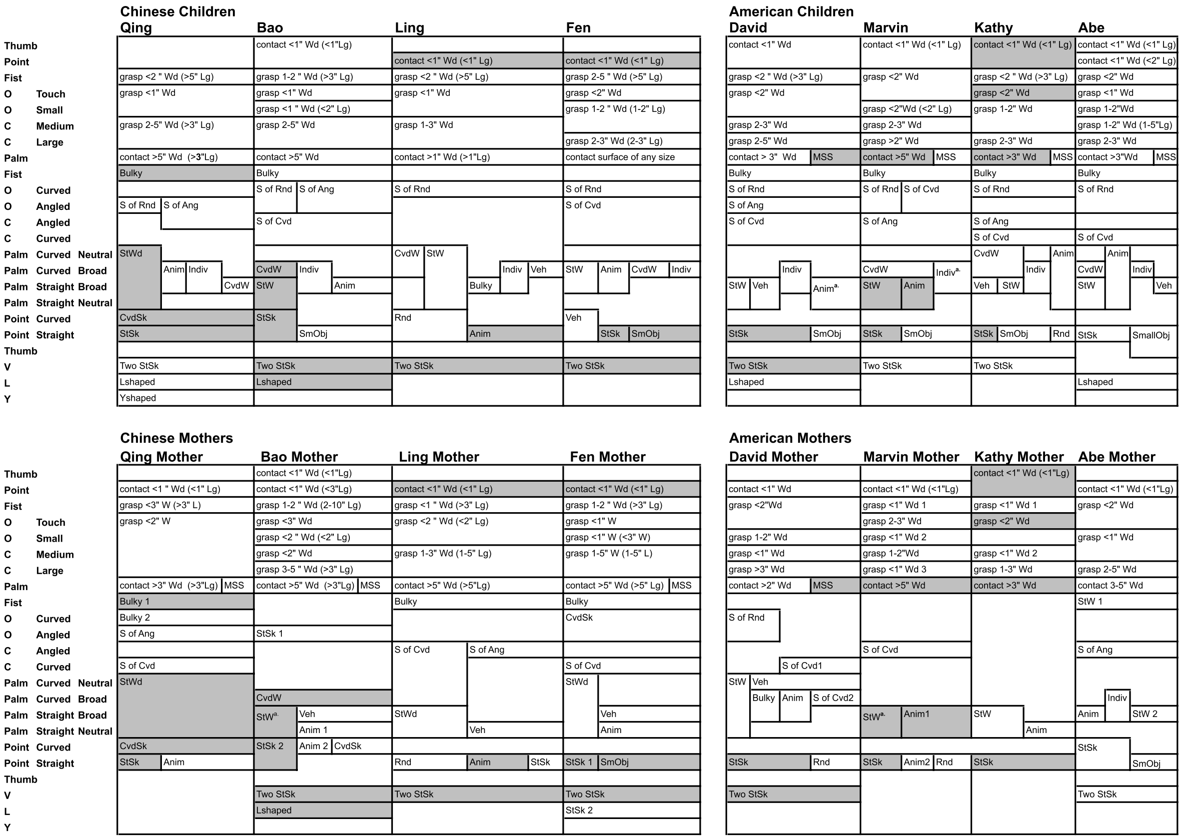
3.5. Comparison of the morphemes in the Chinese and American deaf children's gestures: Is there across-culture variability?

We turn next to the question of cross-cultural variability—do the handshape and motion morphemes developed by the Chinese deaf children resemble those developed by the American deaf children in our original study (Goldin-Meadow et al., 1995)? Fig. 1 displays the handshape morphemes (both *Handle* and *Object*) for the four Chinese deaf children (top left box) and for the American deaf children (top right box). The handshape forms are listed along the left side of the figure; the meanings that each of the eight children consistently conveyed with those forms are displayed in each column. Fig. 2 uses the same type of display to present the motion morphemes used by each of the eight children. What is most striking about Figs. 1 and 2 is that the across-culture variability is no greater than the within-culture variability.

Looking first at the children's *Handle* handshapes, we find that all eight of the children used the Fist, O and C handshapes to represent grasping an object at its diameter and, although the details of their handshapes differed, the children made from 3 to 5 divisions along this dimension (Ling and Qing used 3 different morphemes, Bao, Fen, David, Marvin, and Kathy used 4, and Abe used 5). Seven of the eight children used some combination of the thumb and point to represent contacting a small surface <1 in. wide (Qing was the exception). The only omission that we found in the Chinese children's data was the Palm used as a *Handle* handshape—all four American children used the Palm to represent contacting either a large surface or many small surfaces, but the Chinese children used the Palm only to represent contacting a large surface.

In terms of *Object* handshapes (Fig. 1), six of the eight children used the Fist to represent bulky objects. All eight children used some combination of the O and C handshape forms to represent the surface of round, curved, and angled objects (Ling had only the round meaning in her system, Qing had only the round and angled meanings in hers, and Abe and Fen had only the round and curved meanings in theirs; the rest of the children had all three). With some exceptions, all eight children used a combination of Palm handshape forms to represent animate objects, vehicles, curved wide objects, straight wide objects, and individuated lines or points. The exceptions were Fen who used a Point for vehicles, and Ling who used a Point for animate objects; Qing, Bao and Marvin did not represent vehicles, and David did not represent curved wide objects. Seven of the eight children used a variant of the Point to represent straight skinny objects (Ling was the exception) and another six used it to represent small objects (Qing also used it for curved skinny objects). Seven of the eight children also used the V handshape to represent two straight skinny objects (Abe was the exception). Four children (two from each culture) used the L handshape for L-shaped objects. There were no *Object* meanings conveyed by the Chinese children that were not also found in at least some American children's systems (with the exception of Y = Y-shaped object used only by Qing), and no *Object* meanings conveyed by the American children that were not also found in at least some Chinese children's systems (with the exception of Thumb = small object used only by Abe).

In terms of motion meanings, all eight children used the Linear Path and Long Arc in some combination to represent changing location along a path, either with or without an



a. David used a few instances of Palm Angled to represent Animate Objects, as did Marvin for Individuated Points or Lines and Marvin's and Bao's Mothers for Straight Wide Objects.

Fig. 1. Handshape morphemes in Chinese and American children and their mothers. The figure displays the *Handle* and *Object* handshape morphemes generated by the Chinese and American deaf children and their hearing mothers. The shaded boxes are morphemes found in the gestures of both child and mother within a dyad. Wd, wide; Lg, long; MSS, many small surfaces; S of Cvd, surface of curved object; S of Ang, surface of angled object; S of Rnd, surface of round object; S of Obj, surface of object of any shape; CvdW, curved wide object; CvdSk, curved skinny object; StW, straight wide object; StSk, straight skinny object; Rnd, round object; Anim, animate object; Veh, vehicle; Indiv, individuated points or lines; SmObj, small object. At times, 6 of the mothers used two different, and unrelated, handshape forms to convey the same meaning; these morphemes are marked 1, 2, etc., on the figure.

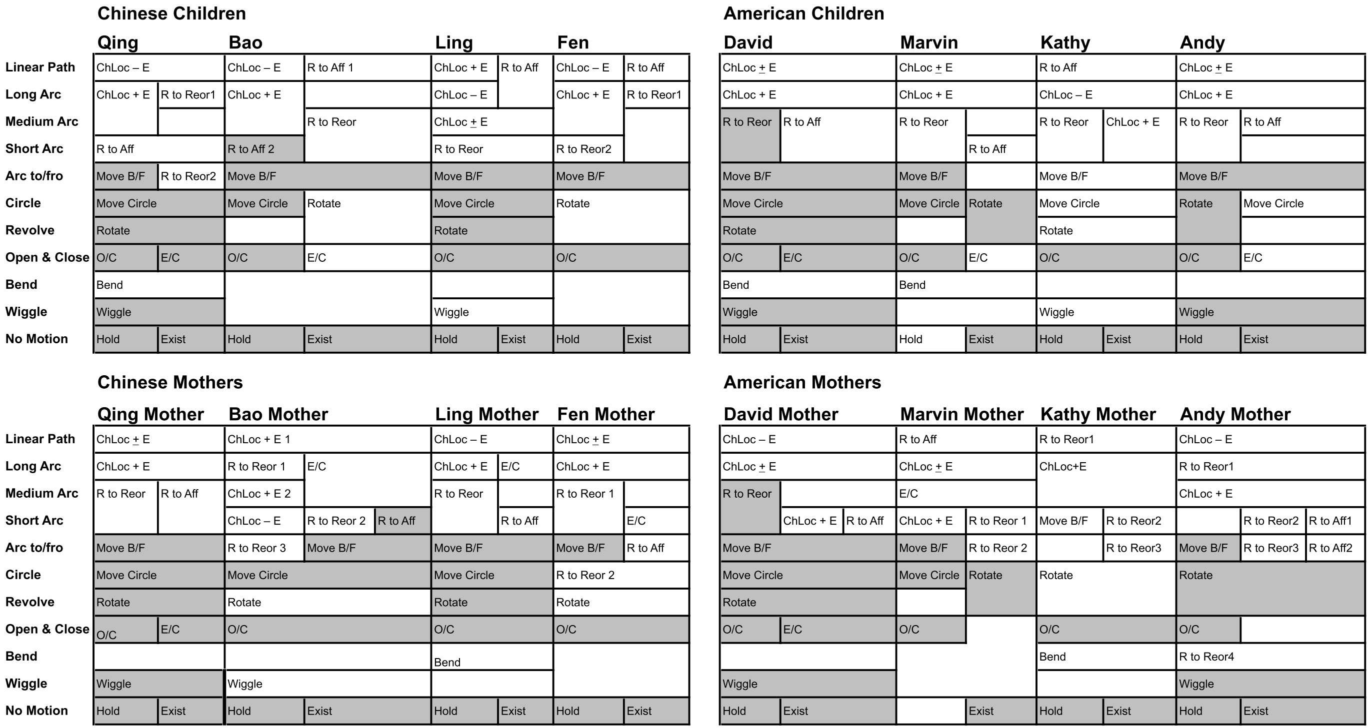


Fig. 2. Motion morphemes in Chinese and American children and their mothers. The figure displays the motion morphemes generated by the Chinese and American deaf children and their hearing mothers. The shaded boxes are morphemes found in the gestures of both child and mother within a dyad. ChLoc ± E, change of location with or without an endpoint; ChLoc – E, change of location without an endpoint; ChLoc + E, change of location with an endpoint; R to Reor, reposition to reorient; R to Aff, reposition to affect an object; Move B/F, move back and forth; Move Circle, Move in circle; O/C, open/close; E/C, expand/contract; Exist, exist in place. At times, 3 American mothers, 2 Chinese mothers, and 3 Chinese children used two different, and unrelated, motion forms to convey the same meaning; these morphemes are marked 1, 2, etc., on the figure.

endpoint. The Chinese children and one American child, Kathy, also used Medium Arc for this meaning. All eight children used Short Arc to represent either repositioning to reorient or to affect an object, or both; the American children also used the Medium Arc and the Chinese children used either the Linear Path or the Long Arc for this meaning (Kathy also joined the Chinese children in using a long form, Linear Path, to represent a repositioning meaning). All eight children used Arc To and Fro to represent moving back and forth, some combination of Circle and Revolve to represent moving in a circle and/or rotating around an axis, Open and Close to represent opening and closing (another five also used Open and Close to represent expanding and contracting), and No Motion to represent holding an object and existing in place. At least one child from each culture also used Bend to representing bending and Wiggle to represent wiggling.

Thus, the details of the Chinese and American deaf children's morphological systems differed across cultures, although no more than the details differed within each culture. The children in both cultures generally used the same types of handshape and motion forms for the same types of handshape and motion meanings, but each child put an individual stamp on the system that he or she developed.

3.6. Gestural input to the system: How well do the children's morphological systems fit gestures produced by mothers and children from their own and other cultures?

None of the deaf children in either culture was exposed to a conventional sign language. However, the children did see the gestures that their hearing parents used when they spoke. Indeed, as we saw earlier, the deaf children's hearing mothers produced many of the handshape and motion forms that their deaf children used, and used their gestures to convey the same types of meanings and in approximately the same distribution (Table 6). The question is whether the mothers mapped their forms onto meanings in the same way as their children.

The first step we took in addressing this question was to see how well the morphological system identified for each child fit the gestures produced by that child's hearing mother. We took the handshape and motion morpheme categories described in Figs. 1 and 2 for each child and imposed those categories on the gestures that the child's mother produced. Table 11 presents the proportion of mother's gestures that fit her child's morphological system (column 4) and, for comparison, the proportion of each child's gestures that fit his or her own morphological system (column 1). Not surprisingly, the children's gestures fit the system that was devised on the basis of those gestures significantly better than the mothers' gestures fit this system ($F(1,6) = 98.45$, $p < .0001$; there was no effect of culture, $F(1,6) = 0.08$, ns, and no interaction, $F(1,6) = 0.05$, ns). But the findings do suggest that the mothers' gestures cannot be characterized by precisely the same system that captured the children's gestures and, as a result, that the mothers' gestures did not serve as a particularly good model for the systems that their children developed.

In fact, the situation may be even worse than it appears in column 4 of Table 11. Recall that on average 25% of the mothers' gestures were ambiguous (compared to only 9% for the children). Since mothers' gestures do not come neatly divided for the child into ambiguous and unambiguous, the more appropriate database to consider for this analysis is the entire set of gestures that each mother produced. If we include all of mother's gestures in the analysis, the proportion of her gestures that fit the morphological system developed by

Table 11
Proportion of gestures produced by children and mothers conforming to a child's morphological system

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Child's fit to child's system	Other children's fits to child's system		Mother's fit to child's system	Other mothers' fits to child's system		Mother's fit to child's system (including mother's ambiguous gestures)
		Own culture	Other culture		Own culture	Other culture	
Chinese dyads							
Qing	0.83	0.65	0.61	0.60	0.60	0.52	0.48
Bao	0.84	0.73	0.69	0.63	0.67	0.63	0.49
Ling	0.83	0.70	0.64	0.58	0.56	0.51	0.47
Fen	0.83	0.66	0.63	0.60	0.54	0.61	0.49
American dyads							
David	0.91	0.73	0.77	0.63	0.57	0.73	0.45
Marvin	0.81	0.77	0.76	0.62	0.67	0.71	0.42
Kathy	0.79	0.71	0.72	0.48	0.58	0.63	0.38
Abe	0.77	0.77	0.71	0.66	0.64	0.68	0.47
Mean	0.83	0.72	0.69	0.60	0.60	0.63	0.46
SD	0.04	0.04	0.06	0.05	0.05	0.08	0.04

her child goes down from 60% (column 4) to 46% (column 7; see Table 11). In other words, less than half of the gestures mother produces provide a useful model for the morphological system derived by the child.

To put the lack of fit between mother and her child into perspective, we examined how well the child's morphological system fit the gestures produced by the *other* mothers and children, from both the child's own culture and the other culture (see Table 11). We analyzed these fits using one between-subjects factor (culture: Chinese vs. American dyads) and two within-subjects factors: (1) how well *children* (columns 1, 2, and 3) vs. *mothers* (columns 4, 5 and 6) fit the child's system; and (2) how well children and mothers *within the child's dyad* (columns 1 and 4) vs. *outside the dyad but within the child's own culture* (columns 2 and 5) vs. *outside the child's culture* (columns 3 and 6) fit the child's system. We found significant effects for the two within-subjects factors ($F(1,6) = 119.31$, $p < .0001$; $F(2,12) = 8.79$, $p < .005$) and an interaction between them ($F(2,12) = 33.29$, $p < .0001$), but no effect of culture ($F(1,6) = 4.32$, ns). The patterns in the data support three points.

First, each child appeared to be developing a unique system. The child's morphological system fit his or her own gestures significantly better than it fit the gestures produced by any of the other children or mothers, either from the child's own culture or outside it (i.e., column 1 vs. columns 2–6; p's < .0005, Scheffe test). Interestingly, the gestures produced by the child's own mother did not fit her child's system any better than the gestures produced by the other mothers, either from the child's own culture or outside it (i.e., columns 4 vs. 5 and 6; p's > .62).

Second, the children's gestures overlapped more with each other than with any of the mothers' gestures. The gestures produced by the other *children* (either from the child's own culture or outside it) fit the child's morphological system better than the gestures produced by any of the *mothers*, including the child's own mother (columns 2 and 3 vs. columns 4, 5, and 6; p's $\leqslant$ .025). Although each child's morphological system was distinct from the other children's systems, the system had more in common with the other children's gestures than with any of the mothers' gestures, reinforcing the claim that the children and mothers were using their gestures in different ways.

Third, there were no differences between the fits for the children who came from the child's culture and those who came from the other culture. The gestures produced by the other children within the child's own culture did not fit the child's system any better than the gestures produced by the other children outside the child's culture (columns 2 vs. 3; $p = .74$). In other words, across-culture differences across the children's gesture systems were no greater than within-culture differences.

3.7. Gestural input to the system: Hand and motion morphemes in the Chinese and American hearing parents' gestures

We now know that if the deaf children did use their mothers' gestures as the basis for their morphological systems, they must have used those gestures selectively. Perhaps the children were able to figure out which of mothers' gestures were ambiguous, discard them, and construct a system on the basis of the remaining gestures. How much overlap would there then be between a system constructed on the basis of mother's (unambiguous) gestures and the system constructed on the basis of her child's gestures? To find out, we applied the procedures for identifying handshape and motion morphemes developed for the children's gestures to the mothers' gestures. The results are shown in Figs. 1 and 2.

Figs. 1 and 2 present the form-meaning pairings for the hearing mothers of the Chinese deaf children (bottom left box) and the hearing mothers of the American deaf children (bottom right box). We find, first, that the form-meaning pairings described in Figs. 1 and 2 do a good job of describing mothers' gestures: on average, 82% ($M = 79\%$, SD = 3%, for the Chinese mothers, and $M = 86\%$, SD = 7%, for the American mothers) of the handshape and motions that a mother produced fit the system described for that mother in the figures. (Note that if we include mothers' ambiguous gestures in the analysis, the fits go down to 63%—$M = 63\%$, SD = 4%, for the Chinese mothers, and $M = 62\%$, SD = 8%, for the American mothers).

However, it is important to note that these "fits" come at the cost of coherence. Each mother's system showed unusual patterns not found in their children's system. For example, in the *Handle* morphemes, Marvin's mother used the OTouch handshape to represent grasping objects 2–3 in. wide but used the wider handshape form, the OSmall, to represent grasping objects that were smaller in width, <1 in. wide. Many of the mothers had such anomalies in the *Handle* morphemes (the OTouch for the mothers of Marvin, Kathy, Abe, and Bao and the OSmall for David's mother), whereas none of the children did. Moreover, two of the Chinese mothers achieved their fits in the *Handle* handshapes by having broad, rather indiscriminate categories (the OTouch, OSmall, CMedium, CLarge, all of which were used for grasping objects <2 in. wide for Qing's mother; the CMedium and CLarge, which were used for grasping objects 1–5 in. wide for Fen's mother). In addition, for the *Object* handshape morphemes and the motion morphemes, each of the mothers used two different, and unrelated, forms to convey the same meaning. For example, Abe's mother used the Fist and the Palm Straight Broad to represent straight wide objects (Fig. 1) and used Short Arc and Arc to and Fro to represent repositioning to affect an object, and Long Arc, Short Arc, Arc To and Fro, and Bend to represent repositioning to reorient (Fig. 2). These morphemes are marked 1, 2, etc. on the figures. Seven of the 8 mothers produced these multiple-form examples in their handshape or motion morphemes or both. Although examples of this sort do not, in principle, count as exceptions to a morphological system since it is always possible to have two forms represent the same meaning (e.g., /t/ and /d/ for past tense in English), too many instances of this sort (as in Abe's mother who used four distinct forms when conveying repositioning to reorient) gives the system an ad hoc feel. In general, the mother's systems have more of these jury-rigged forms than do their children's.

The shaded boxes in each figure represent the morphemes found in both the child's and the mother's gesture systems. On average, the Chinese children shared 4.0 handshape and 6.0 motion morphemes with their mothers, and the American children shared 2.7 handshape and 5.7 motion morphemes with their mothers. These shared morphemes accounted for 31% (SD = 7%) of the children's morphemes, 38% (SD = 10%) of their gestures, (Table 12). What this means is that over two-thirds of the morphemes found in the children's gesture systems could *not* be traced to their mothers' gestures (the proportions for each child are presented in Table 12).

The following picture is emerging from our analyses. The mothers and children pull their gesture forms (Table 4) and the meanings that they convey with these forms (Table 5) from the same set. But the form-meaning mappings that the mothers and children build out of these elements have relatively little in common. Fig. 3 presents summary data that confirm this picture. The figure displays the proportion of forms (white bars), meanings (striped bars), and morphemes (black bars) shared by mother and child. In each bar, the proportion represents the number of different forms, meanings, or morphemes (i.e., types) shared by mother and child divided by the total number of different types of forms, meanings or morphemes produced by both members of the dyad (i.e., the number shared plus the number unique to the mother plus the number unique to the child).

Note that there is substantial overlap between mother and child in the forms they produced (0.65, SD = .13) and the meanings they conveyed (0.61, SD = .14). But there is

Table 12
Morphemes shared with mother and unique to child

	Morphemes shared with mother			Morphemes unique to child		
	Number of morphemes	Proportion of child's morphemes	Proportion of child's gestures	Number of morphemes	Proportion of child's morphemes	Proportion of child's gestures
Chinese dyads						
Qing	12	0.40	0.54	18	0.60	0.46
Bao	11	0.37	0.47	19	0.63	0.53
Ling	9	0.35	0.40	17	0.65	0.60
Fen	8	0.31	0.27	18	0.69	0.73
American dyads						
David	12	0.38	0.45	20	0.63	0.55
Marvin	9	0.30	0.32	21	0.70	0.68
Kathy	7	0.23	0.32	24	0.77	0.68
Abe	6	0.19	0.25	26	0.81	0.75
Mean	9.3	0.31	0.38	20.4	0.69	0.62
SD	2.3	0.07	0.10	3.2	0.07	0.10

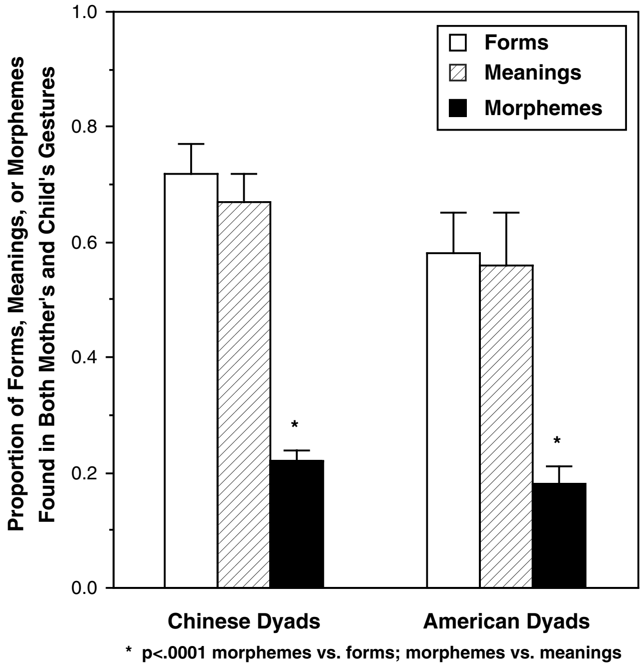


Fig. 3. Forms, meanings, and morphemes shared by child and mother. The graph displays the amount of overlap between mother and child. In each column, the proportion represents the number of types shared by child and mother divided by the sum of the number of types shared by both members of the dyad plus the number of types unique to each member (i.e., the total number produced by both members of the dyad). In both cultures, there was a great deal of overlap in the *forms* and *meanings* that the mothers and children used. However, there was significantly less overlap in the *morphemes* that the mothers and their children constructed out of those forms and meanings.

significantly less overlap between mother and child in the morphemes they constructed (0.20, SD = .05) than in the forms ($F(1,6) = 103.7$, $p < .0001$) or meanings ($F(1,6) = 82.9$, $p < .0001$) they used to construct those morphemes. There were no differences between the two cultures for either forms vs. morphemes ($F(1,6) = 2.8$, ns) or meanings vs. morphemes ($F(1,6) = 1.1$, ns) and no interaction for either analysis ($F(1,6) = 2.0$, ns; $F(1,6) = 0.75$, ns).

3.8. Are the children boosting the frequency of their mother's most frequent gestures?

The children's morphological systems cannot be mapped in a one-to-one fashion onto their mothers' systems—the boundaries of the categories within the two systems, for the most part, do not coincide. It is possible, however, that the children start with their mothers' gestures and use an input-manipulating mechanism like frequency boosting to derive their morphological systems from those gestures. We approached this question in the following way.

We first examined the handshape and motion forms that mother produced and determined the most frequent meaning that the mother used for each form. We divided these form-meaning pairings into those that could be found in the child's morphological system and those that did not appear in the child's system. We then calculated how often mother used the form-meaning pairings that made their way into her child's system, compared to how often she produced the form-meaning pairings that did not make it into her child's system. The proportions are presented in the top graph in Fig. 4. On average, mothers used a form for its most frequent meaning 0.75 (SD = .09) of the time that she used that form for form-meaning pairings that made it into the child's system, and 0.76 (SD = .09) for form-meanings pairings that did not make it into the child's system (see the two black bars in the top graph). Thus, mother did not use form-meaning pairings that could be found in the child's system any more often than she used form-meaning pairings that could not be found in the child's system ($F(1,6) = 0.79$, ns; there was also no effect of culture, $F(1,6) = 0.74$, ns, and no interaction of factors $F(1,6) = 0.38$, ns).

We then asked how often the children used a particular form for mother's most frequent meaning, compared to how often mother used the form. Again, we divided the form-meaning pairings into those that could be found in the child's morphological system and those that were not in the system. We found that, for the form-meaning pairings that could be found in the child's morphological system, the children used mother's most frequent meaning for a particular form no more often than the mothers did (0.69, SD = .09, vs. 0.75, SD = .09, see the black and white bars in the left panel of the top graph; $F(1,6) = 2.5$, ns; there was no effect of culture, $F(1,6) = 4.9$, ns, and no interaction of factors, $F(1,6) = 0.51$, ns). The children were *not* boosting the frequency of their mothers' most frequent form-meaning parings. However, the children did not mirror mother's production rates for all of her frequent form-meaning pairings. For the form-meaning pairings that did *not* become part of the child's morphological system, the children used mother's most frequent meaning for a particular form significantly less often than the mothers did (0.16, SD = .12, vs. 0.76, SD = .09, see the black and white bars in the right panel of the top graph; $F(1,6) = 123.67$, $p < .00001$; there was no effect of culture, $F(1,6) = 0.58$, ns, and no interaction of factors $F(1,6) = 0.48$, ns). The children were thus selective in their use of mother's gestures, maintaining the frequency of some of her frequent form-meaning parings and dramatically reducing the frequency of others.

We then redid the entire analysis starting with meaning; that is, we determined the most frequent form that the mother used for each meaning, and calculated how often mother and child produced these form-meaning pairings, again divided into those that were part of the child's morphological system and those that were not. We found precisely the same patterns (see the bottom graph in Fig. 4): (1) The mothers used their most frequent form for a particular meaning 0.79 (SD = .05) of the time for form-meaning pairings that could be found in the child's morphological system, compared to 0.74 (SD = .05) for form-meaning pairings that could *not* be found in the child's system (see the two black bars in the bottom graph; $F(1,6) = 4.21$, ns; there were no effects of culture, $F(1,6) = 0.15$, ns, and no interaction of factors $F(1,6) = 1.31$, ns). In other words, mother's pairings that made their way into the child's system were no more frequent than those that did not find their way into the system. (2) For form-meaning pairings that could be found in the child's morphological system, the children used mother's most frequent form for a particular meaning no more often than the mothers did (0.76, SD = .06, vs. 0.79, SD = .05; see the black and white bars in the left panel of the bottom graph; $F(1,6) = 0.85$, ns; there was no effect of culture, $F(1,6) = 1.48$, ns, and no interaction of factors $F(1,6) = 1.31$, ns). In other words, the children were not frequency boosting their mothers' productions. (3) For form-meaning pairings that did *not* appear in the child's morphological system, the children used mother's most frequent form for a particular

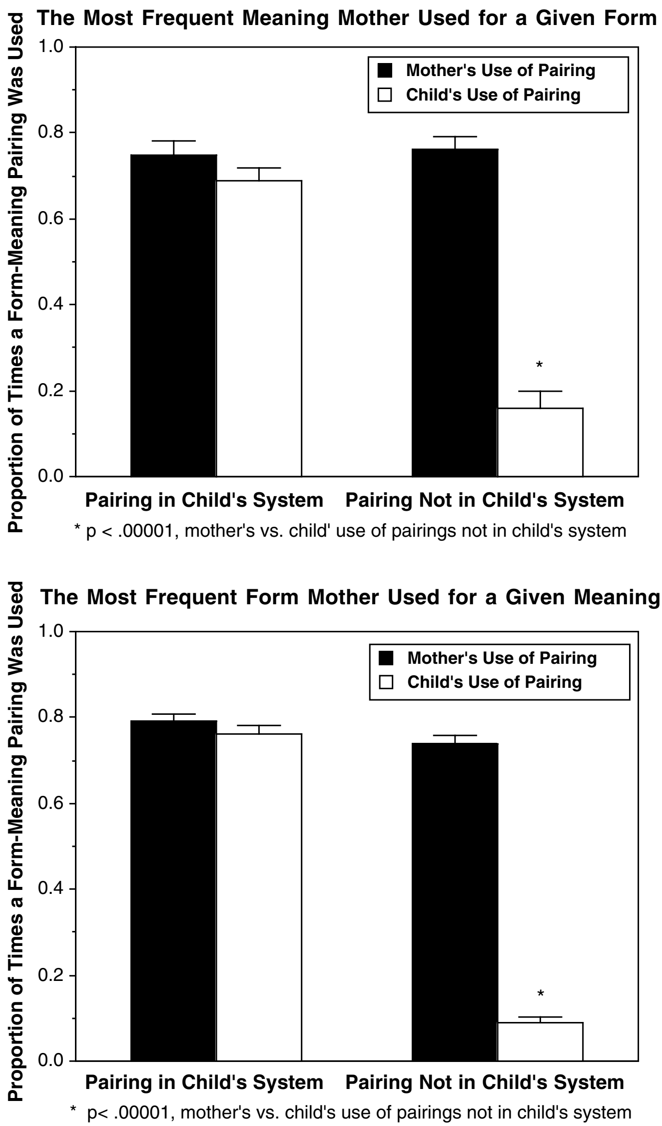


Fig. 4. Mothers' production of form-meaning pairings that were and were not found in their children's morphological systems. The graph displays how often the mothers and their children used mother's most frequent form-meaning pairings. The top graph displays the mothers' (black bars) and children's (white bars) use of the most frequent meaning mother used for a given form; the bottom graph displays their use of the most frequent form mother used for a given meaning. The mothers used form-meaning pairings that were part of their child's system (the black bar on the left in each graph) as often as pairings that were *not* part of their child's system (the black bar on the right in each graph). The children did not produce mother's form-meaning pairings that were part of their systems any more often than their mothers (i.e., they did not frequency boost; compare the black and white bars on the left in each graph). But they were not slavishly copying their mothers—the children produced mother's pairings that were *not* part of their own systems significantly less often than their mothers (compare the black and white bars on the right in each graph).

meaning significantly less often than the mothers did (0.09, SD = .04, vs. 0.74, SD = .05, see the black and white bars in the right panel of the bottom graph; $F(1,6) = 1308$, $p < .00001$; there was no effect of culture, $F(1,6) = 0.71$, ns, and no interaction of factors $F(1,6) = 0.13$, ns). In other words, the children were selective in their use of the pairings that appeared in mothers' gestures.

We took one other approach to the problem of frequency boosting. We determined mother's most frequent meaning for a given form and then asked whether it was also her child's most frequent meaning for that form. We found that a child used the same meaning most frequently for a given form as his or her mother for 61% of the Chinese mothers' forms and 52% of the American mothers' forms. Interestingly, and perhaps not surprisingly, many of the mothers in both cultures used the same meaning most frequently for a given form: 4 or more of the 8 mothers did so on 22 of the 32 forms the mothers produced (all but 2 of these form-meaning pairs were found in mothers from both cultures). The children might well have learned these form-meaning pairings from their mothers. Alternatively, the form-meaning pairings might be so natural to the manual modality that the children might have discovered them on their own.

To summarize, we have found no evidence that a mother used the form-meaning pairings that found their way into her child's morphological system any more frequently than she used the pairings that were not found in her child's system. Nor did we find any evidence that the child was boosting the frequency of mother's most frequent form-meaning pairings.

4. Discussion

We show here that deaf children, even when not exposed to a usable model for a conventional language, can nevertheless invent gesture systems that have many of the properties of natural language. Our data reveal that these systems not only contain syntactic structure but also morphological structure. Combinatorial structure at both word and sentence levels is widely recognized as an important feature of language, one that sets it apart from other forms of communication. Each of the eight deaf children we examined, four from Taiwan and four from the United States, developed morphological systems in their gestures, systems that were similar overall but differed in detail.

Note that the deaf children's morphological systems are different from morphological systems in spoken languages in that they are iconic—the handshape and motion forms are transparently related to the meanings they convey. We feel comfortable using the term "morphology" to describe the deaf children's gestures because they display the paradigmatic structure that is the hallmark of all morphological systems, and because iconicity is also a characteristic of the morphological systems found in sign languages (although, not surprisingly, the set of morphemes in conventional sign systems is far less transparent than the set produced by the deaf children in our study). In addition, the deaf children's morphemes behave like morphemes in signed and spoken languages in one other respect. They combine to create stems that are then modulated to serve different grammatical functions. For example, as we have shown here, in David's morphological system, a C-Medium handshape can be combined with a Revolve motion to create a *twist* stem. As shown in Goldin-Meadow, Butcher, Mylander, and Dodge (1994), when this stem is used as a noun (to refer to a twistable object, e.g., a jar), it tends to be abbreviated; that is, it undergoes a process akin to derivational morphology. When the same stem is used as a verb (to refer to the act of twisting), it is not abbreviated but is displaced in space toward the jar, thus marking the object as its patient; that is, it undergoes a process akin to inflectional morphology. It is in these senses that the deaf child's gestures constitute a morphological system.

In the first part of this discussion, we focus on the similarities across the children's morphological systems, exploring the basis for these similarities and the relation between them and conventional sign languages. In the second part of the discussion, we explore the role that the mothers' gestures might have played in getting the children's morphological systems off the ground. Although not exposed to a conventional language model, the deaf children in both American and Chinese cultures were exposed to the gestures that hearing speakers produce when they talk. We therefore consider whether the deaf children created their gesture systems by applying their language-learning, or more accurately, their language-making skills to the gestures they saw.

4.1. Accounting for within- and across-culture similarities in the morphological systems invented by deaf children

4.1.1. The body as a source of similarities in the deaf children's morphological systems

Each of the eight deaf children we examined developed a morphological system. Although the details of those systems differed, the differences across cultures were no greater than the differences within cultures. Indeed, the impression one gets from examining the children's morphological systems in Figs. 1 and 2 is one of broad-based similarity.

We might have expected broad-based similarities across the deaf children's morphological systems simply because the children were using their gestures to communicate with the hearing people in their worlds. Using a handshape with a small diameter to represent holding an object with a large diameter is likely to be confusing to any communication partner. Thus, in order to be understood, the children had to create relatively transparent gestures. The fact that there were many commonalities in the gesture categories created by deaf children in American and Chinese cultures suggests that what counts as "transparent" is similar in these two cultures.

In addition, many of the morphemes in the deaf children's gestures could have been derived from their haptic knowledge of objects, a process that would also promote commonalities across the children's gestures. Klatzky, McCloskey, Doherty, Peligrino, and Smith (1987) describe a robust connection between the cognitive representation of an object and the shape that the hand would be if it were used to manipulate that object. Klatzky and colleagues have found four types of handshapes that are frequently associated with categories of objects and that turn out to converge nicely with the *Handle* handshapes used by both the American and Chinese deaf children in our study: (1) the Palm, comparable to the Palm handshape in our coding system, which is used to make contact with wide objects; (2) the Poke, comparable to the Point handshape in our system, which is used to make contact with small objects; (3) the Pinch, comparable to the O handshape in our system, which is used to grasp small objects; and (4) the Clench, comparable to the C handshape in our system, which is used to grasp large objects.[10] It is quite likely that the deaf

[10] It is not clear from the description and pictures of handshapes in Klatzky et al. (1987) where our Fist handshape should be classified. It is typically used to represent grasping objects with a small diameter and, in this sense, is comparable to the Pinch. However, it is also used to represent grasping objects that are long and, in this sense, resembles the Clench.

children drew upon the basic object-handshape connections identified by Klatzky et al. (1987) in creating their *Handle* morphemes. Indeed, the patterns we have isolated in the deaf children's morphological systems lend weight to the claim made by Klatzky et al. (1987) that information about how objects are manipulated constitutes part of human cognitive representations of objects.

Like the *Handle* handshapes, the motions that the deaf children used in their morphological systems may also have been derived from actions in the real world. The motion categories found in all eight children appear to be particularly rooted in action: arcing the hand to and fro to represent moving an object back and forth; opening and closing the hand to represent opening and closing a hand around an object; keeping the hand still to represent holding an object in place. But even the motion categories found in only subsets of the children did not stray far from their roots: moving the hand in a linear path or a long arc to represent moving an object from one location to another; moving the hand in a small arc to represent repositioning an object, etc. The children are likely to have borrowed the motions that they use when actually manipulating objects, incorporating those motions into their gestures to represent actions on objects (i.e., to use along with their *Handle* handshapes).

Note, however, that all eight of the deaf children's morphological systems included motions representing actions *by* objects as well as actions *on* objects (that is, actions used with *Object* handshapes as well as with *Handle* handshapes). For example, many of the children used the linear path and long arc motions, not only to represent moving an object by hand, but also to represent the movement of an object moving on its own (e.g., a vehicle or rolling object). Motions of this sort exemplify how the body can be used to represent a non-body motion and, in this sense, provide a concrete example of embodied representation in a linguistic system (cf., Barsalou, 1999; Glenberg, 1997; Glenberg & Robertson, 1999; Glenberg & Kaschak, 2002).

The children's *Object* handshape morphemes also exemplify how the body can be used to represent non-body forms. In these morphemes, the child's hand is not representing a hand but is instead representing an object, either a class of objects, the surface of an object, or the substance of an object described in terms of its size or shape. Although the details of the children's *Object* handshape categories differed, for the most part, children in both cultures used variants of the Palm handshape to represent animate objects, vehicles, and wide objects, variants of the O and C handshapes to represent round, curved, and angled objects, variants of the Point (including the V) to represent skinny objects, and a Palm with fingers spread (Palm Broad) to represent individuated lines or points. Each of the eight children constructed a communication system in which the hand was used, not as a hand, but to evoke an image of an object.

Moreover, the children recruited their hands to represent the same types of object properties—size and shape. Why these properties? The hand could, in principle, be used to represent other types of object properties. For example, Lederman and Klatzky (1987, 1990) have isolated a variety of distinctive hand motions that people use to explore different object properties—repetitive shearing motions along a surface can be used to explore the texture of an object; applying pressure to the surface of an object can be used to explore the hardness of an object; resting the hand on an object can be used to explore the temperature of an object; and unsupported lifting can be used to explore the weight of an object. The deaf children could have recruited exploratory movements of this sort (i.e., movements which highlight the substance or material out of which an object is constructed) as the basis for their object categories, but they did not. Instead, they based their object categories on exploratory movements that extract information about the size and shape of objects. Interestingly, the size and shape properties that the deaf children grammaticized in their morphological systems are routinely grammaticized in both spoken (e.g., Allan, 1997) and signed (Schembri, 2003) languages, unlike properties like texture, hardness, temperature, and weight which have not been found to be grammaticized in any language described thus far. Taken together, these findings suggest that size and shape—but not weight, texture, temperature—may play a special role in human communication (see Talmy, 1988, for similar discussion of aspects of motion events that are preferentially incorporated into grammatical systems).

4.1.2. Similarities across the deaf children's morphological systems and conventional sign languages

The deaf children's gesture systems displayed the properties of morphological systems in conventional languages (spoken or signed), demonstrating paradigms of discrete forms associated with particular meanings. But the children's gesture systems resembled conventional sign languages not only at this broad structural level, but also at a more fine-grained level. For example, all documented conventional sign languages have three types of handshape units that function as classifiers do in spoken languages (but see Schembri, 2003, for discussion): Handle handshape units, which model the shape of the hand as it manipulates an object or the shape of the object being manipulated; Entity handshape units, which are conventional forms that stand for classes of objects; SASS (size and shape specifier) handshape units, which model relevant physical dimensions of an object. Slobin and colleagues (Slobin et al., 2003) make a further distinction within the Handle category—Manipulative Handle units represent the hand that is manipulating the object, Depictive Handle units represent the object that is being manipulated. The deaf children's *Handle* handshapes fulfill the same functions as Manipulative Handle handshapes in conventional sign languages, and their *Object* handshapes fulfill the same functions as Entity, SASS, and Depictive Handle handshapes in conventional sign languages. Our findings suggest that these types of handshape classes are central to the structure of signed languages, so central that they will be introduced into a gesture system by a child even when that child has not been exposed to input from a conventional sign language.

At a still more fine-grained level, the particular handshapes around which the deaf children built their morphological systems can be found in the classifier systems of historically unrelated conventional sign languages. For example, Schembri (2003) displays a set of handshapes typically found in classifiers in sign languages. The deaf children used all of these forms, with the exception of those with finger complexity (the F with the middle, ring, and pinky fingers extended, and the W with the index, middle, and ring finger extended). We might have expected handshapes with finger complexity to be absent from the deaf children's repertoire as they are late to be acquired even when deaf children are exposed to a conventional sign language.

Indeed, the early classifiers acquired by deaf children exposed from birth to a conventional sign language resemble the morphological systems invented by the deaf children in our study. Supalla (1982) has described the development of Entity handshapes in three deaf children ages, 3;6 to 5;11, acquiring ASL from their deaf parents. At the early stages, the children routinely substituted primitive handshapes for more complex Entity handshapes. For example, they used what we have called a Trace handshape (essentially no meaningful handshape, just a fingertip tracing a path) or a Palm handshape to represent vehicles, the same handshape forms used by both the American and Chinese deaf children in our study. Slobin et al. (2003) described the handshapes used by even younger deaf children who were acquiring either ASL or Sign Language of the Netherlands (SLN). The handshapes first used by these children in their classifiers were just the handshapes that our deaf children incorporated into their morphological systems.

The deaf children's gesture systems contain a subset of the handshapes and motions that can be found in conventional sign languages. These are the forms that are easy to produce (they have little finger and joint complexity, cf. Brentari, 1998) and are easy to understand (they are relatively transparent reflections of the objects and actions they are intended to represent). It may therefore not be surprising that these handshape forms are recruited by deaf children who have only their hands to communicate. What is surprising, however, is that the deaf children, without a conventional language model to guide them, fashion the forms into a system that contains the essential properties of a morphology.

Indeed, the deaf children's accomplishments are particularly noteworthy given the fact that morphological structure is not typically found in spoken languages developed under impoverished input conditions. For example, a pidgin is a simplified communication system that arises when speakers of many different languages come into contact and do not share a common language (Holm, 1988). When hearing children are exposed to this kind of impoverished input, they create what is known as a creole. Although creoles have greater structural regularity and complexity than the pidgins from which they were derived, they have little morphological structure (McWhorter, 1998). One could argue that the deaf children in our study had even less consistent input than children exposed to input from a pidgin. Nevertheless, they developed the beginnings of a morphological system, one that has much in common with morphologies found in all documented sign languages.

Following Aronoff, Meir and Sandler (2005; see also Aronoff, Meir, Padden and Sandler, 2003), we suggest that it is the manual modality that makes it possible for deaf children not exposed to any conventional linguistic input to invent a morphological system. In the manual modality, it is possible to create paradigms (systems of handshape form-meaning pairings combined with motion form-meaning pairings) that are relatively transparent, that is, comprehensible to someone who does not know the system. The paradigmatic structure imposed on a gestural form often makes that form a somewhat less true-to-life representation (e.g., change of location is conveyed with a linear path motion regardless of the particular trajectory represented) and, as a result, introduces a hint of arbitrariness into the gesture system. However, the paradigmatic structure does not destroy the transparent relation between form and meaning. The manual modality—but not the oral modality—thus allows children, even those not exposed to a conventional language model, to invent a communication system that contains morphological structure. It also allows signed languages to be invented anew with each generation, unlike spoken languages, which may have been invented only once.

4.2. The role that hearing speakers' gestures play in the development of the deaf children's morphological systems

Although the deaf children in our study were not exposed to a conventional language model, they did see the gestures that their hearing parents used as they talked. We explored the impact of these gestures on the deaf children's morphological systems in two ways. We first ran the handshape and motion systems identified for the child over the gestures that the child's mother produced and found that, particularly when all of the mother's gestures were considered (including the gestures that were ambiguous), the fit between the child's system and the mother's gestures was not good (range from 38% to 49%). We then applied the analytic techniques developed to explore morphological structure in the deaf children's gestures to the mother's gestures and found that, although morphological descriptions could be applied to the mothers' gestures, the resulting systems were less coherent than the morphological descriptions for the children's gestures. Moreover, when the mothers' ambiguous gestures are included in the analyses (a reasonable step since they too are input to the child), the descriptions account for only 63% of the mothers' handshapes and motions, compared to 83% for the children. Why did the mothers' gestures lend themselves less well to morphological description than their children's gestures?

4.2.1. Gesture with speech vs. without it

The deaf children's mothers in both cultures were committed to teaching their children to talk. As a result, the gestures they produced were always accompanied by talk. Much work has shown that the gestures hearing speakers produce when they talk are integrated with that talk, both semantically and temporally (Goldin-Meadow, 2003b; Kendon, 1980; McNeill, 1992). Thus, unlike the deaf children's gestures which assumed the full burden of communication, the gestures that the hearing mothers produced shared the burden of communication with speech. The mothers' gestures needed to be integrated with the speech they accompanied and, as a result, were not free to assume the language-like morphological structure that characterized the deaf children's gestures.

In an experimental demonstration of this phenomenon, Goldin-Meadow, McNeill, and Singleton (1996) asked English-speaking adults to describe a set of vignettes, once in speech and a second time using only their hands. They then compared the structure of the gestures that the speakers produced in the two situations—the gestures spontaneously produced along with speech (gesture + speech), and the gestures produced without speech (gesture-alone). The gestures that the adults produced with speech were qualitatively different from the gestures those same adults produced without speech. For example, the handshapes were less crisp and the motions less demarcated when gesture was produced with speech than when it was produced without it (see Fig. 25 in Goldin-Meadow, 2003b). Moreover, the gestures produced without speech were more likely to be combined into gesture strings than the gestures produced with speech, and those strings were characterized by consistent ordering of semantic elements (Goldin-Meadow et al., 1996).

Not surprisingly, the deaf children's mothers, who could hear, behaved as though they were in a gesture + speech condition. Their gestures resembled the gestures that all hearing speakers produce when they talk and did not display morphological structure. However, it is worth noting that even if the deaf children's mothers had behaved with their children as though they were in a gesture-alone condition, the mothers still might not have invented a morphology. The English-speakers in the Goldin-Meadow et al. (1996) study introduced a number of language-like properties into their gestures when they were prevented from speaking (e.g., they segmented their gestures and introduced a systematic linear order; see also Gershkoff-Stowe & Goldin-Meadow, 2002). However, they did *not* impose a morphological structure on their gestures (see also Singleton, Morford, & Goldin-Meadow, 1993).

It is possible that it takes time to fashion a morphology and that the hearing adults in these experimental situations did not have enough time. But it is also possible that morphological structure of the sort found in the deaf children's gestures can be introduced into a linguistic system only by a child. Additional experimental studies on adults are needed to explore this point.

One final result deserves mention in this context—the hearing mothers, particularly the American mothers, produced many more ambiguous gestures than did their deaf children. Why? Recall that we used the same procedures in analyzing the gestures produced by the deaf children and their hearing mothers; in particular, we attributed meanings to the gestures based on context *without the mothers' speech*. Our reason for ignoring speech was to simulate as closely as possible the conditions under which the deaf children interpreted their mothers' gestures and, of course, they were unable to hear their mothers' speech. When viewed without speech, 25% of the mother's gestures were uninterpretable. But note that the gestures produced along with speech are not meant to be interpreted without speech. Indeed, gesture viewed without the speech it was originally produced with is often difficult to interpret, even when the gestures have been selected to be relatively transparent (Krauss, Morrel-Samuels, & Colasante, 1991). However, when viewed with its original speech, gesture conveys substantive information to listeners, even if those listeners have not been trained in gesture coding (Goldin-Meadow, Kim, & Singer, 1999; Goldin-Meadow & Sandhofer, 1999). It is very likely that most, if not all, of the mothers' gestures would have been interpretable had we viewed them along with the speech they originally accompanied.

4.2.2. Are the deaf children frequency boosting?

The morphological systems that the deaf children constructed were not identical to the systems we were able to induce from their mothers' gestures. But the children and their mothers did draw their handshape and motion forms, and the meanings those forms conveyed, from the same pool (Tables 4 and 5). The question we set out to answer was whether the mothers' gestures provided the children with a starting point from which they could construct a morphological system. In other words, were mothers' gestures, although not a good model for the systems the children eventually developed, nevertheless grist for the children's language-making mill?

Singleton and Newport (2004) have described just such a process in Simon, a deaf child whose deaf parents were late-learners of ASL and, as a result, provided their child with an inconsistent linguistic model of ASL. For example, Simon's parents produced the correct form for a set of *motion/location morphemes* 69% (father) and 75% (mother) of the time; native-signers produced the correct form 94% of the time. We might have expected Simon to be correct only as often as his parents, but in fact he was not—he produced the correct form for these morphemes 88% of the time, significantly more often than his parents. Indeed, Simon had "boosted" the frequency of his parent's productions so that his score on the test was indistinguishable from the scores of children learning ASL from consistent input (who produced the correct form 81% of the time).

Interestingly, however, Simon was less good at boosting the frequency for *handshape morphemes*. His parents used the correct form for a set of handshape morphemes 45% (father) and 42% (mother) of the time, compared to 82% for native-signers. Simon produced the correct form 50% of the time, slightly more often than his parents but significantly less often than children learning from native-signers (69%). Why did Simon do so much worse at regularizing the input he received for handshapes than for motions/locations?[11] One possibility is that seeing the correct form-meaning pairing less than half the time just was not sufficient to cue Simon into the correct response and to activate his frequency boosting mechanism.

For the deaf children in our study, there are no correct or incorrect forms. What then might the deaf children be expected to boost? We explored whether the deaf children might be frequency boosting by first determining the most frequent meaning that a mother used for a given form and then calculating how often she used this particular form-meaning pairing overall. We found that a mother's production of form-meaning pairings that were part of her child's morphological system was no higher (0.75) than her production of form-meaning pairings that were not part of the child's system (0.76). Moreover the children did not boost the frequency of the form-meaning pairings that were part of their system (0.75 for mothers vs. 0.69 for children). Although from these data, it may look like the deaf children were probability matching their input (i.e., reproducing all of the mother's form-meaning pairings at the same rate; cf. Bitterman, 1965), in fact they were not—they produced the mothers' form-meaning pairing that were not part of their morphological systems only 0.16 of the time (compared to 0.76 for mothers). If the children were using their mothers' gestures as a starting point, they were clearly being selective about it.[12]

The deaf children in our study could have boosted the frequencies of the form-meaning pairings that their mothers used—the mothers used a particular form for a given meaning (or a meaning for a given form) around 75% of the time, more often than Simon's parents, but still not 100% of the time. But the children did not boost the frequency of these form-meaning pairings. Why not? We suggest that in order for frequency boosting to take place, the booster must be able to detect some sort of system. Although we were able to eke a morphological description out of each mother's gestures (by eliminating ambiguous gestures and ignoring trace handshapes which convey no object information), it is not at all clear that the children were able to see a system in their mothers' gestures. Without a structure to impose on the gestures, it is difficult to figure out just what the appropriate unit of analysis for boosting ought to be. We ourselves made several passes through the data trying to find the right unit for the frequency boosting analyses and, of course, may have chosen the wrong unit. But note that the difficulty we faced in trying to figure out the appropriate unit of analysis over which to calculate frequency for the mothers' gestures is comparable to the difficulty that the deaf children faced.

[11] It is, however, possible that Simon did not use frequency boosting to arrive at his motion/location morphemes either. The motion/location morphemes tested by Singleton and Newport (2004) were all relatively transparent, so transparent that non-signers are able to succeed on the task. Singleton et al. (1993) asked hearing individuals who knew no sign language to describe the Singleton and Newport (2004) scenes using only their hands and no speech. They found that these speakers-turned-signers produced the correct ASL motion/location form 82% of the time, a rate that fell within the 95% confidence interval for the native-signers. Thus, although Simon may have been boosting the frequency of his parent's input, he could have arrived at forms resembling the correct ASL forms by ignoring his input entirely. In this regard, it is particularly interesting that Simon's parents did not follow this iconic gestural route—they could have done better on the task had they not relied on their conventional system at all and just gestured.

[12] It is possible that the mothers influenced their children's morphological systems in other ways, for example, by responding more often to gestures with particular form-meaning pairings. We have not yet explored this possibility with respect to the deaf children's morphological systems (and, indeed, it is difficult to envision exactly how such a shaping process might work). However, we have explored whether maternal responses to the deaf children's gesture sentences could have shaped the orders that the children eventually adopted in their gesture sentences but found no evidence to support the hypothesis (Goldin-Meadow & Mylander, 1983, 1984).

The interesting question for future research is how much systematicity must be there in a database in order to promote frequency boosting. Hudson Kam and Newport (2005) have recently shown that, when faced with an artificial language-learning situation, learners are able to tolerate a certain amount of inconsistency in a database—tolerate in the sense that they do not regularize the inconsistency in their input but rather probability match it (i.e., match their output to the frequency of the inconsistent form in their input). Interestingly, Hudson Kam and Newport (2005) found that children tolerate less slop in a database than do adults. They may frequency boost a form that occurs only 60% of the time, producing it close to 100% of the time. In contrast, adults tend to match their output to the frequency in the input, producing the form 60% of the time.

But the deaf children in our study neither matched the probability of the input they received, nor did they boost the frequency of a particular form to regularize the system. One difference between the Hudson Kam and Newport (2005) experimental study and the situation facing our deaf children is that it was relatively easy to detect some sort of basic pattern in the experimental situation, but much harder in the deaf children's situation. Frequency of a form must always be assessed relative to some sort of baseline. Our findings suggest that the ease with which a baseline can be discovered may be an important factor in the language-learning process, one that may have to be in place before any sort of copying or regularizing process is set in motion.

4.2.3. The children may provide their own input

The gestures that the deaf children's mothers produced do not appear to have been systematic enough to activate the deaf children's data analyzing processes. But the children's language-making skills may not have needed input from an external source to become engaged—they may have been activated by input that the children generated for themselves. The deaf children in our American sample were observed over a relatively long time period (7 sessions per child), thus allowing us to explore the developmental steps each child took in creating his or her morphological system. We found two points of interest in these developmental data (Goldin-Meadow et al., 1995).

First, the children began by using their gestures as wholes rather than as combinations of parts. For example, the gesture *Fist* + *Arc To and Fro* was initially used in the context of beating a drum and for no other objects or actions, thus functioning as an unanalyzed label for drum-beating. Later, the *Fist* handshape when combined with *Arc To and Fro* was used in relation to a variety of related objects (drumsticks, toothbrushes, handlebars—all of which are narrow and long) and the *Arc to and Fro* motion when combined with *Fist* was used in relation to a variety of related actions (beating, brushing, jiggling—all of which involve repositioning by moving back and forth; Goldin-Meadow et al., 1995). This developmental pattern is reminiscent of children acquiring conventional languages who at the very earliest stages of development learn words as rote wholes but then realize—relatively quickly in some languages, e.g., K'iche' Maya (Pye, 1992), Turkish (Aksu-Koc & Slobin, 1985), West Greenlandic (Fortescue & Olsen, 1992) and more slowly in other languages, e.g., English (Bowerman, 1982), ASL (Newport, 1984)—that those wholes are composed of meaningful parts. At that point, they begin to use parts of words as productive morphemes (MacWhinney, 1978). Thus, there was a period in our deaf children's development when their morphological systems did not appear to be productive.

Second, the patterns seen in Figs. 1 and 2 for the American deaf children—the similarities among the children, as well as the subtle but consistent differences—seemed to be established *before* the point at which the children's morphological systems became truly productive. Even before a child began to consistently use a handshape/motion combination in relation to a variety of objects and actions, the child was already using handshapes (and motions) in different gestures in relation to precisely the range of objects (and actions) that would eventually fall within a given morpheme type in that child's system. Thus, when the child was ready to survey his or her gestures and analyze them to extract handshape and motion components, the outlines of the system were already present. As in children acquiring morphological structure from conventional sign languages (Marchman & Bates, 1994; Plunkett & Marchman, 1993), the deaf children may have needed a minimal number of gestural items in their repertoires before they could induce a morphological structure from those items. Thus, just as children provided with a conventional language model induce rules and categories from the input they receive, the deaf children in our studies induced the structure of their categories from their input—the difference was that the deaf children were forced by their circumstances to provide and reflect on their own gestures as input.

5. Conclusion

We have shown that deaf children in two very different cultures can invent gesture systems with structure at the morphological level even without benefit of a conventional language model. The morphological systems that the children developed were similar in many respects, and those similarities appear to be basic to conventional sign languages—properties of the deaf children's morphological systems are found in historically unrelated sign languages and crop up during the early stages of a deaf child's acquisition of sign language from a conventional language model. The within- and across-culture similarities in the deaf children's morphological systems are likely to have grown out of the fact that the children were using their bodies as a representational device.

There were, however, small but consistent differences across the children's morphological systems. Interestingly, the differences across cultures were no bigger than the differences within cultures. Although the deaf children's morphological systems are essentially iconic (the forms of the gestures are transparently related to their meanings), the subtle differences across the children's systems provide hints of the kind of arbitrariness that characterizes conventional languages. The arbitrary differences across children's systems would presumably have become more pronounced if each child had had a community of signers with whom to share his or her system, and might eventually have grown into a full-fledged linguistic system (as in, for example, the nascent sign language systems developing in communities in Nicaragua (Kegl, Senghas, & Coppola, 1999; Senghas & Coppola, 2001) and Israel (Sandler, Meir, Padden, & Aronoff, 2005)).

Surprisingly, although the children may have borrowed the forms and meanings that were the building blocks of their morphological systems from their mothers' gestures, the particular morphemes that each child introduced into his or her gestures could not be traced back to that child's mother's gestures. The children were not copying the form-meaning pairings in their mothers' gestures and did not even seem to be boosting the frequency of those pairings to regularize them. Instead, the children appeared to be regularizing the input they provided for themselves during the early stages of their gesture development. Children thus seem predisposed to impose word-level structure on their communications and will do so even when such structure is not modeled in their input.

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